Physical and geochemical characteristics of the Lower Sailor Bar 2012, Upper Sunrise 2010/2011, Upper Sailor Bar 2009, and Upper Sailor Bar 2008 gravel additions

Submitted to the US Bureau of Reclamation, Sacramento office

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figures Page

1.0 INTRODUCTION

Anthropogenic forces, including dams, artificial levees, channel modification and overall urbanization have been shown to limit the quantity and quality of available spawning gravel necessary for anadromous salmonid populations in rivers (Vyverberg et al., 1997; Phillips, 2003; Hannon and Deason, 2005). These forces lead to streambed degradation, a primary factor in the continued decline of resident salmonid populations in the Lower American River (Horner, 2004; Kondolf et al., 2008). In response to this problem, a multi-phase remediation project was conducted on the river as part of the Central Valley Project Improvement Act of 1992 (CVPIA section b.13) which mandates the improvement of gravel conditions below federal dams. Project collaborators included California State University Sacramento (CSUS), U.S. Bureau of Reclamation (BOR), Sacramento Water Forum, U.S. Fish and Wildlife Service, CBEC consultants, NOAA Fisheries, and Cramer Fish Sciences.

1.1 OBJECTIVES

This report is a summary of hydrologic and physical data collected at four restoration sites on the Lower American River: Upper Sailor Bar 2008, Upper Sailor Bar 2009, Upper Sunrise 2010/2011, and Lower Sailor Bar 2012. Data was collected before and after restoration of each site, and in subsequent years. Analysis includes an assessment of temporal changes at individual sites and a comprehensive comparison of results between all four sites. Field work and analyses conducted during the 2012/2013 field season fulfilled seven major objectives, described as tasks in a gravel monitoring proposal submitted to the U.S. Bureau of Reclamation, Sacramento office on July 9, 2012. The tasks are summarized below:

(1) Conduct grain size analyses using pebble counts and bulk samples
(2) Conduct gravel mobility tests and analysis using tracer rocks and scour chains
(3) Measure depth and velocity of surface water
(4) Measure gravel permeability with tracer tests

(5) Measure hyporheic pressure head of mini-piezometers vs. surface water (upwelling and downwelling)
(6) Measure temperature data using temperature loggers
(7) Measure hyporheic water quality field parameters (dissolved oxygen, turbidity, electrical conductivity, pH, and temperature) from mini-piezometers

1.2 BACKGROUND

Salmonid species are critical indicators of good water quality, a healthy ecosystem, and effective watershed management (DeVries, 2000). Gravel-bed streams are used by salmonids for spawning and the incubation of embryos. Approximately one third of natural salmonid spawning in Northern California occurs in the Lower American River, making the condition of this stream channel very important. The American River has been the site of at least seven gravel experiments or augmentation projects over the past 20 years (Vyverberg et al., 1997; Hannon 2000, Horner et al., 2004; Horner, 2005; Redd and Horner, 2009; Janes et al., 2012). The focus of these projects has been gravel addition or enhancement to offset the degradation of natural spawning areas on the river. Many of the factors that limit successful natural spawning are part of the physical environment and depend on appropriate water depth and velocity, substrate size, temperature, dissolved oxygen content, and a variety of other more subtle factors like cover, upwelling or downwelling conditions, and hyporheic flow.

Spawning Habitat Requirements

Naturally flowing gravel-bed streams are often characterized by changes in bed gradient that appear as a series of pools and riffles. Pool-riffle sequences provide a heterogeneous environment for salmonid spawning (Figure 1.1). Successful salmon spawning occurs when the female salmon is able to construct a redd (spawning nest) by excavating a pit in streambed gravel, deposit and bury her eggs, the eggs incubate and hatch, and alevins (recently hatched fish) develop and emerge (Kondolf et al., 2008).

Redd construction creates localized flow conditions that direct stream flow through individual redds (Figure 1.2).

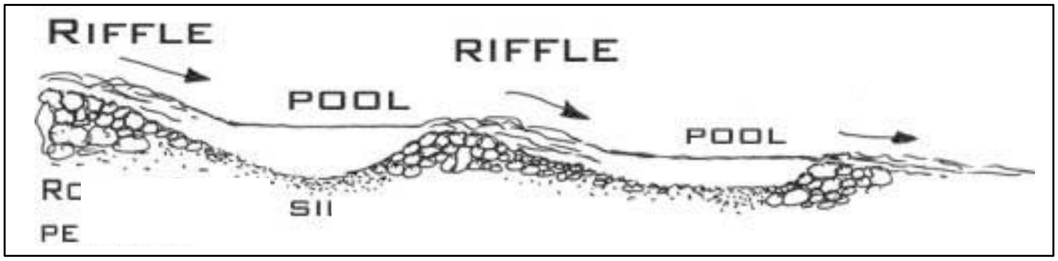


Figure 1.1: Longitudinal cross section of a pool-riffle sequence. (From FSC, 2012)

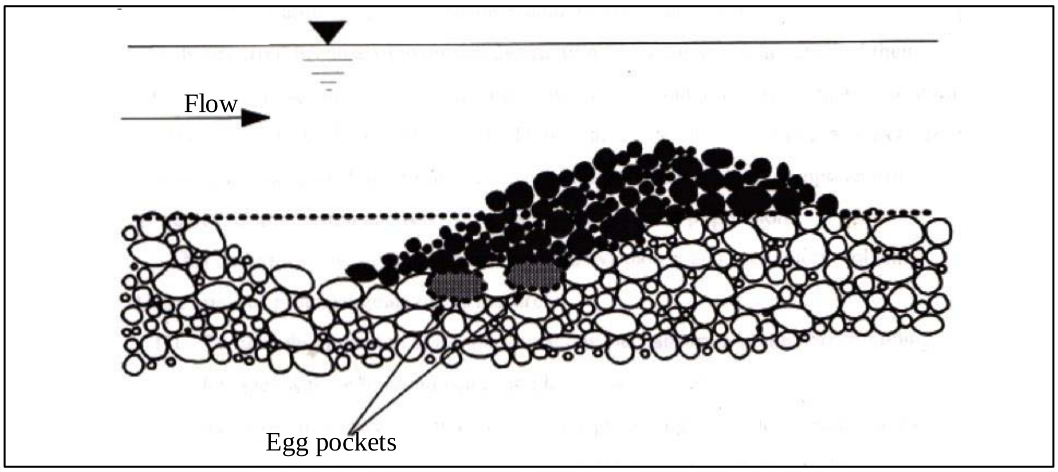


Figure 1.2: Longitudinal cross section of a salmonid redd. Depicted are the original bed surface elevation (dashed line), locations of two egg pockets, and disturbed bed material (shaded particles) forming a tailspill. (From DeVries, 2000)

Salmonids construct redds between 7 in and 12 in deep in the streambed (Hannon, 2000; Monaghan and Milner, 2009) and bury their eggs in the hyporheic zone. The hyporheic zone is the band of shallow gravel where exchange occurs between the stream and the subsurface (Bencala, 2005). This active interface between groundwater and surface water is important for the supply of chemicals, nutrients and organic matter that characterize a healthy ecosystem. Dynamic flow through the hyporheic zone supplies oxygenated water to egg pockets while removing metabolic waste (Coble, 1961; Vaux, 1962; Chevalier et al., 1984).

Hyporheic Zone

The hydraulic, chemical, and temperature gradients that often characterize the hyporheic zone (Bencala, 2005) are linked to the topography and sediment lithology of the stream channel (Hyporheic Network, 2009). Pools and riffles create points of high and low pressure that facilitate the movement of water through the streambed (Figure 1.3). Backwater in the pools creates a high-pressure zone that forces stream water down into the gravel; the water then moves through the subsurface to low-pressure areas at the downstream end of the riffle (Kondolf, et al., 2008). It is within this zone that stream water has a chance to interact with groundwater.

Within a typical hyporheic system, the flow of water across the interface is a function of the hydraulic conductivity of the substrate and the hydraulic gradient acting across the hyporheic zone (Ingebritsen and Sanford, 1998). Hydraulic conductivity varies throughout the streambed based on sediment lithology. Differences in hydraulic head between surface water and groundwater affect the direction and magnitude of subsurface exchange; flow may be upward to the river or downward to the aquifer (Ingebritsen and Sanford 1998). Lateral flows also occur in and out of riverbanks (e.g. Woessner, 2000), and often involve greater amount of flux than the vertical flows (Storey et al., 2003).

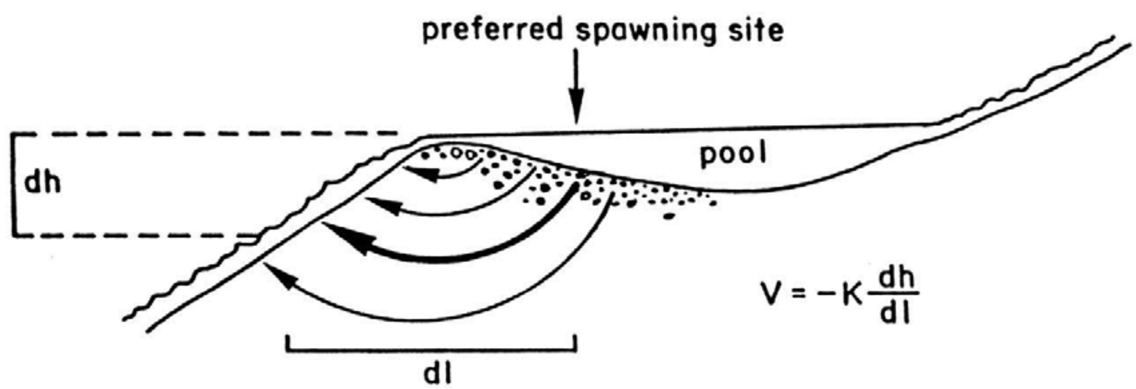


Figure 1.3: Flow through a pool-riffle sequence. Pressure differences induce downwelling in the pool and upwelling at the downstream end of the riffle. K is hydraulic conductivity and V is Darcy's velocity; vertical scale is greatly exaggerated. (From Kondolf et al., 2008)

1.3 STUDY AREA

The American River (Figure 1.4) drains a watershed of over 1,900 mi^2. Elevations range from approximately 9,800 ft at the headwaters, east of Sacramento, at the crest of the Sierra Nevada Mountain Range to nearly sea level at the confluence with the Sacramento River (Fairman, 2007). The drainage basin can be separated into two parts, Upper and Lower. Above Folsom Lake and Lake Natoma, the Upper American River consists of multiple forks with steeper gradient and higher energy flows through steep canyon walls. Below Folsom and Nimbus Dams, the Lower American River presents a gentler gradient, approximately 0.06 (Horner, 2004), with channelized flow across an alluvial plain (Redd and Horner, 2010).

Folsom Dam is the first of two major dams that regulate flow to the Lower American River. It has a reservoir with a 975,000 ac-ft capacity and provides flood protection, stores water for irrigation and domestic uses, and generates hydropower. Seven miles downstream, Nimbus Dam regulates water released from Folsom Dam and provides steady flow through the Lower American River. The primary hydrological purpose of the dams has been to reduce variance in winter runoff and store snowmelt for release in the spring when irrigation needs spike (Williams, 1999). Periodic large water releases from Nimbus Dam have caused the river to become incised, and the dam acts as a sediment trap that causes the river to lose an average of 50,000 ft^3 of gravel per year (Horner, 2004; Fairman, 2007).

In addition to the reduction of suitable gravel for salmonid spawning, the streambed is degraded by armoring. Managed flows winnow away fine material, and the remaining grains are tightly packed and ay be cemented together by a blend of organic material, very fine-grained silt, and clay sediments (Horner, 2004; Redd and Horner, 2009). Furthermore, dams alter the temperature and volume of water flowing through the channel compared to that observed in a naturally flowing riparian environment (Monaghan and Milner, 2009).

The Lower American River comprises the final 23 miles of the watershed downstream of Nimbus Dam (Figure 1.4). Here the river cuts into steep cliffs formed by

Miocene to Pliocene-aged sandstone and siltstone of the Fair Oaks and Mehrten Formations (Schlemon, 1967). The riverbed substrate becomes progressively smaller as it meets its terminus with the Sacramento River, moving from coarse-grained gravels to smaller sand and silt sized material (Vyverberg et al. 1997). The river's south bank is composed of gradually terraced Pleistocene alluvial gravels (Schlemon, 1967). The study area for this report includes four reaches located approximately one mile downstream of Nimbus Dam (Figure 1.4).

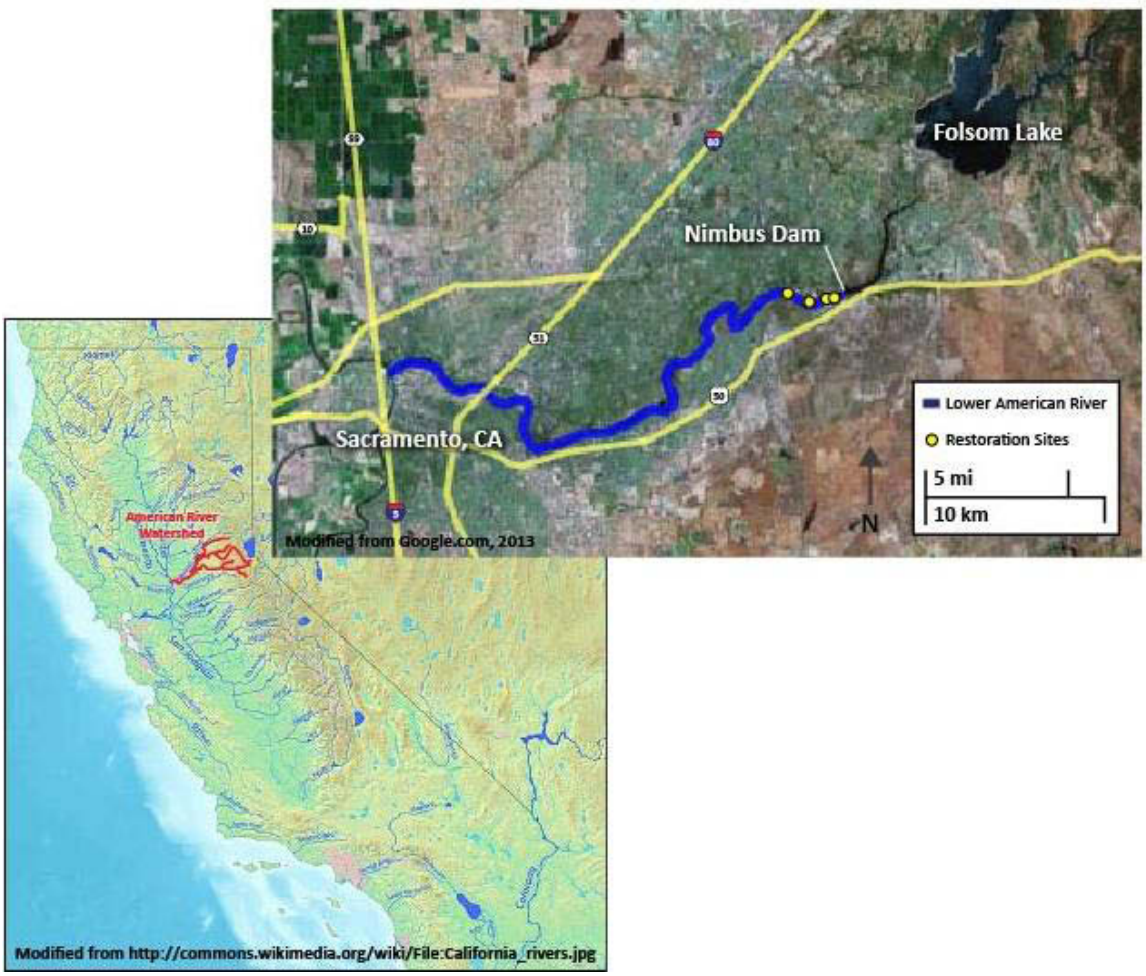


Figure 1.4: Location map of Lower American River Restoration Project

The regional climate is Mediterranean, characterized by warm, dry summers and cool, wet winters. Average precipitation in the watershed ranges from 18.5 in/yr to 78.7

in/yr (NOAA, 2011). Stream flow is highly seasonal (USGS, 2009). Lower elevation run-off is the result of winter rains, and very high flows are the result of winter storms (Williams, 1999). Prior to 1955 (year of completion of Folsom and Nimbus Dams), American River peak flows ranged from 10,000 cfs to180,000 cfs; current annual peak flow ranges between 1,000 cfs and 135,000 cfs (USGS, 2009). Daily peak flows during the duration of this study (2008-2013), ranged from 1,000 cfs to 30,000 cfs (Figure 1.5).

1.4 PREVIOUS WORK

In 1992, Snider et al. conducted redd surveys and determined that 90% of natural spawning on the Lower American River occurred in the six miles of channel directly below Nimbus Dam. Two years later, 18 areas within that river reach were chosen for further analysis. Physical measurements (gravel size distribution, water depth and velocity, and substrate permeability) were compared to spawning activity by Chinook salmon and steelhead populations (Vyverberg et al., 1997). Segments of river where little or no spawning occurred were determined to be the result of low permeability, cemented or interlocking substrate materials, and inappropriate gravel composition (Horner, 2004).

Three of the 18 areas were chosen for gravel enhancement in 1999 based on low suitability for salmonid spawning. These areas were characterized by a combination of excess fine sediment, excess coarse sediment, surficial armoring, clay layers, or the presence of coarse lag deposits. Each site posed a different set of complications for natural spawning, and remediation designs addressed site specific problems. Post-treatment monitoring and evaluation were conducted through 2003, and concluded that some of the river reaches were better suited for rehabilitation projects than others (Horner, 2005). These earlier projects also suggested a variety of approaches for future habitat rehabilitation that included further analysis and monitoring of spawning habitats.

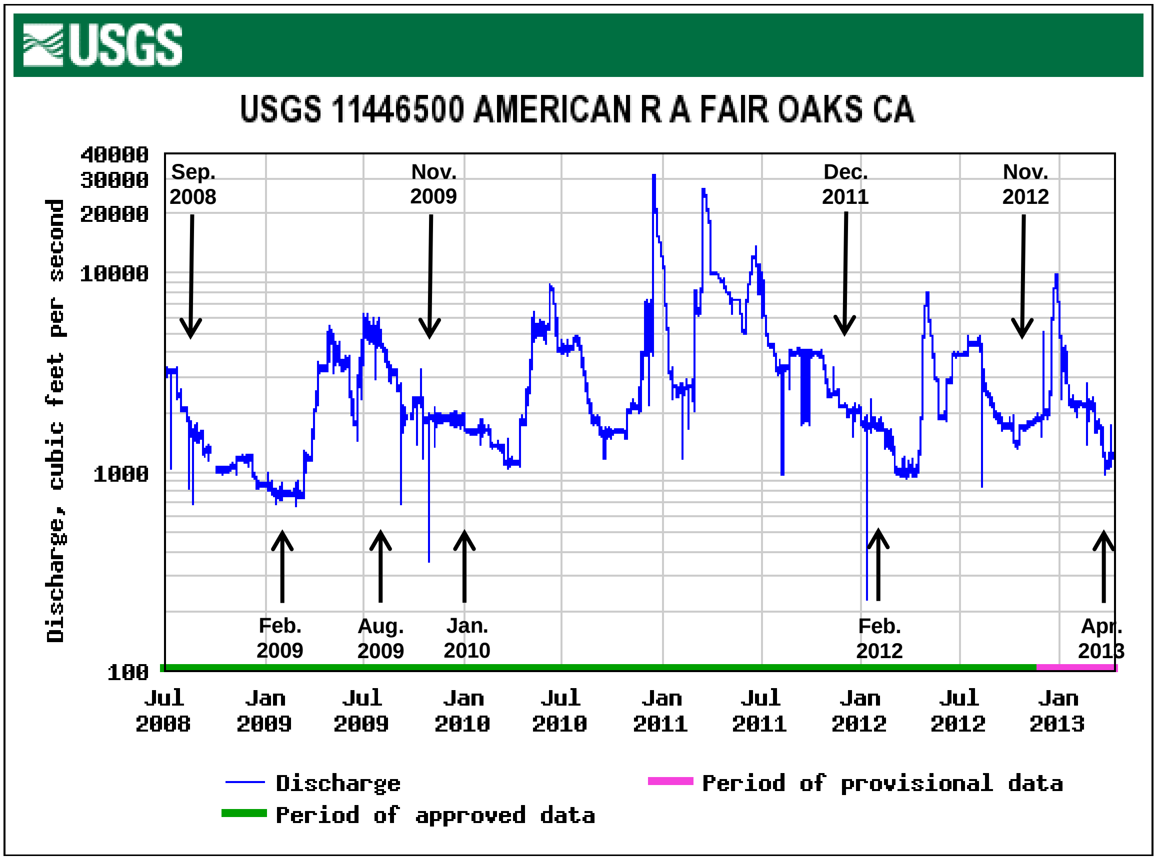


Figure 1.5: Lower American River Peak Discharge from July 2008 through April 2013 (From the USGS, 2012). Black arrows indicate months when water quality parameter data were collected.

1.5 CONTINUED WORK

In 2008, a new phase of remediation began with augmentation of 7,000 tons of gravel at the Upper Sailor Bar 2008 study site (Figure 1.6), followed by five years of post-treatment monitoring and evaluation. The succeeding year, Upper Sailor Bar 2009 was augmented with 9,000 tons of gravel and has been monitored for the past four years. 12,000 and 14,000 tons of gravel were added to the Upper Sunrise 2010/2011 site in 2010 and 2011, respectively, with monitoring through 2013. Finally in September of 2012, approximately 14,000 tons of gravel was added to the Lower Sailor Bar 2012 site (Figure 1.7), followed by post-treatment monitoring and analysis in 2012 and 2013.

Post-treatment monitoring and evaluation attempt to provide an understanding of the hydrologic and geomorphic changes resulting from restoration work by observing the physical environment. Each measurement in the physical environment has a tie to a part of the salmonid life cycle. A better understanding of the physical environment at restoration sites should lead to improved project design and more successful natural spawning.

Figure 1.6: Location of four restoration sites on the Lower American River. Nimbus Dam obstructs the passage of fish further upstream.

Figure 1.7: Komatsu front-end loaders placing sorted gravel across the Lower Sailor Bar 2012 gravel restoration site in September 2012 (From BOR, 2012)

2.0 METHODS

This project used a BACI study design ("Before, After, Control, Impact") to show differences between gravel areas before and after restoration (Horner et al., 2004). Faculty and students from CSUS focused on physical and hydrologic measurements at four gravel addition sites (Figure 1.6) from 2008 through 2013. Measurements included grain size analysis, gravel mobility, surface water depth and velocity, gravel permeability, hyporheic pressure head, temperature, and inter-gravel water quality parameters.

2.1 GRAIN SIZE

Redd construction, egg development and alevin emergence can be limited by the availability of suitable gravel sizes (Nawa et al., 1993; DeVries, 2000; Horner, 2004; Kondolf et al., 2008). An excessive amount of either large grains or fine sediment can be problematic for salmon at different stages in the reproductive cycle. During spawning, the female salmon builds a redd by moving gravel to excavate a pit in the streambed (Figure 2.1). If the grains are too large, she will be unable to move them (Kondolf, 2000). Kondolf et al. (2008) note that some larger grains are acceptable, because the salmon does not move all rocks present; however, most of the grains need to be movable for proper redd construction. After deposition, incubating eggs require hyporheic flux through streambed gravel to supply oxygen and remove metabolic waste. As alevine emerge from egg pockets, they must wriggle through the gravel to reach the stream (Kondolf, 2000). Grains that are too small block pore spaces that reduce hyporheic flow within redds and also obstruct passages between grains for newly emerged fish (Kondolf, 1997; Kondolf et al, 2008).

The altered flow patterns and sediment loads of regulated rivers are known to degrade spawning habitat by impounding nearly all bedload upstream of the dam and diminishing sediment supply below the dam (Kondolf, 1997). Abnormal river flows produced by dams promote the retention of coarse grains, the accumulation of organic material and fine sediment, and the reduction of smaller gravel necessary for salmonid spawning (Bunte and Apt, 2001). The resulting streambed is often armored, consisting of large interlocking grains cemented together by organic matter, silt and clay-sized particles. An armored streambed is problematic for salmon spawning, because it provides obstacles for redd construction and hinders hyporheic flow through riverbed gravel (Horner, 2004; Suttle et al., 2004; Kondolf et al., 2008).

In the Lower American River, female salmon construct redds approximately one foot deep in the streambed (Hannon, 2000), and prefer a median grain size (D_{50} value) of less than 10% of the salmon's length (Vyverberg et al., 1997; Kondolf, 2000). Grain size distribution was measured using Wolman (1954) pebble counts and bulk samples.

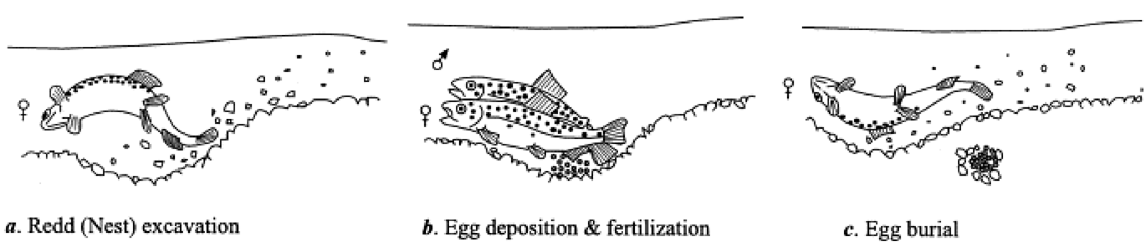


Figure 2.1: Salmonid spawning behavior (from Soulsby et al., 2001)

Cumulative frequency curves were used to present grain size distributions (Figure 3.2) that show the cumulative percent finer than a given grain size (Kondolf et al., 2008). Particle size is expressed in inches on these graphs, but may also be converted to phi units Φ for calculations. For example, the D_{90} value represents the grain size where 90% of the sample is finer and 10% is coarser than the given grain size. The D_{50} value represents the median particle diameter of the sample, and is commonly used because it is easy to read and unaffected by distribution extremes (Inman, 1952; Vanoni and Brooks, 1975).

Pebble Counts

Modified Wolman (1954) pebble counts were used to assess the surface gravel of the study area before and after the addition of gravel at the Lower Sailor Bar 2012 site. In this method, 100 pebbles were randomly selected from transects across the study area

(Figure 2.2). The intermediate axis of each pebble was measured with a template (Figure 2.3C) and the location of the transects was recorded with GPS. To ensure a truly blind study, the field worker took a step forward and, with eyes averted (Leopold, 1970), picked up the pebble directly beneath the big toe of the worker's boot; the first pebble touched was the pebble measured. Pebbles were placed into classes ranging from 5/16 inch to seven inches (Horner et al., 2004), and the data were plotted on a log scale to construct a cumulative size distribution curve, from which statistics like median grain size were extrapolated (Kondolf, 1997).

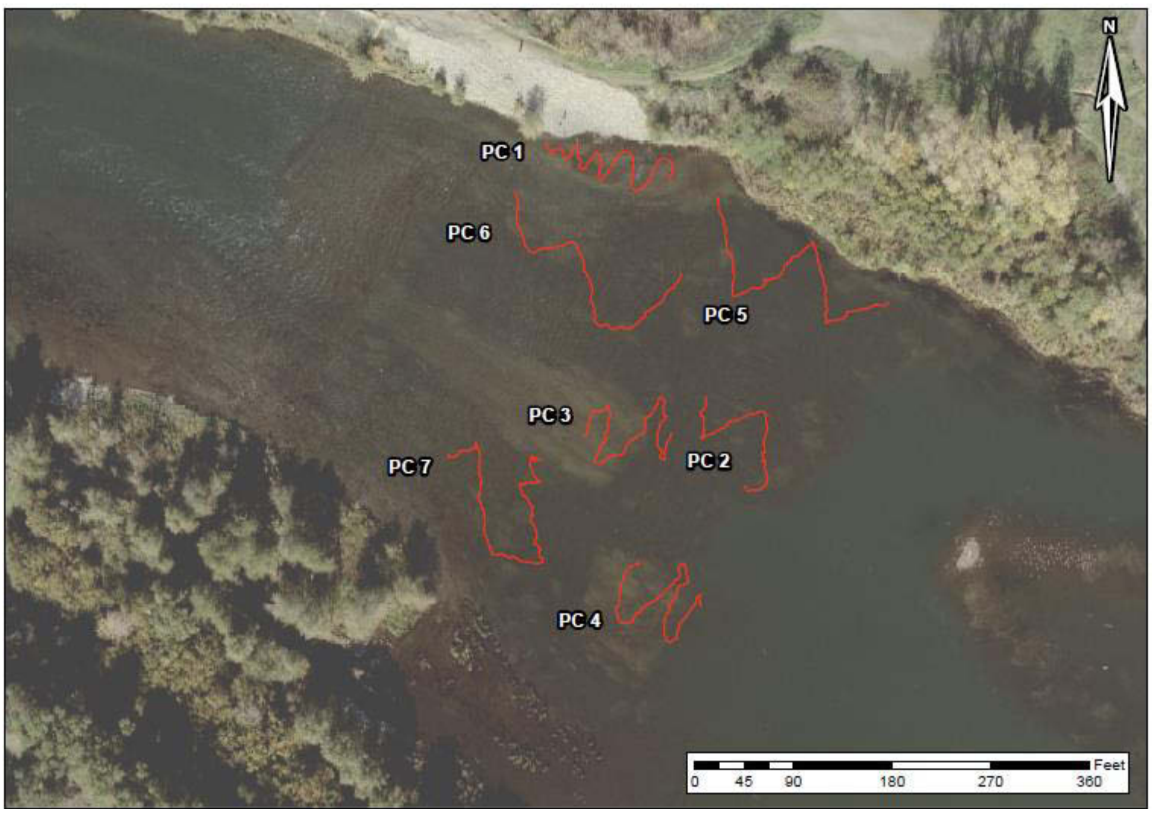


Figure 2.2: Map of Lower Sailor Bar 2012 site showing the location of post-restoration pebble count transects conducted in November 2012.

Bulk Samples

Bulk samples were used to assess the surface and subsurface gravel at the Lower Sailor Bar 2012 site after gravel was added. Pre-project bulk samples were not collected because of high flows and deep water at the site. This method considers fine sediments within the substrate that are not accounted for by pebble counts. In this method, a marker was tossed to randomly determine the center of the bulk sample area, and the location was mapped using GPS. Bulk sample size was calculated by multiplying the weight of the largest surface grain in the sample area by 100 (Ettema, 1984). A metal baffle was placed in the streambed to prevent fine sediments from escaping during collection (Figure 2.3B). Samples were collected with a shovel and transported in five gallon buckets to shore (Figure 2.3A), where they were drained and weighed (Bunte and Abt, 2001).

To distinguish riverbed armoring, Surface and subsurface samples were collected separately (Kondolf, 2000) with the depth of the surface sample equal to the diameter of the largest surface grain (Ettema, 1984). Grains were separated into size classes using rocker sieves with openings approximately 0.313, 0.625, 0.875, 1.25, 1.75, 2.5 and 3.5 in in size (Figure 2.3D), and grains larger than 3.5 in were sorted manually. Each class was weighed on a digital scale and weights were recorded. Grains less than 0.3125 in were sieved in the lab. The total weight of each class was divided by the total weight of the sample to determine the percent weight distribution in the sample area. Data were plotted on a log scale to construct a cumulative percent distribution curve, from which statistics like median grain size were extrapolated.

Sorting

Sorting of grains refers to the range of grain sizes present in a given sample, and the distribution of these sizes around the mean (Boggs, 2011). Analyzing the degree of sorting at a site before and after restoration may be useful in determining the transportation process, as well as the rate, duration, and total energy of deposition (Compton, 1962). While sorting can be estimated in the field using diagrams (Tucker, 1996), a qualitative mathematical determination is more accurate, and can be obtained from cumulative weight percent distribution curves constructed from bulk samples (Boggs, 2011). Sorting (σ_i), the inclusive graphic standard deviation, is defined in equation 2.1 (Folk and Ward, 1957) as:

$$\sigma_i = \frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{95} - \Phi_5}{6.6} \qquad (2.1)$$

where Φ_{84}, Φ_{16}, Φ_{95}, and Φ_5 are obtained by converting the D_{84}, D_{16}, D_{95} and D_5 values from cumulative percent distribution curves (Figure 2.4) using equation 2.2. The degree of sorting is determined by comparing the standard deviation from equation 2.1 to a range of values in Table 2.1.

$$\Phi_x = -\log_2 D_x \qquad (2.2)$$

Figure 2.3: Bulk samples are (a) collected and transported to shore in 5 gallon buckets. (b) A metal baffle prevents fines from escaping during collection. (c) A pebble size template with square openings measures the intermediate axis diameter of grains; the largest opening through which the grain will not fit is considered the upper end of the grain size range. (d) Grains are sorted into size classes using rocker sieves.

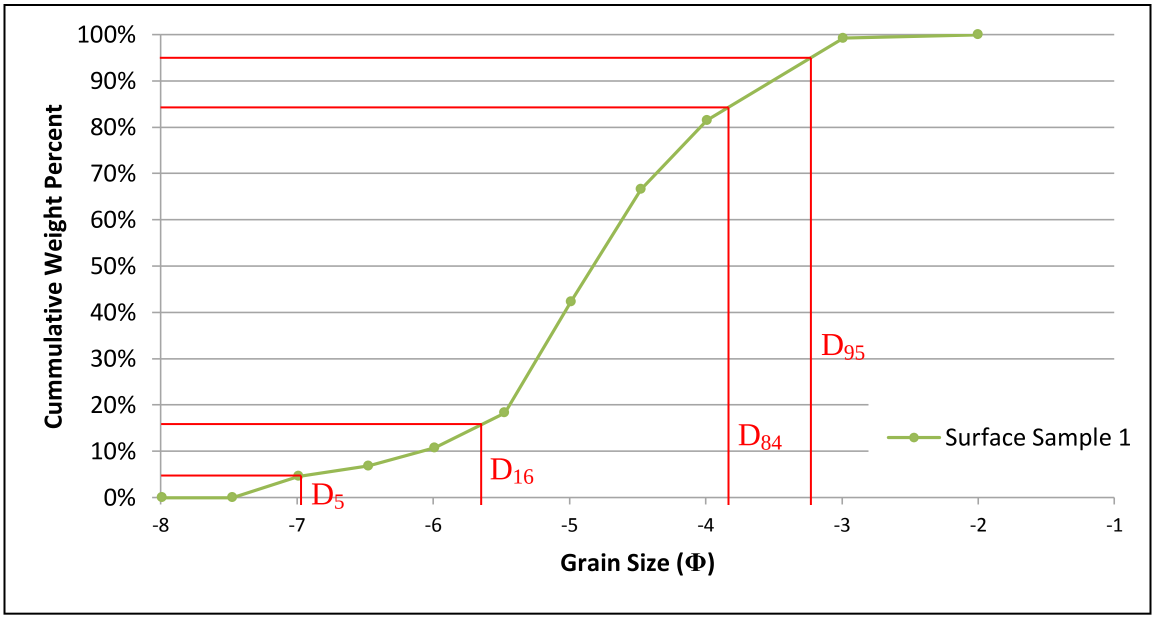


Figure 2.4: Cumulative percent distribution curve for grain size (measured in phi) at the Lower Sailor Bar 2012 site (post-restoration) from bulk sample data. D_{84}, D_{16}, D_{95}, and D_5 values are noted in red.

Table 2.1: Standard deviation range and degree of sorting (From Boggs, 2011)

Standard Deviation	Sorting
< 0.35Φ	Very well sorted
0.35-0.50Φ	Well sorted
0.50-0.71Φ	Moderately well sorted
0.71-1.00Φ	Moderately sorted
1.00-2.00Φ	Poorly sorted
2.00-4.00Φ	Very poorly sorted
>4.00Φ	Extremely poorly sorted

2.2 GRAVEL MOBILITY

Successful salmonid spawning can be impacted by gravel mobilization during high stream flow events (Nawa et al., 1990; DeVries, 2000), because the rounded cobbles and pebbles necessary for spawning are highly mobile. The movement of this material has both biological and physical implications, so the effects of high flows on spawning habitat are very important. Large magnitude flood events are capable of eroding and depositing streambed material over a short period of time, causing changes in bed topography called scour and fill (Leopold, 1964). Scour and fill can lead to the complete washout or crushing of salmonid eggs (DeVries, 1997). Some studies indicate that salmonid embryo survival can be limited if a redd is scoured down to egg elevation (McNeil 1966; Seegrist and Gard, 1972; Kondolf et al., 1991), while others have found that even minor scour can significantly reduce the survival of embryos (Montgomery et al., 1996).

Localized scour and fill are common at restoration sites on the Lower American River, and problematic for the overall longevity of restoration projects (Horner, 2005). Previous studies have shown that the processes of scour and fill are influenced by several factors (Carling, 1987; Haschenberger, 1999; Bigelow, 2005; DeVries, 2000). Some studies indicate that scour and fill are controlled by shear stress levels (Bigelow, 2005), while others point to a correlation between sediment supply, particle size, and the amount of scour and fill that occurs in the stream bed (Lisle and Eads, 1991; Nawa and Frissell, 1993; Harvey and Lisle, 1999; DeVries, 2000). Information about scour and fill will inform managers about the average longevity of projects, and the intervals at which gravel will need to be replenished. For this study, gravel mobility was measured using tracer rocks and scour chains.

Tracer Rocks

Tracer rocks monitor the migration of discreet sizes during varying flow conditions at restoration sites. Three sizes of tracer rocks (Figure 2.5) were deployed following gravel augmentation at the Upper Sailor Bar 2008, Upper Sunrise 2010/2011 and Lower Sailor Bar 2012 sites. The largest rocks (2.5 in. – 3.5 in.) were painted yellow, the middle size rocks (1.25 in. to 1.75 in.) were painted blue, and the smallest rocks (0.625 in. to 0.825 in.) were painted red. Tracer rocks of each size were labeled with permanent ink to show their initial location, and placed along several transects that run across the site perpendicular to flow. The individual placement of each tracer rock was mapped using GPS, and position of the tracer rocks was tracked after various flow events.

