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Continuous Monitoring of Dissolved Oxygen, Conductivity, and Temperature in Surface Water and Hyporheic Zone Water in the San Joaquin River below Friant Dam During the 2012-2013 Salmon Spawning Period

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Abstract

Sensors were used to monitor dissolved oxygen (DO), conductivity, and temperature every 15 minutes from the end of October 2012 to late February 2013 at sites along the San Joaquin River below Friant Dam. Measurements occurred in both surface and hyporheic zone (approximate area where Chinook salmon (*Oncorhynchus tshawytscha*) eggs are found) locations. Dissolved oxygen was chronically low at 44% of the hyporheic zone locations. In general, low concentrations of DO existed during the early egg stage of fall-run Chinook salmon but increased by the time of hatch. This timing may be non-detrimental to salmon early life stage survival because young eggs may require less DO than other later embryo stages. However, high water temperatures, at the lethal limit for Chinook salmon eggs, also occurred during water quality monitoring. Timing of high water temperatures was early in the egg stage and some literature indicates that these temperature (as high as 15.8^{o}C) are harmful to eggs and might also result in mortality that is delayed until hatch of alevins from these eggs. Measures of conductivity tended to be lower in the hyporheic compared to surface water sites. Occasionally conductivity was extremely high at some surface water sites (perhaps at levels harmful to aquatic life) and appeared to be related to precipitation events. Assumptions of impacts to salmon were theoretical and based on literature values because no actual fish bioassays were performed during this monitoring study.

Introduction

The San Joaquin River Restoration Program (SJRRP) has a goal to restore both flows and a Chinook salmon (*Oncorhynchus tshawytscha*) population from Friant Dam to the confluence of the Merced River in the San Joaquin River, California. This effort is also intended to reduce or limit adverse water supply impacts for other users. With completion of the Friant Dam in 1942, both spring-run and fall-run salmon were quickly extirpated from the San Joaquin River by eliminating access to spawning areas and river flows below the dam (Yoshiyama et al. 2001). Reintroduction of both spring-run and fall-run Chinook salmon is a goal of the SJRRP. In the past, spring-run fish would enter the San Joaquin River when snow melt provided a large volume of cold water. Fish migrated upstream and held through the summer in deep, cool holes in the river. Spawning occurred in October and November (Department of Fish and Game 1951) after which fish died. Fall-run salmon did not enter freshwater until cooling occurred in the autumn. These fish would ascend the San Joaquin and spawn in November or December shortly after arrival (Department of Fish and Game 1951) after which they perished. During spawning activity and redd construction, Chinook salmon eggs are buried in the river substrate, at depths from ca. 30 cm (e.g., DeVries 1997) to 45 cm (Geist 2000). The incubation period often lasts 40-50 days before hatching occurs (SJRRP 2010). After hatching, alevins remain buried in the gravel while development continues using mostly yolk-sac derived nutrition. In the nearby Sacramento River Basin, spring-run Chinook salmon alevins remain in the gravel for 2 to 3 weeks after hatching and then emerge into the water column (Fisher 1994). Both strains of fish migrate seaward as juveniles in late winter and early spring with numbers of young fish peaking in February and March in the 1940's (Department of Fish and Game 1951). This long contact time with the redd environment for these early life history stages of salmon signifies its importance to salmon populations.

Salmon embryo survival within the redd environment is dependent on interactions between biological requirements of developing embryos and streambed hyporheic (zone of interaction between surface water and ground water) water quality. Prominent water quality parameters include dissolved oxygen (DO) concentrations and stream water temperatures. Processes controlling hyporheic water quality, however, are complex and may vary temporally; as does the life history response of the intra-gravel stages of salmon.

The average DO value for **no production impairment** of salmonid eggs in gravel has been set by the Environmental Protection Agency (EPA 1986) at > 8 mg/L, with **slight to severe production impairment** at < 6 mg/L DO. The Washington State Department of Ecology (WDOE 2002) has found that growth is reduced by 25% when salmon eggs are incubated at 6 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. More recently, Brown and Hallock (2009) reviewed intragravel DO water quality standards of Pacific Northwest government agencies. The review included western states, tribes, and the Canadian province of British Columbia and found that 1-day minimum criteria ranged from 5 to 8 mg/L. This standard is the minimum concentration and is to be met at all times. This range of values is consistent with the results of Malcolm et al. (2003) who reported negligible survival where mean DO's were < 7.6 mg/L.

The SJRRP (2010) considers water temperatures > 15.6^{o} C as lethal during egg incubation; the optimal temperature for successful Chinook salmon egg incubation is < 13^{o}C (Table 3-1, SJRRP 2010). Extremely low non-optimal temperatures are not a concern in this part of the San Joaquin River. Non-optimal high temperatures may result in mortality that is delayed until later stages. Jewett (1970, as cited by Boles 1988) found when salmon eggs were incubated at 16°C, that mortality occurring post emergence, because of physiological difficulty in yolk absorption, was more severe than that occurring prior to emergence.

Conductivity has received less attention as a limiting factor in salmonid egg development. However, differences in conductivity between surface water and hyporheic zone water may provide information on groundwater/surface water interactions (e.g., Malcolm et al. 2008) which may be important to egg survival because of altered water quality.

This paper addresses San Joaquin River intragravel continuous DO, conductivity, and temperature monitoring and how these parameters compare spatially and under differing conditions of flow. The time period studied relates largely to conditions under which fall-run salmon would be exposed. Flow data for the period of study is presented in Figure 1 and demonstrates high flows for attracting adult spawners in November and spring runoff starting in April. Baseline flows close to 10 cms are maintained through much of the winter. Monitoring data should aid in determination of the quality of spawning habitat below Friant Dam and will also help evaluate the effects of Restoration Flow releases on DO and water temperatures in egg incubation environments.

Methods

Five sets of riffles were examined in the San Joaquin River (Figure 2) below Friant Dam on Millerton Lake. Riffles were designated from upstream to downstream as R1 through R5 with surface water samples identified with an "S" (e.g., R1S). Hyporheic samples were identified with an "L" corresponding to the three intragravel locations at each set of riffles (e.g., R1L1, R1L2, R1L3). Excavations, in which sensors were installed, were made in the stream bed using hand trowels. Water flow at the excavated spot was blocked, to prevent washing of substrate into the hole, with a bottomless bucket. Substrate from the hole was placed in a nearby bucket, and then returned to the hole following the placement of DO and conductivity sensors, after which the bottomless bucket was removed. This disturbance, although limited in extent, is similar in removal of fines to what might occur during redd construction by salmon. This activity does not simulate a natural redd in all regards because it lacks other features common to redds such as a tail spill. The degree to which these diggings represent intragravel conditions that a salmon might produce is uncertain, with Meyer (2003) concluding from a comparison of artificial and natural redds that it was not possible to prove how equivalent artificial redds were to natural redds.

Continuous monitoring—Cabled DO sensors (precise to 0.01 mg/L) (Aquistar®) utilized fluorescence of a stable, immobilized ruthenium-based film matrix, and optical transmission to measure oxygen concentration in the fluid outside of the sensor. Measurement was based on photons of light responding to oxygen outside of the sensor. This design eliminates the need for water flow and frequent cleaning. Sensors were calibrated prior to deployement. Water temperature was also recorded from the sensor. The sensor was very small (4 cm diameter) and easily fit into the constructed holes.

Sensors were connected via cable to control boxes on the shore. Control boxes recorded data (DO and temperature) and powered both the control box and the sensor. Logging period was set for every 15 minutes during the study.