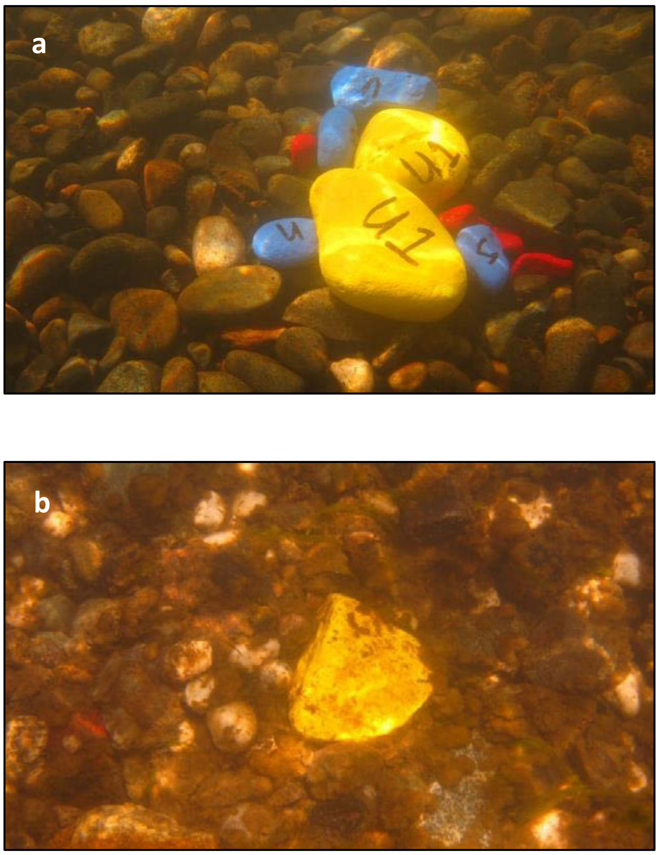


Figure 2.5: (a) Initial placement of yellow, blue, and red tracer rocks; (b) displacement of yellow tracer rock following a higher flow event indicates movement of bedload.

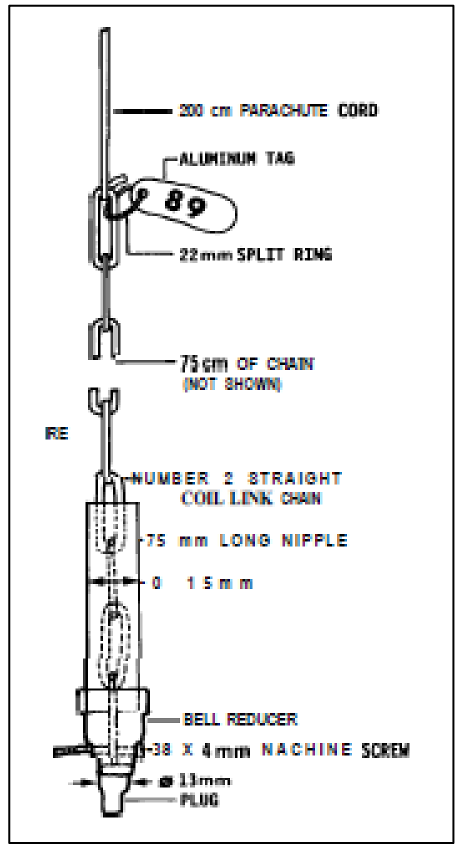


Figure 2.6: Diagram of a scour chain with anchor constructed from pipe fittings. (From Nawa and Frissell, 1993)

Scour Chains

Many studies have used scour chains to directly measure scour and fill in stream channels over time (Leopold et al, 1964; Madej, 1984; Tripp and Poulin 1986; Nawa and Frissell, 1993). A scour chain is composed of a straight linked steel chain, approximately 3 ft long, attached to an anchor constructed of galvanized pipe fittings (Figure 2.6). A brightly colored nylon cord is affixed to the end of the chain to make it easier to find for future measurements. The completed scour chain is inserted approximately 15 in.- 20 in. down into the streambed (anchor side down) using a steel pipe and a post driver.

Scour chains were installed after augmentation at the Upper Sailor Bar 2009, Upper Sunrise 2010/2011, and Lower Sailor Bar 2012 sites to measure scour and fill of the restored gravel. Chain locations were placed at regular intervals across each restored site and locations were recorded using GPS. The initial exposed length of chain was recorded (Lisle and Eads, 1991), and re-measured periodically to show erosion or deposition. If more chain was exposed, then less material was present and scour (erosion) had occurred. If less chain was exposed, then more material was present and fill (deposition) had occurred (Figure 2.7).

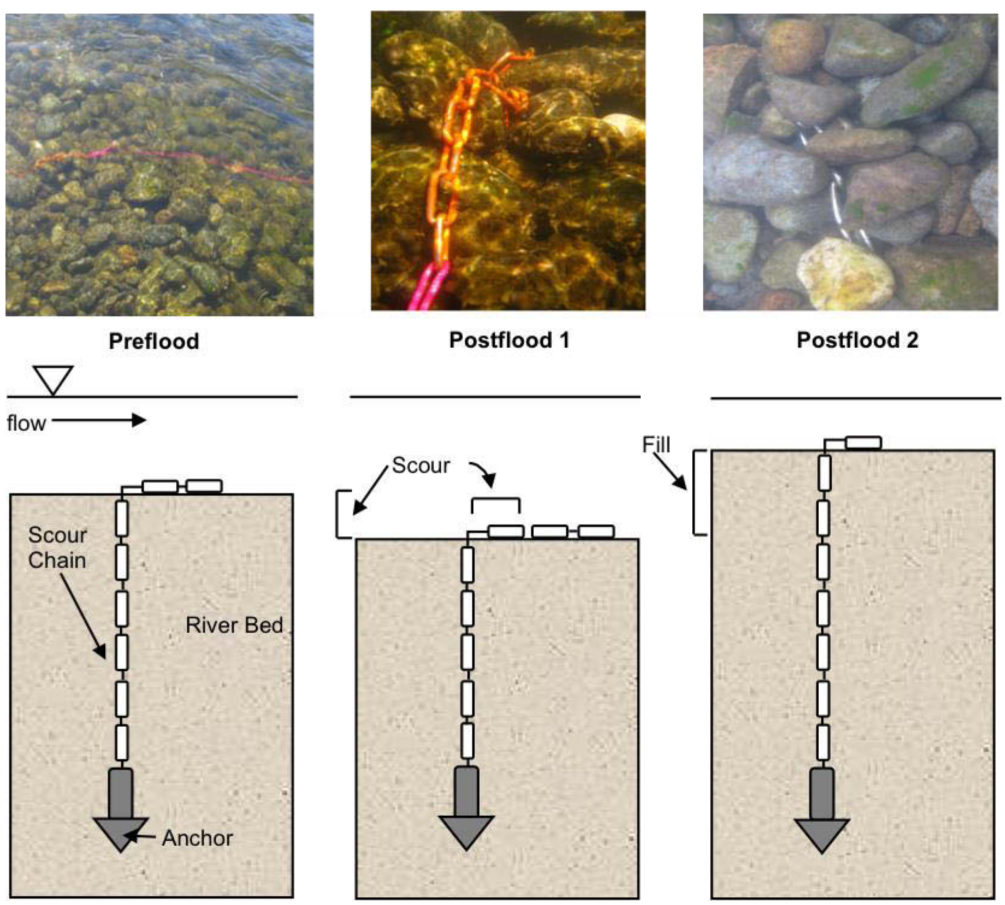


Figure 2.7: Schematic of scour chains in the riverbed showing initial placement of a scour chain in streambed; exposed chain after a scour event; buried chain after a fill event (From Janes et al., 2012).

2.3 SURFACE WATER DEPTH AND VELOCITY

Surface water depth and velocity are key factors in the selection of suitable redd sites by spawning salmonids. If velocities are too high, the female salmon must expend excessive amounts of energy fighting the current and spends less time on her redd when compared to optimal conditions (Chapman et al., 1986, Hannon, 2000). If velocities are too low, hyporheic exchange is lessened and oxygen and nutrients are not delivered to the developing eggs. In 2004, Horner et al. reported that optimal salmonid spawning in the Lower American River occurred at water depths ranging from the fin height of the salmon to approximately six feet of stream depth. Chapman et al. (1986) found that Chinook salmon prefer water velocities between 1.3 ft/sec. and 6.3 ft/sec.

Depth and velocity were measured at all four restoration site using standard USGS stream gaging procedures (1980). A topset wading rod was used to determine depth. A Price AA current meter or a Marsh-McBirney electronic velocity meter was attached to the wading rod to measure surface water velocities (Figure 2.8). Measurements were made at locations where mini-piezometers had been installed throughout the study area. When using the current meter, the number of revolutions (R) completed by current meter cups was counted for a 60 second interval, and then converted to velocity (V) using equation 2.2 (USGS, 1980).

$$V=2.2048(R)+0.0178 \qquad (2.2)$$

The Marsh-McBirney electronic velocity meter automatically calculated a velocity value in feet per second. Two velocity measurements were taken at each mini-piezometer location, at 60% and 80% below the water surface. The 60% measurement represents the average velocity of the water column, and the 80% measurement represents the “snout velocity” of the salmonid. The direction of flow was measured using a Brunton compass.

Depth and Velocity data are reported on maps showing depth, velocity and direction of flow, and in tables that include range, mean, standard deviation, and the coefficient of variation. The coefficient of variation (CV) is a normalized measure of the dispersion in a distribution that does not depend on the unit of a given parameter, in this case depth and velocity. CV is a dimensionless value defined as the ratio of the standard deviation (σ) to the mean ($\bar{x}$) multiplied by 100, as in equation 2.3 (Neville and Kennedy, 1964), and shows the extent of variability in relation to the mean: the higher the coefficient, the greater the dispersion in the parameter. The CV can only be used if the mean of a variable is not zero or close to zero, and if all sampled values are positive (UCLA, 2013).

$$CV = \frac{\sigma}{\bar{x}} \times 100 \qquad (2.3)$$

While standard deviation is a useful way to look at the dispersion of a single variable, it is unit dependent and cannot be compared to variables with differing units in a meaningful way. The advantage of the CV is that it is dimensionless. As a ratio of the standard deviation and the mean (both of which are expressed in the same units, allowing for the cancellation of units), CV's of different variables (and differing units) can be compared in a meaningful way: the variable with the greater CV is more dispersed than the variable with the smaller CV (UCLA, 2013).

Figure 2.8: Field team determining surface water depth and velocity using a wading rod and Price AA current meter.

2.4 GRAVEL PERMEABILITY

When eggs have been deposited in the redd, it is imperative that flow persist through the streambed. The ability of water to move through hyporheic gravels, or permeability, is used as an indicator of spawning gravel quality. Highly permeable gravels allow the exchange of oxygenated water and other nutrients between the stream channel and hyporheic zone (Barnard and McBain, 1994). When excess fine sediment intrudes into the streambed, the decreased permeability effects this active exchange, and can have negative effects on egg and fry survival (Cordone and Kelley 1961). According to Terhune (1958), the survival of eggs is highly dependent on the oxygen available to them in the surrounding water.

In past studies (Janes et al., 2012), gravel permeability was evaluated using saltwater tracer tests to measure subsurface seepage velocities in the shallow gravel where salmonids construct redds. Tracer Tests are dependent on stream flow, require long field tests, and may cause swelling of clay minerals in the subsurface. Additionally, tracer tests produce a seepage velocity that is not directly comparable to the hydraulic conductivity (K) value that typically describes permeability. Because of these factors, it was determined that standpipe drawdown tests (Terhune 1958; Barnard and McBain, 1994) are more effective at evaluating gravel permeability, and therefore standpipe drawdown tests were conducted at all four restoration sites during the 2011/2012 field season.

Standpipe Drawdown Test

Permeability was measured using the standpipe drawdown test, pioneer by Terhune (1958) and adapted by Barnard and McBain (1994). In this method, a modified Terhune Mark IV standpipe (Figure 2.9a) was inserted into the streambed, and a pumping apparatus used to create a constant one inch drawdown in the intragravel water (Figure 2.9b). The volume of water collected during drawdown was measured and duration of the test recorded.

The pumping apparatus was composed of two capture tanks with individual intake valves attached to a vacuum pump and extraction hose (Figure 2.10a). One tank was used to collect test water, and the other to collect residual water. Residual water was a byproduct of the initial drawdown volume, and the water that drained out of the system following the test. To clear the screen of debris and stabilize recorded measurements, the pipe was developed before testing. To develop the standpipe, the extraction hose was inserted into the standpipe and approximately five gallons of water removed. Water was pumped from the standpipe until it was clear, indicating that silt and clay were removed from the standpipe and screened area. In cases where this volume of water could not be extracted, water was removed until turbidity was sufficiently low.

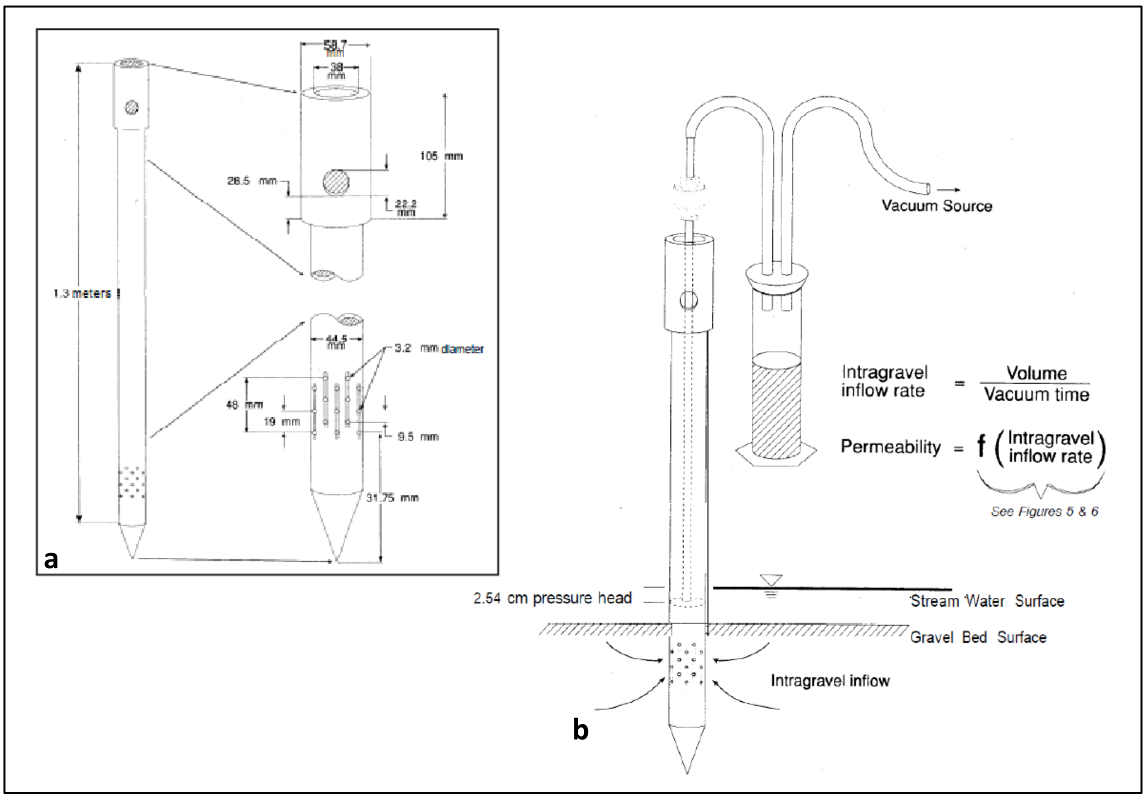


Figure 2.9: (a) Modified Terhune Mark IV standpipe; (b) permeability measurements using a modified Terhune (1958) standpipe (From Barnard and McBain, 1994).

After the standpipe was appropriately developed, the extraction hose was lowered into the pipe and positioned one inch below the water level. Water level was determined by a “slurping” sound indicating that the end of the hose had made contact with the water surface (Figure 2.10d). A clamp was affixed to the hose one inch from the top of the standpipe (Figure 2.10b). The clamp rested on the top of the standpipe, insuring that the hose remained one inch below the water surface. The test began with the residual tank open (Figure 2.10c). The pump was activated, removing water from the pipe until drawdown was obtained. At that point, the residual tank was closed, the testing tank opened and the timer started. Intragravel water was continuously drawn through the standpipe and into the testing tank until .75 gal to 1 gal (3000 ml to 4000 ml) was collected or an appropriate amount of time had elapsed. A graduated cylinder was used to measure the volume of water extracted, and the procedure repeated at least one additional time. Drawdown measurements were collected from four to ten locations at each study site. The test durations and the volumes of water extracted were used to determine hydraulic conductivity (K) values based on a calibration chart (Figure 2.11). Permeability data are reported in tables that include range, mean, standard deviation, and the coefficient of variation. The coefficient of variation is explained in Chapter 2.3.

Figure 2.10: Drawdown testing uses a pumping apparatus (a) with two capture tanks. An extraction hose is inserted into the standpipe (b) one inch below the water level. The field team determined the water level in the pipe by listening for a “slurping” sound (d) that indicated the end of the hose had made contact with the water. When drawdown was achieved, the main capture tank was opened to collect the sample (c).

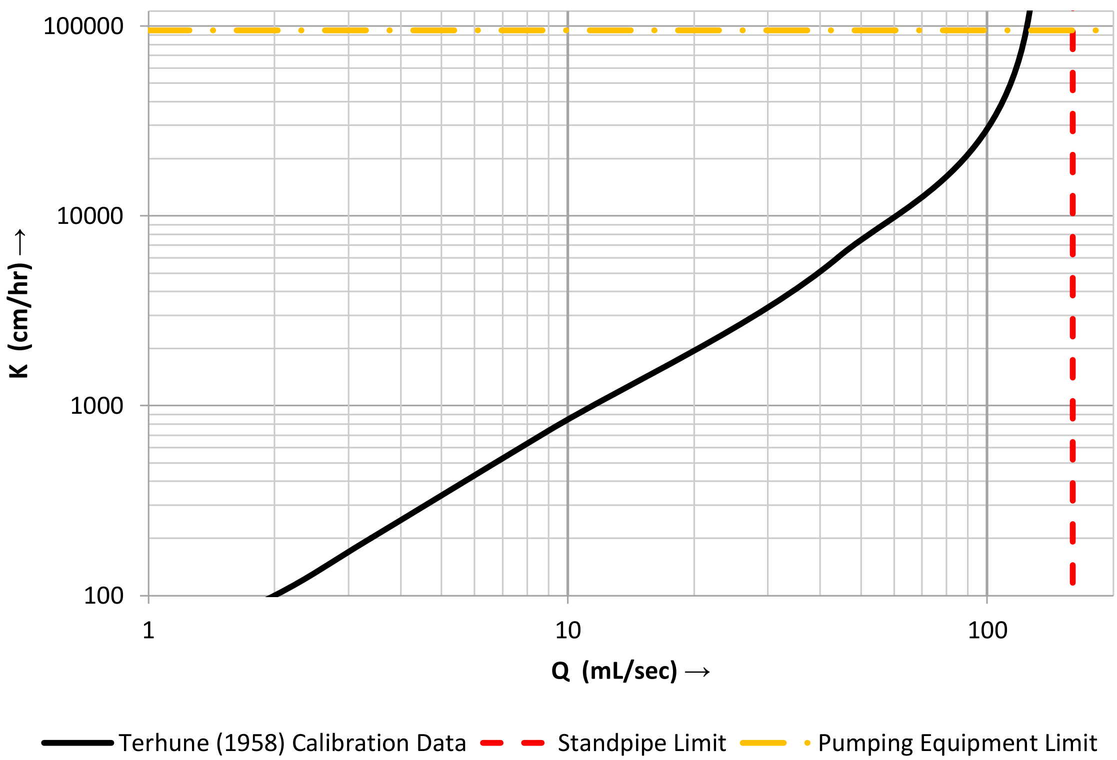


Figure 2.11: Modified Terhune (1958) calibration chart; Standpipe limit is 160 mL/sec (Terhune, 1958); Pumping equipment limit is approximately 9.5 x 10^4 cm/hr or 124 mL/sec.

2.5 HYPORHEIC PRESSURE HEAD

The direction of subsurface flow may be a significant factor in salmonid redd site selection (Geist and Dauble, 1998). Upwelling and downwelling increase the exchange of water through salmonid redds which replenishes oxygen and removes waste (Becker et al., 1983). Geist et al. (2001) found that Chinook salmon spawned where downwelling conditions occurred in the riverbed. Vronskiy and Leman (1991) propose that hyporheic exchange is critical, and suggest that if hyporheic exchange rates are high the direction of exchange may not be critical. According to Grieg et al. (2007), pool-riffle sequences are effective in creating upwelling and downwelling zones; female salmon create similar upwelling and downwelling zones on a much smaller scale when constructing a redd (Figure 2.12).

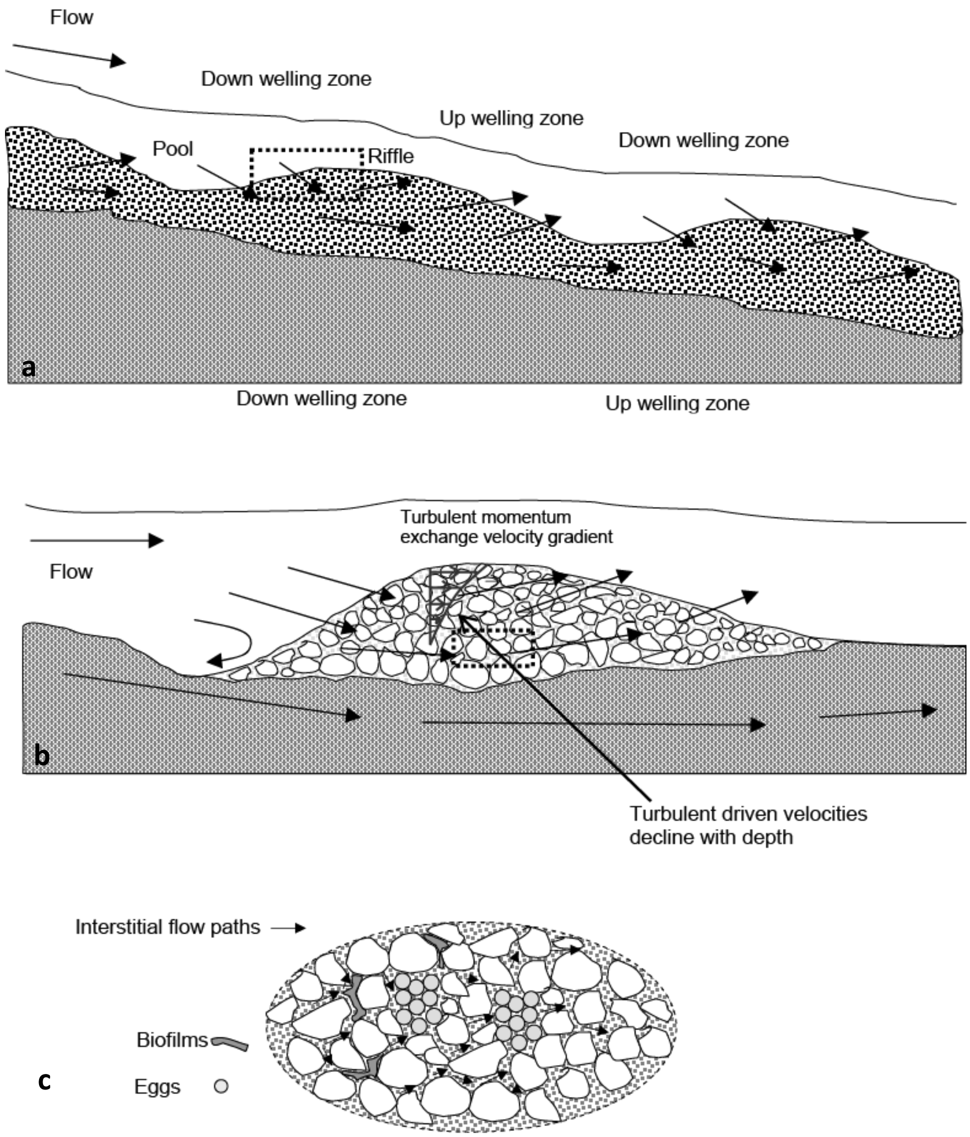


Figure 2.12: Subsurface flows; (a) reach-scale exchange flows. (b) Micro-scale exchange flows like in redds. (c) Interstitial flow paths in the gravel bed (From Grieg et al., 2007).

Water flows from high pressure to low pressure, so pressure head fluctuations can show upwelling and downwelling between the river channel and the hyporheic zone. Higher pressure head in the river vs. the subsurface indicates a downwelling area (losing condition), while higher pressure head in the subsurface vs. the river indicates an upwelling area (gaining condition). Pressure head differences between subsurface and surface waters were measured with a mini-piezometer, baffle bubble, and manometer board (Figure 2.13). Mini-piezometers were placed approximately one foot deep into the streambed at 30-40 locations at each study site to measure the pressure head of the hyporheic zone at discrete points. The baffle bubble was placed on the bottom of the streambed and used to stabilize surface water by removing the effects of stream flow on surface water pressure measurements. The manometer board was composed of a glass tube in the shape of an inverted "U" attached to a graduated board (Zamora, 2006).

One end of the glass tube was connected to the mini-piezometer, and the other was attached to the baffle. Measurements were made by connecting a peristaltic pump to the top of the manometer. The pump pulled both intragravel and surface waters through the glass tube until all air bubbles were removed. When the pump was stopped, a small amount of air was allowed to re-enter the tube through the top. While holding the manometer level, the difference in pressure head between subsurface and surface waters was read. The vertical gradient was calculated by dividing the manometer reading(difference in head) by the vertical distance between the screened interval of the piezometer and the river bottom (usually 1 ft).

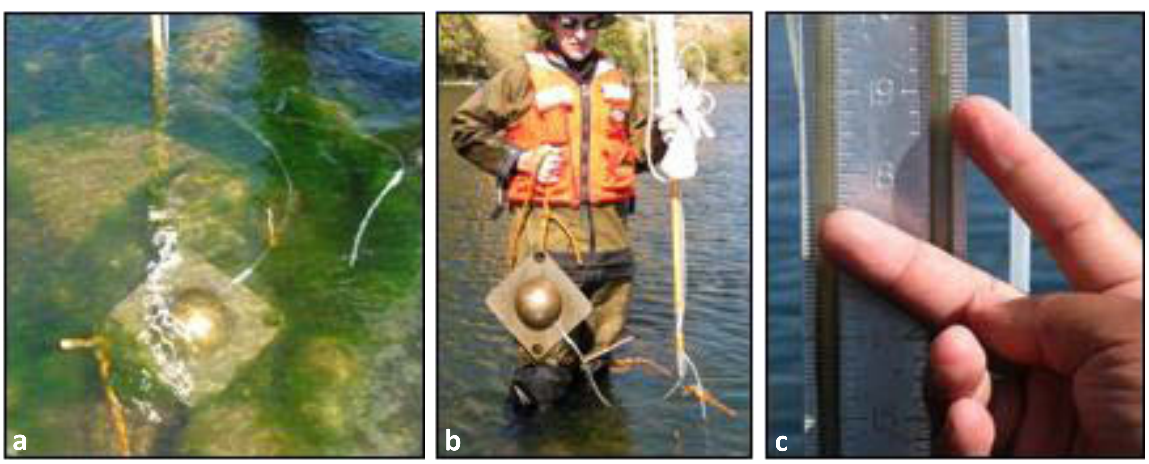


Figure 2.13: Dr. Tim Horner holding manometer board and baffle (b). Baffle (a) in water next to piezometer and both are connected to manometer board. Pressure head reading on the manometer board (c) showing downwelling conditions where the pressure measurement on the left is from the subsurface, which is lower than the river pressure measurement on the right.

2.6 TEMPERATURE

Surface water and hyporheic zone temperatures each play an important role in successful salomonid spawning. Upstream Chinook salmon migration is triggered when surface water temperatures drop to a critical threshold (Bjornn and Reiser, 1991), and salmonid eggs nested in stream gravel need cold oxygen-rich water for proper development (Becker et al., 1983). According to Stonestrom and Constanz (2003), water exchange between shallow aquifers and the river channel influence both surface water and substrate temperatures.

Surface water temperatures vary diurnally and seasonally (Fetter 2001; Ingebritsen and Sanford, 1998), while groundwater is relatively constant (Stonestrom and Constanz, 2003). The temperature difference between these two zones allows for both advective heat flow, where heat follows a flow path between two points within flowing water, and conductive heat flow, where heat travels between non-moving fluids and solids (Zamora, 2006). This transfer of heat can be used as a tracer to detect water movement in the hyporheic zone, and creates a distinct temperature signal between new gravel and old substrate (Figure 2.14). Temperature analysis from past projects has shown that new gravel is much more permeable than underlying streambed material (Horner, 2010).

Temperature in the shallow gravel was monitored using two methods. Ten to 15 mini-piezometers located one foot deep in augmented gravel were used to document temperatures at depths where eggs are laid at all four restoration sites. Larger upwelling and downwelling temperature patterns were measured with Hobo Water Temperature Pro v2 data loggers placed deeper in the augmented gravel to intercept heat tracer at the Upper Sunrise 2010/2011 and Lower Sailor Bar 2012 sites. Two pvc pipes, four feet in length, were inserted vertically into the gravel at the upstream and downstream ends of the study site with a sleeve and bar assembly, slide hammer, sledge hammer, and post driver (Figure 12.15). The temperature loggers were placed into the pipes at 0 ft, 1 ft, 2 ft, 3 ft, and 4 ft depths, and recorded temperature data at 30 minute intervals. Because small fluctuations in temperature can impact salmonid spawning negatively (Hannon, 2000 and Merz and Setka, 2004), temperature loggers were carefully calibrated in a 0°C ice bath, prior to installation, in order to ensure the loggers were functioning correctly. Data patterns were plotted to show shallow aquifer recharge (losing stream) and discharge (gaining stream) over time and space. This provides information about upwelling and downwelling conditions deeper into the gravel than the hyporheic pressure head measurements described in the previous section.

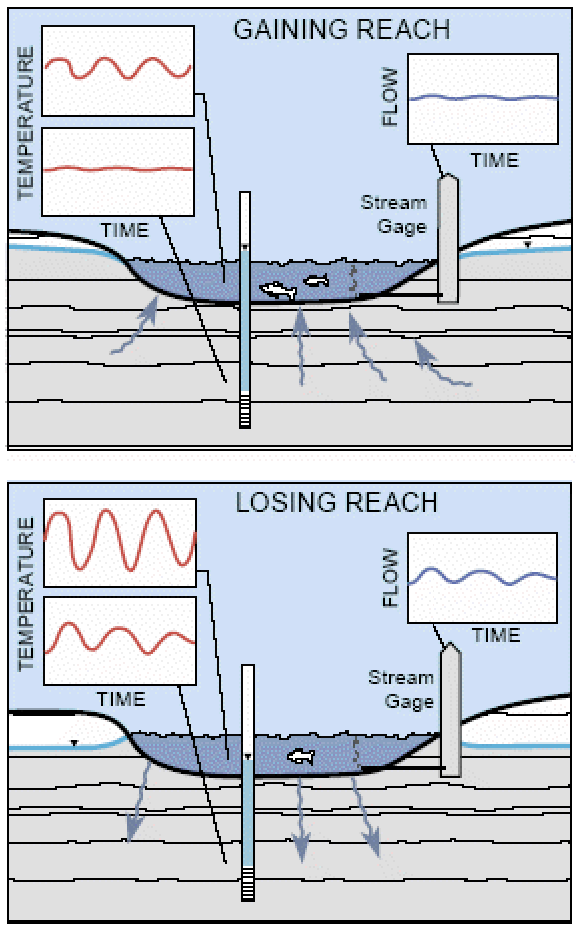


Figure 2.14: Stream flow and temperature histories for (a) gaining and (b) losing reaches of a stream coupled to a local groundwater system. Temperature fluctuations in/beneath gaining reaches are muted compared to temperatures in/beneath losing reaches. Groundwater is buffered from temperature fluctuations at the land surface (From Stonestrom and Constantz, 2003).

Figure 2.15: A string of (c) Hobo water Temp Pro v2 data loggers are affixed at (b) 0 foot (gravel river interface), 1 foot, 2 foot, 3 foot, 4 foot intervals and inserted into the streambed using a (a) sleeve assembly and post driver. Data is retrieved by (d) connecting each logger to a computer and uploading information.

2.7 HYPORHEIC WATER QUALITY

On the American River, salmonids construct redds approximately one foot deep in streambed gravels (Hannon, 2000), taking advantage of the groundwater-surface water interface in the hyporheic zone. Stream water flows through this zone, exchanging oxygen and transporting dissolved ions through the gravel. Incubating eggs are exposed to this environment and dependent on intragravel flow of hyporheic water for the delivery of oxygen and the removal of metabolic waste (Youngson et al., 2004; Kondolf, 2008). Dissolved oxygen, pH, electrical conductivity and turbidity each provide information about water quality and flow in the hyporheic zone.

Dissolved oxygen can be a limiting factor in salmonid reproduction. Multiple factors control oxygen content in the hyporheic environment (Malcolm et al., 2002), including temperature (Davis, 1975). Low dissolved oxygen content has been linked to salmonid egg mortality, as well as low overall fitness of eggs and alevin (Nawa et al., 1990; DeVries, 2000; Malcolm et al. 2003; Youngson et al. 2004; Horner, 2004; Kondolf et al., 2008). The minimum oxygen necessary for developing salmonid embryos is between 4 mg/L and 6 mg/L (Table 2.2). Additionally, dissolved oxygen saturation is inversely correlated with electrical conductivity. Low dissolved oxygen and high electrical conductivity levels are representative of groundwater with long residence times and low intragravel flow. Mineral ion dissolution results in a rise in electrical conductivity, while low dissolved oxygen content may produce reducing conditions (Figure 2.16) and result in anaerobic bacterial activity in the hyporheic zone (Youngson et al., 2004).

A high percent of suspended sediment or turbidity can be an indicator of an impaired stream habitat, and fine sediment intrusion and accumulation in riverbed gravels can significantly reduce permeability (Wu, 2000; Soulsby et al., 2001; Bash et al., 2001). The Environmental Protection Agency (EPA) has identified siltation as the most important source of water quality degradation on rivers. From a biological standpoint, the density and diversity of macro-invertebrates can be impacted by turbidity, thereby negatively affecting the food web at higher trophic levels and older salmonid life stages such as fry and adult salmon (Henley et al., 2000, Bash et al., 2001).

At each restoration site, subsurface water quality parameters were measured to characterize the chemical conditions experienced by incubating eggs. Ten to 15 mini-piezometers were installed one foot deep into the gravel at each study site and sampled for dissolved oxygen (D.O.), turbidity, electrical conductivity (EC), pH, and temperature. Mini-piezometers were sampled seasonally at each location (Figure 2.17). During sampling, a mini-piezometer was attached to a peristaltic pump and developed to clear the well screen of debris. When the water ran clear, it was pumped through a sealed flow through-cell to prevent contamination with atmospheric conditions. The flow-through cell contained D.O., EC, and pH probes. Water was pumped for three to five minutes until each of the measurements had stabilized. After each sample was collected, the water was drained from the flow-through cell before moving on to the next piezometer. Water quality measurements were also collected from surface water samples at the start and finish of each sampling run. Surface water parameters were compared to hyporheic conditions to estimate groundwater-surface water interaction and exchange.

Dissolved oxygen was measured using a YSI model 95 D.O. meter. An Orion model 210 pH meter was used to measure pH. Electrical conductivity was measured with an Orion model 128 E.C. meter. A DRT meter was used to measure turbidity. All meters were calibrated within 30 minutes prior to the start of data collection. 15 new mini-piezometers were installed at the Lower Sailor Bar 2012 site. Four, eight, and 11 mini-piezometers were maintained at the Upper Sailor Bar 2008, Upper Sailor Bar 2009 and Upper Sunrise 2010/2011 study sites respectively. Water quality data are reported in tables that include range, mean, standard deviation, and the coefficient of variation. The coefficient of variation is explained in Chapter 2.3.

Table 2.2: Response of freshwater salmonid larvae and eggs to variable dissolved oxygen levels (From Davis, 1975). Oxygen is more soluble in water at colder temperatures.

Response	Oxygen (mg/l)	Saturation at given temperature, °C (°F)					
		0 (32)	5 (41)	10 (50)	15 (59)	20 (68)	25 (77)
		Percent					
Function w/o impairment	7.75	98	98	98	98	100	100
Initial oxygen distress	6.00	76	76	76	79	87	95
Widespread oxygen impairment	4.25	54	54	57	64	71	78

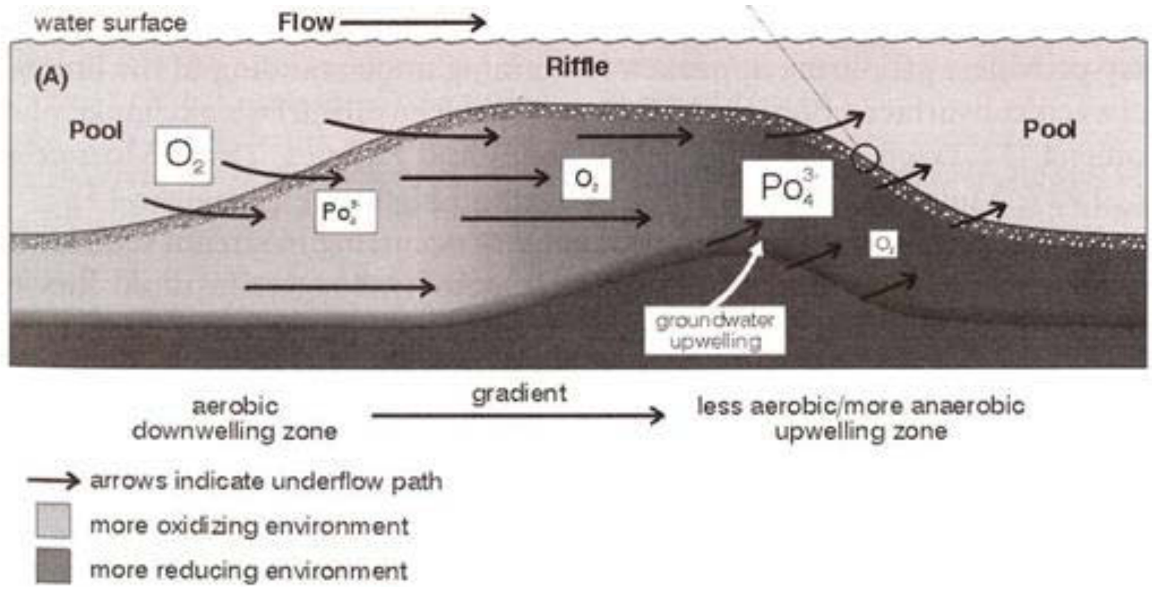


Figure 2.16: Conceptual model of flow through a pool tailout/riffle sequence. Notice the upwelling of groundwater at the downstream end of the riffle. (From Jones and Mulholland, 2000)

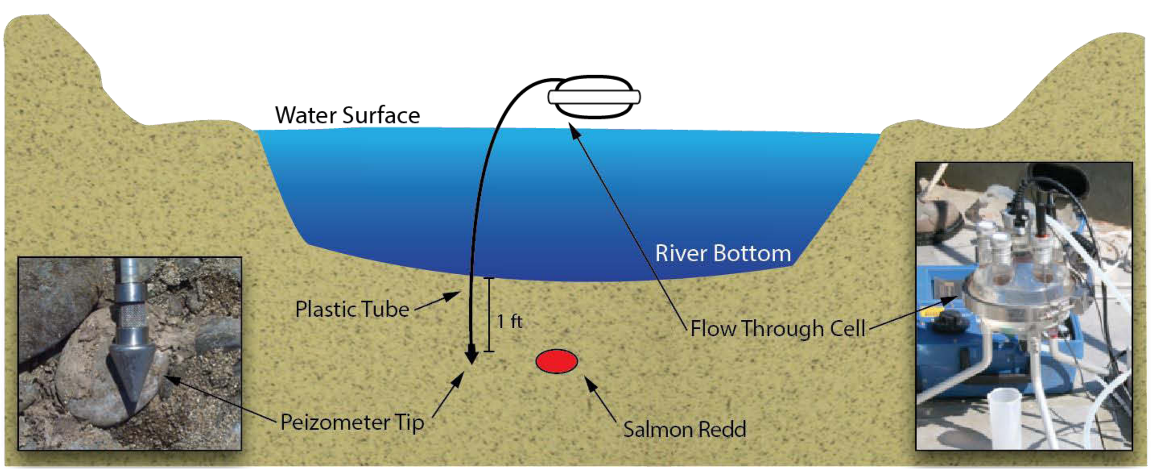


Figure 2.17: Cross section of hyporheic water quality measurements at a single piezometer location.