We also used the HOBO U26 Dissolved Oxygen Logger (also measures temperature) which has an optical sensor that provides 0.2 mg/L accuracy. This logger has an advantage over the other sensors we used in that it does not require cabling to onshore control boxes. Data from 15 minute intervals was downloaded from these sensors at the end of the study.

Conductivity data was collected with the HOBO U24 conductivity logger (resolution of 1 µS/cm), which also measures temperature. These sensors were set to log at 15 minute intervals.

Flow data was obtained from USGS gage 11251000 at Friant, California. This site was upstream of our site R1. In addition to trends in streamflow, we examined air temperature and precipitation over the study area using measurements collected by Reclamation at Friant Dam (California Data Exchange Center, site FRT).

Results

Data were not recovered from all locations. Some sensors were lost, cables were vandalized, sensors failed, or were, in some cases, inadvertently not launched.

Twelve out of 20 DO sensors provided at least partial data, 16 of 20 provided conductivity data, and 18 of 20 provided temperature data. Temperature data was obtained from both conductivity and DO sensors and in some cases where one type of probe was missing or had malfunctioned another sensor type was available for temperature data. Some of the more pertinent results from continuous monitoring data are presented in Table 1.

Dissolved oxygen—Surface DO was typically high (only data for 3 out of 5 sites) (Figures 3a-7a), although data at R4 indicated that concentrations dropped below 6 mg/L on occasion (Figure 6a). Dissolved oxygen tended to be high during the high early November flows, then declined for approximately 1 month, and then increased during the last part of December when water temperatures (influenced by air temperatures, Figure 7) decreased (Figures 3-7). Five of nine hyporheic sensors detected deleterious conditions (<6 mg/L DO) during the egg incubation period. Four of these (44%) were at DO concentrations that were consistently <6 mg/L for an extended time (see Table 1).

Conductivity—Low values (< 50 µS/cm) were recorded for conductivity in most cases. Spikes in conductivity of ca. 100 µS/cm occurred on a few occasions. A major increase in surface water conductivity was evident at R3 with values ranging from 500-1500 µS/cm several times (Figure 5b, note log scale). A similar, but diminished, pattern of spikes occurred downstream at R4 (Figure 6b). Hyporheic locations at these sites tended to be protected from the very large conductivity increases that occurred in surface waters. Precipitation patterns appeared to be associated, to some degree, with conductivity increases at R3 (Figure 9). It is unknown what the source of conductivity was at this site, but it appears to be located between R2 and R3.

Conductivity gradually increased over time with a small jump in conductivity on about December 20th (Figures 3b-7b, Table 1). This may indicate a slight increase in groundwater composition in the hyporheic zone and could be related to earlier precipitation events that may have recharged floodplain groundwater and led to a rising water table. Surface water conductivity, however, increased in a similar manner and was typically greater than that measured at hyporheic locations.

Temperature--High flows in early November appeared to lower water temperature (Figures 3C-7C), however, water temperatures quickly warmed when flows were decreased. It also appeared that release temperatures at Friant dam increased at this time (Figure 10). All of the monitored hyporheic locations experienced temperatures >15°C (e.g., Table 1) that could result in increased salmon egg mortality. Water temperatures from Friant dam have increased over the past few years (compare the salmon intragravel periods in 2011-2012 and 2012-2013 in Figure 10) possibly related to water release timing and drought conditions in the area (http://restoresjr.net/flows/data-reporting/2013/2013_USBR_Millerton-Lake-Temp-Monitoring.pdf, accessed 4-15-14) which may lead to increasingly negative effects to salmon.

The optimal temperature for successful Chinook salmon egg incubation of < 13°C (Table 3-1, SJRRP 2010) did not occur consistently at San Joaquin River sites until approximately December 20th. Optimal water temperatures of <13°C (for salmon egg incubation) appeared to be related to declining air temperatures where average air temperatures were consistently below 10°C (12-12 to1-17) (Figure 8). Cooler groundwater, however, may have played some role in decreased hyporheic zone temperatures. There was a slight increase in conductivity, perhaps indicative of an increased proportion of cool groundwater in the hyporheic zone, which also occurred in late December. Arguing against this explanation is that conductivity also increased in surface water. Water temperature at many of the hyporheic locations was decreased in variability relative to surface water temperatures towards the end of January (see for example Figure 11), which might suggest fewer interactions between surface water and groundwater. These lower and less variable temperatures were maintained despite an increase in air temperature (Figure 8).

The SJRRP is conducting a trap and transport study where stray salmon are captured and then hauled to the spawning areas near Friant Dam. Salmon that are able to get past the Hills Ferry Barrier near the confluence of the Merced River are being used in this effort. The purpose of the barrier is to redirect salmon to the Merced River and away from the San Joaquin River; however, some fish do manage to penetrate the barrier. Fish that get past the barrier confront reaches of the San Joaquin River that are dry and bereft of suitable spawning habitat. These fish are considered lost and unable to contribute to other viable populations. Therefore, a portion of these fish have been moved around these unsuitable areas into upstream reaches that are not dewatered.

Salmon redds, built by fish transported from Hills Ferry Barrier, were noted on November 27th at some of our study sites. It is unknown when spawning occurred, but two weeks prior to redd detection, temperatures would have been near optimum (ca. 13°C) when flows were near 20 cms. Flows that declined to 11 cms were associated with temperatures near 15°C on November 28th. These decreased flows and above optimum temperatures were maintained for approximately a month after the first redds were detected. Figure 3a shows early life history stage timing of fall-run Chinook salmon overlaid on hydrology and DO concentrations.

Discussion

All five of the studied sites experienced DO < 6 mg/L for a portion of the early egg stage of fall-run Chinook salmon. Forty-four percent (4/9) of hyporheic locations had DO concentrations < 6 mg/L for an extended time. In many cases, however, these low DO's were measured early in the incubation period. Dissolved oxygen requirements vary with life stage of salmon within the redd. Oxygen demand during the egg stage may be lower than that required at hatching (Greig et al. 2007). At sites along the San Joaquin it seems that the flow regime and air temperature during the fall/winter of 2012/2013 resulted in DO concentrations which were lower during egg incubation, but that increased at the time of hatching and on through alevin emergence. It seemed that this pattern was influenced to some degree by air temperature effects (along with flow) on water temperature and DO.

While low DO may have a decreased effect on young eggs relative to alevins, mortality effects on eggs in the San Joaquin may be complicated by the relatively high water temperatures experienced by the early egg stages. All of the monitored locations at San Joaquin River sites experienced temperatures >15^{o}C. Oxygen demands by developing ova are amplified with increased temperature (e.g., Malcolm et al. 2008). Thus the very high water temperatures in November and the early part of December may impact egg oxygen demand and require greater DO concentrations for successful egg development. There appears to be some ambiguity associated with temperature effects, with Boles (1988) indicating that egg survival may be exceptional, even with exposure to temperatures as high as 15.6^{o}C, if they are subjected to declining temperatures afterwards (no specific time frame is provided). However, Boles (1988) goes on to claim that, while egg survival at these temperatures may be high, sac fry may experience mortality rates as high as 50% from latent temperature effects. This occurs even when eggs are maintained at temperatures between 13 and 14^{o}C. Even if alevins survive, both high hyporheic temperatures and hypoxia may lead to deformities (e.g., Finn 2007, Castro et al. 2011) that ultimately decrease survival. Boles (1988) indicated that no data were available for the case where water temperatures increased post-spawning as occurred for redds in 2012.