3.0 LOWER SAILOR BAR 2012 RESULTS

3.1 GRAIN SIZE

Pebble Counts

Six pebble counts were conducted across Lower Sailor Bar 2012 before restoration (Figure 3.1). Grain sizes ranged from fine-grained sand to cobbles up to 7 inches in diameter, and were poorly sorted. The cumulative frequency graph for the pebble counts (Figure 3.2) show median grain size diameters (D_{50}) ranging from approximately 0.5 in. to 1.5 in. Ten pebble counts were conducted after gravel was added to the site (Figure 3.3). Grain sizes ranged from coarse sand, with diameters less than 0.3125 in., to cobbles with 5 inch diameters. D_{50} values ranged from less than 0.3125 in. to 2.1 in. (Figure 3.4). Figure 3.5 is a comparison between the average cumulative percent pebble distribution before and after restoration. D_{50} values were similar (approximately 0.875 in.) before and after restoration, but pre-restoration pebble counts were positively skewed (more coarse material) and post-restoration pebble counts were negatively skewed (more fine material).

During past projects, grains were sorted and spread across study sites evenly. . As part of a biological experiment to determine which gravel sizes American River salmonids prefer for redd construction, and to test egg-to-fry survival rates, gravel was added to Lower Sailor Bar 2012 in a patchwork style of coarse, medium and fine gravel patches. While pre-restoration pebble counts showed similar distribution curves (Figure 3.3), post-restoration pebble counts clustered into three groups (Figure 3.4): PC 1, PC 3, and PC 4 were negatively skewed, PC 2 was positively skewed, and PC 5 through PC 10 were normally skewed. The negatively skewed pebble counts were found in finer grained patches, the positively skewed pebble count was in a coarser patch, and the normally skewed pebble counts were in gravel with medium sized grains.

When results from pebble counts were averaged, the gravel appeared to be slightly coarser after restoration (Figure 3.6), contrary to expected results. However, when post-restoration grain size was calculated for each of the clusters (Figure 3.7), the influence of finer gravel patches is clear, and all new gravel has a higher level of sorting, and fine, medium and coarse grained-gravel patches were all moderately sorted. This improvement in sorting is better aligned with anticipated results.

Figure 3.1: Pre-restoration pebble count traces at Lower Sailor Bar 2012.

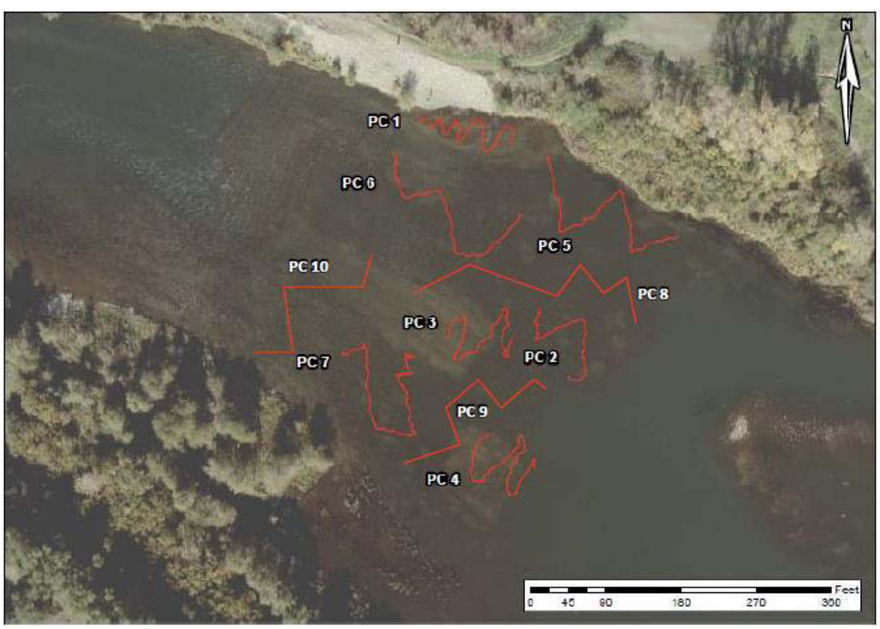


Figure 3.2: Post-restoration pebble count traces at Lower Sailor Bar 2012.

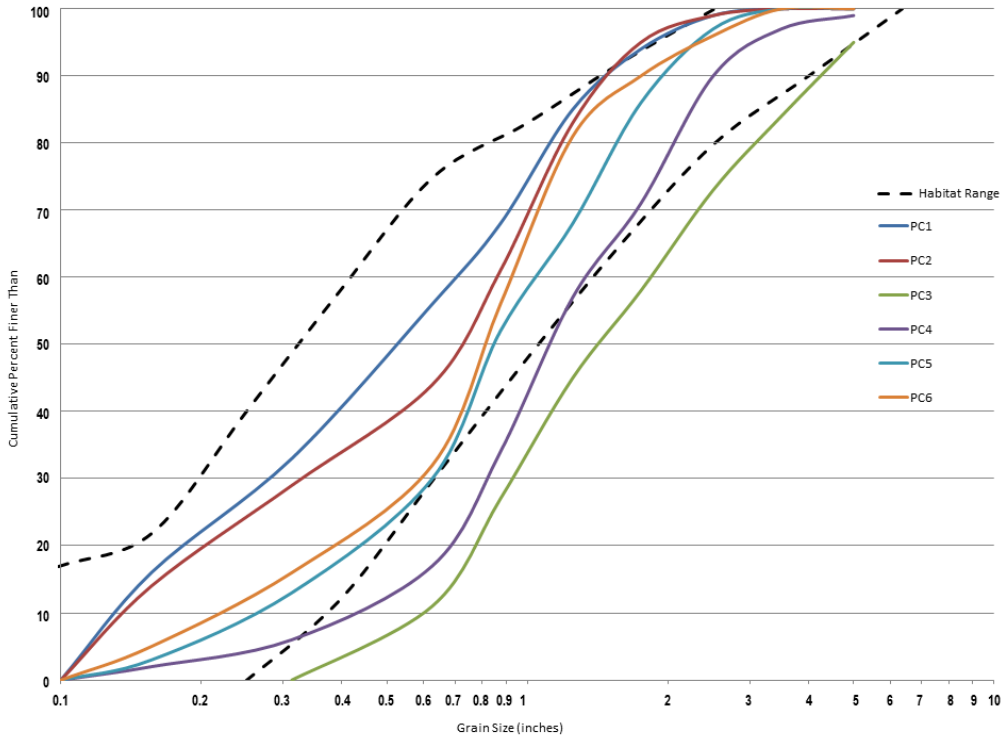


Figure 3.3: Pre-restoration pebble counts for the Lower Sailor Bar 2012 site.

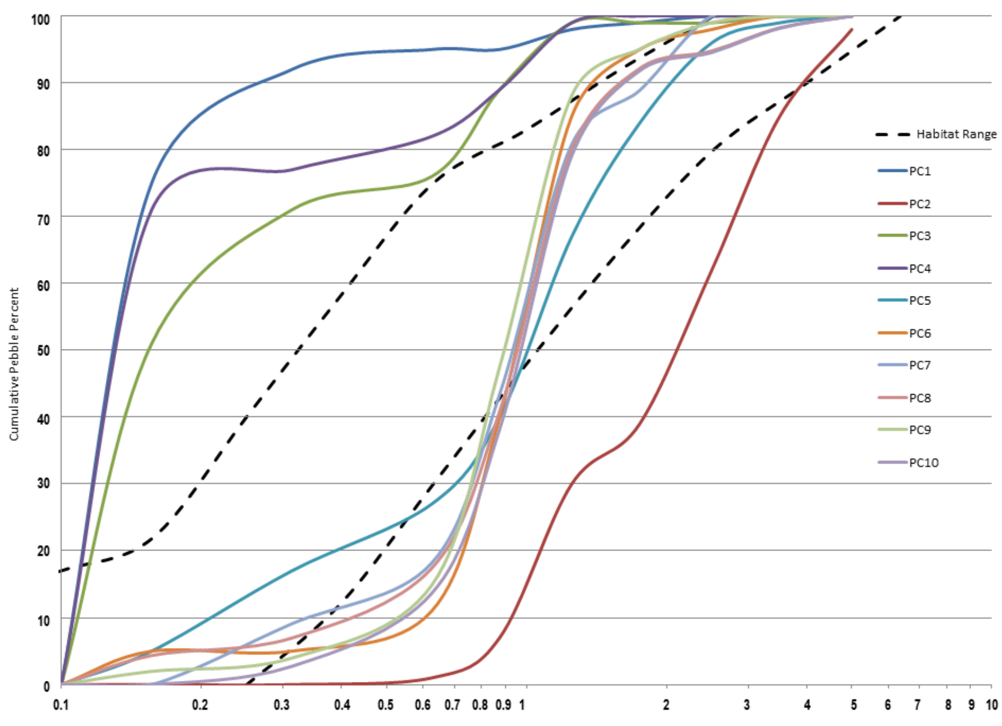


Figure 3.4: Post-restoration pebble counts for Lower Sailor Bar 2012. Outliers are patches of coarse and fine gravel that were added as an experiment to test spawning use.

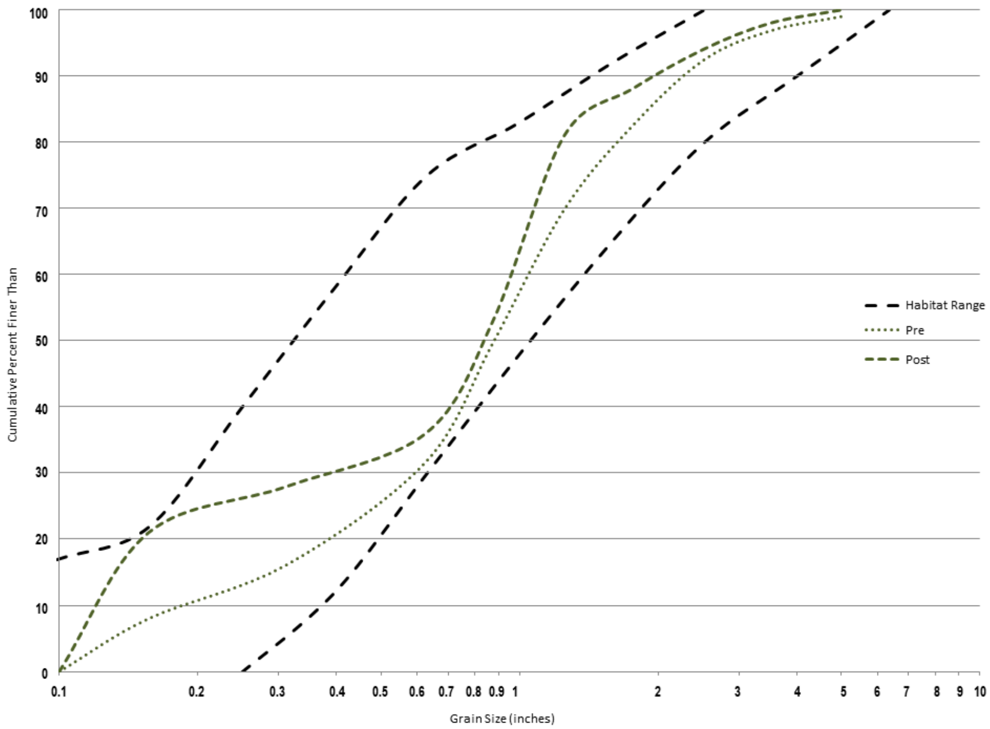


Figure 3.5: Lower Sailor Bar 2012 average pebble frequency before and after restoration.

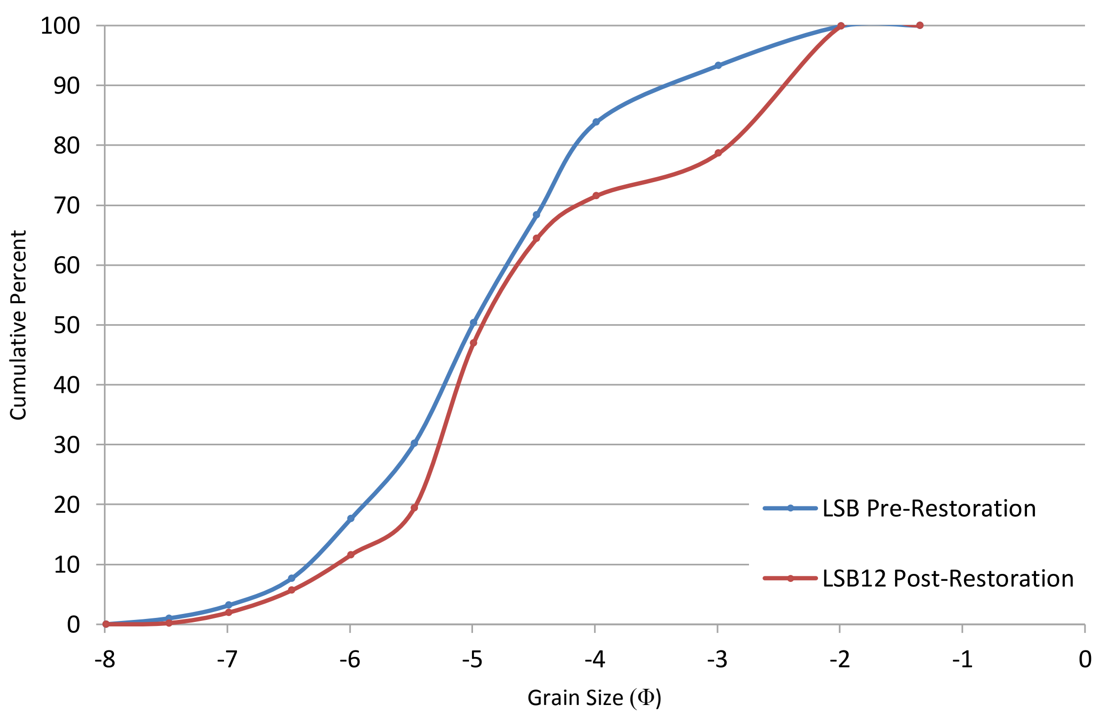


Figure 3.6: Pebble count averages at Lower Sailor Bar 2012 before and after restoration.

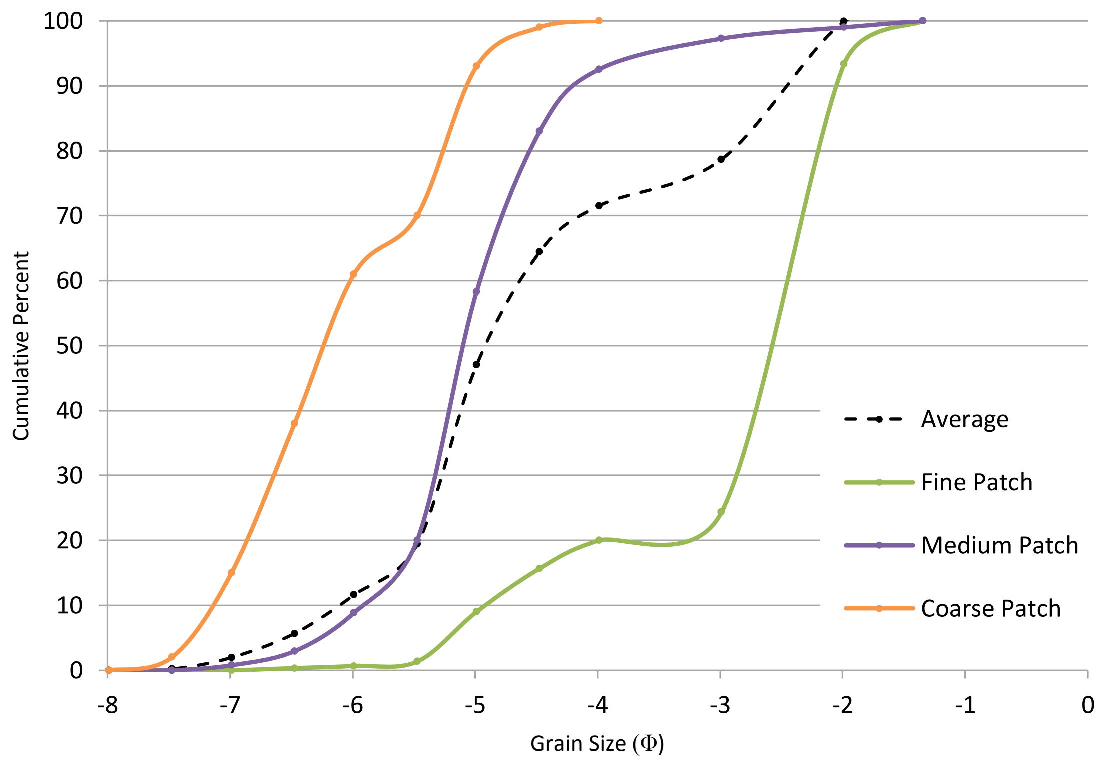


Figure 3.7: The average post-restoration cumulative percent distribution curve for grain size at LSB12 compared to curves for fine, medium, and coarse patches of material.

Bulk Samples

The Lower Sailor Bar 2012 site was too deep to collect bulk samples prior to restoration. However, an assessment of the Lower American River conducted by Snider et al., (1992) and re-examined by Vyverberg et al. (1997) included an evaluation of 18 habitat areas within Reach 4 of the river (Figure 3.8). Surface and subsurface grain size analysis were conducted at areas located within less than one mile of the Lower Sailor Bar 2012 restoration site. Site 3 was classified as a bar-complex run (Snider et al., 1992) that received very low to no spawning use by fall-run Chinook salmon. This site is assumed to be representative of the Lower Sailor Bar 2012 site prior to gravel augmentation. Site 3 was armored, and surface grains were too coarse for suitable salmonid spawning. D_{50} values reported for surface and subsurface gravels in the 1992 report were 2.6” and 2” respectively.

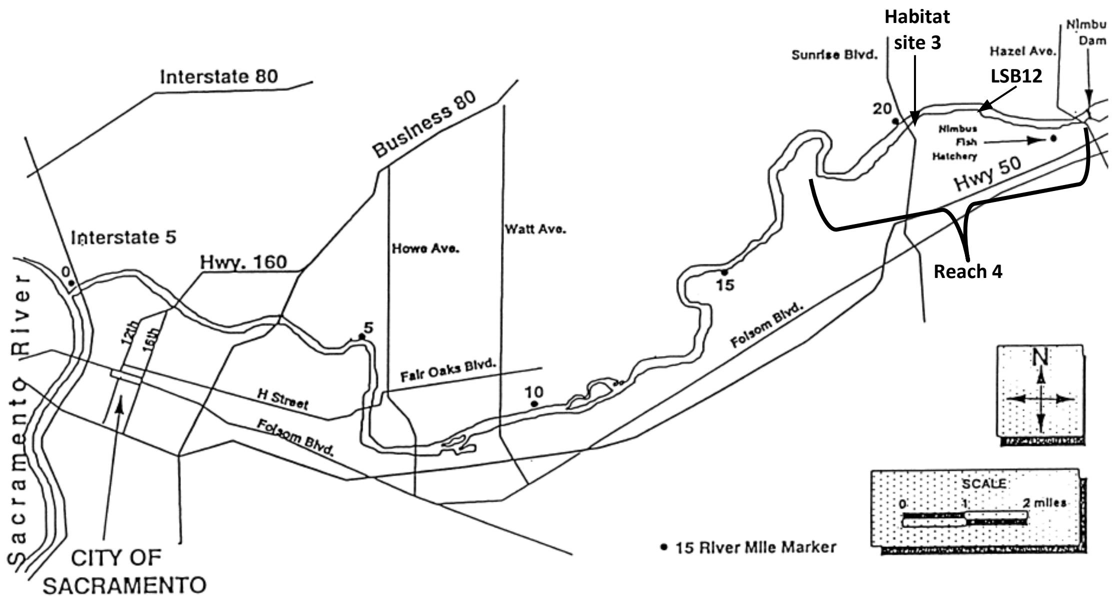


Figure 3.8: Map of the Lower American River (Modified from Snider et al.,1992). Reach 4 includes the Lower Sailor Bar 2012 site and Habitat site 3.

Two bulk samples were conducted post-restoration in April 2013 (Figure 3.9). Figures 3.10a and 3.10b show cumulative percent finer distributions for each bulk sample. Both post-restoration bulk samples were within the suitable habitat range, with D_{50} values between 0.675 in. and 1.25 in., although site 2 was slightly coarse. Surface and subsurface samples were similar, lacking an excessive amount of fine sediments or coarse grains. Both surface samples displayed slightly larger grains than subsurface samples, and both subsurface cumulative percent distribution curves were negatively skewed (more fine material).

There was not enough information available from Site 3 (Vyverberg et al., 1997) to calculate pre-restoration sorting values based on bulk samples. However, sorting results constructed from the post-restoration bulk samples are presented in Table 3.1. Surface sample 1 and subsurface sample 1 were both moderately sorted (0.97Φ and 0.83 Φ respectively), while surface sample 2 and subsurface sample 2 were both poorly sorted (1.15Φ and 1.17Φ respectively). The difference in degree of sorting may be related to the patchwork style distribution of augmented gravel discussed in the previous section.

While bulk sample 1 was conducted near pebble count 6, and bulk sample 2 was conducted near pebble count 3, there is no obvious correlation between the sorting values constructed from pebble counts and bulk samples in similar locations.

Figure 3.9: Location of post-restoration bulk samples at the Lower Sailor Bar 2012 site.

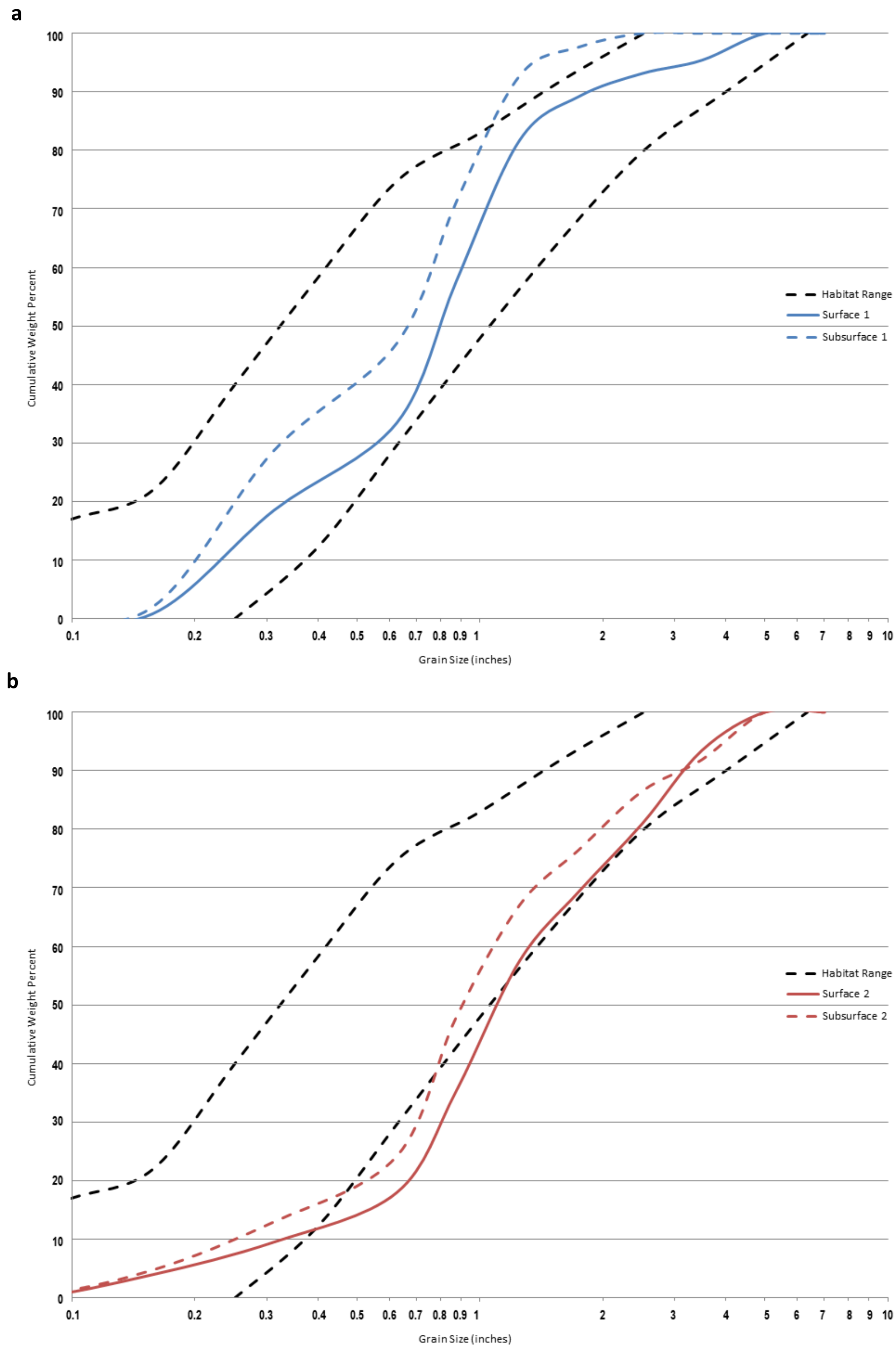


Figure 3.10: Post-restoration cumulative percent finer than weight distributions for two bulk samples (a and b) conducted at the Lower Sailor Bar 2012 site.

Table 3.1: Sorting results for post-restoration bulk samples at the Lower Sailor Bar 2012 site collected in April 2013.

	Surface Sample 1	Subsurface Sample 1	Surface Sample 2	Subsurface Sample 2
D_{84}	-3.8 Φ	-3.5Φ	-4.35Φ	-4.55Φ
D_{16}	-5.59Φ	-5.25Φ	-6.58Φ	-6.8Φ
D_{95}	-3.2Φ	-3.1Φ	-3.15Φ	-3.6Φ
D_5	-6.71Φ	-5.69Φ	-7.05Φ	-7.6Φ
σi	**0.97Φ**	**0.83Φ**	**1.15Φ**	**1.17Φ**
Sorting	Moderately sorted	Moderately sorted	Poorly sorted	Poorly sorted

3.2 GRAVEL MOBILITY

Tracer Rocks

Figure 3.11: Post gravel addition map of Lower Sailor Bar 2012 showing initial placement of tracer rocks. Large (2.5 in. - 3 in.), medium (1.25 in. - 1.75 in.), and small (0.625 in. - 0.875 in.) tracer rocks were placed at each point on the map.

Tracer rocks were deployed at the study site following gravel augmentation in September 2012. Small groupings of tracer rocks (small, medium, large) were placed at discrete points along one of three transects across the study site (upstream, middle, downstream) as shown in Figure 3.11. Tracer rocks were relocated in April 2013 following the winter season. River flows between October 2012 and April 2013 ranged from a low of 942 cfs to a high of 9,980 cfs with a mean flow of 2,382 cfs. Flows above 5,000 cfs persisted throughout the month of December. As of April 16, 2013, tracer rocks showed little to no movement.

Scour Chains

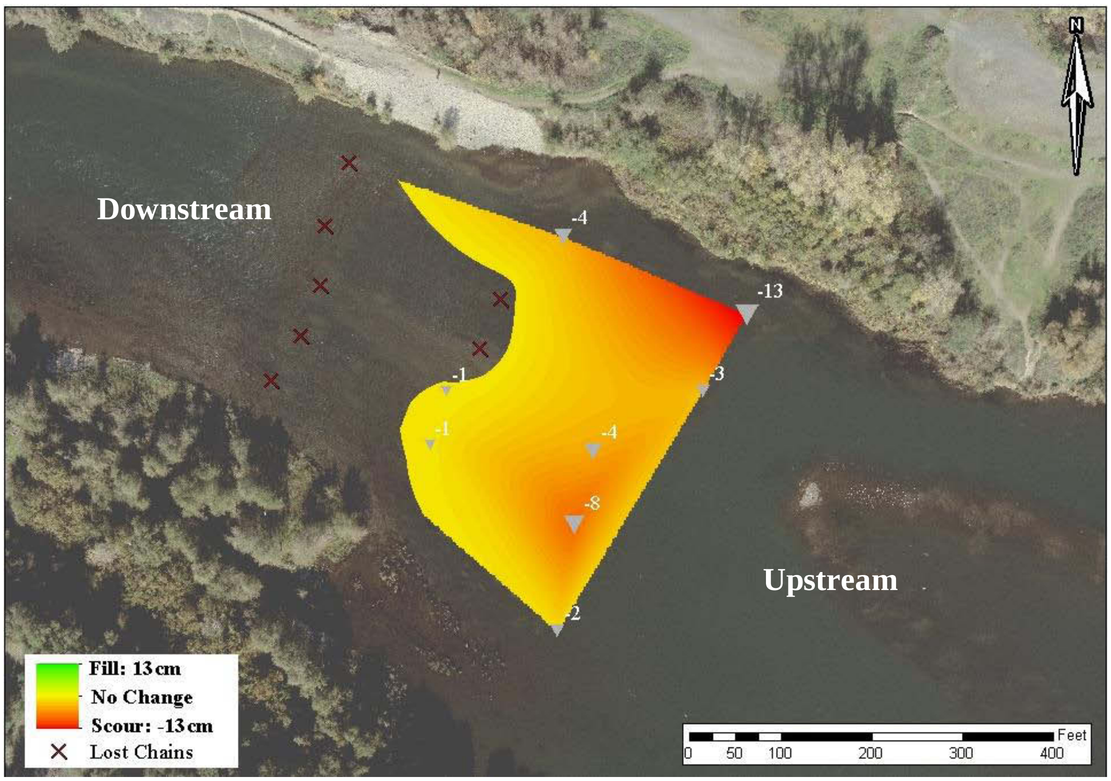


Figure 3.12: Scour and fill map of the Lower Sailor Bar 2012 site.

Following gravel augmentation in September 2012, 15 scour chains were installed at the Lower Sailor Bar 2012 study site (Figure 3.12). As of April 2013, eight of the original chains were recovered. The missing chains were primarily at the downstream end of the site, and may have been buried as gravel was eroded from the head of the riffle and redeposited in downstream locations. The remaining chains all displayed an increase in chain length indicating scour across the site. The greatest amount of scour (5.12 in.)

was found at the upstream end of the site closest to the north bank of the river. The least amount of scour (0.394 in.) was found near the center of the site. Figure 3.13 is a map showing the scour pattern across the site based on the initial chain lengths taken after restoration minus the measurements collected in 2013.

3.3 SURFACE WATER DEPTH AND VELOCITY

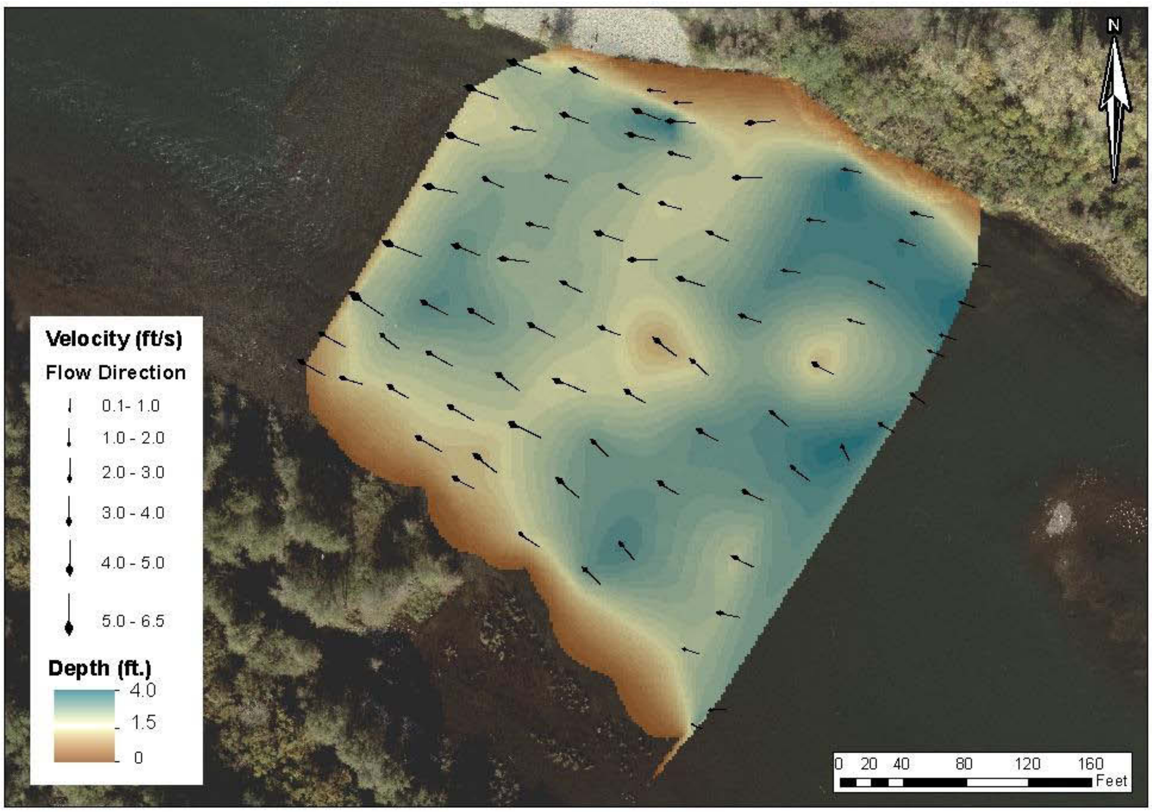


Figure 3.13: Depth, velocity and direction of flow for 80 measurements taken at the Lower Sailor Bar 2012 site in November 2012, at a flow of approximately 1,750 cfs.

No velocity measurements were recorded and only six depth measurements were recorded, due to the excessive depth of the site pre-restoration. The portions of the site where depth measurements could be taken averaged about 4 ft. The majority of the site was greater than 4 ft deep, with some areas (particularly the center portion of the channel) greater than 6 ft deep. Surface water depth and velocity data were collected from the Lower Sailor Bar 2012 site in November 2012 (after gravel augmentation) at a flow of approximately 1,750 cfs. Measurements were recorded at 80 locations across the site as presented in Figure 3.13 and Table 3.2. The arrows in figure 3.13 show that velocities are lower at the upstream end of the site and gradually increase downstream. This change in velocity is the result of a transition from an upstream pool to a downstream riffle.

Table 3.2: Summary of results for depth and velocity after restoration of the Lower Sailor Bar 2012 site in November 2012.

Measurement	Range	Mean	Standard Deviation	Coefficient of Variation	Number of Measurements
Velocity @ 60%	0.7 – 6.4 ft/s	1.05 ft/s	1.03	36	80
Depth	0.6 – 3 ft	1.95 ft	0.54	28	80

3.4 GRAVEL PERMEABILTY

Figure 3.14: Location of permeability tests at the Lower Sailor Bar 2012 site.

On January 18, 2013, 10 post-restoration permeability tests were conducted at the site (Figure 3.14). River flows averaged 2,500 cfs during testing. Six successful tests produced very high hydraulic conductivity values ranging from 23,000 cm/hr to 86,000 cm/hr (Table 3.3). Permeability exceeded equipment limitations for the remaining four tests, producing hydraulic conductivity values in excess of 95,000 cm/hr (the limitation of the pumping apparatus). Results for these tests (2, 5, 6 and 7) were reported as the maximum pumping value (95,000 cm/hr), but actual values for permeability are higher.

Table 3.3: Permeability results for the Lower Sailor Bar 2012 site. Results for tests 2, 5, 6 and 7 exceeded equipment limitations and are reported as the pumping equipment limitations.

Test Number	Test Date	K (cm/hr)	Test Number	Test Date	K (cm/hr)
1	1/18/2013	**22,960**	**7**	1/18/2013	**>95,000**
2	1/18/2013	**>95,000**	**8**	1/18/2013	**55,544**
3	1/18/2013	**55,031**	**9**	1/18/2013	**86,851**
4	1/18/2013	**69,272**	**10**	1/18/2013	**68,616**
5	1/18/2013	**>95,000**	**Mean**		**60,000**
6	1/18/2013	**>95,000**	**Coefficient of Variation**		**33**

3.5 HYPORHEIC PRESSURE HEAD

Upwelling and downwelling measurements were conducted in November 2012 (after restoration) at a flow of approximately 1,750 cfs. Upwelling and downwelling measurements were not collected before restoration, because water depth at the site precluded wading measurements. Positive numbers indicate upwelling, negative numbers indicate downwelling, and a value of zero indicates no upwelling or downwelling conditions. Pressure head measurements were taken at 40 discrete locations across the Lower Sailor Bar 2012 site (Figure 3.15). The majority of the site was dominated by upwelling or even conditions. 42.5% of measurements indicated upwelling conditions, 40% indicated neutral conditions, and 17.5% indicated downwelling conditions. Gradient values ranged from 2.00 in. to -0.50 in. across the site. Areas of downwelling are limited and appear to be confined to the southern downstream edge of the site and a small zone in the middle of the site. The deep pool located directly upstream of the site may account for the high level of upwelling. Water from this deep pool rises and is forced through the new gravel as it moves downstream.