Geist et al. (2006) is one of the few studies to examine how early life stages of Chinook salmon respond to both elevated temperatures and reduced DO concentrations that are then followed by decreased temperatures and increased DO. They showed that when fall Chinook salmon embryos were exposed to DO concentrations as low as 4 mg/L during the first 40 days, over a range of temperatures from 15-16.5^{o}C, that mortality was not increased. Embryo mortality, however, increased significantly when initial incubation temperatures were 17^{o}C. The declining thermal regime that they used mimicked Snake River temperatures and resulted in a reduction of impacts related to elevated spawning temperatures. The declining thermal regime after fertilization also resulted in high survival at lower DO's. However, embryo abnormalities were twice as high in the 4 mg DO/L compared to higher DO groups.

The SJRRP has a limited volume of water in the fall with dual objectives of maintaining temperature in the spring-run redds and attracting fall-run adults. Value for spring-run would be greatest when air temperatures still exceed Friant release temperatures. Although Friant release temperatures continue to increase until Millerton Lake receives winter runoff, air temperatures cool in the late fall and control river temperatures. The pulse should occur prior to this transition. Pulse flow value for fall-run as an attractant depends on migration timing. The SJRRP would need to understand fall-run movement in the system in order to benefit the greatest number of migrants.

Delaying the attractant flow to the middle or until late November might limit exposure to high temperatures in some years. Lower air temperatures would then allow for lower water temperatures and increased DO. The baseflow of ca. 10 cms in the San Joaquin River seems to be largely appropriate for maintenance of suitable DO's. Extremely low flows (<3cms for most of December in 2010, e.g. Nelson and Reed 2011; and low flows of ca. 3 cms in November of 2011, e.g. Nelson et al. 2012) resulted in many DO measurements of less than 2 mg/L (in 2010) or declines, in one case, to 2.12 mg/L DO (in 2011). In an earlier study (Nelson and Reed 2011) that examined the hyporheic environment in September, October, December, and February, 73% of locations experienced DO concentrations < 6 mg/L (spot measurements, data not from continuous loggers). Cooler temperatures and higher flows in the present study, which took place later in the year, appear to have resulted in decreased deleterious DO conditions (only 44% of hyporheic locations with DO < 6 mg/L). The present data collection largely deals with fall-run Chinook; the needs of spring-run salmon might complicate management of fall-run fish. Timing of spawning activity for the two salmon strains differed historically (Department of Fish and Game 1951) with spring-run spawning in late October/November while fall-run spawning occurred in November/December. If the attractant flow is delayed until the middle of November this might still correspond to some extent with spawning activity of spring-run (this timing, however, could result in dewatering of spring-run redds after flows are diminished) and would likely be suitable for fall-run needs. An earlier study (Nelson et al. 2012) indicated optimum temperatures for egg development of $\leq 13^{o}$C did not consistently occur at San Joaquin River sites in 2011 until November. Attractant flows that lower stream temperatures in October (as in 2011) for spring-run fish spawning might result in high temperatures post-spawning. It also seems there could be yearly differences in air temperature or volume of the cool water pool behind Friant Dam that might alter the value of the attractant flow. Studies in 2011 and 2012 both indicated the attractant flow lowered temperatures, but after high flows were halted, temperatures increased several degrees, often nearing 16^{o}C. Timing of pulse flows may need to be adjusted according to air temperatures. As suggested by this and earlier studies (Nelson et al. 2012), the influence of cooling from air temperature differs through the egg incubation season and may outweigh the heating or cooling caused by a high or low flow pulse. Timing of flows so that flow-induced stream cooling to the egg optimum is continued with air temperature cooling of water would seem to be desirable. Primary controls to hyporheic zone temperature in this portion of the San Joaquin River include air temperature, flow volume, and temperature of upstream surface and reservoir water (Nelson et al. 2012). The effect that air temperature has upon water temperature will depend largely on flow volume at any given time.

Conductivity as an indicator of groundwater was ambiguous from the 2012 data and there did not appear to be a strong association between DO and conductivity. In many cases conductivity at hyporheic locations was lower than that measured in surface water. In December and February of 2010 (Nelson and Reed 2011) high conductivities (high of 264 µS/cm) were measured in the hyporheic and seemed to be related to extremely low flows. Perhaps the higher flows of 10 cms during the present study mitigates against extremes in conductivity from groundwater intrusion. However, some of the conductivity values observed in surface water in the middle portion of our study reaches along the San Joaquin River may be deleterious to aquatic life. While there is no standard for the Western United States, the chronic aquatic life benchmark value for conductivity derived from West Virginia is 300 µS/cm (EPA 2011). Caution is always required when applying criteria derived for one ecoregion to another, especially those that are not contiguous. Despite this caveat, conductivity at 5X the West Virginia standard in the surface water at R3 suggests that it may be important to find and mitigate the source of this conductivity in the San Joaquin River. The absence of a strong conductivity signal associated with groundwater suggests that a more sensitive method of detection, such as measurement of ^{222}Rn (Acuña and Tockner 2009), may be required for this sort of study.

The findings of low DO and relative high water temperatures suggest that habitat improvement of the shallow hyporheic zone may be important to salmon production in 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, indicated 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. Reduction in the diel thermal amplitude by hyporheic flows may reduce temperature extremes (Acuña and Tockner 2009) that impact salmonid use of streambed gravels. 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 is the use 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 water moving through gravel bars 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 localized cooling effects. Burkholder et al. (2008) suggested that creation of cool patches from hyporheic exchange can offset thermal degradation. Hester et al. (2009) observed decreased hyporheic zone temperatures downstream of a test weir and suggest that weirs and other similar structures are more consistent in decreasing temperatures when compared to gravel bars. Seedang et al. (2008) described three general categories of methods used for reducing river temperatures: (1) increased 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 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 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. Different scales may be involved in creating thermal heterogeneity, with step-pool and riffle-pool sequences driving hydrologic exchange at spatial scales of meters to 10's of meters, while exchanges at larger reach-level scales are influenced by channel sinuosity, point bar interflow, and flow through paleochannels (e.g, Acuña and Tockner 2009)

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 habitat complexity. 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. 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. (2011) 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.

In the absence of habitat improvement, issues with DO and temperature may result in relatively high mortality at some locations along the San Joaquin River; and years with very low flows or drought years that impact the cool water pool behind Friant Dam could exacerbate these concerns. Issues with metals toxicity that appears around the time of alevin emergence could also impact survival (Nelson and Reed 2014). Natural recruitment may be limited by low DO's, high temperatures (but see Geist 2006), and intragravel toxicity. There is a great deal of uncertainty surrounding salmon embryo survival within the redd environment because of interactions between biological requirements of developing embryos and processes controlling hyporheic water quality. Hatchery facilities could diminish some of this uncertainty and be an important resource for augmenting production above and beyond what may be reduced natural recruitment in some years. The ultimate test of natural recruitment success will be based on the ability found within salmon populations to tolerate this mixture of deleterious variables and controlling timing of flows to avoid some impacts. The historic strain of fall-run San Joaquin salmon may have been exceptionally tolerant of high air and water temperatures (Yoshiyama et al. 2001) and perhaps some of these attributes are retained within the extant population. Timing of fish release into the area in which spawning occurred could make a large difference in alevin production. If for example, fish spawned approximately 1-2 weeks later than were observed in this study, temperatures would have been declining and theoretical survival would have been higher. Spawning typically takes place over several weeks and it is likely that some fish will spawn at more opportune times and avoid high water temperatures. If so, DO concentrations should be high enough for elevated egg/alevin survival in the majority of redds if future conditions are similar to those encountered in 2012/2013.

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Table 1. Essential values observed at sites along the San Joaquin River.

Site	DO in hyporheic	Conductivity	Temperature in hyporheic
R1	o.k. but lower during incubation (minimum of 5.8 mg/L). High (around 10 mg/L) at hatch.	Two / three hyporheic locations lower in conductivity than surface water. Increased conductivity third week of December.	Temperatures were > optimum, highs between 15 and 15.4^{o}C for several weeks post-spawning.
R2	Two / three locations < 6 mg/L (minimum 5.4 mg/L DO) during incubation. One sensor consistently < 5 mg/L (minimum 2.5 mg/L). Single functioning sensor near 8 mg/L at hatch.	Surface water and R2L1 track closely, while R2L2 is much lower in conductivity.	Temperature variability increased at this site. Maximum hyporheic temperatures reached 15.6^{o}C during incubation.
R3	Only two sensors operable, these stopped logging after Dec. 11th. Both declined to near 6 mg/L with R3L2 remaining < 7 mg/L mostly. Minimum DO at R3L1 was 4.3, at R3L2 5.1 mg/L.	Conductivity very high (ca 1,500 µS/cm) in surface water (surface water impacted hyporheic at R3L1). Perhaps related to precipitation events?	Minimum temperature values post-high flow were lower at this site than at R1 and R2. However, temperatures were still > 15^{o}C for a period and reached a maximum of 15.7^{o}C.
R4	DO variable, but mostly >6 mg/L and between 7 - 9 mg/L. Higher DO's with temperature decline mid-late Dec.	Conductivity spikes similar to R3 but diminished.	Temperatures > 15, up to 15.8^{o}C at some locations post high flows. After Dec. 20th temperatures were < 13.
R5	While R5L2 DO concentrations were mostly >7, concentrations at R5L3 were often below 5 mg/L (minimum of 0.2 mg/L DO) during egg incubation stage.	A single conductivity sensor, R5L3, at site. Conductivity increased after high flows halted and then again around December 25th.	High temperature of 15.6^{o}C after high flows halted. Temperatures dropped to 13^{o}C and less after Dec.19th.
General overall conditions	Four/nine hyporheic sensors consistently <6 mg/L DO	High conductivity at R3, values mostly low elsewhere	All locations experienced temperatures > 15^{o}C

Figure 1. San Joaquin River hydrograph during the study period.

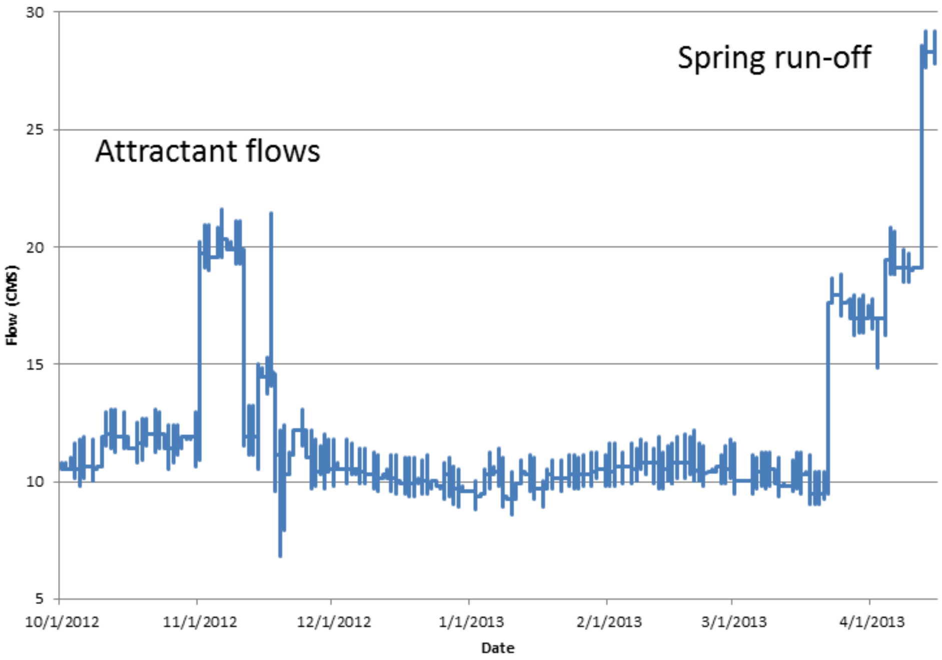


Figure 2. Map of area showing study sites. Friant Dam and Millerton Lake are in the upper right corner of the figure.

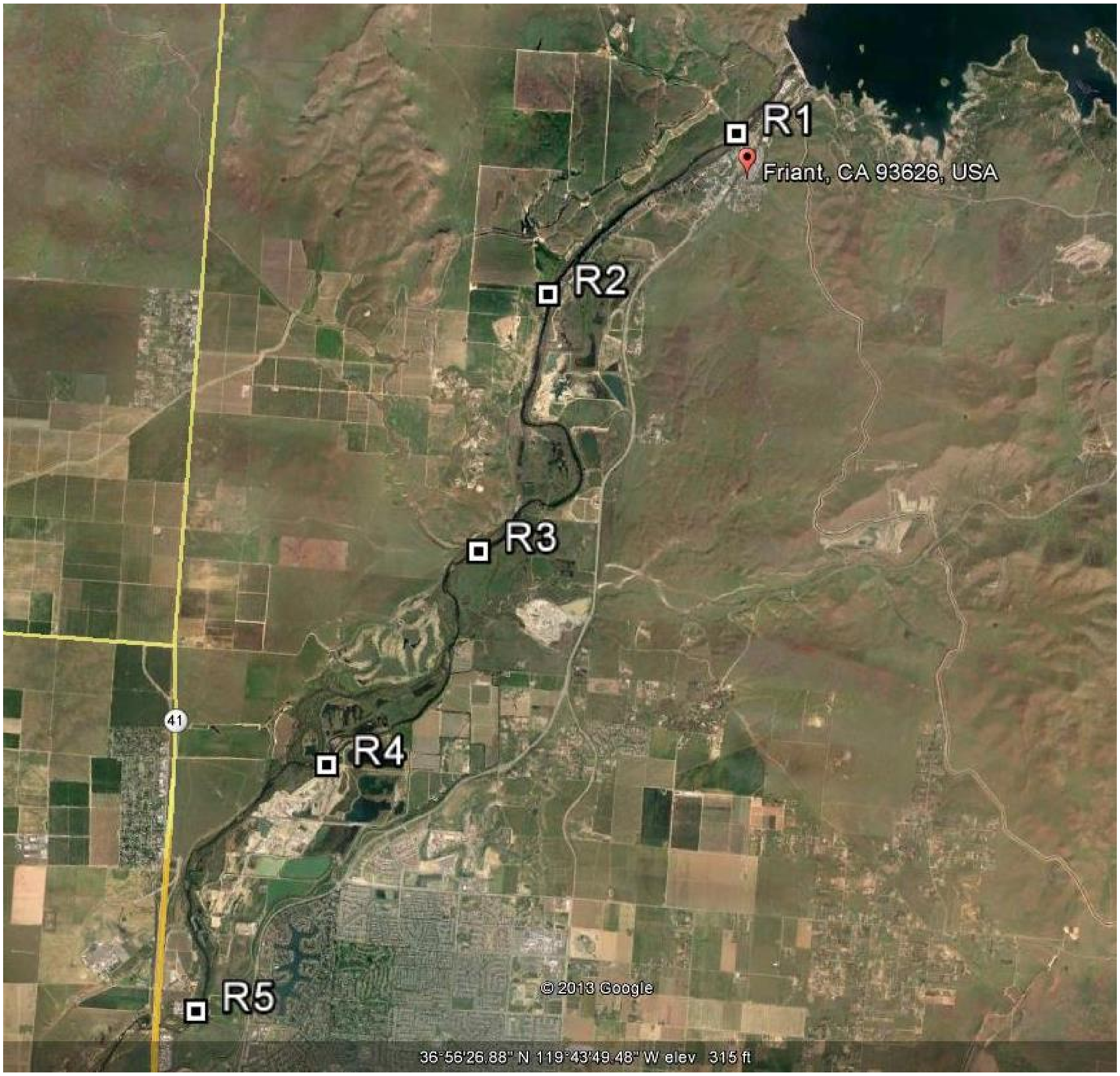


Figure 3. Continuous measurement data for DO (3a), conductivity (3b), and temperature (3c) at R1. Information on flow is also provided. Life history events of intragravel stages of fall-run Chinook salmon are shown in 3a.