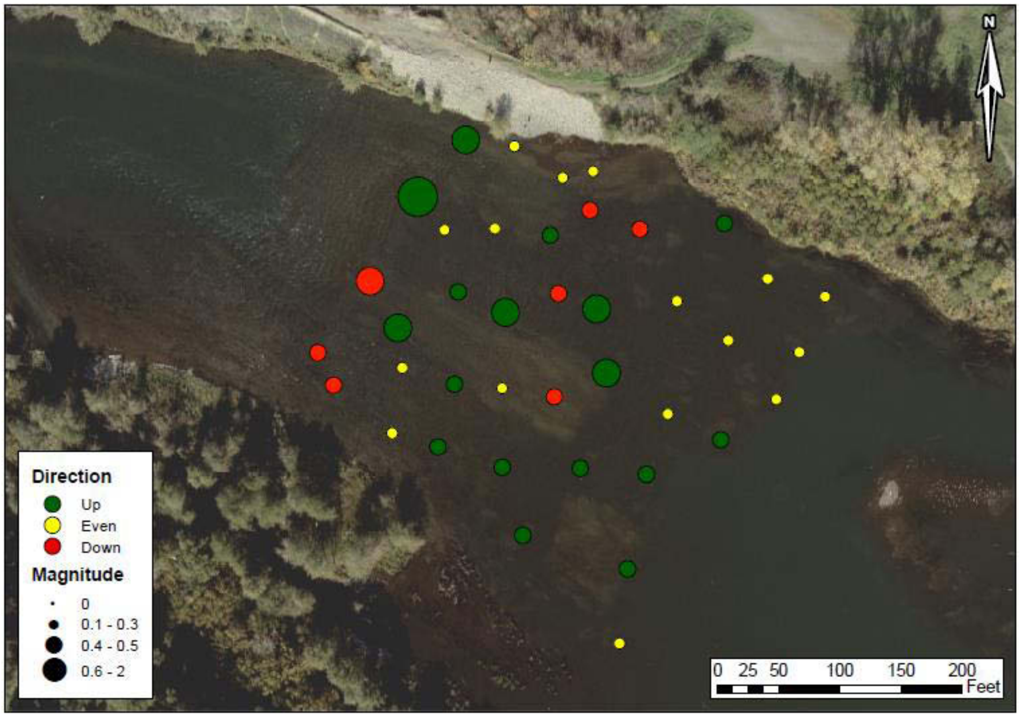


Figure 3.15: Lower Sailor Bar 2012 upwelling and downwelling map at 1,750 cfs. Data was collected on November 2, 2012.

3.6 TEMPERATURE

Two temperature housings (wells) were installed at the Lower Sailor Bar 2012 site in April 2013 (Figure 3.16). Temperature loggers recorded data every 30 minutes beginning in April 18, 2013. Although the record in this report ends in May 20, 2013, wells are still in place and are recording temperature over the next year for further study. Results are presented in Figure 3.17. Diurnal temperature fluctuations were evident in both wells, and both wells showed an overall increase in temperature during the study period regardless of depth. In the upstream well (LSB-1), temperatures at all depths well were virtually identical and mimicked the surface water pattern. This indicates strong downwelling conditions that drive the diurnal temperature signal to a depth of 4 ft with little or no lag or delay. In the downstream well (LSB-2), temperatures at 1 ft, 2 ft, and 3 ft depths were similar, and showed a strong diurnal signal. The temperature logger four feet deep in the gravel showed the same diurnal signal, but the magnitude of the fluctuation was dampened. Daily low temperatures at the 4 ft depth were close to surface temperature lows (no more than a ±0.33°C difference), but daily highs were reduced (as much as a 1.63°C lower). During restoration, new gravel was placed directly on top of the heavily armored streambed. This signal reduction could represent the boundary between pre-restoration substrate and augmented gravel. Highly permeable gravel would allow the diurnal signal to move freely at depth, whereas the compacted material would reduce the ability of the diurnal signal to move through the substrate. If so, the LSB-2 temperature pattern indicates a substrate boundary between 3 ft and 4 ft deep. The presence of the diurnal signal deep into the streambed suggests that stream water is downwelling into the gravel at both wells.

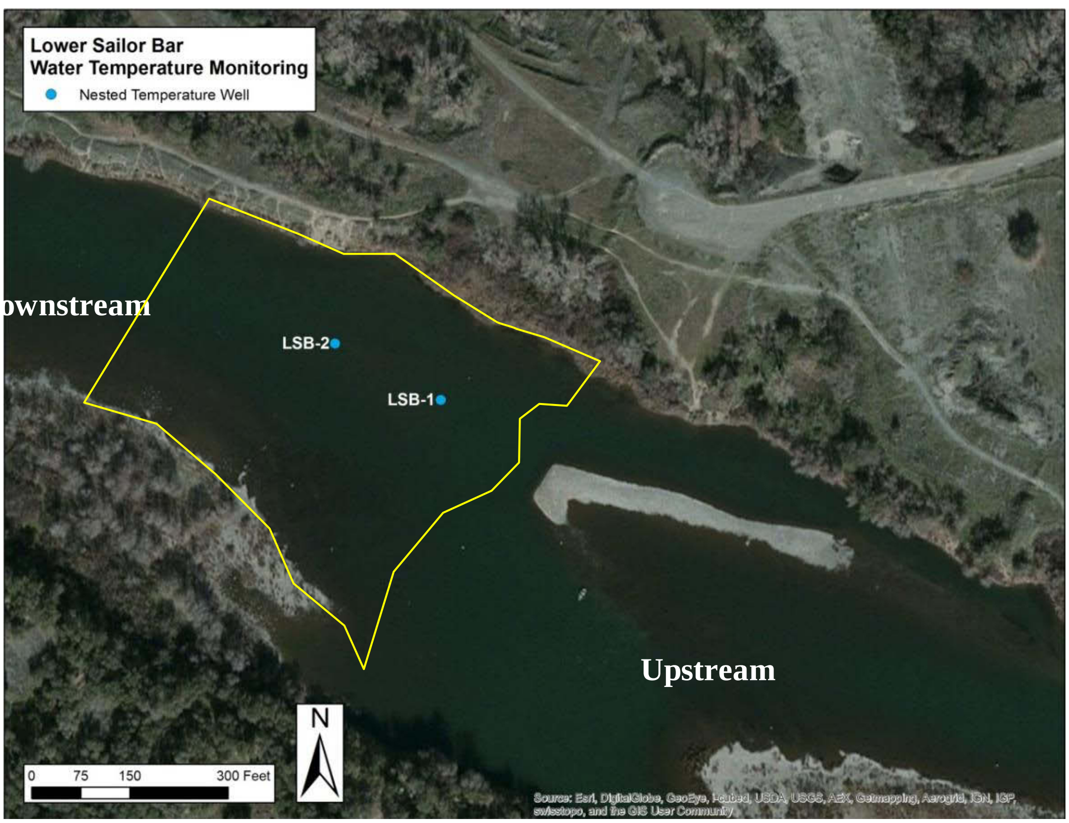


Figure 3.16: Map of temperature housing locations at the Lower Sailor Bar 2012 site. The yellow outline mars the gravel addition boundary.

a) LSB-1

b) LSB-2

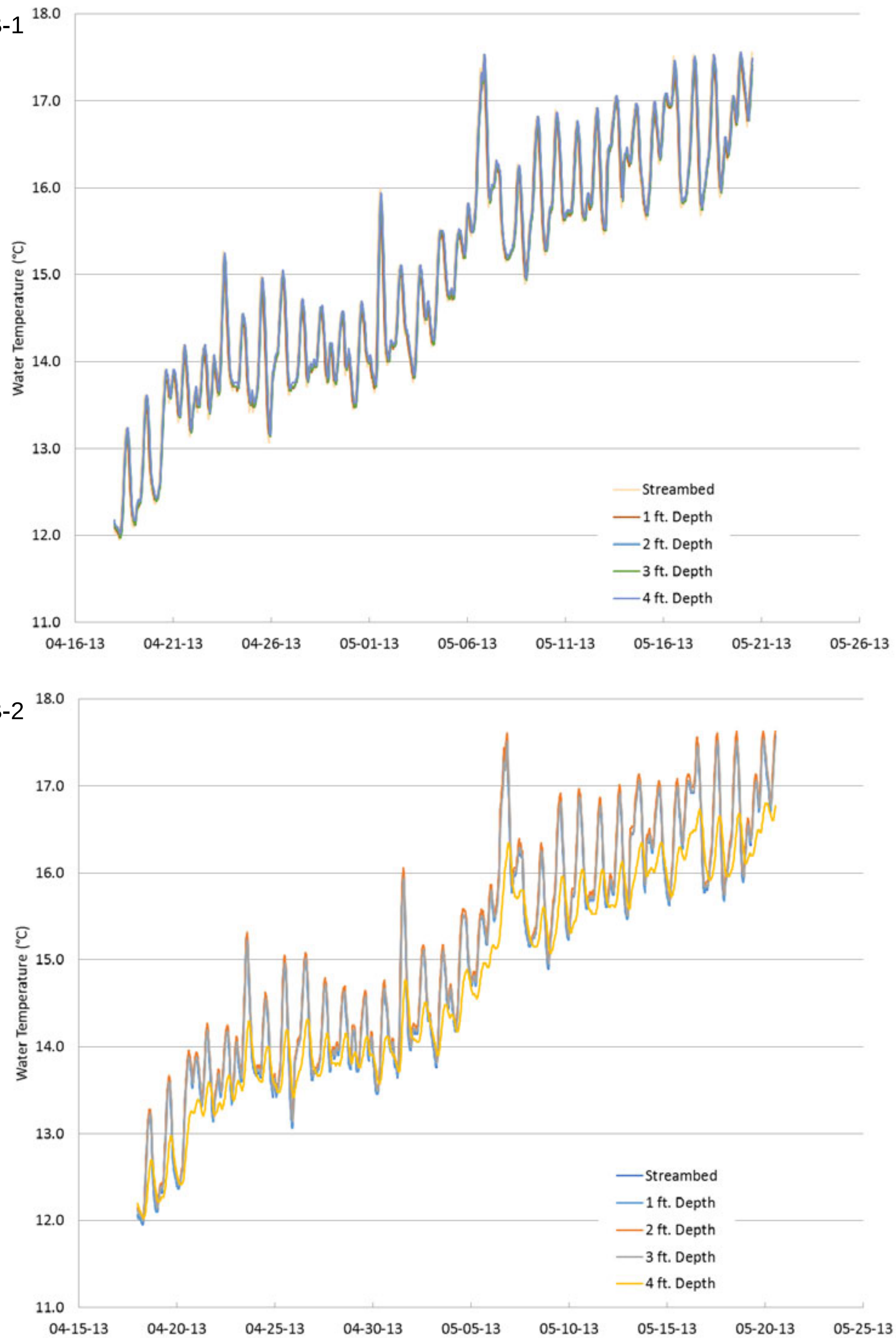


Figure 3.17: Water temperature after restoration of Lower Sailor Bar 2012 (from April 2013 through May 2013) at the (a) LSB-1 well where surface temperatures are propogated to a depth of at least 4 ft in the new gravel, and the (b) LSB-2 well where surface temperatures signals are propogated to a depth of 3 ft.

3.7 HYPORHEIC WATER QUALITY

Water quality parameters were measured before and after gravel was added to each study site and in subsequent years. Typically, post-restoration water quality samples are collected three times within the salmonid life cycle: during redd construction in the fall, during egg incubation in the winter, and during fry emergence in the spring. Discharge on the river between December 2012 and January 2013 was high and produced flow conditions that were unsafe for field workers (Figure 1.5). Therefore, only two sampling events were conducted during the 2012/2013 field season, in the fall of 2012 and the spring of 2013. Measurements are summarized in tables and presented on maps.

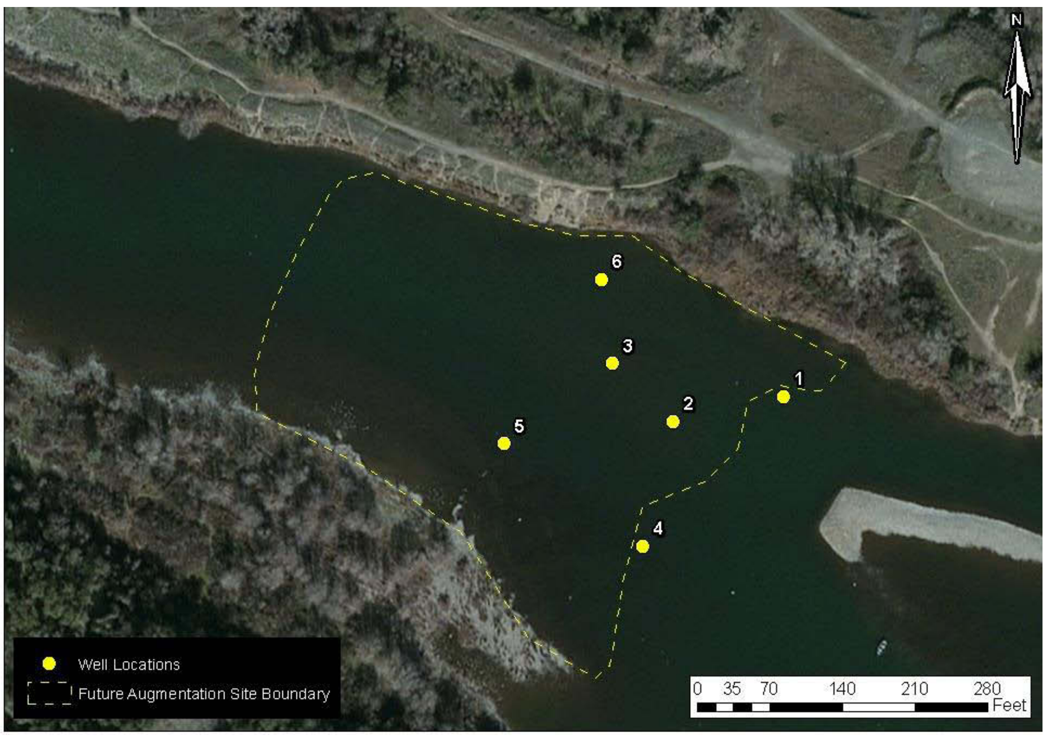


Figure 3.18: Location of pre-restoration wells at the Lower Sailor Bar 2012 site.

Due to extreme armoring and excessive depth, only six mini-piezometers were installed and sampled in September 2012, before restoration of the Lower Sailor Bar 2012 (Figure 3.18). Only two successful measurements could be taken, because four of the six piezometers were clogged. This often indicates high clay content and low permeability. Table 3.4 shows pre-restoration water quality data. The dissolved oxygen (D.O.) levels ranged from 2.53 mg/L to 3.26 mg/L, and D.O. saturation ranged from 36% to 40%.

Table 3.4: Lower Sailor Bar 2012 Pre-Restoration Water Quality Parameters

Location	D.O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
2	2.53	40	56.8	6.54	8.5
3	3.26	36	59.5	6.61	26.8
Surface 1	9	69	47.1	6.77	18
Surface 2	9.14	99.2	47.2	678	18.6

Parameters were collected in September 2012 at approximately 1,750 cfs with an average hyporheic temperature of 18.5°C. Piezometers at locations 1, 4, 5 and 6 were clogged.

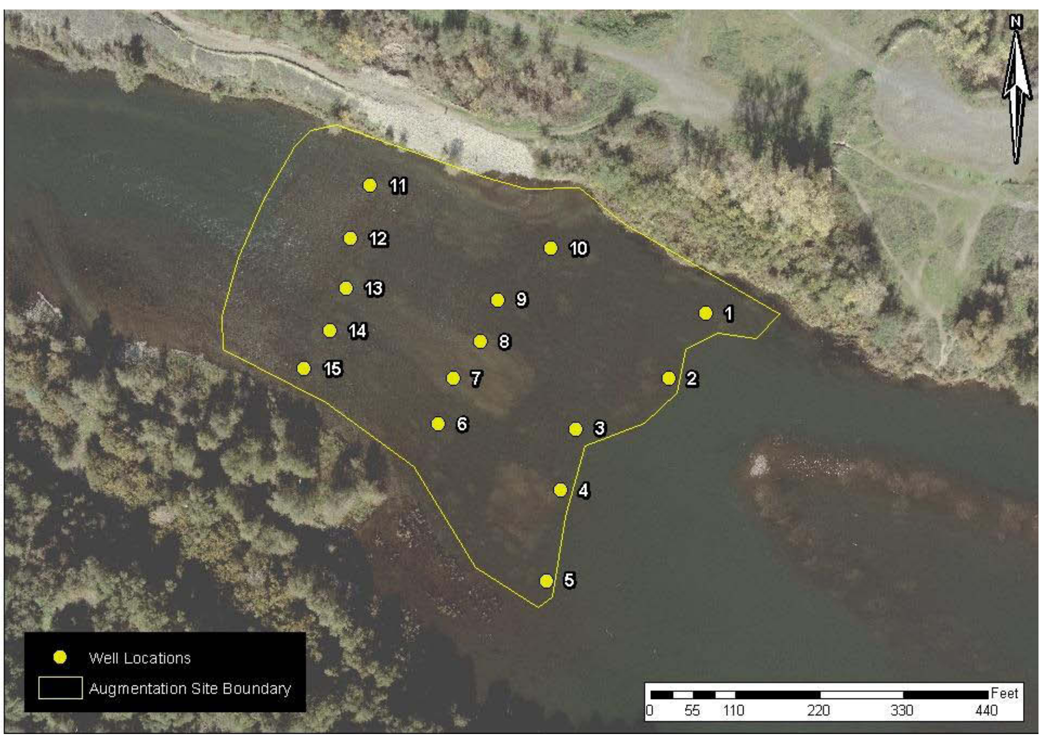


Figure 3.19: Location map of mini-piezometers after restoration.

After restoration, 15 mini-piezometers were installed at the site (Figure 3.19) and sampled in November 2012 and April 2013. Tables 3.5 and 3.6 show post-restoration Fall and Spring water quality data respectively. In November, 13 samples were collected successfully. The mean D.O. level during redd construction was 9.52 mg/L with values ranging from 8.95 mg/L to 9.98 mg/L, and the mean D.O. saturation was 93.7% with values ranging from 88.1% to 97.8%. In April, water quality measurements were collected from 11 locations. The mean D.O. level decreased during fry emergence to 7.94 mg/L with values ranging from 7.02 mg/L to 8.25 mg/L, and the mean D.O. saturation dropped to 77.2% with values ranging from 69% to 83%. The well at location 8 showed the greatest difference in D.O. levels between the fall and spring sampling events (9.67 mg/L and 7.33 mg/L respectively).

Table 3.5: Lower Sailor Bar 2012 Water Quality Parameters as of November 2012

Location	D.O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
1	9.62	94.2	48.2	7.14	17
2	9.38	93.4	47.9	7.05	4.5
3	9.69	96.8	47.7	7.12	16
4	9.47	94.5	47.5	7.06	3.9
5	9.61	93.6	47.3	7.04	1.6
7	9.76	96.2	47.5	7.23	10
8	9.61	95.9	47.2	7.14	10
9	9.38	92	47.5	7.14	30
10	9.98	97.8	47.8	7.13	42
11	9.04	88.8	48.1	7.24	18
12	9.3	88.1	47.9	7.19	17
13	8.95	90.7	47.4	7.26	3
15	9.98	96	47.3	7.09	50
Mean	**9.52**	**93.69**	**47.64**	**7.14**	**17.15**
Coefficient of Variation	**3**	**3**	**1**	**1**	**88**
Surface 1	9.24	91.6	50.8	7.23	4
Surface 2	9.8	97.4	47.4	7.04	1.4

Data were collected in November 2012 (after restoration) at 1,430 cfs. Mean hyporheic temperature was 15°C. Piezometers 6 and 14 were clogged.

Figures 3.20 and 3.21 show Fall and Spring D.O. saturation levels on the Lower Sailor Bar 2012 Map. Green dots represent high D.O. percentages that are within 90% of surface water levels and may indicate good intragravel flow. Yellow dots represent D.O. percentages that are within 60%-90% of surface water measurements. These sites are reasonable for egg development and survival, but may indicate lower intragravel flow.

Red dots represent D.O. percentages that are critically low for egg development and survival. During Fall sampling, the majority of wells showed high D.O. values and high saturation. During Spring sampling, all wells showed lower D.O. levels and moderate saturation.

Table 3.6: Lower Sailor Bar 2012 Water Quality Parameters as of April 2013

Location	**D.O. (mg/L)**	**D.O. (% sat)**	**E.C. (uS)**	**pH**	**Turbidity (NTU)**
1	8.4	83	53	7.2	12
2	8.12	78	54	7.2	6
3	8.25	80	54	7.3	68.5
4	8.01	77	53	7.3	15
5	7.75	75	53	7.2	1.5
7	8.24	80.8	54	7.3	6.5
8	7.33	73	54	7.3	9.5
9	8.03	77	54	7.3	66
10	8.06	78	54	7.3	54
12	8.09	78	54	7.1	20
14	7.02	69	54	7.1	80
Mean	**7.94**	**77.16**	**53.73**	**7.24**	**30.82**
Coefficient of Variation	**5**	**5**	**1**	**1**	**96**
Surface	10	99	53	7.3	1.5

Data were collected in April 2013 at 1,300 cfs. Mean hyporheic temperature was 13.8°C. Piezometer 6 was clogged, and piezometers 11, 13, and 15 were missing.

Figures 3.22 and 3.23 illustrate turbidity levels across the study site during Fall and Spring sampling events. Darker colors represent higher turbidity values and lighter colors represent lower values. Pre-restoration and fall post-restoration mean turbidity values were similar at 17.65 NTU and 17.15 NTU respectively. When compared to the Fall sampling event, mean turbidity from Spring sampling increased by over 40% from 17.13 NTU to 30.82 NTU. Turbidity in most of the wells increased between the Fall and Spring sampling events, but well location 3 had the largest increase from 16 NTU to 68.5 NTU.

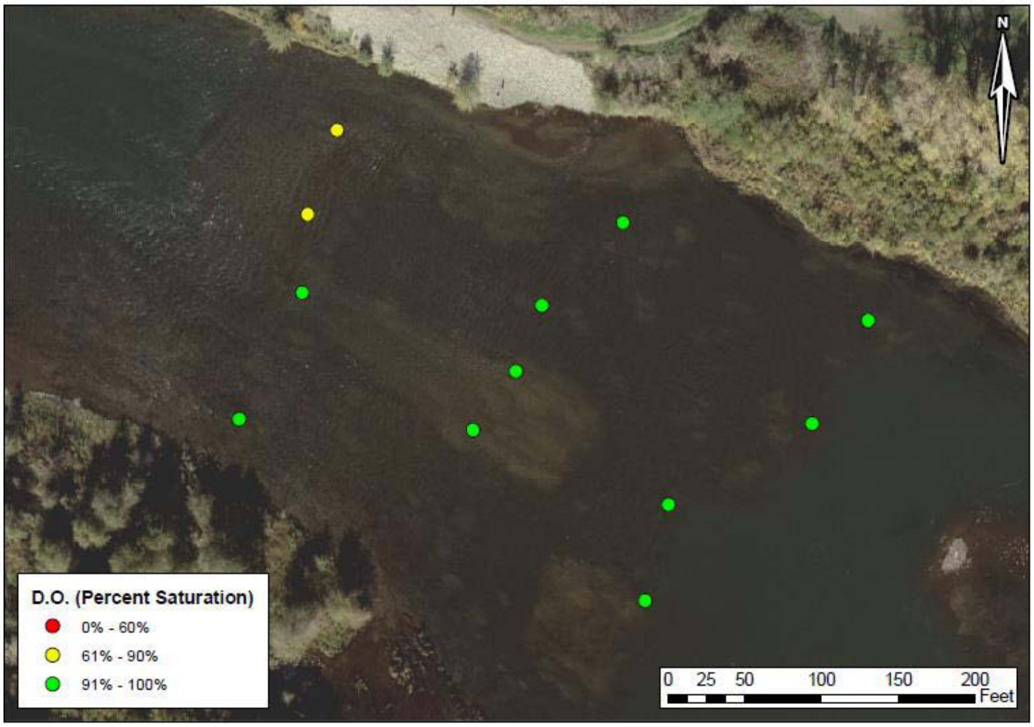


Figure 3.20: Post-restoration percent D.O. saturation levels at the Lower Sailor Bar 2012 Site collected in November 2012.

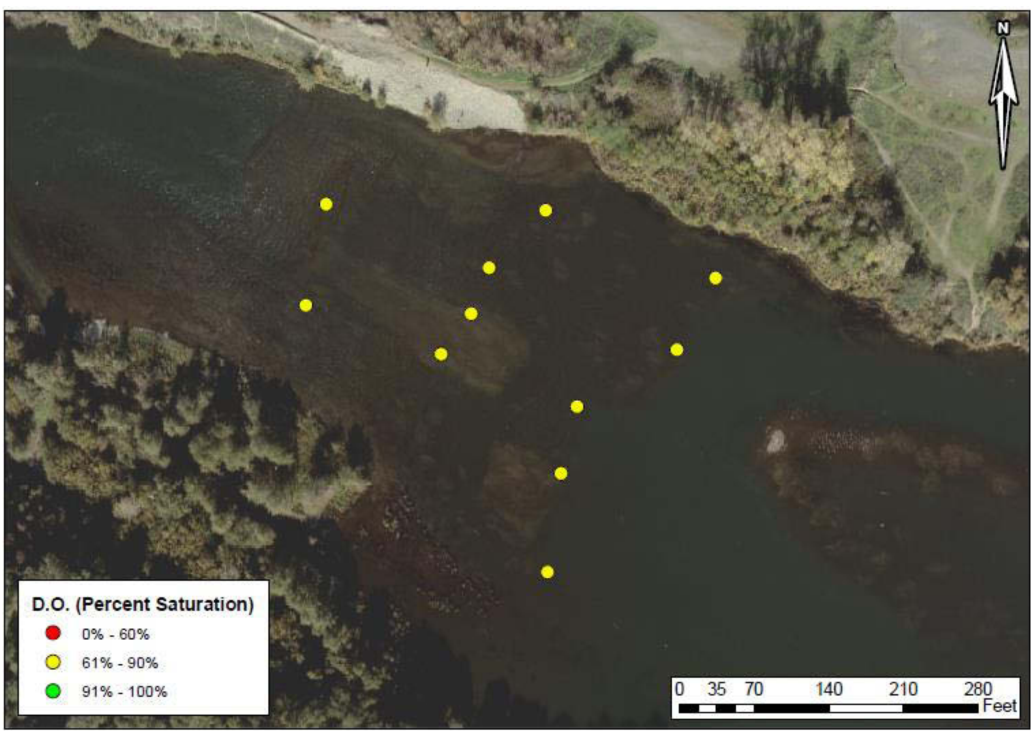


Figure 3.21: Post-restoration percent D.O. saturation levels at the Lower Sailor Bar 2012 Site collected in April 2013.

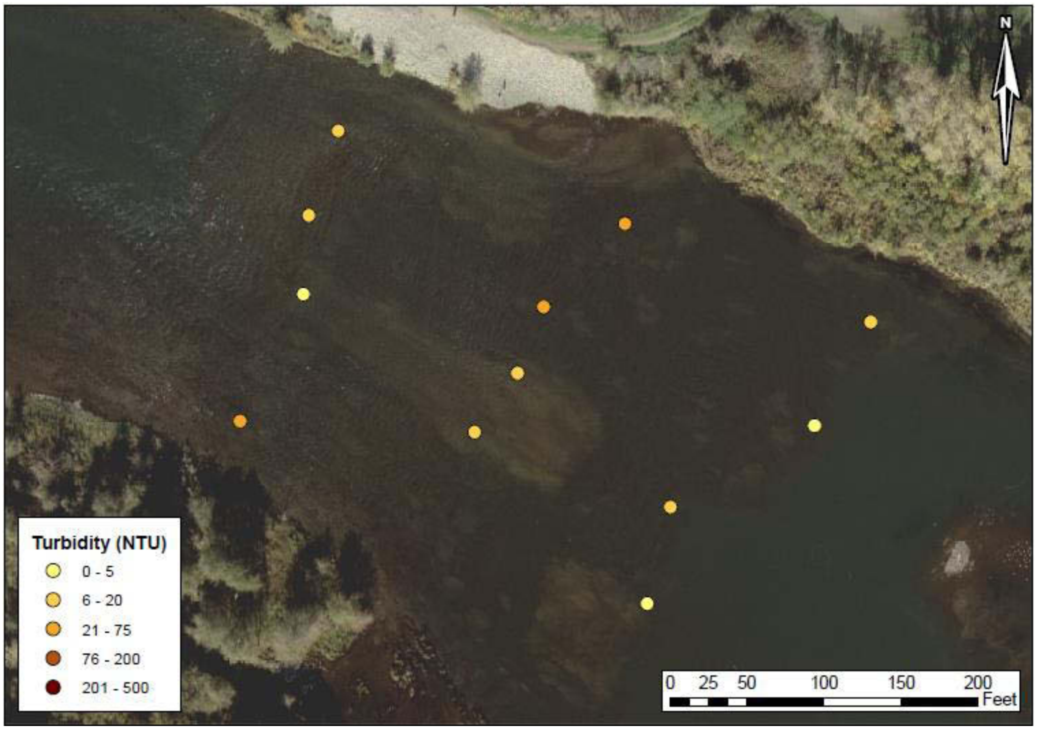


Figure 3.22: Post-restoration turbidity levels at the Lower Sailor Bar 2012 Site collected in November 2012.

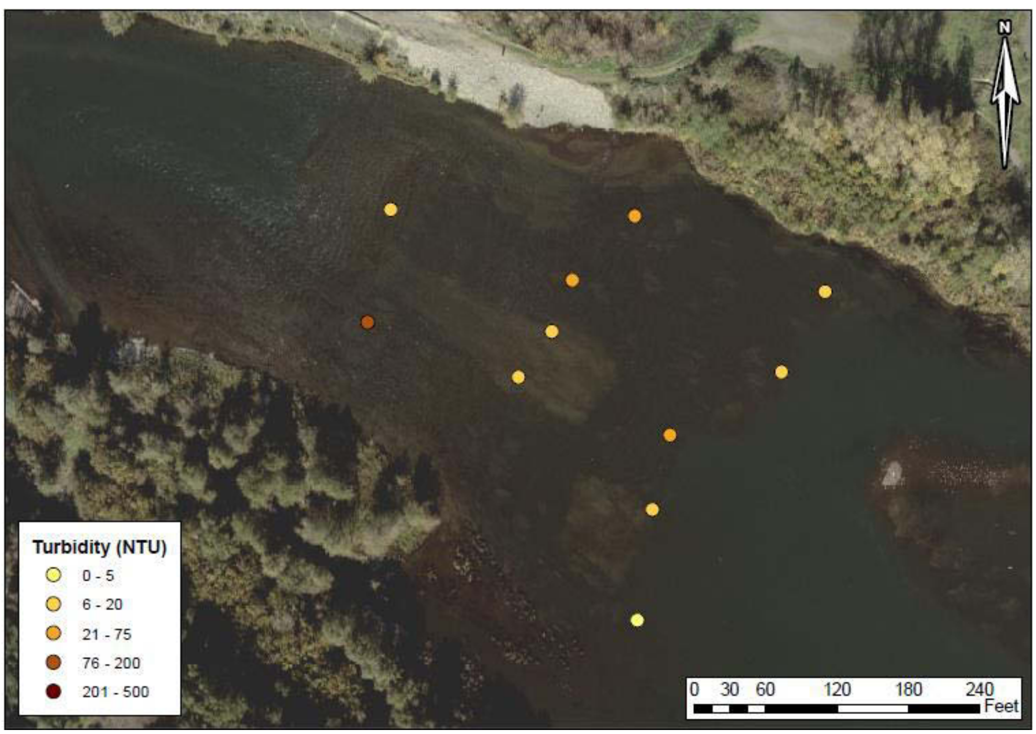


Figure 3.23: Post-restoration turbidity levels at the Lower Sailor Bar 2012 Site collected in April 2013.

3.8 DISCUSSION

Augmentation of the Lower Sailor Bar 2012 site created an area of well-sorted clean gravel that spanned the river channel. Grain size, surface water depth and velocity, gravel permeability, and water quality were all positively impacted by the augmentation. Prior to restoration, the site consisted of a deep centralized channel with an armored streambed, larger than optimal grain sizes, low intragravel flow, and low D.O. content. After restoration, the central channel was converted into a pool-riffle structure with hummocky topography and surface water no more than 3 ft deep (average depth 1.95 ft). The addition of optimally sized spawning gravel (D_{50} between 0.675 in. and 1.25 in.) eliminated streambed armoring while increasing substrate permeability and D.O. at the site. Prior to restoration, permeability was unmeasurable due of the excessive water depth at the site and tightly compacted streambed, and D.O. levels were below 3.5 mg/L. After restoration, average permeability was approximately 59,000 cm/hr with a relatively high (36) coefficient of variation, and average D.O. was 9.52 mg/L with a relatively low (3) coefficient of variation.

As expected, the augmented gravel was highly mobile and began migrating downstream less than one year after placement. While tracer rocks showed little to no movement, erosion was evident at scour chain locations. The loss of nearly all scour chains across the downstream end of the site points to a significant amount of sediment transport and deposition, but this is speculation. Based on the amount of erosion found at the upstream end of the site, and trends seen at older restoration sites, it is likely that the missing scour chains are buried beneath the material scoured from upstream. It is also possible, but less likely, that (1) the highly permeable gravel allowed enough movement that scour chains were dislodged from the substrate, (2) the downstream end received enough erosion that chains were completely uncovered and released from the substrate, or (3) scour chains were removed by humans (it is unlikely that a fisherman or rafter would have removed all six scour chains from this area, especially because flow conditions and high velocities made it difficult to see beneath the water). The most efficient way to determine if erosion or deposition is occurring is to dig down into the gravel at the missing scour chain location, during a low flow event, and search for scour chains.

Upwelling and downwelling results obtained from hyporheic pressure head measurements show shallow conditions and short flow paths, while temperature records at Lower Sailor Bar 2012 provide a deeper record. Pressure head data indicated that the majority of the shallow gravel where salmonids spawn was dominated by upwelling and neutral conditions except for two narrow midstream zones and one downstream zone of downwelling. This information was collected in the top one foot of gravel. The two temperature wells installed at the site both indicated downwelling conditions on a broader scale, and were from depths of up to four feet into the gravel. This is discussed in greater detail in chapter 7.

High resolution aerial images taken during the Fall-run Chinook salmon spawning season on November 26, 2012 showed that the Lower Sailor Bar 2012 site received high spawning usage. Figure 3.24 shows the location of approximately 150 redds observed post-restoration. This is a three-fold increase from pre-restoration levels when 50 redds were observed in 2011. Many post-restoration redds were clustered in select portions of the site. The white polygons in Figure 3.24 outline four zones that showed particularly high redd density compared to the rest of the site. Zones 1 and 2 were pods of smaller substrate material (approximately 70% of grains were ≤ 0.13 inches in diameter based on post-restoration pebble counts 3 and 4). Zone 3 was characterized by a hummocky topography with medium grain sizes (the majority of grains ranged from 0.625 in. to 1.75 in. based on post-restoration pebble counts 7, 9 and 10). The depth of these zones was generally ≤ 2 ft with velocities ranging from 3 ft/s to 5 ft/s. Like the rest of the site, the high use zones were dominated by upwelling conditions with narrow zones of neutral and downwelling conditions. Zone 4 was in an area that was not easily accessible by the field team because of high flows.

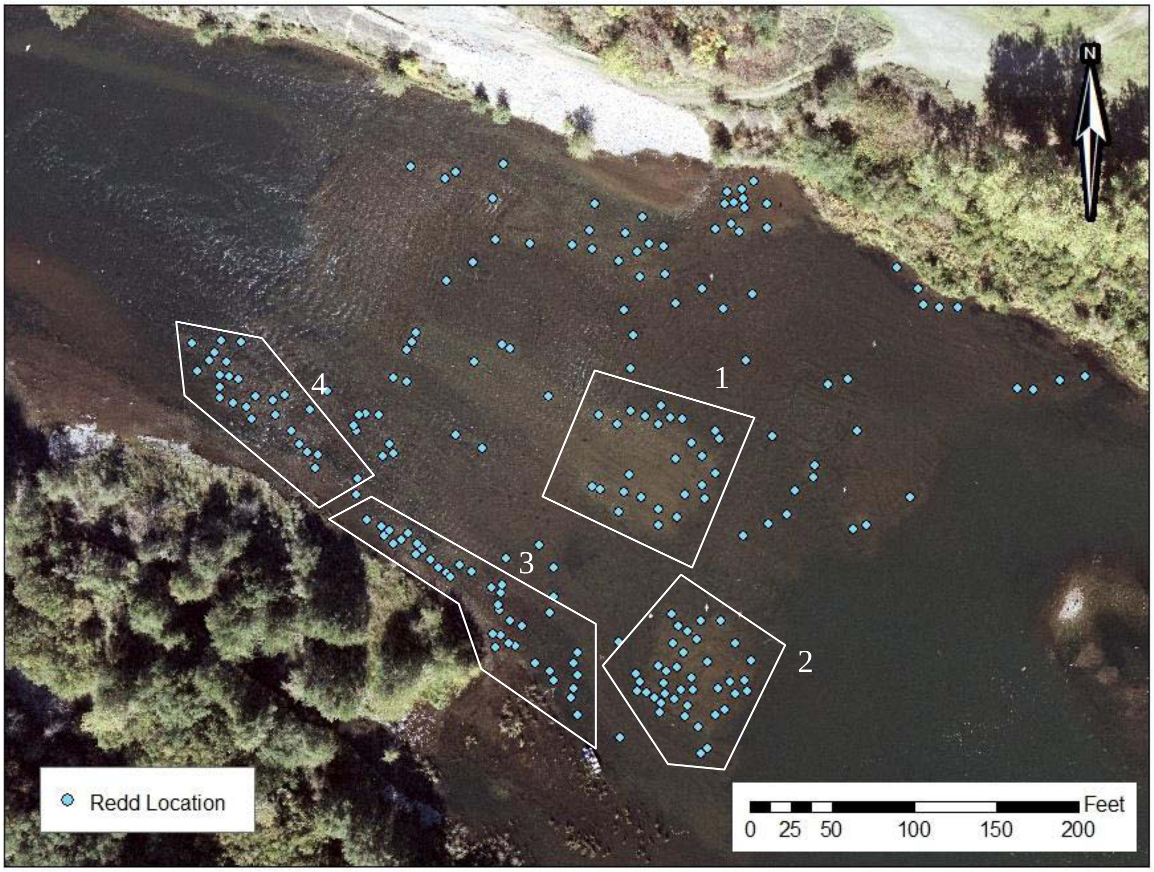


Figure 3.24: Fall-run Chinook salmon redd locations at the Lower Sailor Bar 2012 site during the 2012 spawning season. Approximately 150 redds were counted from photos of the site as of November 26, 2012. Zones with particularly high use are outlined by white polygons. Redd counts may be underestimated, because shadows or substrate conditions may prevent detection of all redd locations from aerial photos. (High resolution aerial images courtesy of John Hannon, USBOR)

4.0 UPPER SUNRISE 2010/2011 RESULTS

4.1 GRAVEL MOBILITY

Tracer Rocks

Tracer rocks were deployed at the study site immediately following gravel augmentation in 2011 and positions tracked in 2012 and 2013. As of May 2012, the majority of tracer rocks had moved no more than 10's of cm downstream of initial placement (Figure 4.1). Tracer rocks were located again in April 2013 following the Winter season. River flows between October 2012 and April 2013 ranged from a low of 942 cfs to a high of 9,980 cfs with a mean flow of 2,382 cfs. Flows above 5,000 cfs persisted throughout the month of December. As of April 2013, tracer rocks showed little to no additional movement.

Figure 4.1: Post gravel addition map of Upper Sunrise 2010/2011 showing initial placement of tracer rocks (pink) and location of rocks located in May 2012 (green). Large (2.5 in. - 3 in.), medium (1.25 in. - 1.75 in.), and small (0.625 in. - 0.875 in.) tracer rocks were placed at each point on the map.