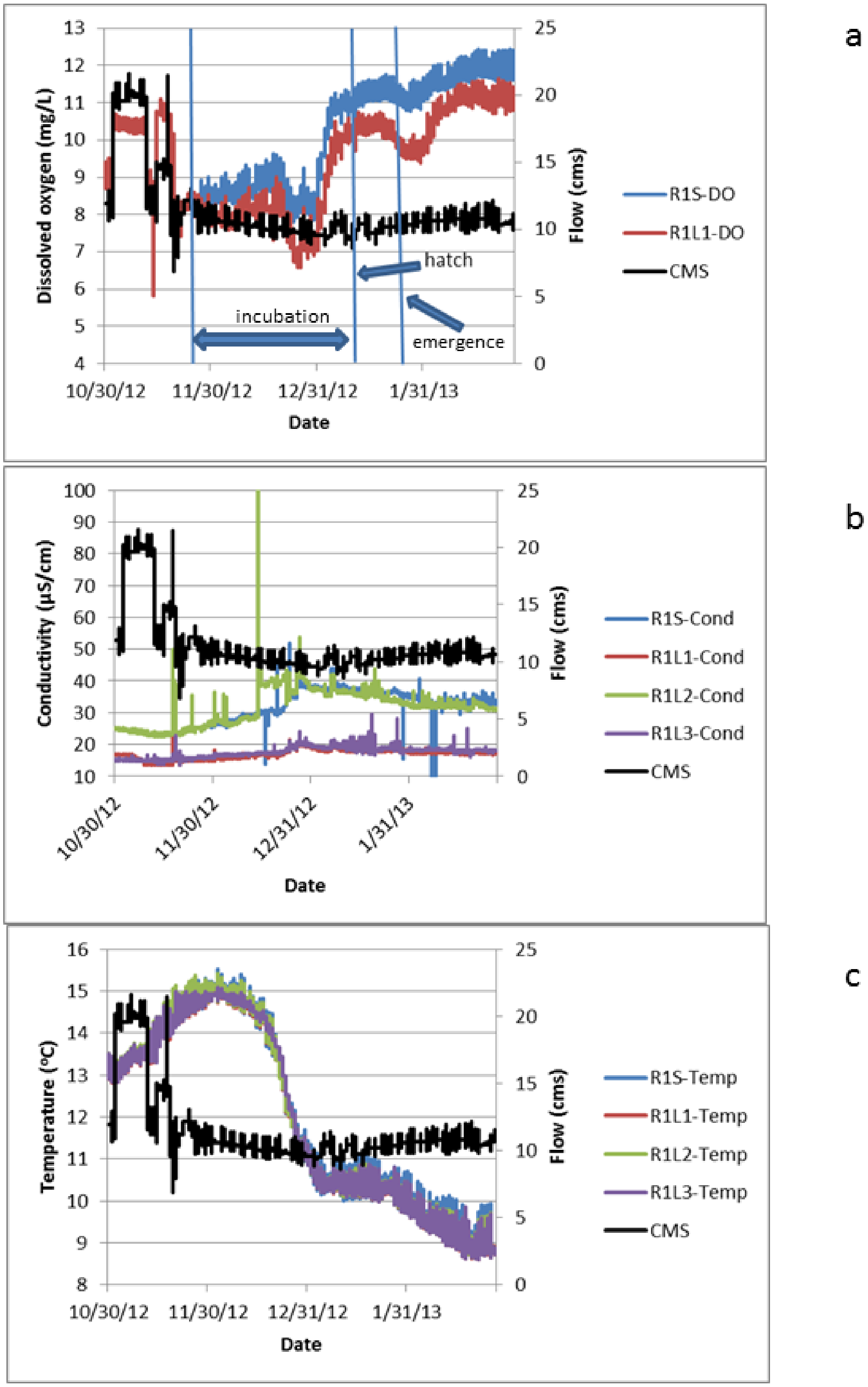


Figure 4. Continuous measurement data for DO (4a), conductivity (4b), and temperature (4c) at R2. Information on flow is also provided.