Scour Chains

Fourteen scour chains were installed at the Upper Sunrise 2010/2011 site following gravel augmentation in October 2011 (Figure 4.2). An initial round of scour chain measurements was made in January 2012. In April 2013, eight of the original chains were recovered (Figure 4.3). Three chains from the upstream end of the site were missing, along with the furthest downstream scour chain. Data collected from these two sampling events indicated that the upstream and downstream ends of the site are experiencing erosion, while the middle portion of the site is experiencing deposition. Erosion is evidenced by increasing scour chain length over time, ranging from 4 in. to 5.5 in. Deposition is evidenced by decreasing scour chain length over time, ranging from 1 in. to 6.5 in. Data from 2011 (Figure 4.2) were compared to maps from 2013 (Figure 4.3). Scour chains that were missing in 2013 were from highly scoured areas, so it is likely that the missing chains were lost due to erosion.

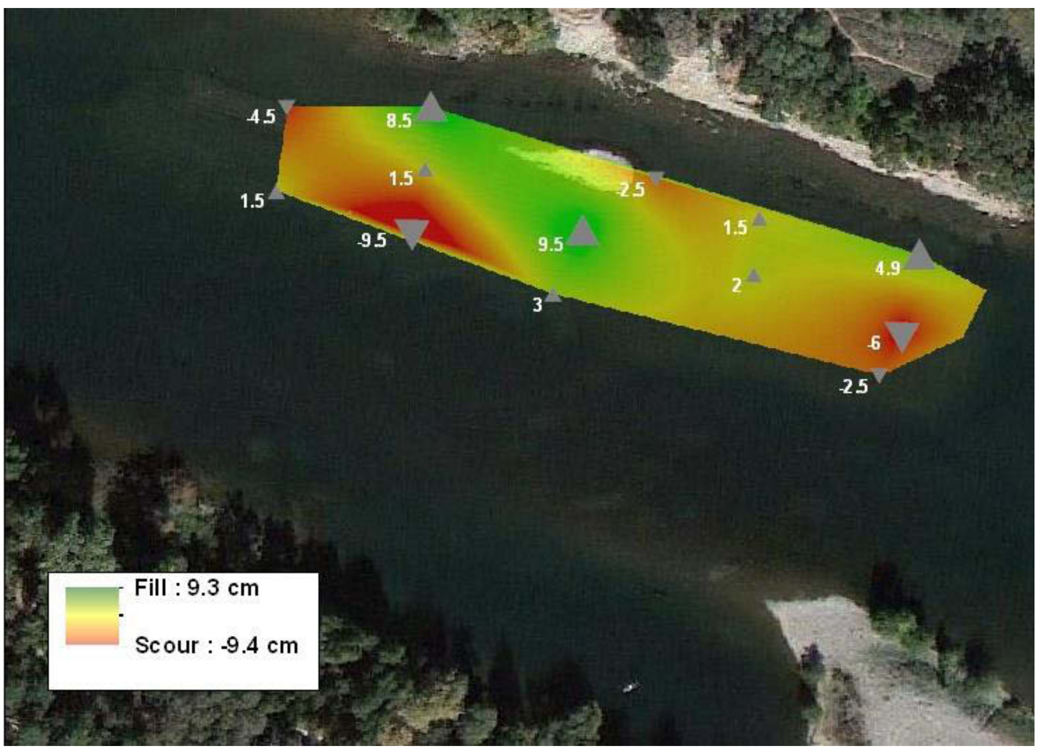


Figure 4.2: Scour and fill map of Upper Sunrise 2010/2011 site after the 2011 restoration based on the initial chain lengths and measurements collected in January 2012. (From Janes et al, 2012)

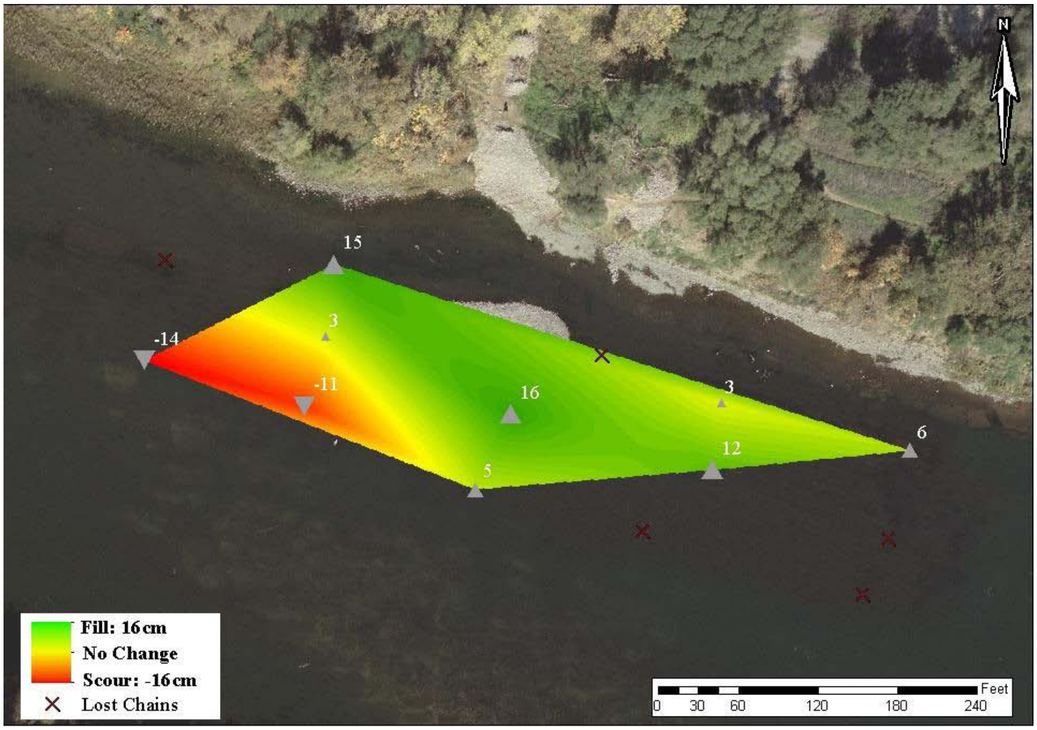


Figure 4.3: Scour and fill map of Upper Sunrise 2010/2011 site following restoration, based on the initial chain lengths and measurements collected in April 2013.

4.2 SURFACE WATER DEPTH AND VELOCITY

Surface water depth and velocity data have been collected from the Upper Sunrise 2010/2011 site since December 2011. The site is characterized by a long gravel ridge parallel to flow with little variation in streambed topography and a moderate sized pool just upstream. Figure 4.4 is a map of the 59 locations where depth, velocity and current direction measurements were recorded at the study site. Measurements were made in October 2012 at a flow of approximately 1,700 cfs. Velocities ranged from 0.3 ft/s to 3.5 ft/s (Table 4.1) and depth ranged from 0 ft to 2.8 ft (Table 4.2). The arrows in Figure 4.4 show little variation in velocity at the site, and a somewhat uniform direction of flow parallel to the gravel ridge.

In 2012, we began to monitor surface water depth and velocity at a natural spit on the south bank of the river channel adjacent to the restoration site. The natural spit was characterized by a hummocky riverbed with surface water depth averaging approximately

1.5 ft. Figure 4.4 includes the 27 locations where measurements were recorded at the natural spit in November 2012 at a flow of 1,800 cfs. Depth and velocity at the spit (Table 4.2) were similar to those at the Upper Sunrise 2010/2011 site. The arrows in Figure 4.4 show that the direction of flow was perpendicular to the spit.

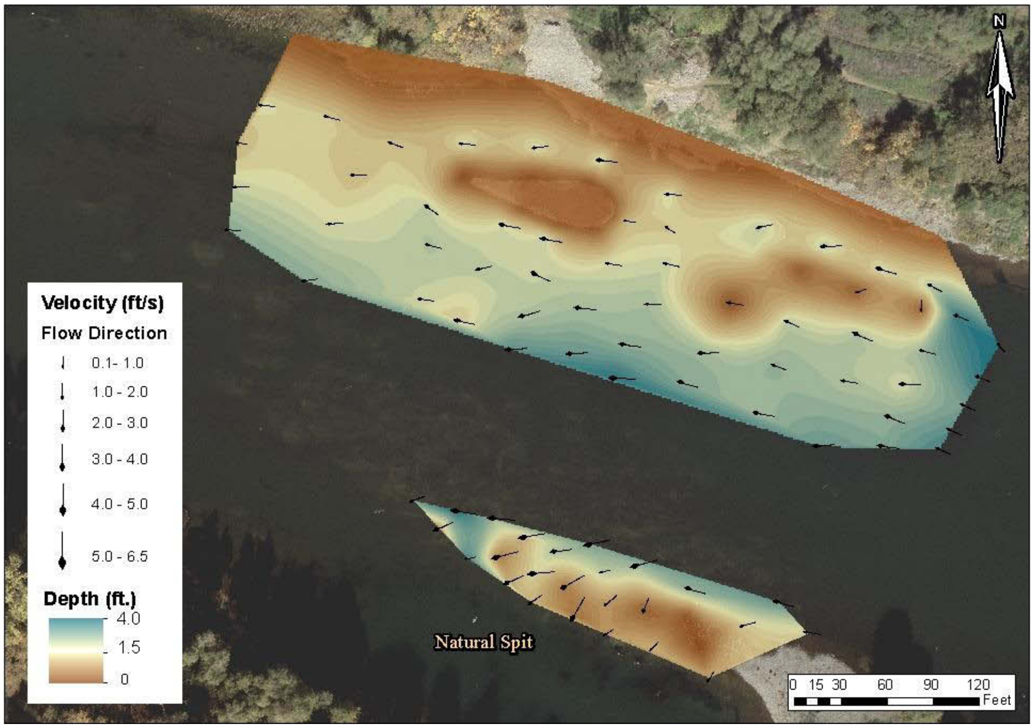


Figure 4.4: Depth, velocity and direction of flow for 59 measurements taken at the Upper Sunrise 2010/2011 site in October 2012 at a flow of approximately 1,750 cfs. 27 measurements were also taken at the Upper Sunrise Natural Spit in November 2012 at a flow of 1,800 cfs.

Table 4.1: Summary and statistical comparison of surface water depth and velocity at the Upper Sunrise 2010/2011 site from December 2011 to October 2012.

	Flow (cfs)	Range	Mean	Standard Deviation	Coefficient of Variation	Number of Measurements
Velocity October 2012	1,700	0.3-3.5 ft/s	1.84 ft/s	0.37	33	59
Velocity December 2011	2,040	0.53-2.52 ft/s	1.52 ft/s	0.56	37	14
Depth October 2012	1,700	0.10-3.5 ft	2.04 ft	0.70	35	59
Depth December 2011	2,040	0.5-2.7 ft	2.08 ft	0.70	34	14

Table 4.2: Summary of results for depth and velocity at the Upper Sunrise Natural Spit in November 2012.

	Range	Mean	Standard Deviation	Coefficient of Variation	Number of Measurements
Velocity	0.33 – 2.8 ft/s	1.58 ft/s	0.74	47	27
Depth	0.3 – 2.9 ft	1.45 ft	0.70	48	27

4.3 GRAVEL PERMEABILTY

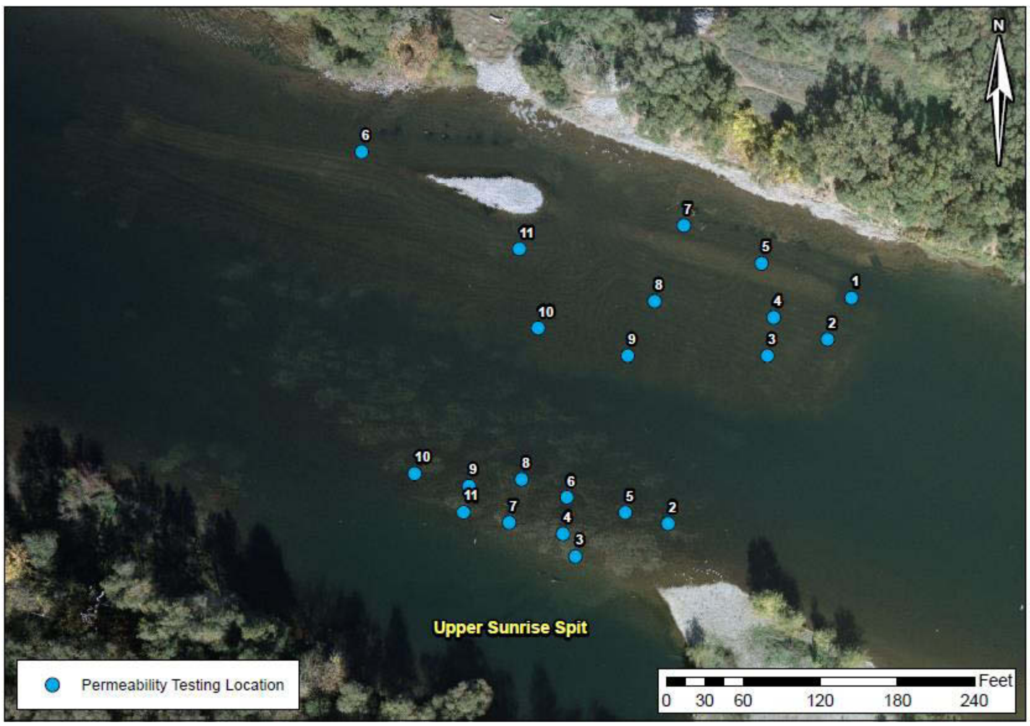


Figure 4.5: Locations of permeability tests at the Upper Sunrise 2010/2011 restoration site and adjacent natural spit.

On February 27 and April 12, 2013, 11 permeability tests were conducted at the Upper Sunrise 2010/2011 site (Figure 4.5). River flows averaged 2,250 cfs and 1,400 cfs during testing. Permeability for all tests exceeded equipment limitations, producing hydraulic conductivity values in excess of 95,000 cm/hr (the limitation of the pumping apparatus). Results were reported as the maximum pumping value (95,000 cm/hr), but actual values for permeability are higher. Eleven additional tests were conducted at the

Upper Sunrise Natural Spit located on the south bank of the river channel adjacent to the Upper Sunrise 2010/2011 site (Figure 4.6) on November 12, 2012 and February 11, 13, and 20, 2013. River flows average between 1,900 cfs and 2,200 cfs during testing. Hydraulic conductivity values ranged from 33 cm/hr to 15,000 cm/hr (Table 4.3).

Table 4.3: Permeability results for the Upper Sunrise Natural Spit.

Test Number	Test Date	K (cm/hr)	Test Number	Test Date	K (cm/hr)
1	11/12/2012	1,135	8	2/20/2013	9,329
2	2/11/2013	12,282	9	2/20/2013	15,329
3	2/11/2013	1,205	10	2/20/2013	7,003
4	2/11/2013	4,626	11	2/20/2013	306
5	2/11/2013	33	**Mean**		**5,000**
6	2/11/2013	584	**Coefficient of Variation**		**101**
7	2/11/2013	3,189			

4.4 HYPORHEIC PRESSURE HEAD

Upwelling and downwelling measurements were conducted in October 2012 at a flow of approximately 1,750 cfs. Positive numbers indicate upwelling, negative numbers indicate downwelling, and a value of zero indicates no upwelling or downwelling conditions. Pressure head measurements were taken at 51 discrete locations across the Upper Sunrise 2010/2011 site (Figure 4.6). The site was dominated by upwelling conditions. 61% of measurements indicated upwelling, 31% indicated neutral, and 8% indicated downwelling conditions; values ranged from 0.50 in. to -0.25 in. across the site. At the upper half of the site, high magnitude upwelling conditions were prominent along the southern edge of the gravel addition, adjacent to the thalweg, and toward the center of the site. The few zones where downwelling occurred were found in the topographically high areas that form a gravel ridge that runs parallel to the stream channel. Neutral conditions were most common in the upstream half of the site (river right) near the north bank, and on the downstream end of the site.

Pressure head measurements were also taken at 12 locations at the Upper Sunrise natural spit on November 8, 2012 at a flow of approximately 1,800 cfs (Figure 4.6). The spit was dominated by upwelling (58%) and neutral (42%) conditions; values ranged from 0 in. to 0.75 in. across the site. Upwelling conditions were prominent at the upstream half of the spit and neutral conditions at the downstream half of the spit.

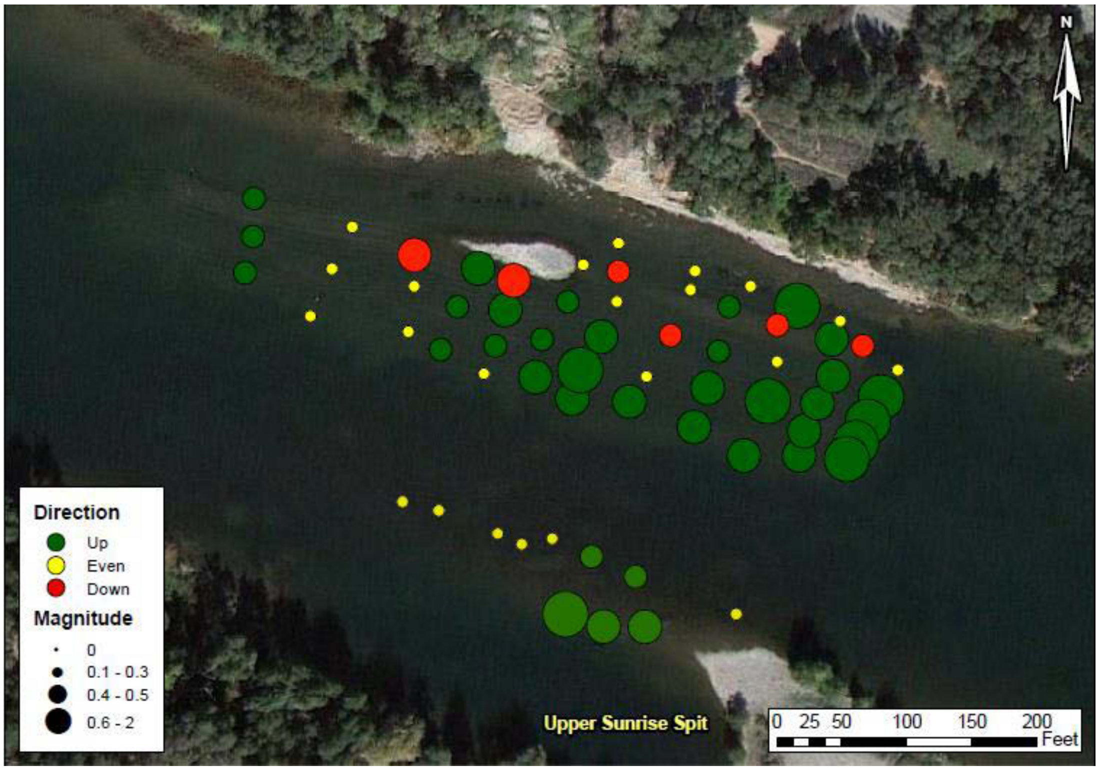


Figure 4.6: Upper Sunrise 2010/2011 upwelling and downwelling data recorded on October 25, 2012 at 1,750 cfs and natural spit data recorded on November 12, 2012 at 1,800 cfs.

4.5 TEMPERATURE

Five temperature housings (wells) were installed at both the Upper Sunrise 2010/2011 site and adjacent natural spit in April 2013 (Figure 4.7). Temperature loggers recorded data every 30 minutes beginning on April 26, 2013. Although this report ends in May 17, 2013, wells are still in place and will record temperature over the next year for further study. Results from the Upper Sunrise 2010/2011 site are presented in Figures 4.8a, 4.8b, and 4.8c and results from the natural spit are presented in Figures 4.9a, 4.9b, and 4.9c. Data from well US-1 is limited because the temperature loggers were vandalized on May 4, 2013.

All wells at the Upper Sunrise 2010/2011 site showed an overall increase in temperature during the study period regardless of depth. Diurnal temperature fluctuations at all depths in the upstream and middle wells (US-1, US-2 and US-5) indicated strong downwelling conditions (Figure 2.12). Well US-5 showed a slight dampening of the diurnal tracer at 3.5 ft in the gravel indicating a slight reduction in downwelling conditions in the middle of the site (Figure 4.8c). In the downstream wells (US-3 and US-4), there was a distinct difference between temperatures 1 ft to 2 ft in the gravel and those 3 ft to 4 ft into the gravel (Figure 4.8b). At shallower depths, temperatures showed a strong diurnal signal. At greater depths, the temperature pattern showed a very weak diurnal signal if any at all. This may indicate that groundwater is upwelling into the shallow gravel at the downstream end of the site. This flow pattern is common in riffles, with downwelling at the head of the riffle (pool tail-out) and upwelling at the tail of the riffle (Stonestrom and Constantz, 2003). However, it may also indicate a change in substrate material. During restoration, new gravel was placed directly on top of the heavily armored streambed. This signal reduction could represent the boundary between pre-restoration substrate and augmented gravel. Highly permeable gravel would allow the diurnal signal to move freely at shallow depth whereas the compacted material would reduce the ability of the diurnal signal to move through the deeper substrate. If so, the temperature patterns from US-3 and US-4 indicate a substrate boundary between 3 ft and 4 ft deep.

All wells at the natural spit showed an overall increase in temperature during the study period regardless of depth. Wells located on the south bank of the spit (GS-2 and GS-4) showed a very strong upwelling signal (Figure 4.9a). Diurnal temperature fluctuations were barely visible 1 ft. into the substrate and nonexistent at 2 ft to 4 ft depths. Wells located on the north bank of the spit (GS-3 and GS-5) showed a slight decrease in diurnal temperature fluctuation 1 ft in the gravel, and a highly dampened diurnal signal below 2 ft (Figure 4.9b). This may indicate reduced upwelling conditions or a substrate boundary. The most upstream well on the spit (GS-1) showed a similar temperature pattern as GS-3 and GS-5, but the diurnal temperature fluctuations were strong up to 3 ft in the gravel (Figure 4.9c). The upwelling and downwelling conditions indicated by temperature data represent deeper flow paths and may contradict the hyporheic pressure head conditions (Figure 4.6) that show shallow flow paths. This will be addressed in the discussion portion of this chapter.

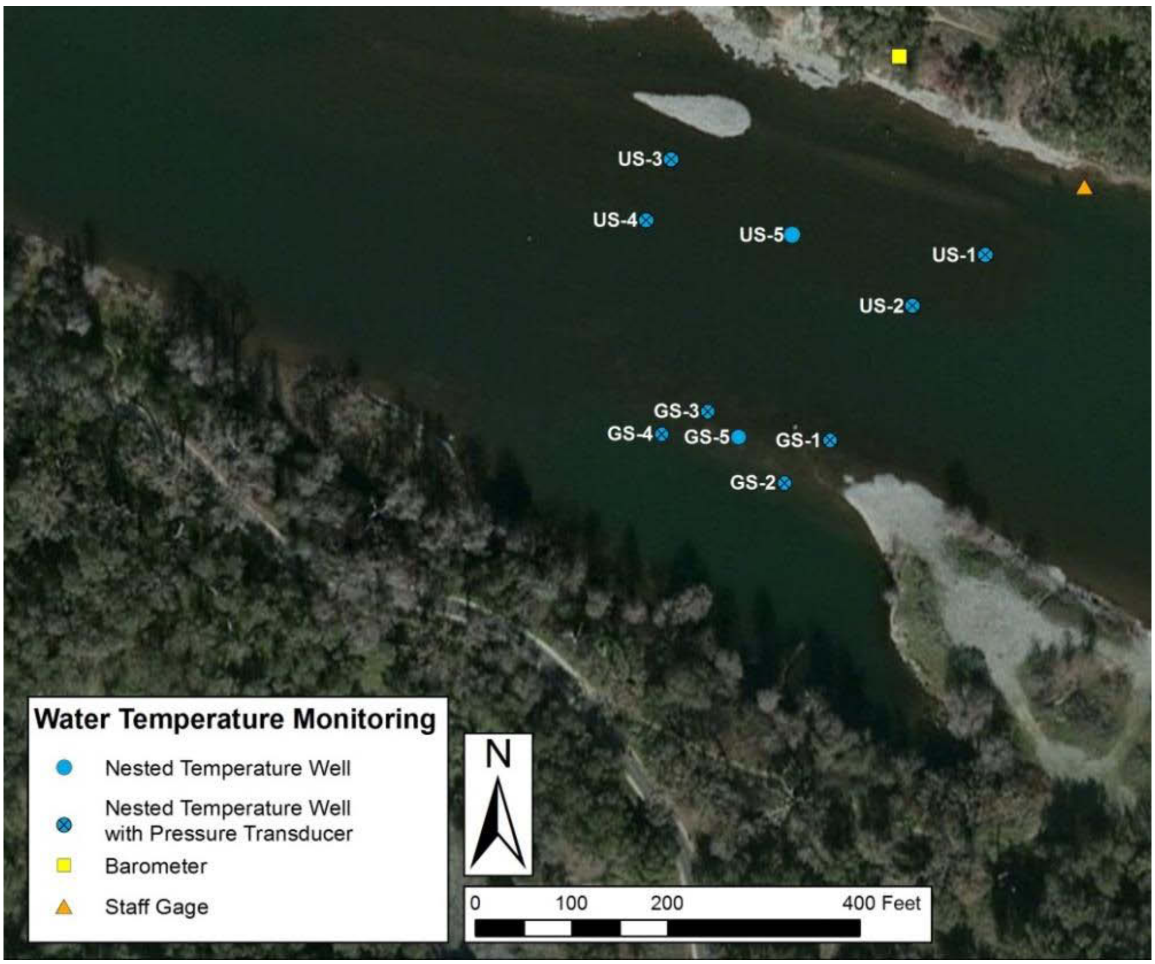


Figure 4.7: Map of temperature housing locations at the Upper Sunrise 2010/2011 restoration site and at the adjacent natural spit.

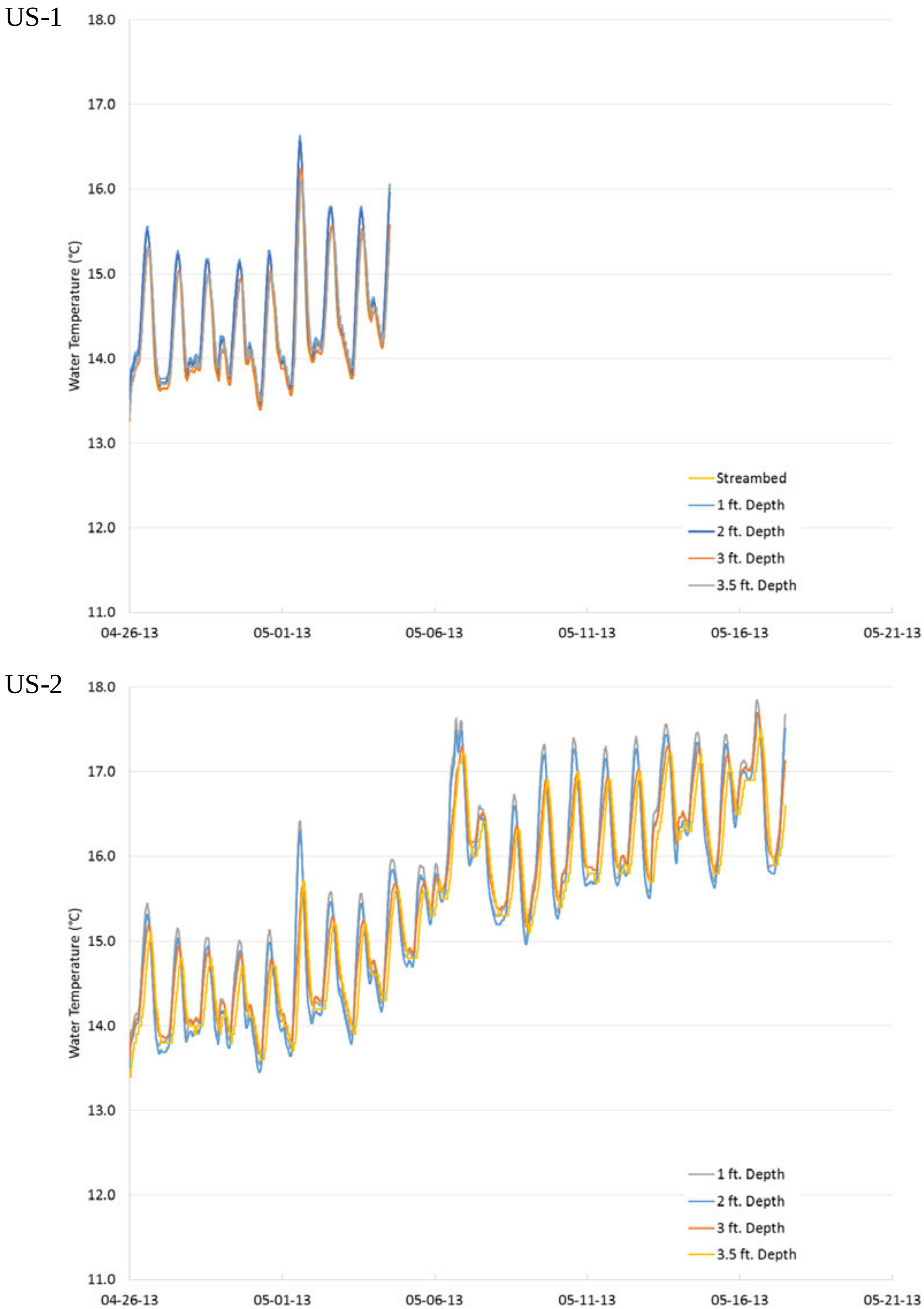
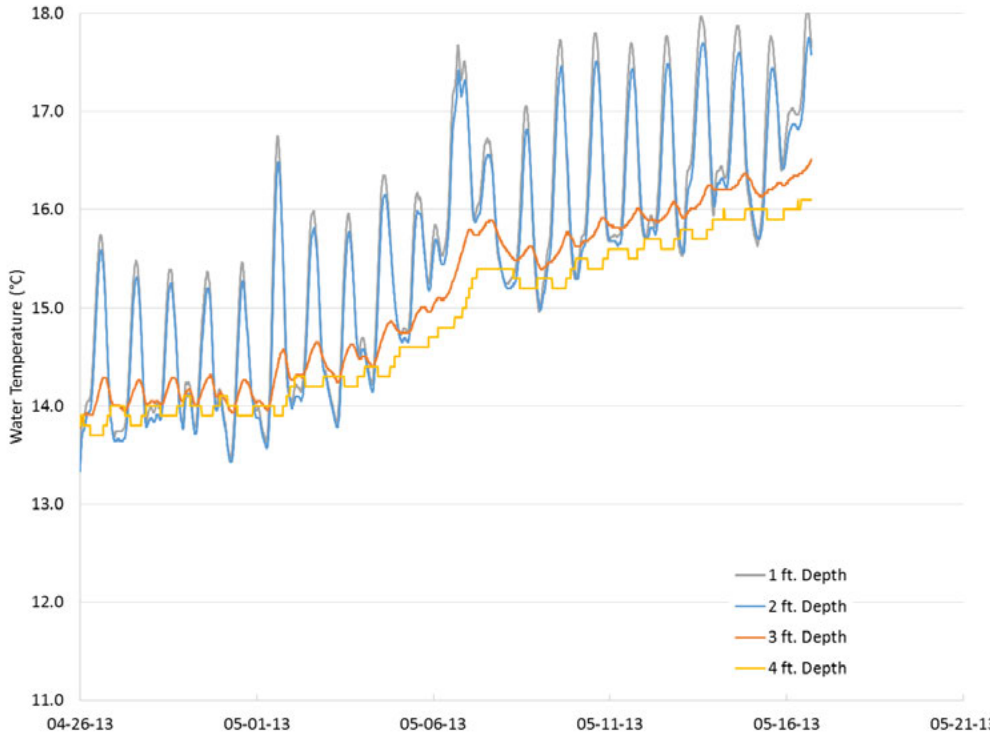


Figure 4.8a: Water temperature at the Upper Sunrise 2010/2011 site. US-1 and US-2 were located upstream and show a strong downwelling signal.

US-3



US-4

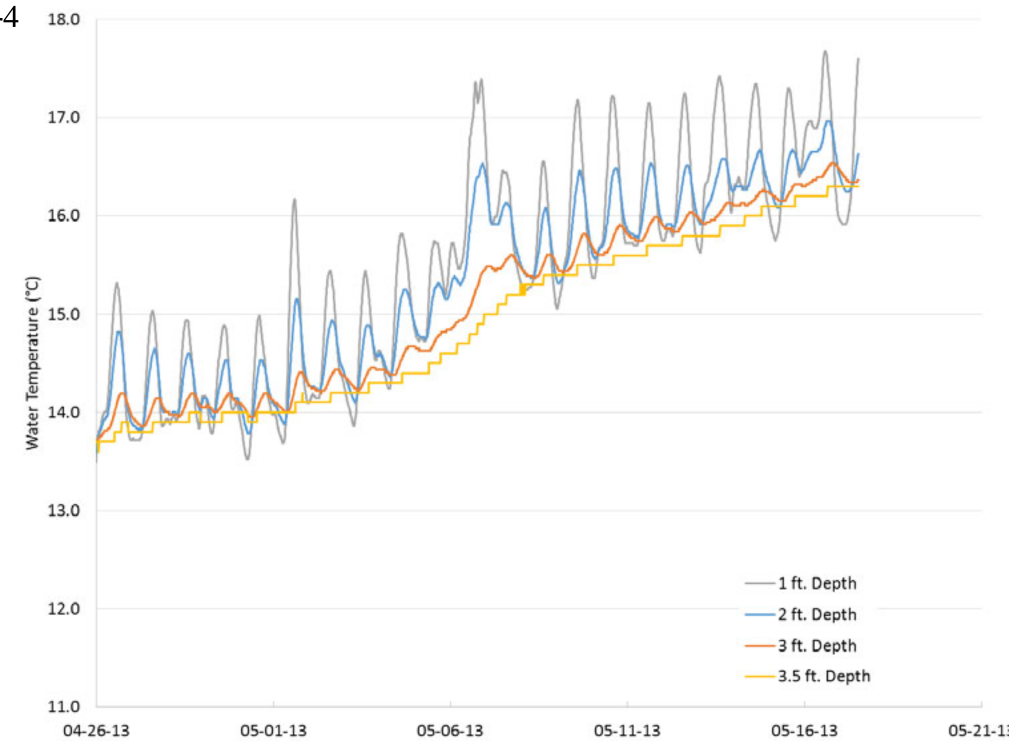


Figure 4.8b: Water temperature at the Upper Sunrise 2010/2011 site. US-3 and US-4 were located downstream and show less heat exchange below 2 ft depth in the gravel. This may indicate upwelling conditions or denser impermeable substrate.

US-5

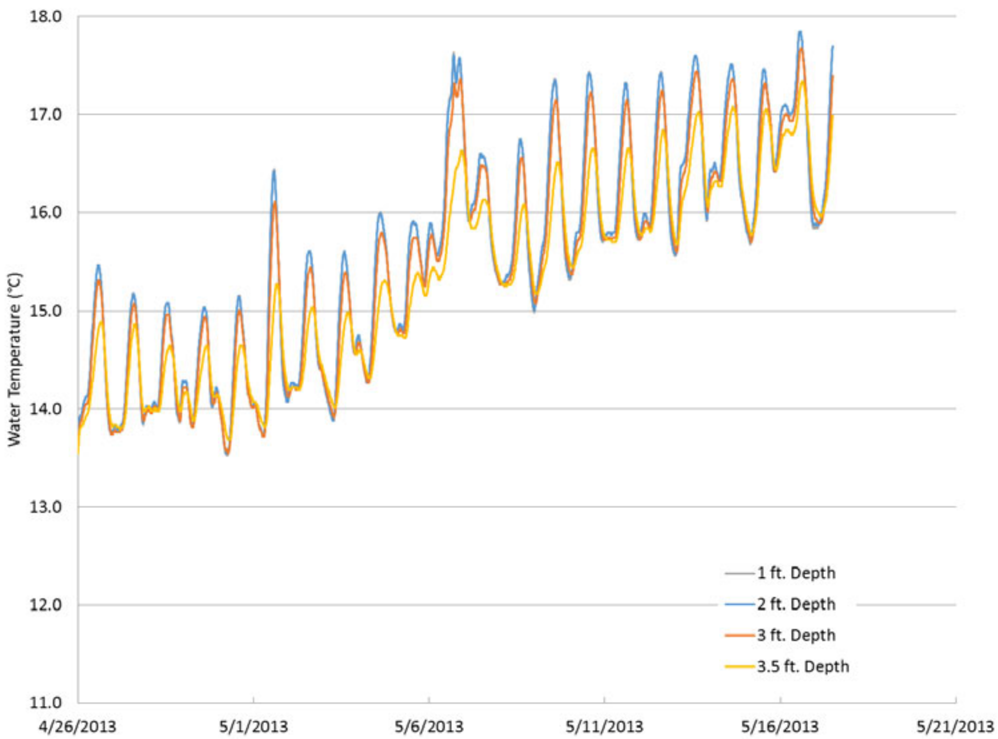
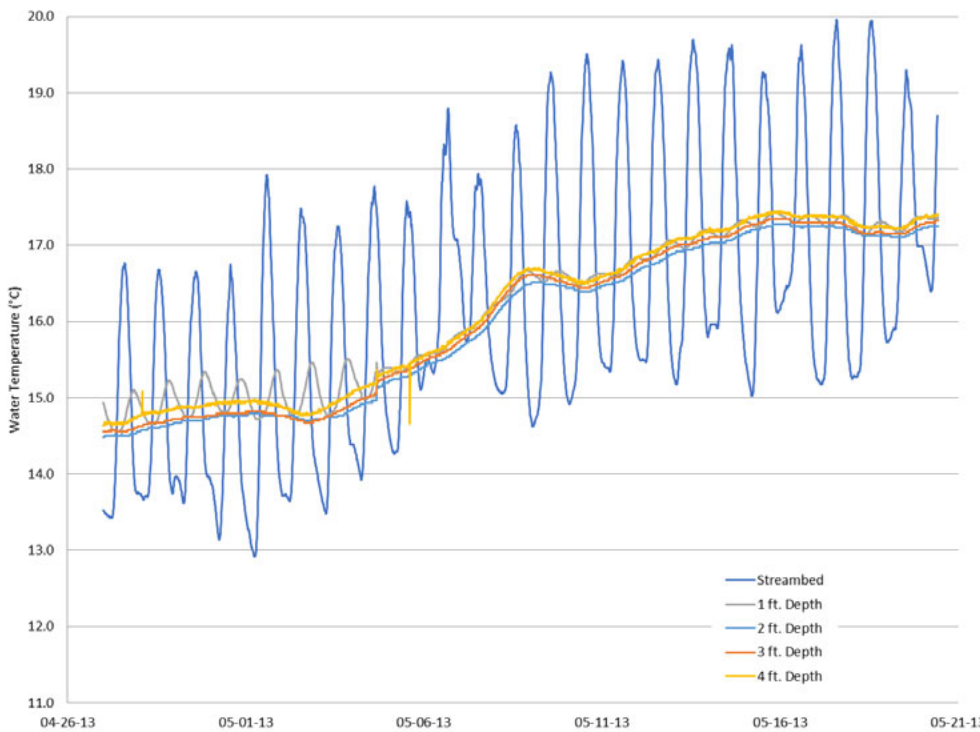


Figure 4.8c: Water temperature at the Upper Sunrise 2010/2011 site from April 2013 through May 2013. US-5 was located in the middle of the site and shows a downwelling signal, with strong exchange to a depth of 3.5 ft.