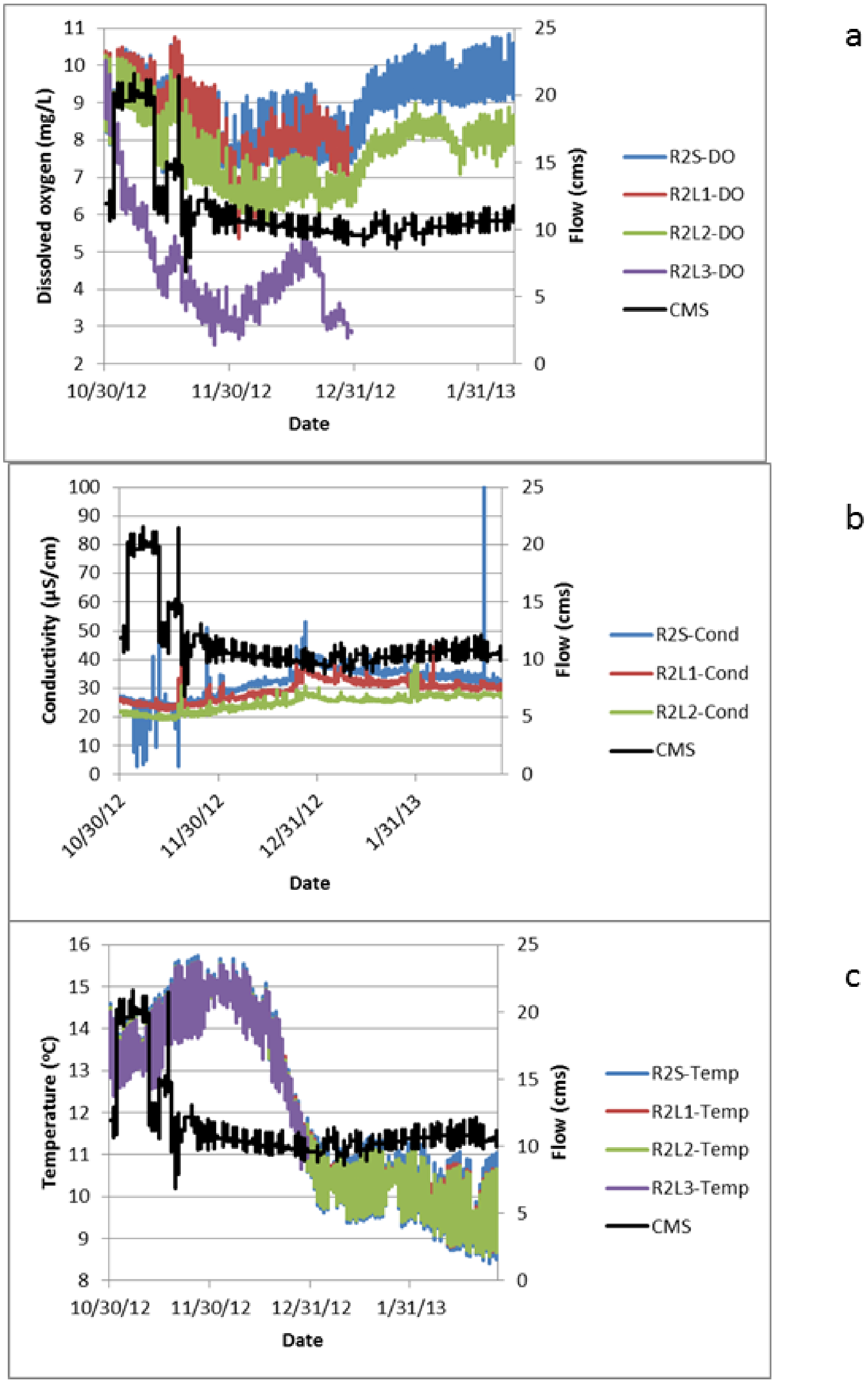


Figure 5. Continuous measurement data for DO (5a), conductivity (5b, note log-scale), and temperature (5c) at R3. Information on flow is also provided.

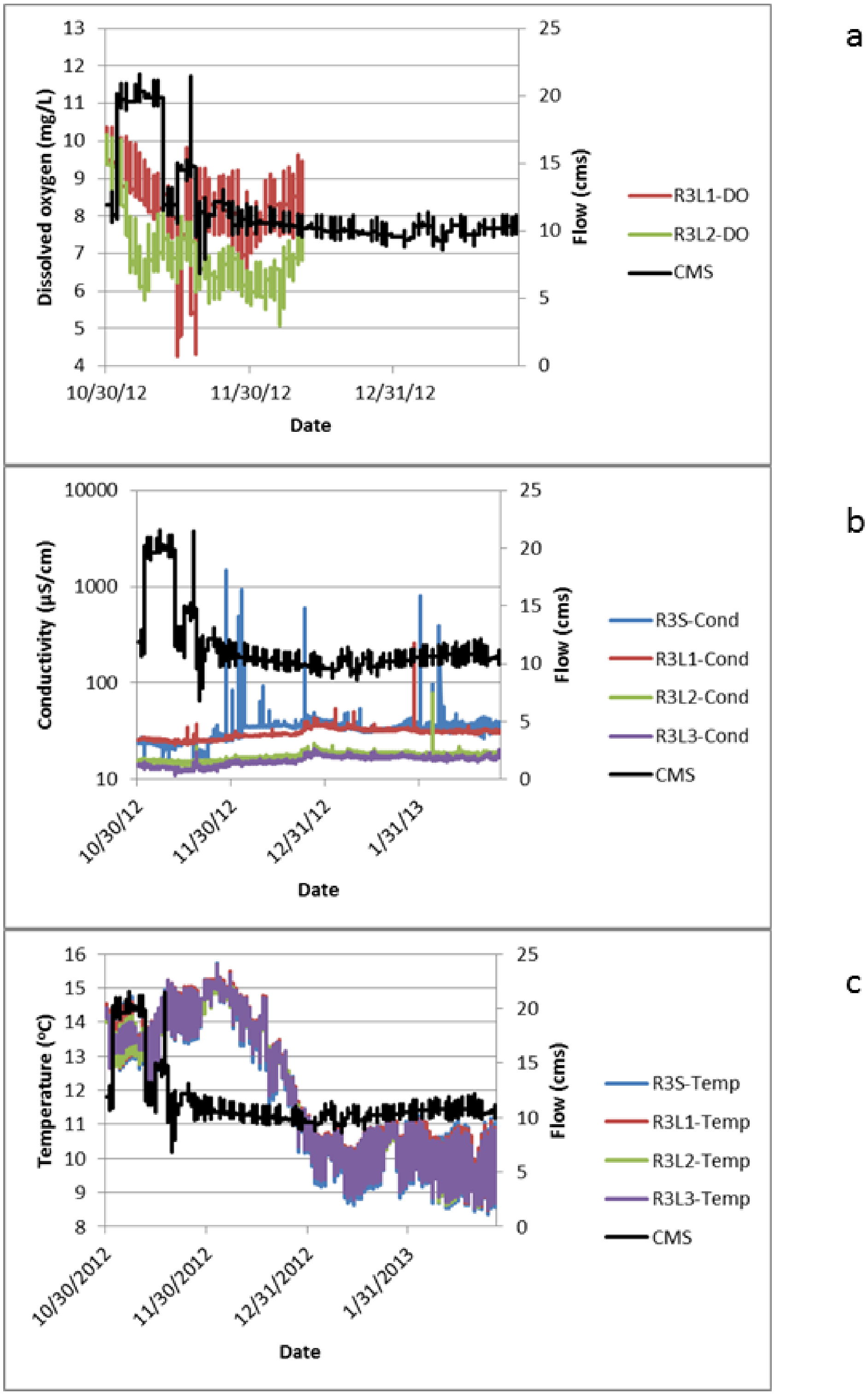


Figure 6. Continuous measurement data for DO (6a), conductivity (6b), and temperature (6c) at R4. Information on flow is also provided.

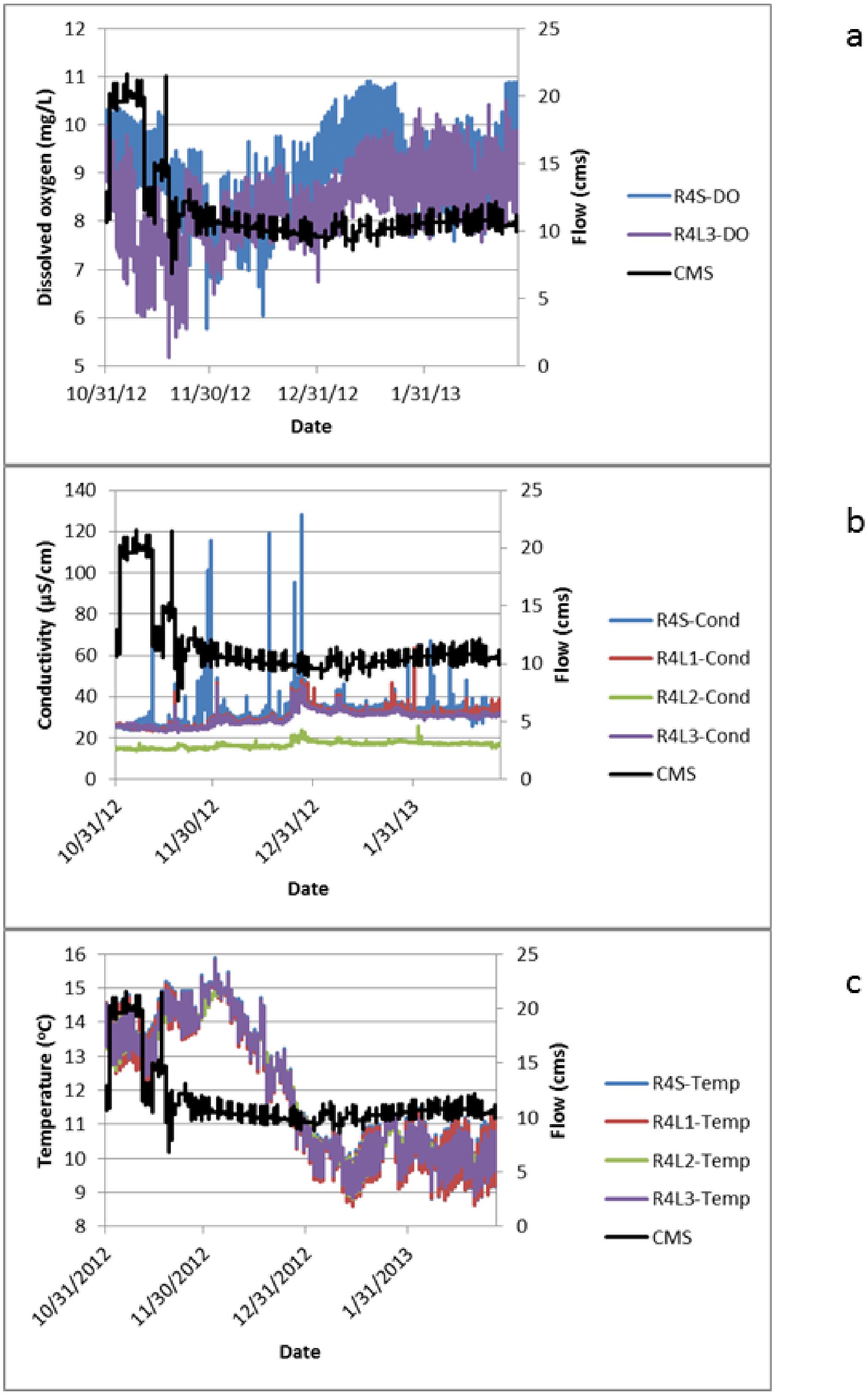


Figure 7. Continuous measurement data for DO (7a), conductivity (7b), and temperature (7c) at R5. Information on flow is also provided.

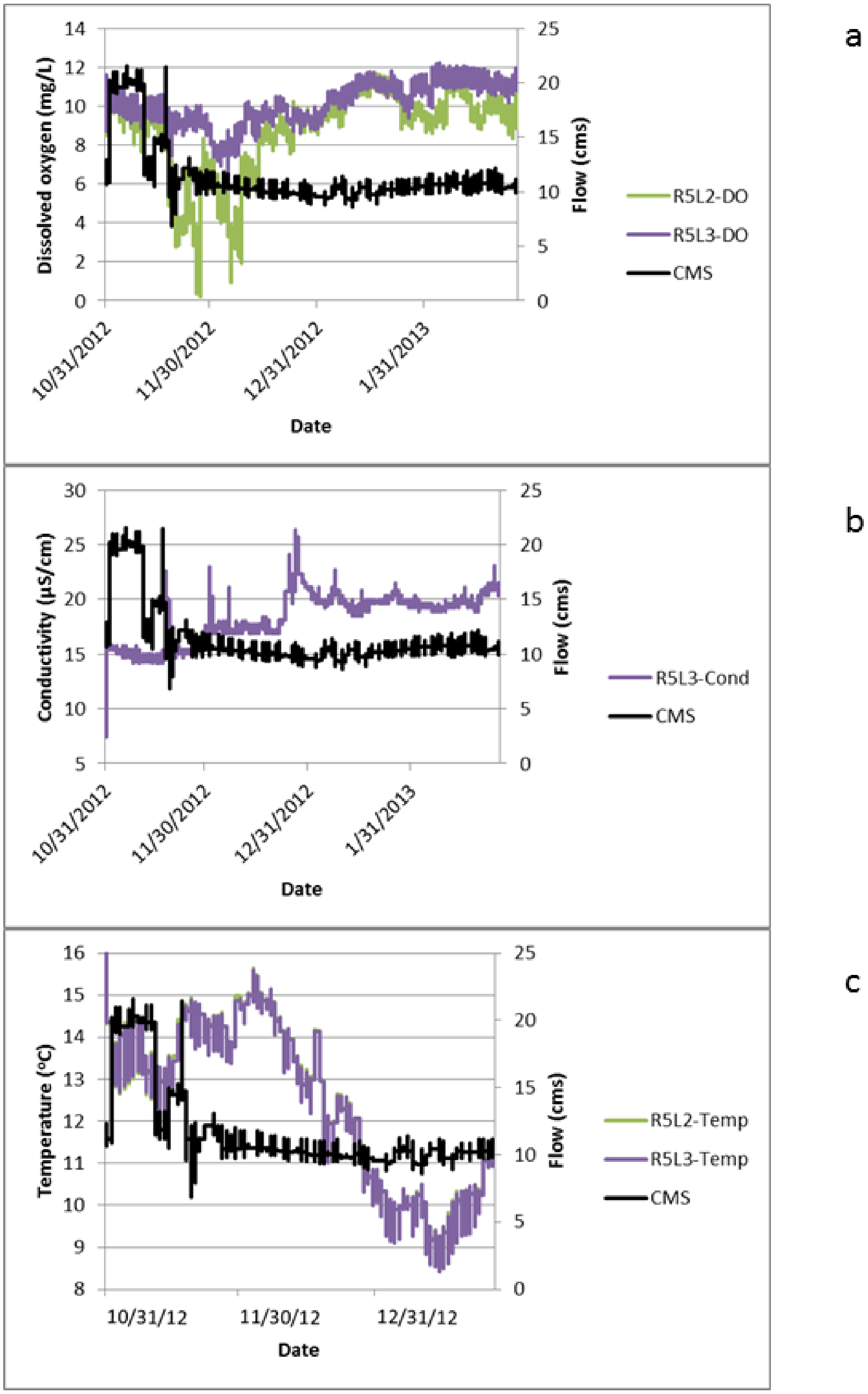


Figure 8. Average air temperature during the study period.

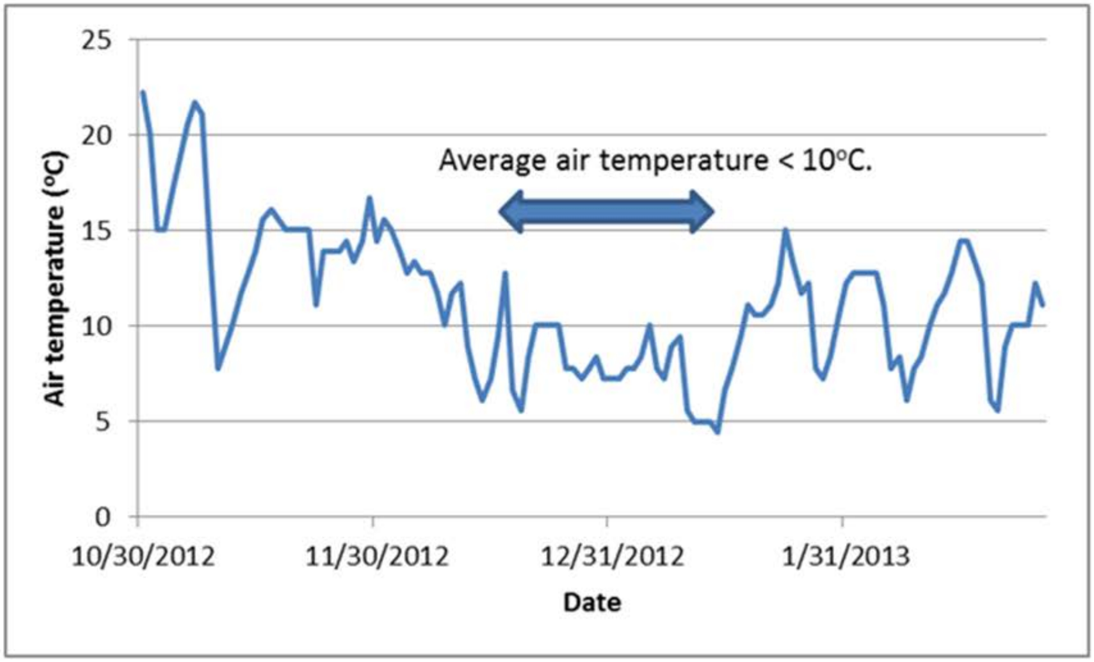


Figure 9. Comparison of average conductivity at R3S and precipitation in the area.