GS-2



GS-4

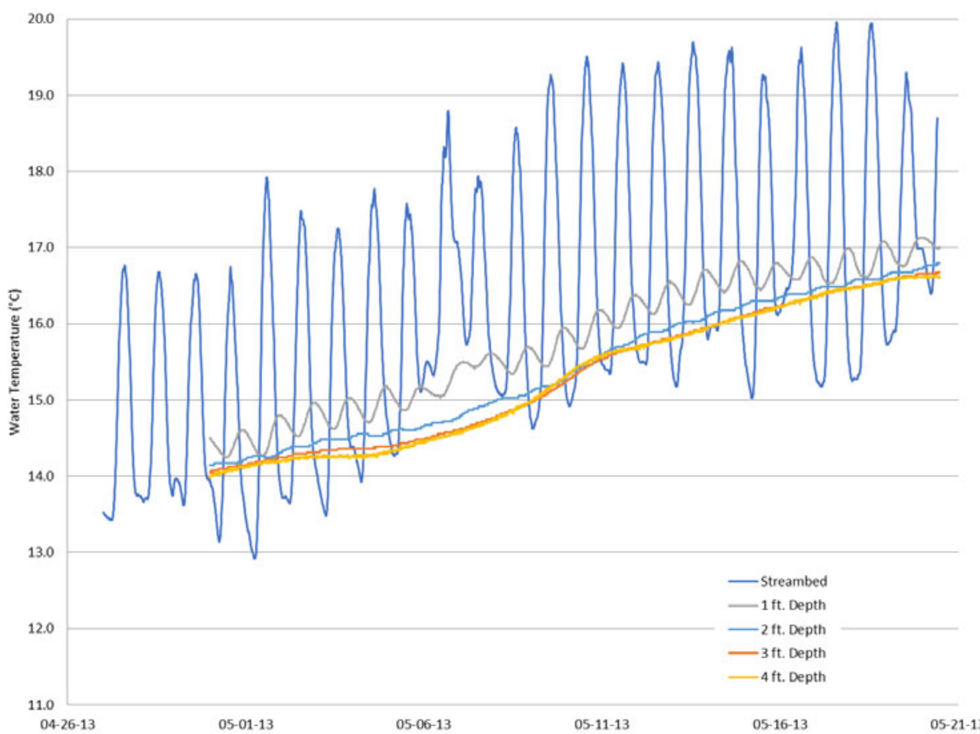
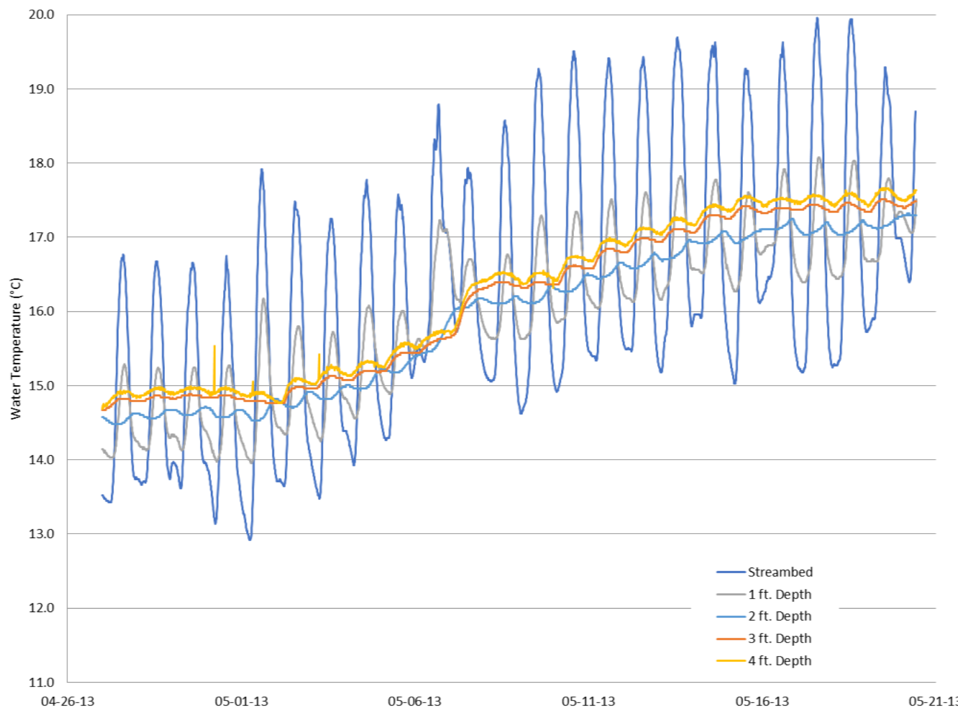


Figure 4.9a: Water temperature at the natural spit. GS-2 and GS-4 were located on the south bank of the spit and show a strong upwelling signal.

GS-3



GS-5

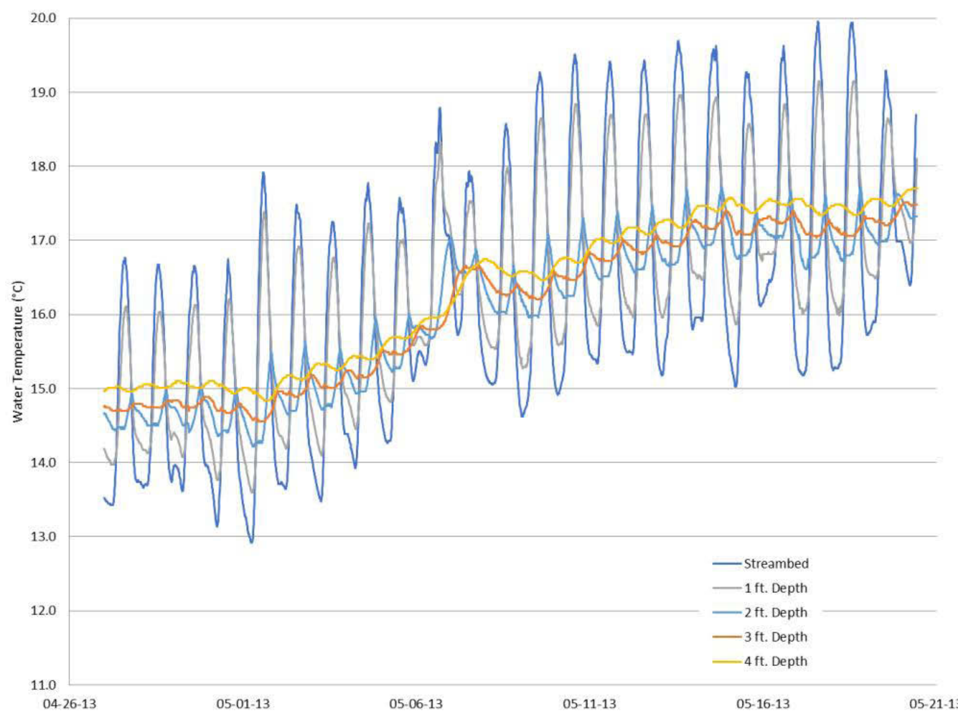


Figure 4.9b: Water temperature at the natural spit. GS-3 and GS-5 were located on the north bank of the spit (closest to the main channel) and show less heat exchange below 2 ft depth in the gravel. This may indicate a denser less permeable substrate 2 ft and below.

GS-1

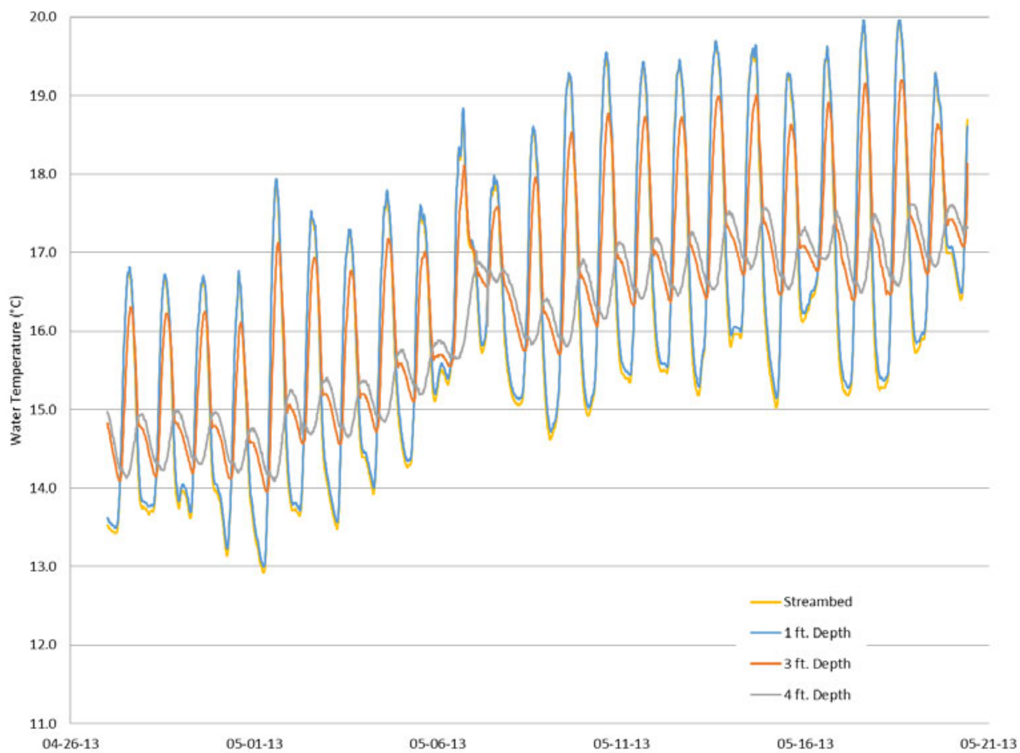


Figure 4.9c: Water temperature at the natural spit from April 2013 through May 2013. GS-1 was located on the north bank of the spit (closest to the main channel). The GS-1 well is the most upstream well on the spit and positioned closest to the main channel. The temperature pattern at this well shows a strong downwelling signal 1 ft to 3 ft in the streambed and a reduced signal 4 ft in the streambed. This may indicate a less permeable substrate 4 ft into the gravel.

4.6 HYPORHEIC WATER QUALITY

Water quality parameters have been collected at the Upper Sunrise 2010/2011 site since August 2009. Typically, post-restoration water quality samples are collected three times within a spawning season; during redd construction in the Fall, during egg incubation in the winter, and during fry emergence in the Spring. Discharge on the river between December 2012 and January 2013 was high and produced flow conditions that were unsafe for field workers (Figure 1.5). Therefore, only two sampling events were conducted during the 2012/2013 field season, in the Fall of 2012 and the spring of 2013. Measurements are summarized in tables and presented on maps.

Figure 4.10 is a location map of 16 mini-piezometers maintained at the site during the 2012/2013 field season. Table 4.4 shows water quality data collected in November 2012 from 15 of the 16 piezometers. D.O. levels ranged from 2.62 mg/L to 10.81 mg/L with a mean of 7.06 mg/L, and D.O. saturation ranged from 22.4% to 101.1% with a mean of 77.2%. The well at location 8 had significantly lower intragravel flow than the majority of the site. If the data from location 8 was classified as an outlier and removed from the data set, then the mean D.O. level is 8.44 mg/L and the mean D.O. saturation of 81.8%. Table 4.5 shows water quality data collected in December 2011, during the previous spawning season. D.O. levels ranged from 8.7 mg/L to 9.1 mg/L with a mean of 8.85, and percent D.O. saturation ranged from 80.3% to 85.4% with a mean of 83.68 %.

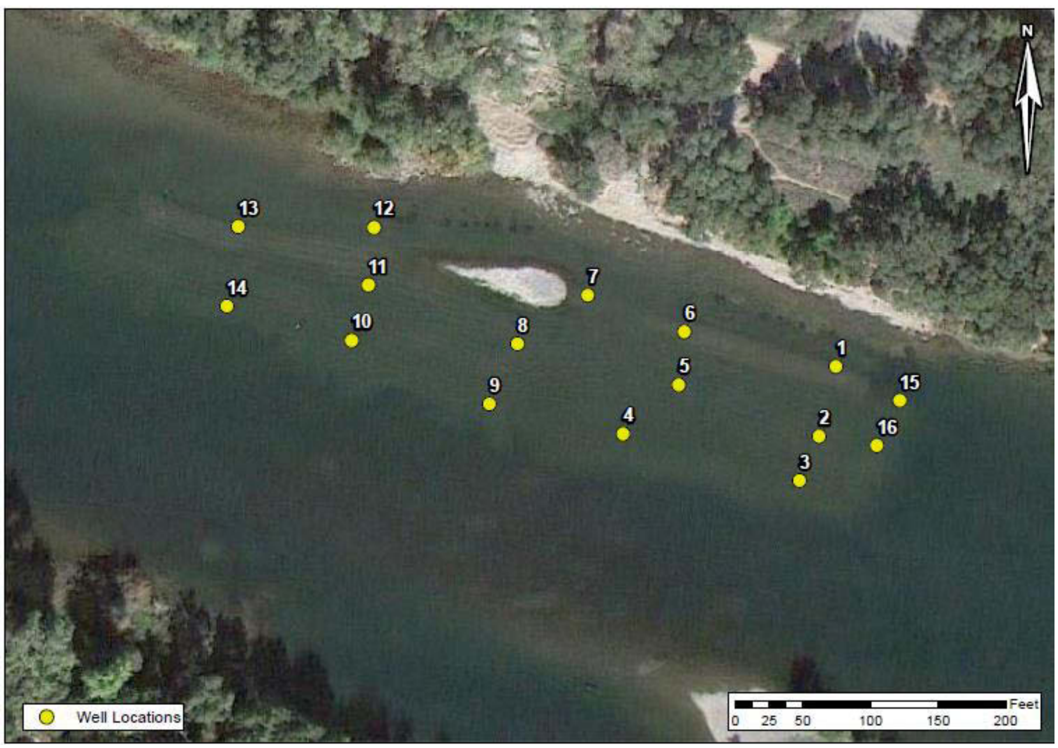


Figure 4.10: Locations of piezometers after restoration of the Upper Sunrise 2010/2011 site.

Figure 4.11 shows fall 2012 D.O. saturation levels on the Upper Sunrise 2010/2011 Map. Green dots represent high D.O. levels that are within 90% of surface water levels and therefore indicate good intragravel flow. Yellow dots represent D.O. percent levels that are within 60% -90% of surface water measurements. These sites are reasonable for egg development and survival, but may indicate lower intragravel flow. Red dots represent D.O. percentages that are critically low for egg development and survival. D.O. levels were highly variable across the site.

Table 4.4: Upper Sunrise 2010/2011 Water Quality Parameters as of November 2012

Location	D. O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
1	10.22	90.03	50.7	7.15	35
2	9.8	97.5	44.1	7.1	50
3	10.46	101.1	44.5	7.1	7
4	9.89	98	47.3	6.89	80
5	4.09	39.3	58.3	6.81	90
6	7.99	79.7	44.3	6.83	170
8	2.62	22.4	55.6	6.78	6.7
9	9.81	97.4	49.3	7.08	11.9
10	10.81	99.6	48.4	7.14	77.1
11	4.89	49	42.9	6.53	58.5
12	5.07	48.5	44.8	6.57	14.1
13	9.88	97.9	48.8	7.03	3.4
14	8.31	83.2	50.8	7.06	49.1
Mean	**7.06**	**77.2**	**48.4**	**6.93**	**50.2**
Coefficient of Variation	**36**	**36**	**10**	**3**	**94**
Surface 1	10.33	101.6	44.2	7.15	5
Surface 2	10.22	100.1	46.1	7.15	4.1

Parameters were collected in November 2012 at approximately 1,800 cfs with an average hyporheic temperature of 14.9°C. Location 7 was clogged**.**

Areas with high and moderate D.O. values are located along the south bank (river left) of the study area, and are closest to the thalweg. Low D.O. values were found near the middle portion of the site where gravels are at a high elevation and form a ridge that runs parallel to the stream channel. Figure 4.12 illustrates turbidity levels across the study site in November 2012. Darker colors represent higher turbidity values and lighter colors represent lower values. Turbidity levels in pore water are highly variable across the site, ranging from 7 NTU to 170 NTU with a mean of 50.2.

Table 4.6 summarizes the mean water quality parameters before restoration of the site (Aug. 2009) and in the years following restoration (Dec. 2011 – Apr. 2013). Prior to restoration, mean D.O. was very low at 3.58 mg/L. Following restoration, mean D.O. improved to 8.06 mg/L. Since then, mean D.O. levels at the site have remained high, fluctuating between 9.8 mg/L and 14.7 mg/L. D.O. values are highly temperature dependent, so some of this fluctuation is caused by variations in temperature. Percent saturation, the amount of oxygen in the hyporheic sample relative to the amount of oxygen in the surface water, is not subject to this variability and shows a slight decline in intragravel D.O. over time.

Table 4.5: Upper Sunrise 2010/2011 Water Quality Parameters as of December 2011

Location	D. O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
1	8.9	84.3	36.9	7.4	4.3
2	8.8	83.3	36.3	7.4	4.4
3	8.9	84.3	36.3	7.4	3.9
4	9	85.4	36.8	7.5	8.9
5	8.9	83.9	36.5	7.4	7.8
6	8.7	82.4	36.8	7.4	5.2
7	9	85.2	36.6	7.3	10.9
8	9	84.7	51.2	7.5	23.3
9	8.8	82.8	36.2	7.4	21.5
10	8.8	83.3	36.8	7.4	16.6
11	9.1	86.2	36.7	7.4	11.5
12	8.6	81.3	36.4	7.3	4
13	8.5	80.3	36.9	7.4	4.5
14	8.9	84.1	36.9	7.4	3.9
Mean	**8.85**	**83.68**	**37.66**	**7.4**	**9.34**
Coefficient of Variation	**2**	**2**	**10**	**1**	**72**
Surface 1	9.6	91.1	36.2	7.5	4.7
Surface 2	9.1	86	36.3	7.4	1.9

Parameters were collected in December 2011 at approximately 2,040 cfs with an average hyporheic temperature of 12.79°C.

Table 4.6: Upper Sunrise 2010/2011 Mean Water Quality Parameters

	D.O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
Aug. 2009	3.58	38.66	54.80	6.68	23
Dec. 2011	8.06	76.90	36.01	7.25	67
Nov. 2012	9.8	77.2	48.4	6.93	50.2
Apr. 2013	14.7	68.5	64.1	7.3	47.1

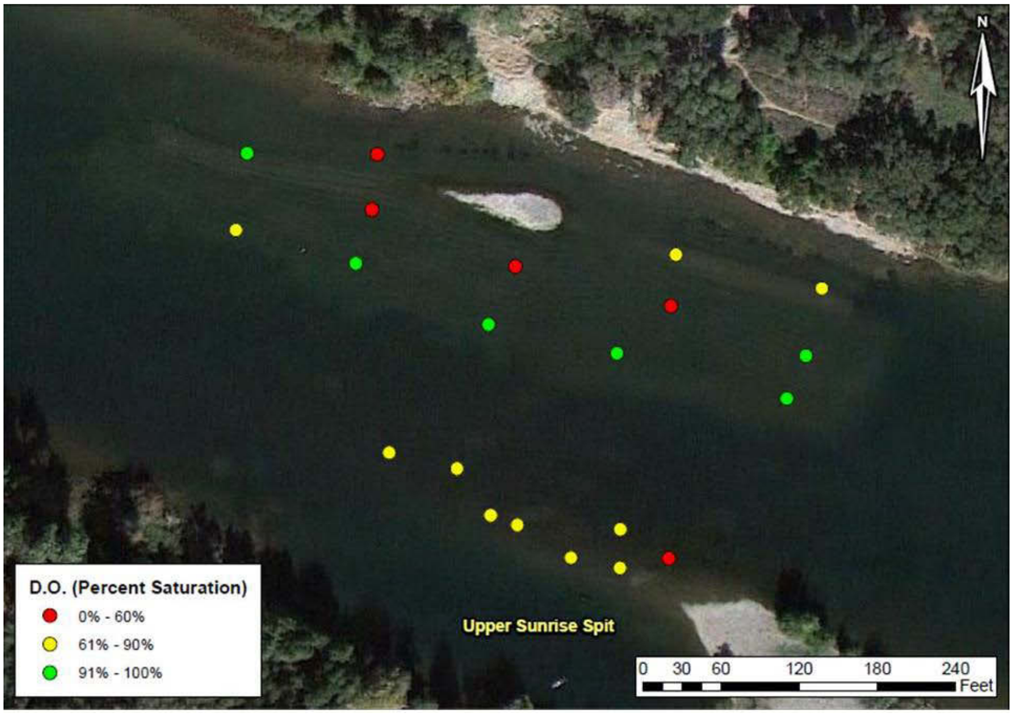


Figure 4.11: Post-restoration percent D.O. saturation levels at Upper Sunrise 2010/2011 sampled in November 2012.

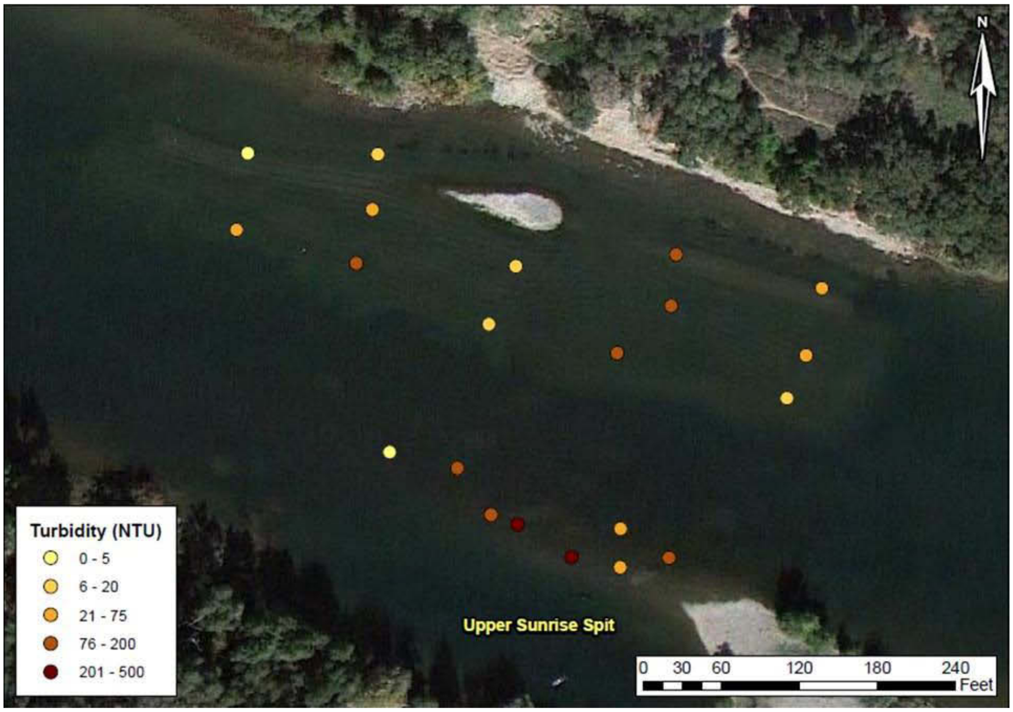


Figure 4.12: Post-restoration turbidity levels at the Upper Sunrise 2010/2011 site sampled in November 2012.

4.7 DISCUSSION

Since augmentation of the Upper Sunrise 2010/2011 site in September 2011, grain size and surface water depth and velocity have remained within optimal ranges for salmonid spawning. Scour chain data indicated gravel was being eroded from the upstream end and deposited along the middle portion of the site. The augmented gravel remained highly permeable, with intragravel flow so high (>95,000 cm/hr) that the standpipe drawdown method could not be used. Overall, hyporheic D.O. levels remained reasonable for salmonid egg development, but showed a slight decline from December 2011 (average D.O. 8.85 mg/L) to November 2012 (average D.O. 7.06 mg/L). Turbidity levels were highly variable in 2012, and increased significantly from December 2011 (average turbidity 9.4 NTU) to November 2012 (average turbidity 50 NTU). The slight decrease in D.O. and strong increase in turbidity indicated that augmented gravel was just starting to become seasoned 1.5 years after placement. The gravel was settling into a more natural state, biofilms were emerging, and finer sediments and organic materials were making their way into the substrate.

Upwelling and downwelling results obtained from hyporheic pressure head measurements show shallow conditions and short flow paths, while temperature well records at Upper Sunrise 2010/2011 provide a deeper record. Pressure head data indicated that the majority of the shallow gravel where salmonids spawn was dominated by upwelling conditions with a few narrow zones of neutral or downwelling conditions. Data from the two upstream and the midstream temperature wells (Figure 4.8a: US-1, US-2, and Figure 4.8c: US-5) indicated strong downwelling conditions in the upper portion of the site on a broader scale. Data from the two downstream temperature wells (Figure 4.8b: Wells US-3 and US-4) showed moderate downwelling conditions on a broader scale. This is discussed in greater detail in chapter 7.

While physical conditions at the Upper Sunrise 2010/2011 site were within optimal conditions for salmonid spawning, high resolution aerial images taken on November 26, 2012 showed that the site received extremely low usage by Fall-run Chinook salmon. Figure 4.13 shows that only six redds were observed. Four redds were clustered at the uppermost boundary of the site where surface water depth ranged from 1.5 ft to 4 ft and velocities ranged between 1 ft/s and 2 ft/s. Two redds were located near the North bank of the site where surface water depths were less than 1.5 ft and velocities ranged from 1ft/s to 3 ft/s Direction of flow showed little variation at both locations. This is the second spawning season since restoration, and in both years less than 15 redds were observed at the site. Conversely, the neighboring natural spit was highly used in both 2011 (>50 redds) and 2012 (>130 redds).

Differences in a variety of data may explain why salmon chose the natural spit was for spawning and not the Upper Sunrise 2010/2011 site. The natural spit is characterized by an elongated ridge of gravel that runs parallel to the main river channel with hummocky topography. The ridge separates the main channel from a large pool on the south bank of the river (the pool is filled by a back current of water off the main channel). In 2012, depth and velocity averaged approximately 1.5 ft and 1.5 ft/s respectively, and the direction of flow was perpendicular to the gravel ridge. This is unlike the Upper Sunrise 2010/2011 site, where surface water flows parallel to the gravel ridge. The D.O. saturation levels at the spit were in a reasonable range (60% to 90%) for salmonid egg development, but average D.O. was lower than the Upper Sunrise 2010/2011 site.

Upwelling and downwelling results at the natural spit obtained from hyporheic pressure head measurements show that the shallow gravel at the upstream half of the spit was dominated by upwelling conditions and shallow gravel at the downstream half was dominated by neutral conditions. Temperature data provided a deeper record of intragravel flow, and indicated that downwelling was occurring on the north side of the spit (closest to the main channel) and upwelling was occurring on the south side of the spit (closest to the pool and south bank of the river).

Permeability measurements at the spit were highly varied. Some tests showed surprisingly low values (33 cm/hr and 306 cm/hr), much lower than the Upper Sunrise 2010/2011 site where all values were > 95,000 cm/hr. Additionally, the average turbidity level at the spit was significantly higher (136 NTU) than the Upper Sunrise 2010/2011 site (50 NTU).

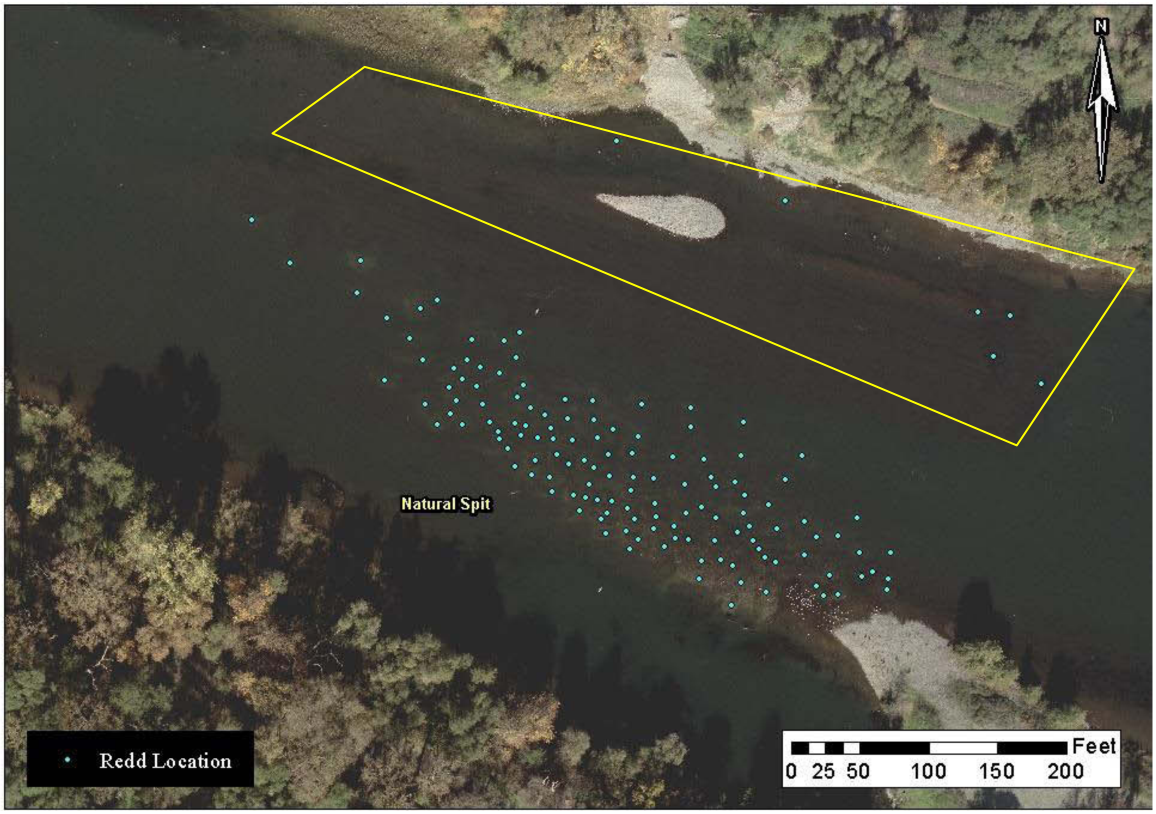


Figure 4.13: Fall-run Chinook salmon redd locations at the Upper Sunrise 2010/2011 site (outlined in yellow) and the natural spit during the 2012 spawning season. Six redds were counted from photos at the study site and 130 redds were counted from photos at the spit as of November 26, 2012. Redd counts are inexact, because shadows or substrate conditions may prevent detection of all redd locations from aerial photos. (High resolution aerial images courtesy of John Hannon, USBOR)

5.0 UPPER SAILOR BAR 2009 RESULTS

5.1 GRAVEL MOBILITY

Scour Chains

Following gravel augmentation, 25 scour chains were installed at the Upper Sailor Bar 2009 study site. As of February 2012, only six of the original chains could be recovered. In April 2013, no scour chains could be located at the site. Although limited, data collected between 2009 and 2012 indicate that the site is experiencing erosion. This is evidenced by increasing scour chain length over time as seen in Table 5.1.

Table 5.1: Upper Sailor Bar 2009 original chain length installed in October 2009 compared to chain length measured in February 2012.

Chain	Original Length (in.) October 2009	Length (in.) as of February 2012	Change	Scour/Fill
J1	16.14	18.5	2.36	Scour
J2	7.28	23.43	16.15	Scour
J6	13.39	19.69	6.3	Scour
J7	9.06	16.93	7.87	Scour
J12	13.58	14.57	0.99	Scour

5.2 SURFACE WATER DEPTH AND VELOCITY

Surface water depth and velocity data have been collected from the Upper Sailor Bar 2009 site since November 2009, and in each subsequent year through 2012. The site was characterized by meter scale pool-riffle sequences visible in Figure 5.1, and a series of much smaller undulating bars (gravel waves) that were perpendicular to flow. Figure 5.1 is a map of the 52 locations where measurements were recorded in October 2012 at a flow of approximately 1,710 cfs. Velocities ranged from 0 ft/s to 3.27 ft/s (Table 5.2) and depth ranged from 0 ft to 3.5 ft (Table 5.3). The arrows in Figure 5.1 show that velocities were highly variable across the site, while the direction of flow showed less variation. The color-coded depths on the map clearly show the micro scale pool-riffle sequences mentioned above.

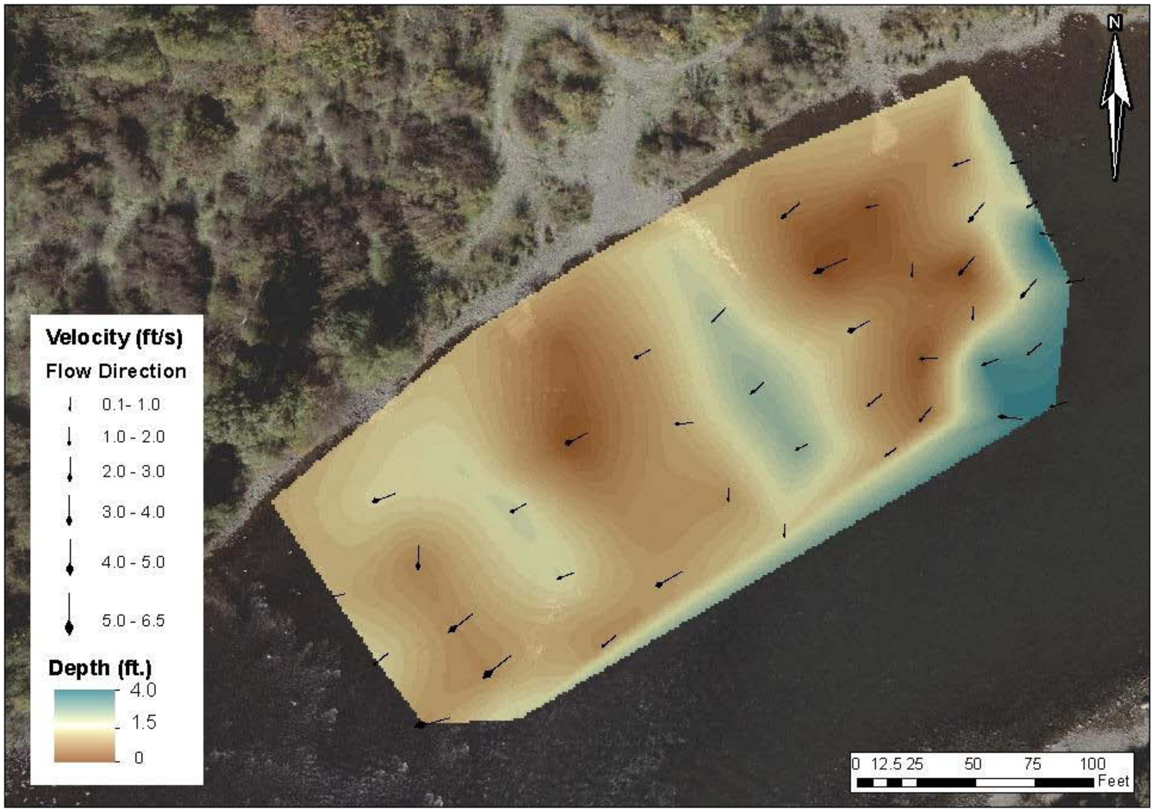


Figure 5.1: Depth, velocity and direction of flow for 52 measurements taken at the Upper Sailor Bar 2009 site in October 2012 at a flow of approximately 1,710 cfs.

Table 5.2: Summary and statistical comparison of surface water velocity at the Upper Sailor Bar 2009 site from November 2009 to October 2012.

Date	Flow (cfs)	Velocity Range (ft/s)	Velocity Mean (ft/s)	Standard Deviation	Coefficient of Variation	Number of Measurements
October 2012	1,710	0.00-3.27	1.36	0.93	68	52
February 2012	1,640	0-3.86	1.65	1.1	67	40
December 2011	2,040	1.19-3.21	2.24	0.73	33	8
January 2010	1,600	0.12-3.69	2.48	1.09	44	10
November 2009	1,900	0.16-3.84	2.58	1.11	43	10

Table 5.3: Summary and statistical comparison of surface water depth at the Upper Sailor Bar 2009 site from November 2009 to October 2012.

Date	Flow (cfs)	Depth Range (ft)	Depth Mean (ft)	Standard Deviation	Coefficient of Variation	Number of Measurements
October 2012	1,710	0-3.5	1.47	0.81	55	52
February 2012	1,640	0.2-3	1.44	0.81	54	40
December 2011	2,040	0.8-3.1	1.91	0.67	35	8
January 2010	1,600	0.7-2	1.47	0.41	28	10
November 2009	1,900	0.8-2.2	1.61	0.45	28	10

5.3 GRAVEL PERMEABILTY

Figure 5.2: Locations of permeability tests at the Upper Sailor Bar 2009 site.

Between January and February 2013, 16 permeability tests were conducted at the site. River flows averaged 2,300 cfs during testing (Figure 5.2). Nine successful tests produced a wide range of hydraulic conductivity values ranging from 500 cm/hr to 19,000 cm/hr and a coefficient of variation of 83 (Table 5.4). Permeability exceeded equipment limitations for the remaining six tests, producing hydraulic conductivity values in excess of 95,000 cm/hr (the limitation of the pumping apparatus). Results for these tests (5, 7, 8, 10, 11, 12 and 16) were reported as the maximum pumping value (95,000 cm/hr), but actual values for permeability are higher. Test 6 had particularly low permeability (580 cm/hr) compared to the mean permeability for the site (50,000 cm/hr). This test was located near the shore line on the north side of the river.

Table 5.4: Permeability results for the Lower Sailor Bar 2012 site. Results for tests 5, 7, 8, 10, 11, 12 and 16 exceeded equipment limitations and are reported as the maximum value obtainable by the pumping equipment, but actual permeability are higher.

Test Number	Test Date	K (cm/hr)	Test Number	Test Date	K (cm/hr)
1	1/23/2013	5,682	10	2/8/2013	>95,000
2	1/23/2013	5,490	11	2/8/2013	>95,000
3	1/23/2013	17,920	12	2/8/2013	>95,000
4	1/23/2013	39,981	13	2/8/2013	19,026
5	1/23/2013	>95,000	14	2/8/2013	8,803
6	1/23/2013	580	15	2/8/2013	24,057
7	2/6/2013	>95,000	16	2/8/2013	>95,000
8	2/6/2013	>95,000	**Mean**		**50,000**
9	2/8/2013	18,339	**Coefficient of Variation**		**83**

5.4 HYPORHEIC PRESSURE HEAD

Upwelling and downwelling measurements were conducted in November 2012 at a flow of approximately 1,700 cfs. Positive numbers indicate upwelling, negative numbers indicate downwelling, and a value of zero indicates neutral conditions (no upwelling or downwelling). Pressure head measurements were taken at 34 discrete locations across the Upper Sailor Bar 2009 site (Figure 5.3). The majority of the site was dominated by upwelling conditions (50% of measurements indicated upwelling conditions, 25% indicated neutral conditions, and 25% indicated downwelling conditions); values ranged from 0.50 in. to -0.50 in. across the site. A zone of high magnitude upwelling was found along the southern edge of the site adjacent to the thalweg.

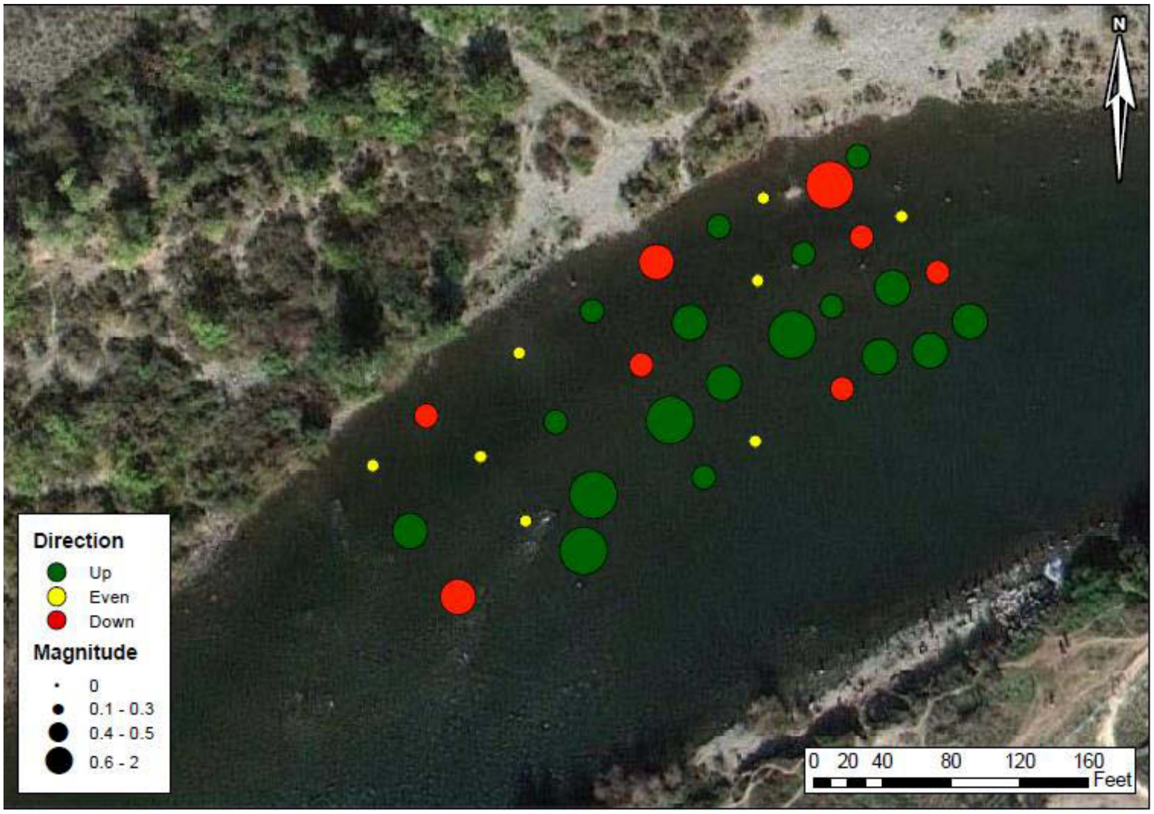


Figure 5.3: Upper Sailor Bar 2009 upwelling and downwelling map at 1,700 cfs. Data was recorded on November 1, 2012.

5.5 HYPORHEIC WATER QUALITY

Water quality parameters have been collected at the Upper Sailor Bar 2009 site since August 2009. Typically, post-restoration water quality samples are collected three times within a spawning season; during redd construction in the Fall, during egg incubation in the winter, and during fry emergence in the Spring. Discharge on the river between December 2012 and January 2013 was high and produced flow conditions that were unsafe for field workers (Figure 1.5). Therefore, only two sampling events were conducted during the 2012/2013 field season, in the fall of 2012 and the spring of 2013. Measurements are summarized in tables and presented on maps.

Figure 5.4 is a location map of 14 mini-piezometers maintained at the site during the 2012/2013 field season. Table 5.5 shows current water quality data collected in November 2012 from 10 of the 14 piezometers. D.O. levels ranged from 5.82 mg/L to

10.04 mg/L with a mean of 9.0 mg/L, and D.O. saturation ranged from 55.6% to 91.3% with a mean of 87.5%. Table 5.6 shows water quality data collected in December 2011, during the previous spawning season. D.O. levels were lower compared to 2012, ranging from 6.0 mg/L to 9.1 mg/L with a mean of 8.06. Percent D.O. saturation was also slightly lower in 2011, ranging from 57.2% to 82.2% with a mean of 76.9%.

Figure 5.5 shows fall 2012 D.O. saturation levels at the Upper Sailor Bar 2009 site. Green dots represent > 90% saturation and good intragravel flow. Yellow dots represent moderate D.O. levels that are reasonable for egg development and survival but may indicate lower intragravel flow. Red dots represent D.O. percentages that are critically low for egg development and survival. Across the site, the majority of D.O. saturation levels are high, a few were in the reasonable range, and only one well showed critically low D.O. levels.

Figure 5.6 illustrates turbidity levels across the study site in November 2012. Darker colors represent higher turbidity values and lighter colors represent lower values. Current turbidity levels across the site are highly variable, ranging from 5 NTU to 273 NTU with a mean of 85. This is a strong increase in mean turbidity across the site when compared to values for December 2011 (67 NTU) and November 2009 (5 NTU).

Table 5.7 summarizes the mean water quality parameters before restoration of the site (Aug. 2009) and in the years following restoration (Nov. 2009 – Apr. 2013). Prior to restoration, mean D.O. was very low at 3.58 mg/L and a mean D.O. saturation of 38.66%. Immediately following restoration, mean D.O. improved to 11.20 mg/L. Since then, mean D.O. levels at the site have remained high, fluctuating between 8.06 mg/L and 11.45 mg/L. D.O. values are highly temperature dependent, so some of this fluctuation is caused by variations in temperature. Percent saturation, the amount of oxygen in the hyporheic sample relative to the amount of oxygen in the surface water, is not subject to this variability and shows a slight decline in intragravel D.O. over time.

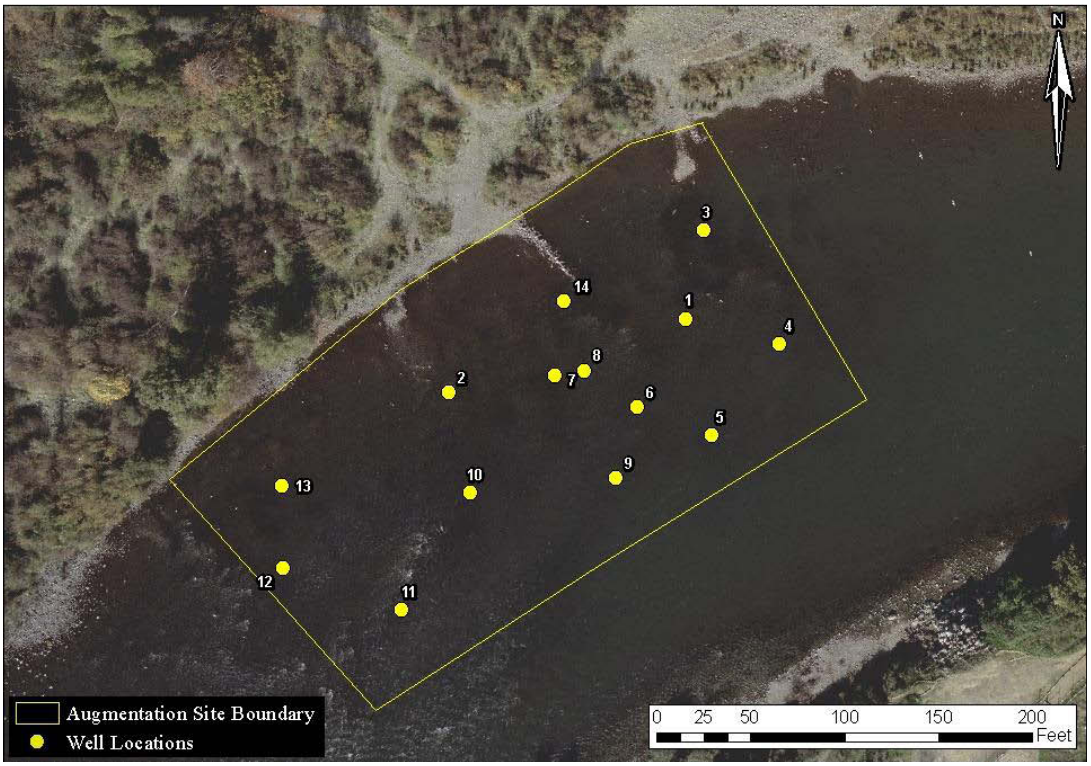


Figure 5.4: Location of mini-piezometers after restoration at Upper Sailor Bar 2009.

Table 5.5: Upper Sailor Bar 2009 Water Quality Parameters as of November 2012

Location	D.O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
1	6.99	68.2	40.9	6.98	273
4	5.82	55.6	45.3	6.83	160
5	9	86.7	46.1	7.05	225
6	9.57	92.6	43.9	6.99	28
7	10.04	97.6	44	7.14	5
8	9.65	95.5	43	7.15	108
10	9.9	96.6	43.9	7.13	10
11	8.06	80	44.7	7.17	20
12	9.8	96.2	43.9	7.15	25
13	9.97	97.3	44.1	7.13	10
Mean	**9.0**	**87.5**	**44.0**	**7.1**	**85**
Coef. of Var.	**16**	**16**	**3**	**1**	**112**
Surface 1	9.17	91.7	45	7.4	0.7
Surface 2	10.04	98.2	44	7.19	5

Parameters were collected in November 2012 at approximately 1,430 cfs with an average hyporheic temperature of 14.51°C. Piezometers at locations 2, 3, 9, and 14 were missing. The piezometer at location 1 had a redd build around it.

Table 5.6: Upper Sailor Bar 2009 Water Quality Parameters as of December 2011

Location	D. O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
pz1	8.7	82.2	36.1	7.3	33.1
mw2	6	57.2	34.4	6.8	101.7
pz2	7.7	73.9	36.4	7.2	41.5
pz3	8.2	78.3	36.3	7.3	155.8
mw4	7.8	74.4	36.1	7.2	102.8
jmw7	9.1	87.1	36.5	7.4	36.6
mw7	8.4	80.1	36.2	7.4	14.9
mw9	8.6	82	36.1	7.4	49.4
Mean	**8.06**	**76.9**	**36.01**	**7.25**	**66.98**
Coef. of Var.	**12**	**12**	**2**	**3**	**72**
Surface 1	11.2	104.9	35.6	7.3	1.6
Surface 2	8.6	81.8	36	7.4	2.2

Parameters were collected in December 2011 at approximately 2,150 cfs with an average hyporheic temperature of 13.23°C.

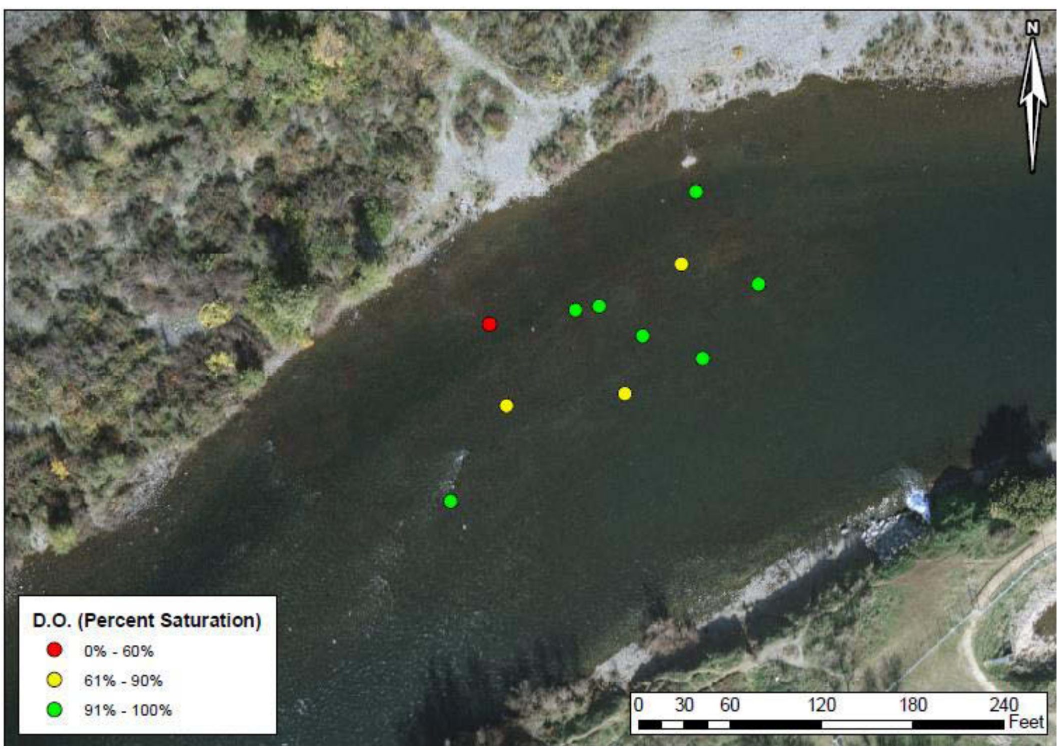


Figure 5.5: Post-restoration percent D.O. saturation levels at Upper Sailor Bar 2009 collected in November 2012.

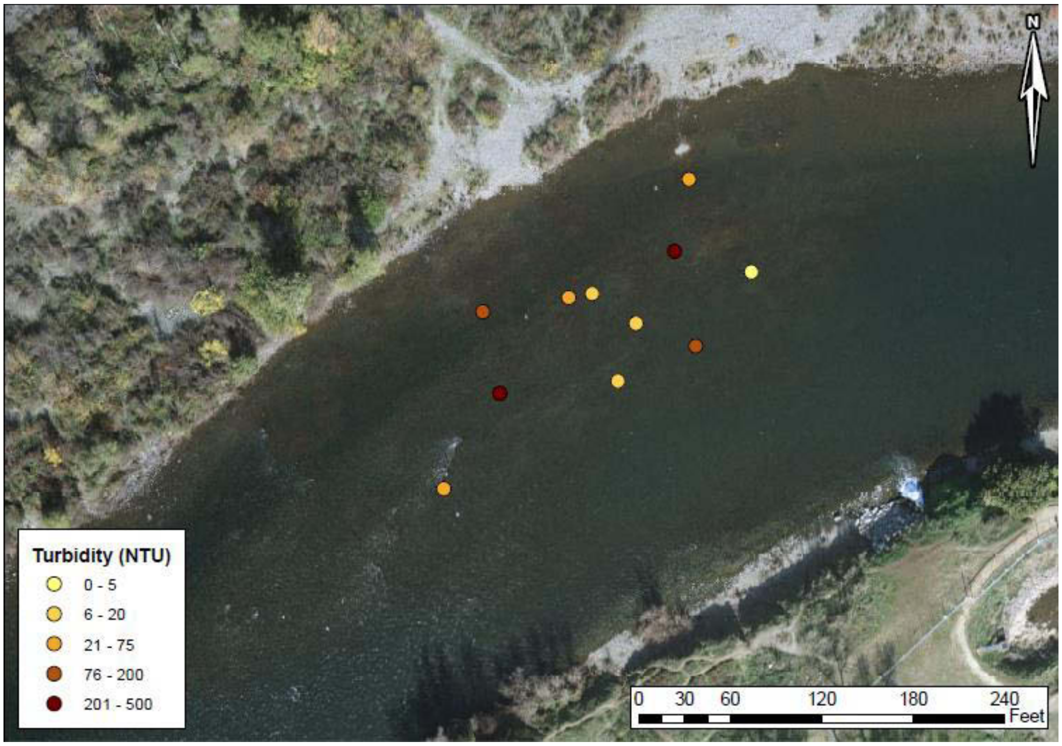


Figure 5.6: Post-restoration turbidity levels at Upper Sailor Bar 2009 collected in November 2012.

Table 5.7: Upper Sailor Bar 2009 Mean Water Quality Parameters

	D.O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
Aug. 2009	3.58	38.66	54.80	6.68	23
Nov. 2009	11.20	95.73	52.20	7.20	5
Jan. 2010	11.45	99.79	58.30	7.20	5
Dec. 2011	8.06	76.90	36.01	7.25	67
Feb. 2012	10.00	84.00	43.40	7.30	65
Nov. 2012	9.00	87.50	44.00	7.10	85
Apr. 2013	8.82	86.00	22.80	7.40	56

5.6 DISCUSSION

Grain size and surface water depth and velocity have remained within optimal ranges for salmonid spawning since augmentation of the Upper Sailor Bar 2009 site in August 2009. Scour chain data indicated that gravel was eroded throughout the site. The site was dominated by upwelling conditions. Permeability was highly variable ranging from < 580 cm/hr to 19,000 cm/hr. Between November 2009 (immediately following restoration) and November 2012, average intragravel D.O. levels remained high, but decreased from 11.20 mg/L to 9.00 mg/L. Turbidity levels initially decreased to an average of 5 NTU after restoration, but increased to an average of 85 NTU three years later (November 2012). The increase in turbidity, decrease in D.O., and variable hydraulic conductivity suggests that the gravel has become seasoned 3.5 years after augmentation. The gravel has settled into a more natural state, biofilms and biota have taken hold, and finer sediments and organic materials have made their way into the substrate. Furthermore, the field team observed that portions of the streambed were beginning to show signs of armoring.

High resolution aerial images taken on November 26, 2012 showed that the Upper Sailor Bar 2009 site received moderate usage by Fall-run Chinook salmon. Figure 5.7 shows that 63 redds were observed, which is a two-fold increase from the previous season when <30 redds were observed. Many of the 2012 redds were clustered in portions of the site characterized by riffles where depths averaged < 1.5 ft, velocities were highly variable (ranging from .1 ft/s to 5 ft/s), and direction of flow displayed moderate variability. Redds were found in areas of upwelling, downwelling, and neutral conditions.

Figure 5.7: Fall-run Chinook salmon redd locations at the Upper Sailor Bar 2009 site during the 2012 spawning season. 63 redds were counted from photos of the site as of November 26, 2012. Redd counts may be underestimated, because shadows or substrate conditions may prevent detection of all redd locations from aerial photos. Yellow line indicates augmentation boundary. (High resolution aerial images courtesy of John Hannon, USBOR)

6.0 UPPER SAILOR BAR 2008 RESULTS

6.1 GRAVEL MOBILITY

Tracer Rocks

Tracer rocks were deployed at the study site immediately following gravel augmentation in August 2008, and movement tracked in 2009, 2010 and 2012. Small groupings of tracer rocks (small, medium, and large) were placed at discrete points along one of three transects (upstream, middle, downstream) as shown in Figure 6.1. In the year that followed initial placement, significant numbers of tracer rocks were lost (one third at the downstream end) due to gravel scour and burial by salmonids during redd construction.

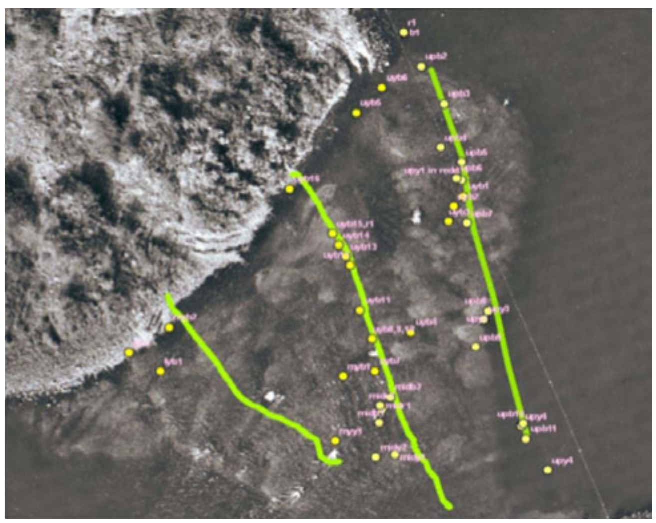


Figure 6.1: Post gravel addition map of Upper Sailor Bar 2008 showing initial tracer rock transects (green) and location of rocks located in June 2009 (yellow). Large (2.5 in. - 3 in.), medium (1.25 in. - 1.75 in.), and small (0.625 in. - 0.875 in.) tracer rocks were placed along each transect on the map.

As of June 2009, few of the remaining large rocks were displaced, while many of the medium and small rocks had moved downstream. The majority of movement was found to occur adjacent to the southern bank of the site, closest to the thalweg. As of June 2010, 21% of large, 3% of medium, and < 2% of small tracer rocks were located, and little to no movement was evident (Figure 6.2). Tracer rocks were again located in April 2013 following the winter season. River flows between October 2012 and April 2013 ranged from 942 cfs to 9,980 cfs with a mean flow of 2,382 cfs. Flows above 5,000 cfs persisted throughout the month of December. As of April 2013, the majority of remaining tracer rocks were large (yellow) and showed little to no movement.

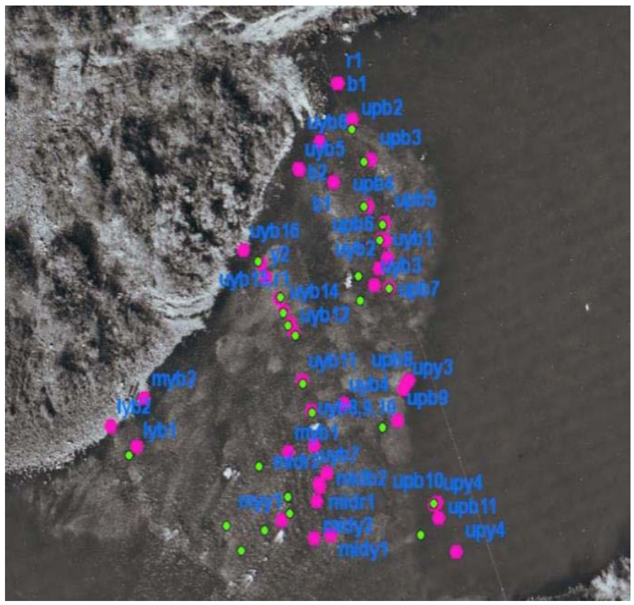


Figure 6.2: Post gravel addition map of Upper Sailor Bar 2008 showing tracer rock locations from June 2009 (pink) and location of rocks located in June 2010 (green).

6.2 SURFACE WATER DEPTH AND VELOCITY

Surface water depth and velocity data have been collected from the Upper Sailor Bar 2008 site since August 2008, and in each subsequent year through 2012. The site has evolved into a series of small undulating bars (gravel waves) that are perpendicular to flow, and a large pool located immediately upstream of the site. This site was initially flat, and the undulating topography is the result of several seasons of spawning activity by salmonids. Figure 6.3 is a map of the 52 locations where depth and velocity measurements were recorded in October 2012 at a flow of approximately 1,710 cfs. Velocities ranged from 0 ft/s to 4.26 ft/s (Table 6.1) and depth ranged from 0 ft to 3.9 ft

(Table 6.2). The arrows in Figure 6.3 show that velocities were higher near the downstream end of the site, and the direction of flow was heterogeneous.

Table 6.1: Statistical comparison of surface water velocity at Upper Sailor Bar 2008 from August 2008 to October 2012.

Date	Flow (cfs)	Velocity Range (ft/s)	Velocity Mean (ft/s)	Standard Deviation	Coef. of Var.	Number of Measurements
October 2012	1,710	0-4.26	1.47	1.02	69	52
February 2012	1,680	0-4.48	1.59	1	63	34
December 2011	2,150	0.15-3.57	1.74	1.16	67	8
January 2010	1,600	0.72-3.29	1.99	0.92	46	11
November 2009	1,900	0.75-3.39	2.10	0.96	46	11
February 2009	780	0.2-5.01	2.58	1.47	57	8
August 2008	1,300	0.68-1.49	1.1	0.3	27	9

Table 6.2: Statistical comparison of range, mean, standard deviation, and variance for surface water depth at Upper Sailor Bar 2008 from August 2008 to October 2012.

Date	Flow (cfs)	Depth Range (ft)	Depth Mean (ft)	Standard Deviation	Coef. of Var.	Number of Measurements
October 2012	1,710	0-3.9	1.64	0.86	52	52
February 2012	1,680	0.1-2.9	1.64	0.7	43	34
December 2011	2,150	1-3.3	2.09	0.7	33	8
January 2010	1,600	1.5-3.2	2.35	0.66	28	11
November 2009	1,900	1.6-3.4	2.21	0.67	30	11
February 2009	780	0.5-1.4	0.89	0.33	37	8
August 2008	1,300	1.9-3.1	2.61	0.38	15	9

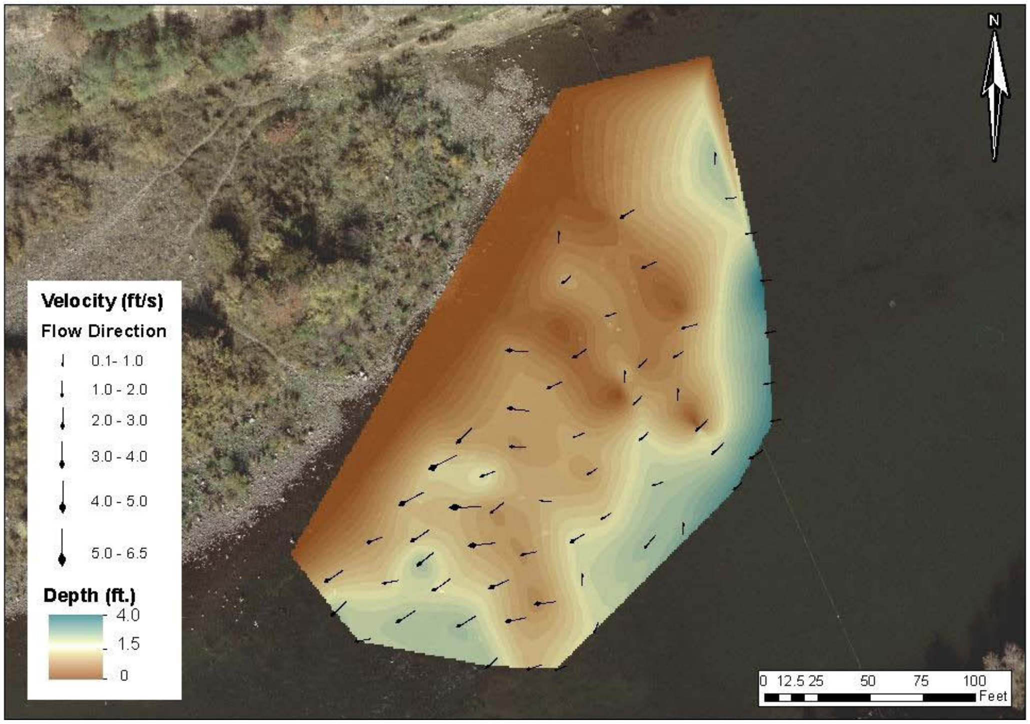


Figure 6.3: Depth, velocity and direction of flow for 52 measurements taken at Upper Sailor Bar 2008 in October 2012 at a flow of approximately 1,710 cfs.

6.3 GRAVEL PERMEABILTY

On February 22 and February 25, 2013, 17 permeability tests were conducted at the Upper Sailor Bar 2008 site (Figure 6.4). River flows averaged 2,500 cfs during testing. Fifteen successful tests produced highly variable hydraulic conductivity values ranging from 1 cm/hr to 19,000 cm/hr and a coefficient of variation of 179 (Table 6.3). Fifteen successful tests produced a wide range of hydraulic conductivity values ranging from < 1 cm/hr to >19,000 cm/hr with a 90.34% coefficient of variation (Table 6.3). Permeability exceeded equipment limitations for the remaining two tests, producing hydraulic conductivity values in excess of 95,000 cm/hr (the limitation of the pumping apparatus). Results for these tests (6 and 14) were reported as the maximum pumping value (95,000 cm/hr), but actual values for permeability are higher. Tests 2, 12, and 17 had extremely low permeability (< 1 cm/hr). Two of these tests (12 and 17) were located closest to the shore line on the north bank of the river. Test 2 was the furthest upstream location measured.

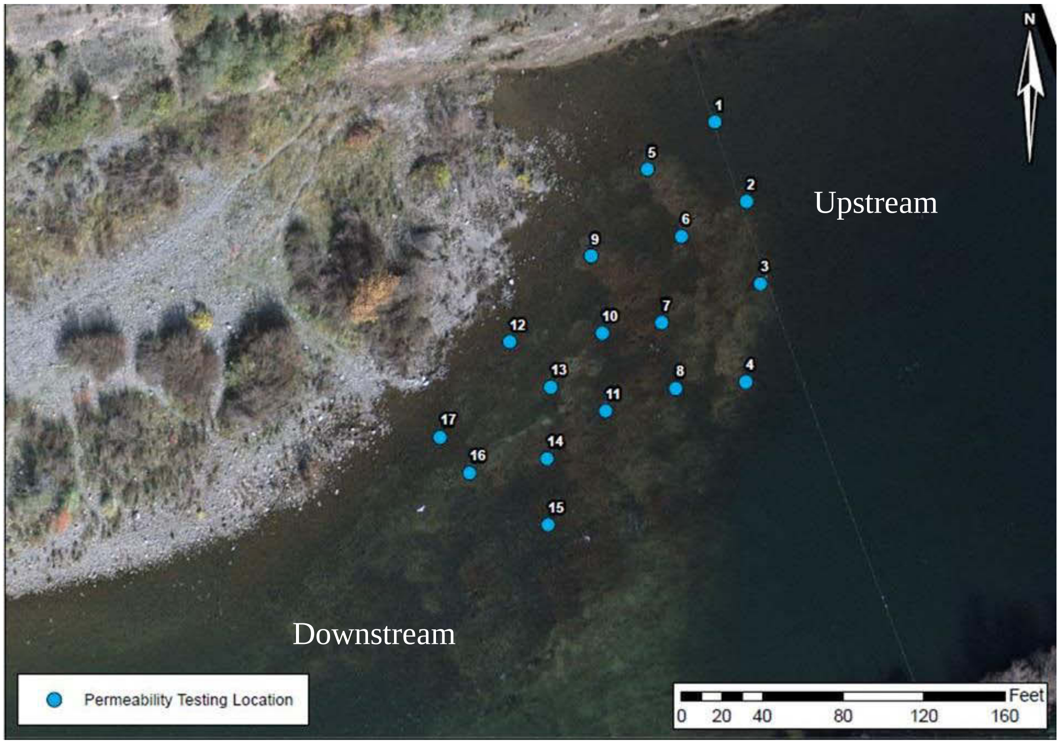


Figure 6.4: Locations of permeability tests at Lower Sailor Bar 2008.

Table 6.3: Permeability results for Upper Sailor Bar 2008. Results for tests 6 and 14 exceeded equipment limitations and are reported as the maximum value obtainable by the pumping equipment, but actual permeability are higher.

Test Number	Test Date	K (cm/hr)	Test Number	Test Date	K (cm/hr)
1	2/22/2013	5,376	11	2/25/2013	2,512
2	2/22/2013	1	12	2/25/2013	1
3	2/22/2013	14,906	13	2/25/2013	3,587
4	2/22/2013	626	14	2/25/2013	>95,000
5	2/22/2013	773	15	2/25/2013	19,214
6	2/22/2013	>95,000	16	2/25/2013	18,120
7	2/22/2013	6,002	17	2/25/2013	1
8	2/22/2013	7,281	**Mean**		**17,000**
9	2/25/2013	1,832	**Coefficient of Variation**		**179**
10	2/25/2013	15,643			

6.4 HYPORHEIC PRESSURE HEAD

Upwelling and downwelling measurements were conducted in November 2012 at a flow of approximately 1,750 cfs. Pressure head measurements were taken at 22 discrete locations across the Upper Sailor Bar 2008 site. Results are presented in Figure 6.5. Positive numbers indicate upwelling, negative numbers indicate downwelling, and a value of zero indicates neutral conditions (no upwelling or downwelling). The site was dominated by upwelling conditions. 68% of measurements indicated upwelling and 32% indicated neutral; values ranged from 1.25 in. to -0.25 in. across the site. Neutral pressure conditions and lower magnitude upwelling conditions were found in the upstream half of the site. Higher magnitude upwelling conditions were prominent on the downstream end of the site.

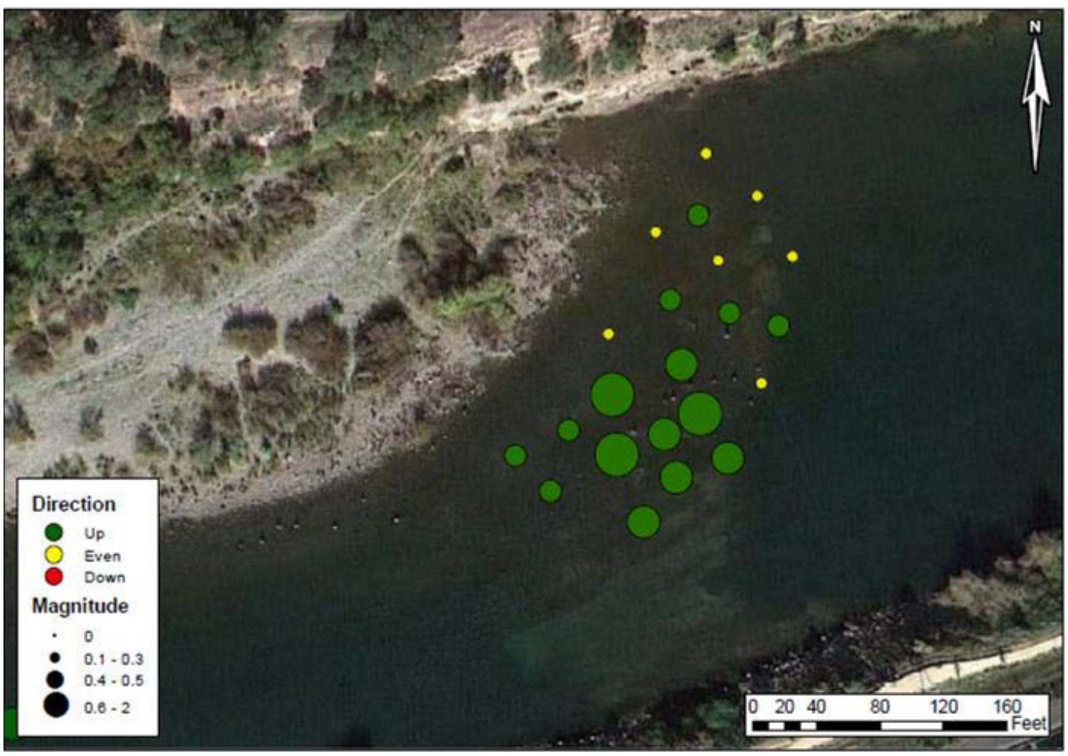


Figure 6.5: Upper Sailor Bar 2008 upwelling and downwelling map at 1,750 cfs. Data was collected on November 3, 2012.

6.5 HYPORHEIC WATER QUALITY

Water quality parameters have been collected at the Upper Sailor Bar 2008 site since September 2008. Typically, post-restoration water quality samples are collected three times within a spawning season; during redd construction in the Fall, during egg incubation in the winter, and during fry emergence in the Spring. Discharge on the river between December 2012 and January 2013 was high and produced flow conditions that were unsafe for field workers (Figure 1.5). Therefore, only two sampling events were conducted during the 2012/2013 field season (in the fall 2012 and spring 2013). Measurements are summarized in tables and presented on maps.

Figure 6.6 is a location map of 13 mini-piezometers maintained at the site during the 2012/2013 field season. Table 6.4 shows current water quality data collected in November 2012 from nine of the 13 piezometers. D.O. levels ranged from 3.75 mg/L to 9.49 mg/L with a mean of 7.98 mg/L, and D.O. saturation ranged from 43% to 91.3% with a mean of 77.76%. Table 6.5 shows water quality data collected during the previous spawning season (December 2011). D.O. levels were similar to 2012, ranging from 3.4 mg/L to 9.0 mg/L with a mean of 7.46 mg/L. Percent D.O. saturation was slightly lower, ranging from 31.5% to 84.3% with a mean of 69.5%.

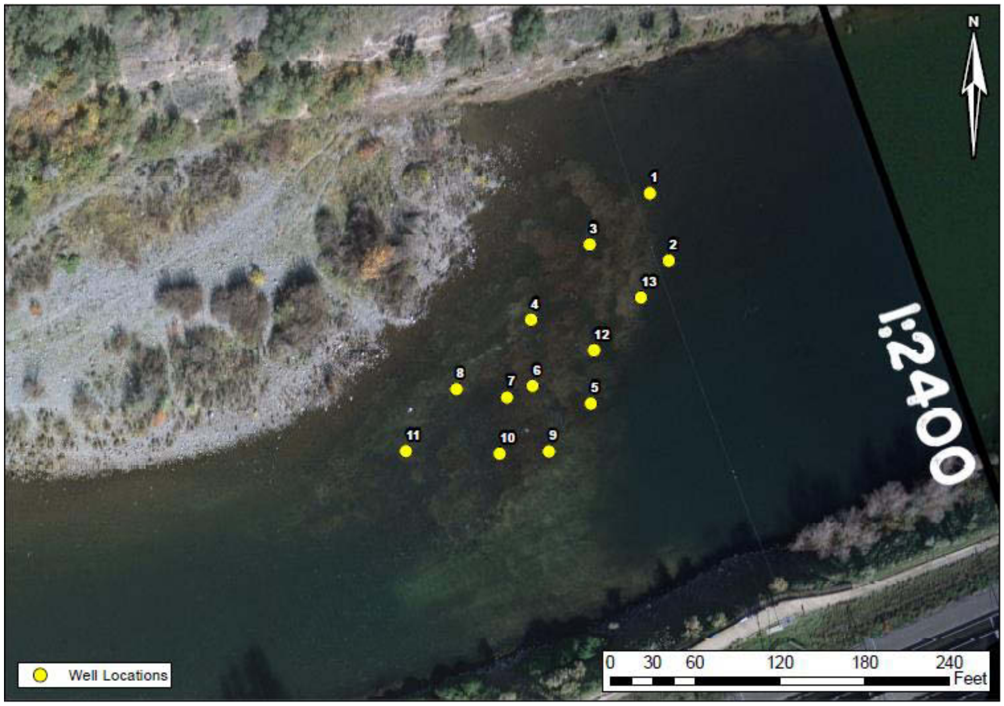


Figure 6.6: Piezometer locations after restoration at the Upper Sailor Bar 2008 site.