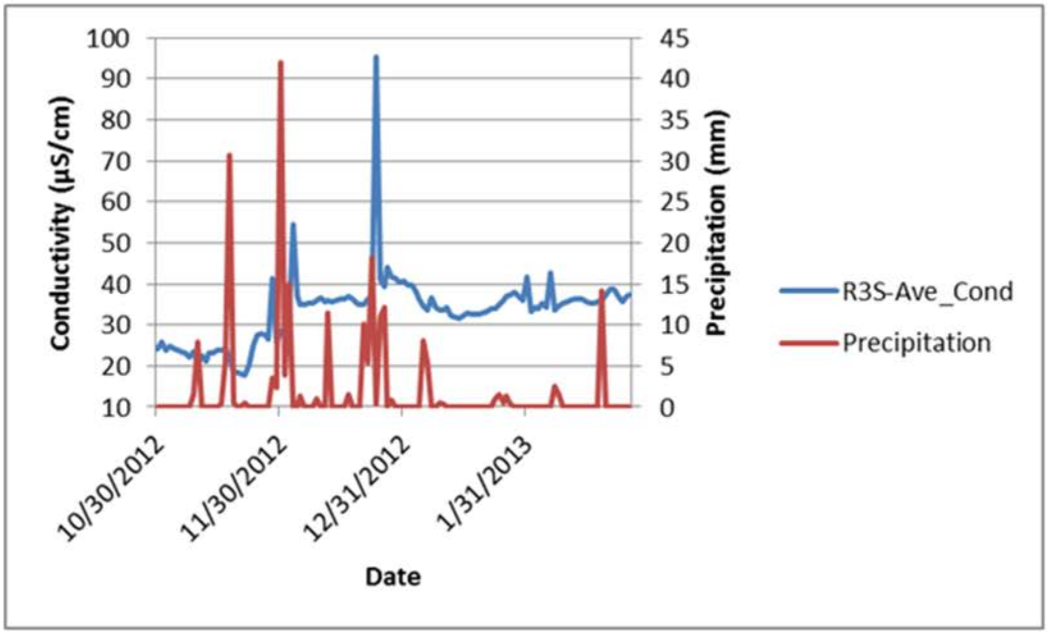


Figure10. Water temperatures out of Friant Dam during the salmon intragravel period. Data from 2011-2012 is presented in blue, while information in red represents 2012-2013 data.

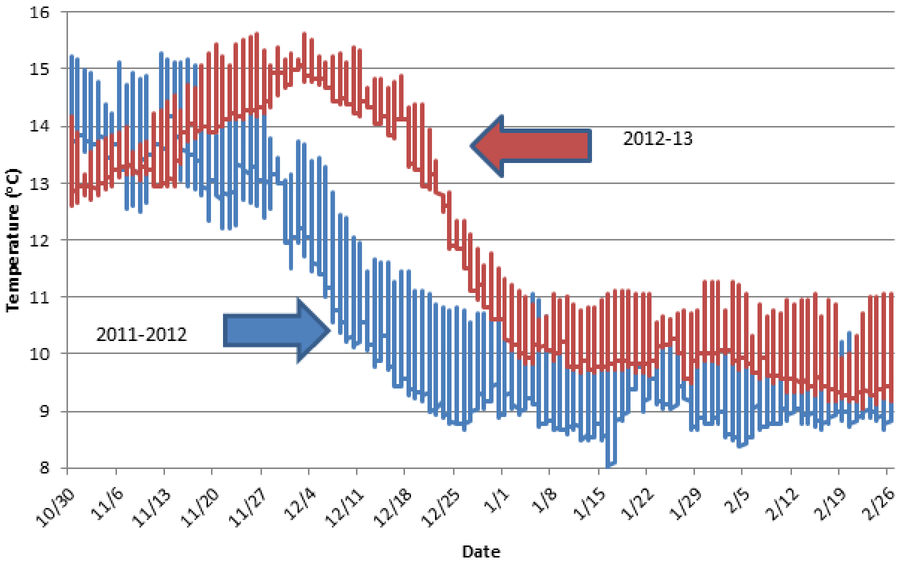
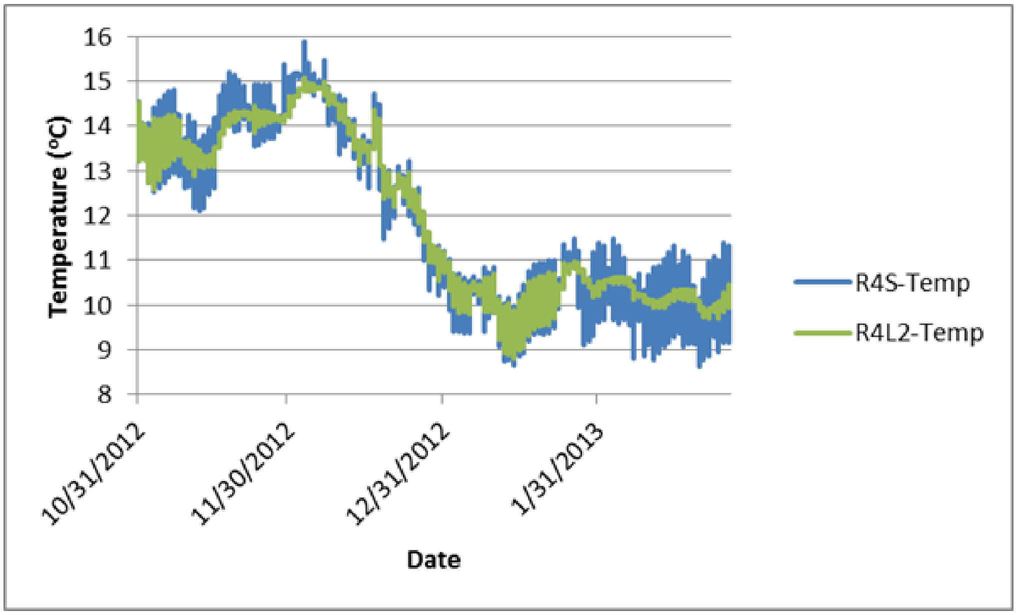


Figure 11. Comparison of water temperature variability in surface water (R4S) and hyporheic zone water (R4L2).



PEER REVIEW DOCUMENTATION

PROJECT AND DOCUMENT INFORMATION

Project Name San Joaquin River Monitoring WOID A207F

Document Continuous Monitoring of Dissolved Oxygen, Conductivity, and Temperature in Surface Water and Hyporheic Zone Water in the San Joaquin River below Friant Dam During the 2012-2013 Salmon Spawning Period

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(Peer Reviewer of Peer Review/QA Plan)

Peer Reviewer Erin Rice, Carl Mesick, and Matt Meyers

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REVIEW REQUIREMENT

Part A: Document Does Not Require Peer Review

Explain

Part B: Document Requires Peer Review: SCOPE OF PEER REVIEW

Peer Review restricted to the following Items/Section(s): Reviewer:

REVIEW CERTIFICATION

Peer Reviewer - I have reviewed the assigned Items/Section(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer: See acknowledgements Review Date:
Signature

Reviewer: Review Date:
Signature

Preparer I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member: S. Mark Nelson Date: 4-17-14
Signature