Table 6.4: Upper Sailor Bar 2008 Water Quality Parameters as of November 2012

Location	D.O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
1	6.7	57.4	47.5	7.04	180
2	8.28	81.7	53.9	7.27	120
3	3.75	43	128.6	7.1	400
4	9.22	88.4	44.2	7.14	60
5	6.84	66	44.2	7.14	60
6	9.04	88.9	44.1	7.02	9
7	9.37	91.3	43.8	7.01	5
8	9.16	90.1	43.9	7.19	15
10	9.49	93	43.9	7.19	15
Mean	**7.98**	**77.76**	**54.90**	**7.12**	**96**
Coefficient of Variation	**24**	**23**	**50**	**1**	**134**
Surface 1	9.17	91.7	45	7.4	15
Surface 2	10.04	98.2	44	7.19	14.4

Parameters were collected in November 2012 at approximately 1,430 cfs with an average hyporheic temperature of 14.5°C. Piezometers 12 and 13 were missing; 9 and 11 were clogged.

Figure 6.7 shows D.O. saturation levels at the Upper Sailor Bar 2008 site in November 2012. Green dots represent >90% saturation and good intragravel flow. Yellow dots represent moderate D.O. percent that are reasonable for egg development and survival, but indicate lower intragravel flow. Red dots represent D.O. percentages that are less than 60% saturated, and are critically low for egg development and survival. Upstream D.O. saturation was critically low, wells located in the middle of the site showed moderate levels, and downstream D.O. levels were high.

Figure 6.8 illustrates turbidity levels across the study site in November 2012. Darker colors represent higher turbidity values and lighter colors represent lower values. Current turbidity levels across the site are highly variable, ranging from 5 NTU to 400 NTU with a mean of 96 NTU. This is a strong increase in mean turbidity when compared to values for December 2011 (54.54 NTU) and November 2009 (9.10 NTU).

Table 6.5: Upper Sailor Bar 2008 Water Quality Parameters as of December 2011

Location	D.O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
MPC	8.2	75.6	37.8	7.1	40
9	6.7	62.1	39.4	7	82.5
5	8	74.4	37	7	11.6
3	3.4	31.5	68	7.3	110.5
12	8.9	84.3	37.1	7.3	40
7	8	75.2	38.6	7.2	71
1	9	83.5	37.1	7.2	26.2
Mean	**7.46**	**69.51**	**42.14**	**7.16**	**54.54**
Coefficient of Variation	**26**	**26**	**27**	**2**	**64**
Surface 1	9.3	83.3	36.6	7.3	2.4
Surface 2	9.1	85.2	36.9	7.3	3.8

Parameters were collected in December 2011 at approximately 2,150 cfs with an average hyporheic temperature of 12.17°C. Piezometers 6, 8, 10, 11 and 13 were missing, 3 was clogged, and 2 and 4 could not be accessed because of high redd density.

Table 6.6 summarizes the mean water quality parameters before restoration of the site (Sep. 2008) and in the years following restoration (Feb. 2009 – Nov. 2012). Prior to restoration, mean dissolved oxygen (D.O.) was very low at 4.52 mg/L. Immediately following restoration, mean D.O. improved to 10.48 mg/L. Since then, mean D.O. levels at the site have remained high, fluctuating between 7.14 mg/L and 11.10 mg/L depending on the season. D.O. values are highly temperature dependent, so some of the variability after restoration is caused by seasonal temperature variations. The percent saturation value compares surface water D.O. levels to subsurface levels, and avoids this issue.

Table 6.6: Upper Sailor Bar 2008 Mean Water Quality Parameters

	D.O. (mg/L)	D.O. (% sat)	E.C. (uS)	pH	Turbidity (NTU)
Sep. 2008 (before restoration)	4.52	51.66	51.34	6.79	N/A
Feb. 2009	10.48	93.61	79.55	7.36	N/A
Nov. 2009	7.14	85.56	47.10	6.90	9.10
Jan. 2010	11.10	92.99	57.70	7.10	4.95
Dec. 2011	7.46	69.51	42.14	7.16	54.54
Feb. 2012	10.94	99.20	44.80	7.48	24.78
Nov. 2012	7.98	77.76	54.90	7.12	96.00

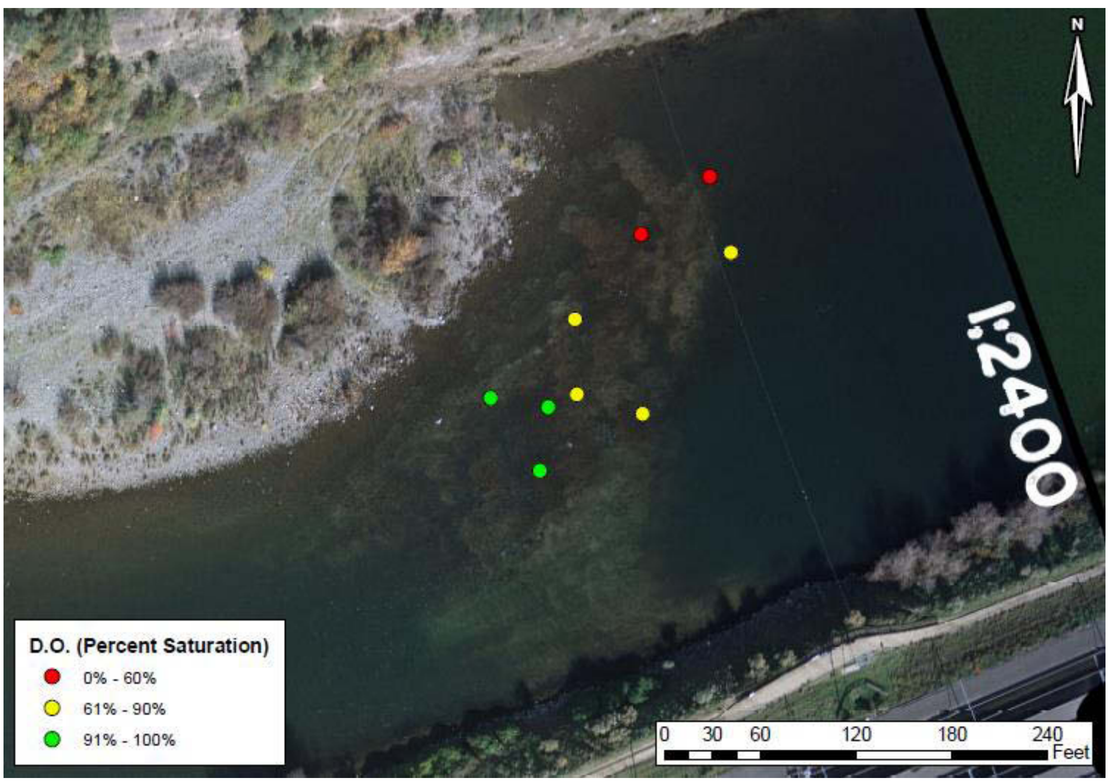


Figure 6.7: Post-restoration percent D.O. saturation levels at the Upper Sailor Bar 2008 site collected in November 2012.

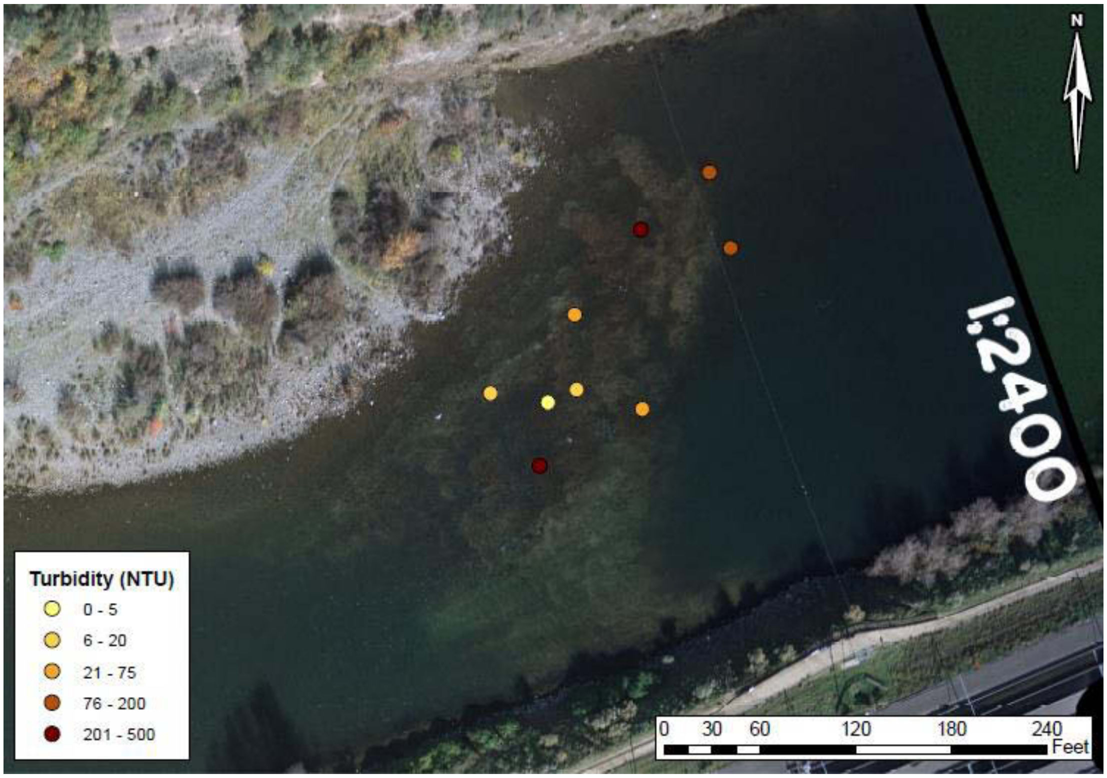


Figure 6.8: Post-restoration turbidity levels at Upper Sailor Bar 2008 collected in November 2012.

6.6 DISSCUSSION

Grain size and surface water depth and velocity have remained within optimal range for salmonid spawning since augmentation of the Upper Sailor Bar 2008 site in September 2008. Most of the original tracer rocks deployed at the site have been lost, and those recovered in April 2013 showed little to no movement between 2012 and 2013. Five years after restoration, the site was dominated by upwelling conditions, and the permeability was generally high with an average of 17,000 cm/hr. Between February 2009 and November 2012, intragravel D.O. levels decreased and became more variable. D.O. values ranged from 10.0 mg/L to 11.0 mg/L in February 2009 and 3.75 mg/L to 9.49 mg/L in November 2012. Turbidity was not measured at the site until one year after gravel placement (November 2009). Since then, turbidity levels have increased from an average of 9.10 NTU in November 2009 to 96.00 NTU in November 2012.

The increase in turbidity, decrease in D.O., and variable hydraulic conductivity suggests that 4.5 years after augmentation, the site was well seasoned. The gravel had settled into a natural state, biofilms and biota were established, and finer sediments and organic materials were part of the substrate. The field team observed that segments of the streambed were showing clear signs of armoring, and fish have modified the streambed during spawning to produce a series of shallow ridges perpendicular to flow. High-resolution aerial images taken on November 26, 2012 showed that the Upper Sailor Bar 2008 site received high usage by Fall-run Chinook salmon. Figure 6.9 shows that 166 redds were observed in 2012, which is a two-fold increase from the previous season when >70 redds were present. The majority of 2012 redds were clustered in the upstream half of the site where depths averaged < 1.5 ft, velocities were <3 ft/s, and direction of flow was highly variable. Redds were found in areas of upwelling and neutral conditions.

Figure 6.9: Fall-run Chinook salmon redd locations at Upper Sailor Bar 2008 during the 2012 spawning season. 166 redds were counted on November 26, 2012. Redd counts are inexact, because shadows or substrate conditions may prevent detection of all redd locations from aerial photos. The yellow line is the augmentation boundary for the site. (High-resolution aerial images courtesy of John Hannon, USBOR)

7.0 CONCLUSIONS

Gravel has been enhanced at four locations on the Lower American River to offset the degradation of natural salmonid spawning habitat since 2008. The deterioration of this habitat can be linked to anthropogenic forces that include dams, levees, and urbanization. Factors that impact the suitability of salmonid spawning habitats include grain size, gravel mobility, surface water depth and velocity, upwelling or downwelling, temperature, dissolved oxygen content, and hyporheic flow. Assessment of the Upper Sailor Bar 2008 (USB2008), Upper Sailor Bar 2009 (USB2009), Upper Sunrise 2010/2011 (US2010/2011), and the Lower Sailor Bar 2012 (LSB2012) restoration sites revealed that augmentation has positively impacted the suitability of spawning habitats at all four sites.

Grain Size, Gravel Mobility, and Permeability

As of 2012, grain sizes at all four sites remained suitable for salmonid spawning. However, there was a slight increase in the median grain size of surface gravel with time at all sites. Table 7.1 shows the average D_{50} values for each site before and after restoration and in 2012 based on pebble count data. The increase in median grain size suggests that a portion of the smaller grains added during augmentation have been winnowed away over time. The field team also observed that USB2008 and USB2009 were beginning to show signs of streambed armoring. To determine the amount of armoring present and take a closer look at current surface and subsurface grain size, it is recommended that three to five bulk samples be conducted at each site and at the natural spit within the next year.

Table 7.1: Average median grain sizes for each study site before restoration, immediately after restoration, and as of 2012 based on pebble counts.

Site	D_{50} Before (in.)	D_{50} Immediately After (in.)	D_{50} as of 2012 (in.)
LSB2012	0.9	0.9	0.9
US210/2011	2.0	1.4	1.25
USB2009	2.3	1.1	1.25
USB2008	1.25	1.1	1.25

Because suitable spawning gravel is highly mobile, sediment transport is expected over time. Cumulative data collected from scour chains and tracer rocks indicated downstream movement of gravel at all four restoration sites. The majority of movement seen at the older sites occurred in the first two years following restoration. Little to no movement was seen at the USB2008 site between 2011 and 2013, and the loss of all scour chains at USB2009 makes it difficult to determine erosion or deposition patterns between 2012 and 2013 (four years after restoration). Both US2010/2011 and LSB2012 showed upstream erosion and mid or downstream deposition. However, the loss of multiple scour chains at US2010/2011, and LSB2012 makes it difficult to accurately assess sediment transport patterns. The missing scour chains leave a hole in the data that is an important piece to understanding the longevity of augmentation sites. Further study is necessary to fully understand sediment transport at restoration sites, and it is suggested that the following recommendations be employed to assess gravel mobility in the future:

(1) Have a field team visit each site during the next low flow event and dig out areas where scour chains should be located. At the moment, it is not clear if the scour chains have been released due to erosion or completely buried from deposition.

(2) Replace missing scour chains at USB2009, US2010/2011, and LSB2012 and install new scour chains at USB2008.

(3) Survey each site within the next year using a total station and compare the topography to survey data collected immediately following each augmentation to get a clear view of how the sites have morphed over time.

(4) Consider abandoning the use of tracer rocks, because the majority of useful data obtained on sediment transport in this study has come from scour chains. While tracer rocks can show discreet movement of individual grains, they do not show what is happening at the site on a larger scale. Furthermore, the small amount of movement produced by tracer rocks is often too small to be illustrated on a map to get an overall picture of movement at the site. It also requires a good deal of time and labor to locate tracer rocks. Despite the bright colors, seasoned tracer rocks are difficult to see, especially in higher flow conditions. It would be useful to explore

new methods to determine sediment transport or spend more resources on scour chains instead of tracer rocks.

(5) Annual site surveys using surveying equipment would help identify and quantify scour and fill at restoration sites.

Figure 7.1 is a graphical representation of hydraulic conductivity measurements at each restoration site using the Barnard and McBain (1994) standpipe method. US2010/2011 had the highest hydraulic conductivity (all tests were greater than 95,000 cm/hr), followed by LSB2012, USB2009, USB2008 and finally the natural spit adjacent to US2010/2011. Research is still being conducted to determine the density of tests needed to characterize the hydraulic conductivity (permeability) of a site. At this point, 10 to 17 tests were conducted at each site. Some of these tests were not successful, because either intragravel flow exceeded the limitations of the standpipe drawdown method or the well was clogged and drawdown could not be obtained. To gain a better understanding of the permeability of restoration sites and the effects of permeability on salmonid spawning in the Lower American River, it is important that data be collected from a greater number of locations at each site.

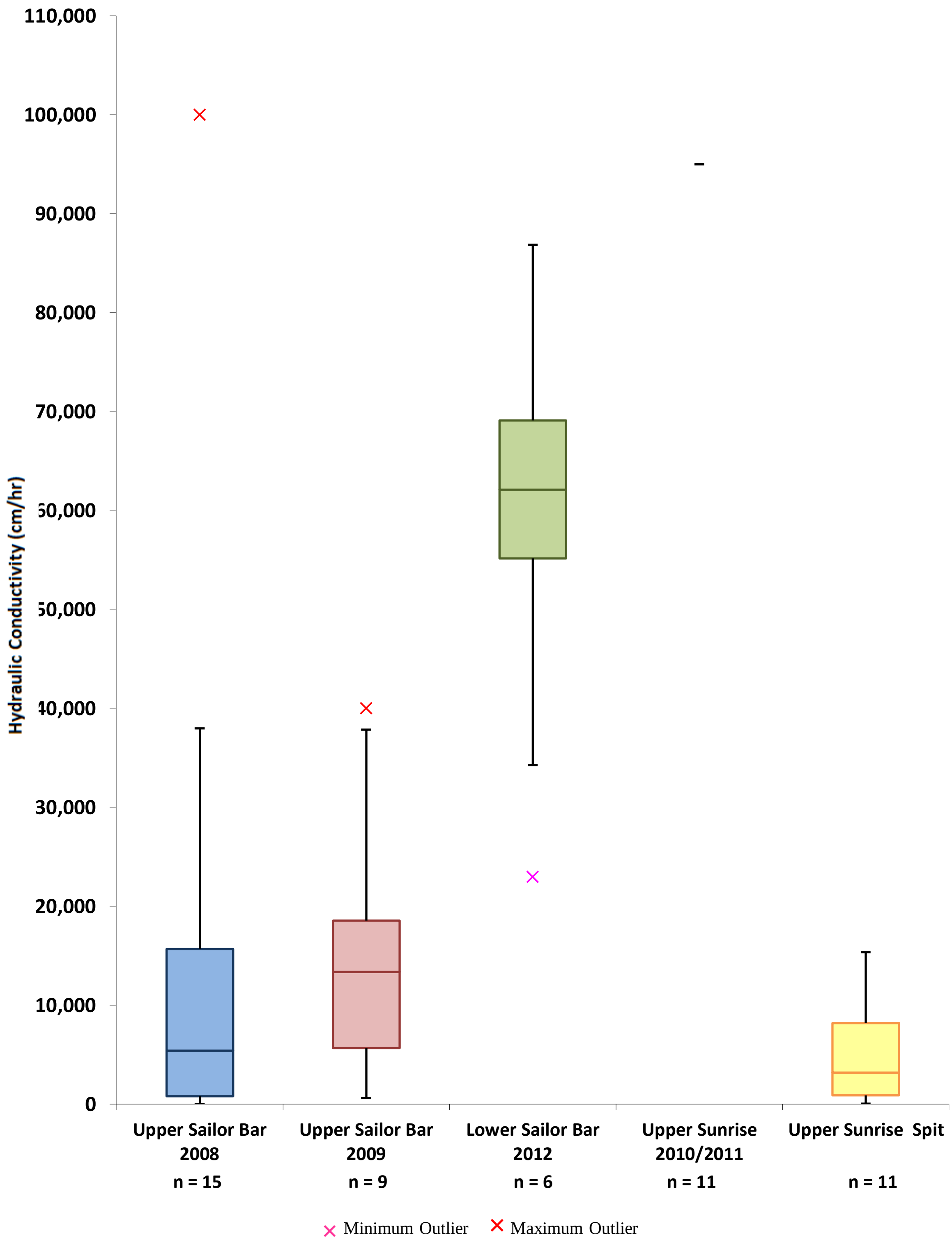


Figure 7.1: Box and whisker graph of hydraulic conductivity at four restoration sites and the natural spit. Tests were conducted using the Barnard and McBain (1994) modified standpipe method.

Highly permeable gravels allow the exchange of oxygenated water and other nutrients between the stream channel and hyporheic zone (Barnard and McBain, 1994). When excess fine sediment intrudes into the streambed, the decreased permeability effects this active exchange, and can have negative effects on egg and fry survival (Cordone and Kelley 1961). According to Terhune (1958), the survival of eggs is highly dependent on the oxygen available to them in the surrounding water. This is why the low hydraulic conductivity values (33 cm/hr and 306 cm/hr) at the spit were so surprising. We would expect salmonids to spawn in areas with high permeability, but in 2012 the salmon showed just as strong a preference for the natural spit (Table 7.4) as for the engineered sites (even more so than the US2010/2011 site), despite the lowest hydraulic conductivity median and range of values of all the sites. Therefore, it is possible that the static permeability of the substrate tested in this study is not as important as the permeability in the redd itself. When the female salmon builds her redd, she moves gravel. This process can winnow away fine sediment and redistribute grains, thereby creating greater pore space that allows for increased permeability.

Surface Water Depth and Velocity, Upwelling and Downwelling, and Water Quality

Table 7.2 summarizes depth and velocity measurements collected in 2012 at all four restoration sites. LSB2012 had the highest range of depth and velocity values, and USB2010/2011 had the highest mean depth and velocity. USB2009 had the highest coefficient of variation (CV) for depth, and USB2008 had the highest CV for velocity, which means that depth and velocity values were more dispersed at USB2009 and USB2008 respectively. The majority of depth and velocity measurements collected at all four restoration sites were within the optimal salmonid conditions suggested by Chapman (1986). By comparing redd location maps to depth and velocity maps it is evident that the majority of natural salmonid spawning at restoration sites occurred in waters ≤1.5 ft. and velocities between 1.5 and 3 ft/s.

The most notable difference between the four restoration sites was the topography of the streambeds. Both USB2008 and USB2009 were characterized by a hummocky streambed with smaller scale gravel waves situated perpendicular to flow. LSB2012 showed a gradual slope along the south bank of the river channel, and the remainder of the site had more varied depth and velocity. The long gravel ridge that characterized the US2010/2011 streambed was distinctly different. Surface water flowed parallel to this ridge, and the topography was somewhat regular, with little small-scale variability in depth. A long gravel ridge also characterized the natural spit, but the topography was hummocky and surface water flowed perpendicular to the ridge.

Table 7.2: Surface water depth, velocity and direction ranges and coefficient of variation for restoration sites as of 2012

Site	Depth (ft.)	Mean Depth (ft.)	Coefficient of Variation	Velocity (ft/s)	Mean Velocity (Ft/s)	Coefficient of Variation	Direction of Flow (Azimuth°)
LSB12	0.6-3	1.95	28	0.7-6.4	1.03	36	85-154
US2010/2011	0.10-3.5	2.04	34	0.3-3.5	1.84	33	67-136
USB2009	0.0-3.27	1.47	55	0.0-3.5	0.93	68	39-96
USB2008	0.0-3.9	1.64	52	0.0-4.26	1.47	69	21-96
Spit	0.3-2.9	1.45	48	0.33-2.8	1.58	47	22-105

Streambed topography can have a strong impact on groundwater/surface water interactions, characterized by upwelling and downwelling conditions. While upwelling and downwelling varied at each restoration site, hyporheic pressure head measurements (that show upwelling and downwelling on a small scale in near surface environments) indicated that upwelling dominated all four sites (Table 7.3). USB2008 showed the highest average magnitude of upwelling. In addition to upwelling, USB2009 showed a substantial amount of downwelling (24%), and US2010/2011 and LSB2012 showed a significant degree of neutral conditions (>25%). The natural spit also showed significant upwelling (42%) along with a significant amount of neutral conditions (42%). The temperature wells installed at US2010/2011 and LSB2012 (that show deeper broader patterns) indicated upwelling and downwelling at US2010/2011 and downwelling at LSB2012.

Both pressure head measurements and temperature loggers provide important information about different parts of the hyporheic zone. Although there is the potential for both human and mechanical errors, pressure head measurements provide a large quantity of good data at a relatively low cost. Temperature loggers leave less room for human and/or mechanical error, but each logger is expensive and the potential for vandalization is greater, because the loggers must remain in the streambed over a long period. Furthermore, a greater number of temperature wells would be necessary to characterize restoration sites, and the installation of wells can be difficult depending on the compaction of the substrate. That being said, the data collected from the temperature wells allows for a deeper look into the substrate over a much longer period, and temperature data can provide information on seepage rates that pressure head measurements cannot.

Table 7.3: Summary of hyporheic pressure head data at four restoration sites and the natural spit on the Lower American River as of 2012.

Site	Number of Measurements	% up	Average magnitude of upwelling	% down	Average magnitude of downwelling	% neutral	% clogged
USB2008	22	54	0.58	14	0.17	14	18
SUSB2009	34	53	0.25	24	0.20	15	8
US2010/2011	53	59	0.26	11	0.17	26	4
LSB2012	40	42	0.38	18	0.23	30	10
Spit	12	42	0.43	0	n/a	42	16

Several studies (Lorenz and Eiler, 1989; Leman, 1993; Geist and Dauble, 1998; Geist et al., 2002; Mull, 2005) have suggested that differences in upwelling and downwelling conditions can influence spawning site selection by salmonids. It is recommended that:

(1) the number of temperature loggers be increased at LSB2012, and that temperature loggers be installed at USB2008 and USB2009;

(2) hyporheic pressure head data collection continue at all four sites, measurements be collected at greater depths, and a higher density of measurements be collected in areas showing higher redd density; and

(3) a thermal imaging camera be used to look for groundwater seeps that would indicate upwelling at each of the sites.

As of 2012, D.O. levels at the four sites remained suitable for salmonid spawning. In general, all sites presented low D.O. prior to restoration. Immediately after restoration, D.O. levels significantly increased and showed less variability. In subsequent years, the median D.O. levels for USB2008, USB2009 and US2010/2011 remained high, but the range of values became more dispersed. Figure 7.2 is a box and whisker graph of percent D.O. levels at each site over time. As of November 2012, the median D.O. levels for USB2008, USB2009 and US2010/2011 were still much higher than the levels immediately before restoration. However, the minimum D.O. values at these sites decreased over time, and the range of values were more variable compared to levels immediately following restoration.

The difference in variability at US2010/2011 between December 2011 and November 2012 is considerable. While the median value changed from 84% saturation in December 2011 to 90% saturation in November 2012, the minimum levels decreased from 80% to 22% and the CV grew from 2 to 36. This data suggests that after the initial increase in D.O. provided by gravel augmentation levels become more variable overtime. Continued monitoring of the sites is essential to determine at what point D.O. will reach pre-restoration levels.

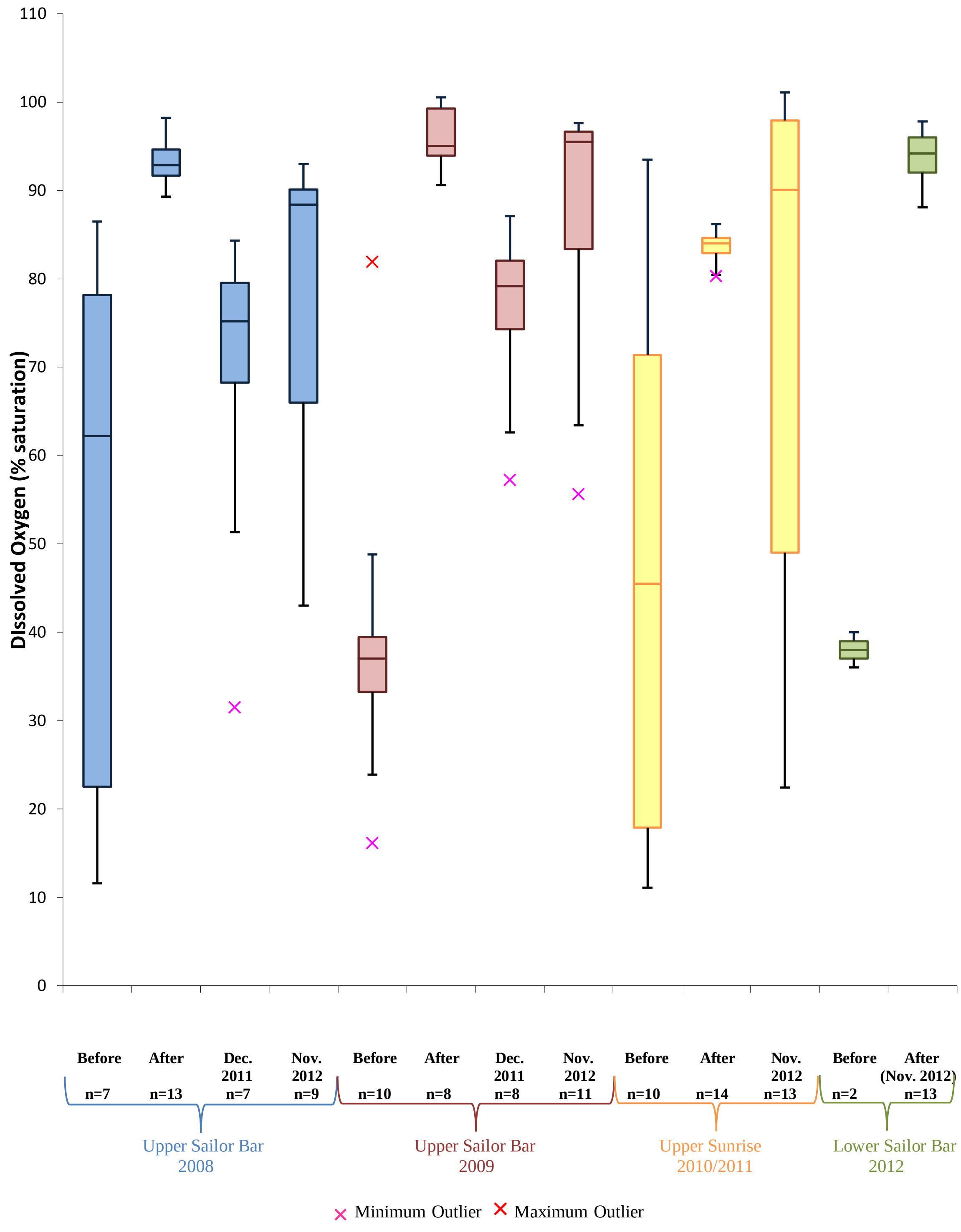


Figure 7.2: Box and whisker graph of dissolved oxygen levels (% saturation) over time (before and after restoration) at all restoration sites.

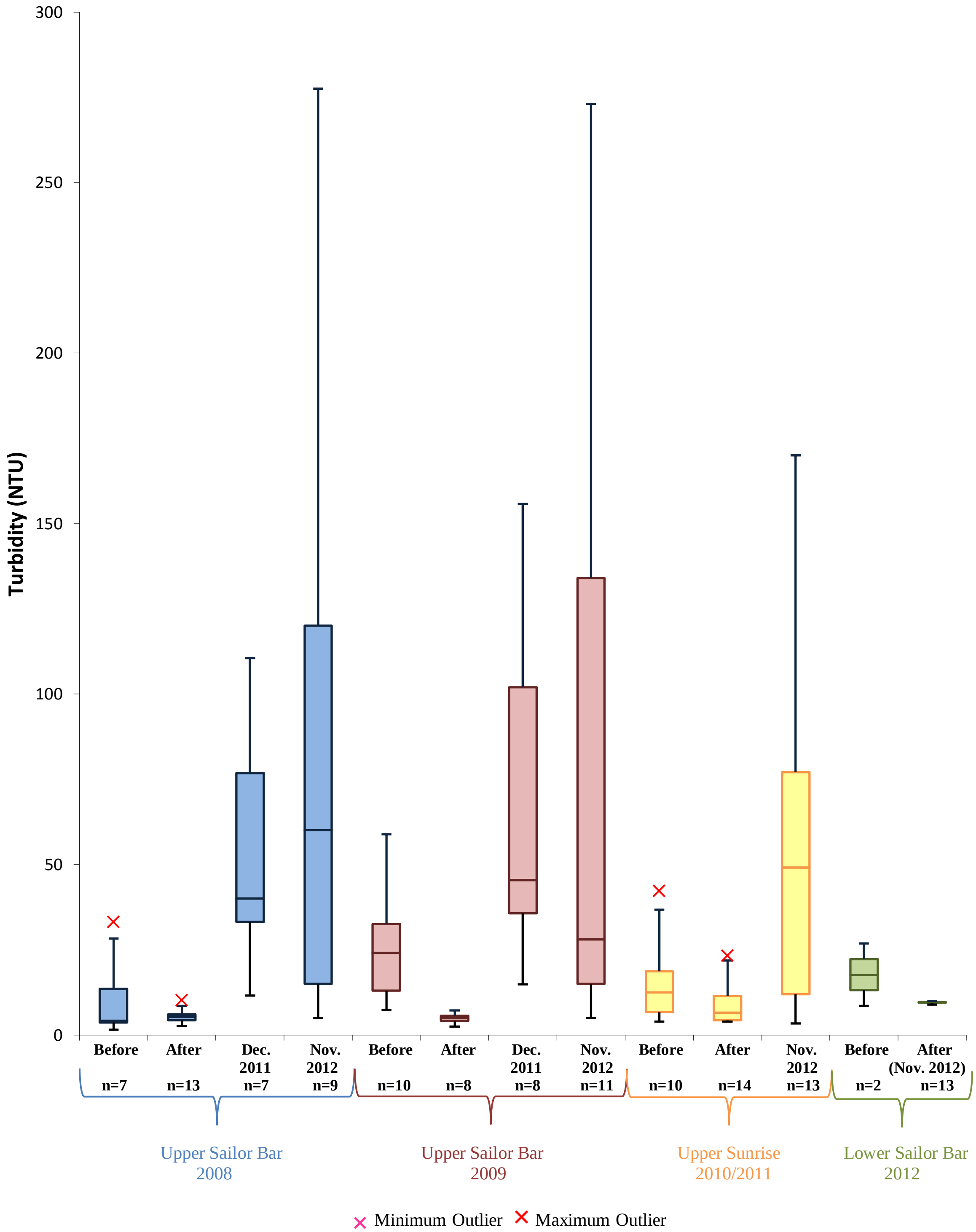


Figure 7.3: Box and whisker graph of turbidity levels (NTU) over time (before and after restoration) at all restoration sites. Turbidity was not measured at the 2008 site pre-restoration or immediately following restoration.

Turbidity shows an increase with time at restoration sites. It is clear from Figure 7.3 that turbidity levels decreased immediately after gravel augmentation. This may be due to screen washing before new gravel is added to the sites. However, in subsequent years turbidity measurements became highly variable and many increased to levels well above pre-restoration conditions. It is not clear if increases in intragravel turbidity levels will affect salmonid spawning, because salmonids move gravel when constructing a redd and this process may reduce the amount of sediment in completed redds. Future data collection at the restored sites will be critical for understanding how increases in turbidity will affect spawning habitats over time.

Spawning Usage

Salmonid response to augmentation projects was observed over time by examining the use of each restoration site during Fall-run Chinook salmon spawning seasons. From 2007 to 2012, the U.S. Bureau of Reclamation used high-resolution aerial images of the American River to estimate the number of redds at each restoration site and the total number of redds for the entire river (Hannon, 2012) before augmentation, immediately after augmentation, and during subsequent spawning seasons. Using this data, we calculated the percent of total redds at restoration sites by dividing the number of actual redds at each site by the total number of redds on the entire river. A summary of this data is in Table 7.4.

All of the restoration sites showed an increase of redds during the spawning season immediately following restoration. The two oldest sites (USB2008 and USB2009) showed an increase in redds every year following restoration. Four years after restoration, USB2008 had the highest number of redds seen at the site since 2007 (166 in 2012). Part of this is an overall population increase, but it is also a clear indication that gravel augmentation is improving the spawning habitat for Chinook Salmon for at least four years after restoration.

At first glance, USB2008 and USB2009 seem to show the greatest improvement immediately after augmentation based on percent of total redds; USB2008 went from 0%

to 14%, and USB2009 went from 2% to 15% of total redds (Table 7.4). The percent of total redds remained high at these sites until the 2011 spawning season when USB2008 dropped to <5% and USB2009 dropped to <2% of total redds. Both sites remained at their respective levels in the 2012 spawning season. This sudden drop could mean that the USB2008 and USB2009 sites deteriorated suddenly between 2010 and 2011. However, the physical parameters measured at the sites did not support this possibility, and indicated that both sites were still optimal for spawning. Moreover, despite the low percentages, both sites showed their highest actual number of redds since 2007 during the 2011 and 2012 spawning seasons.

Based on the percent of total redds, LSB2012 only showed a modest improvement immediately after augmentation from <3% to 6% of total redds (Table 7.4). This improvement seems low compared to the percent of total redds at the USB2008 and USB2009 sites immediately after augmentation. However, the actual number of redds at the LSB2012 site was the highest of all of the sites during the 2012 spawning season. Both of these issues may be related to the total number of redds counted in the American River from year to year. From 2008 to 2010, the total number of redds counted in the entire American River remained below 400. In 2011, that total increased to nearly 2,400, and in 2012, the total number of redds topped 3,600. This means that the percent of total redds at the USB2008 and USB2009 restoration sites were higher when there was less natural spawning on the river, and could be related to fish density.

During smaller spawning runs, there are fewer salmon competing for space. A female salmon would have more room to construct her redd and less rivals trying to hone in on her territory, which means she could choose a prime location. During years with greater ocean escapement and higher numbers of adults in the river, there are more salmon competing for space, which means less room to spawn, more rivals, and the female salmon could not be as particular in her choice of location. If this is the case, then the USB2008 and USB2009 sites did not decrease in redds, but may have hit a threshold capacity for redds or salmon that exerted excessive energy looking for space decided to spawn in less desirable locations. Either way, the percent of total redds would drop at the restoration sites, but not because of reduced habitat conditions or lower spawning usage. This would also mean that the improvement at the LSB2012 site immediately after augmentation was much greater than the percent of total redds indicated. This distinct improvement is particularly evident in the locations of redds from year to year at LSB2012 as seen in Figure 7.4. In 2011 (before restoration), the majority of redds were located near the upstream portion of the south bank of the river. In 2012 (after restoration), redds were distributed throughout the entire site.

Table 7.4: Redd counts on the Lower American River from 2007 to 2012 (Hannon, 2012)

Site	Photo Date		Total Redds in the River	Redds per Site	% of Total Redds
USB2008	11/27/2007	Before	839	0	0.00%
	12/1/2008	Immediately after	312	43	13.78%
	12/1/2009	1 year after	145	48	33.10%
	11/11/2010	2 years after	359	66	18.38%
	11/21/2011	3 years after	2394	116	4.85%
	11/26/2012	4 years after	3619	166	4.59%
USB2009	11/12/2008	Before	239	5	2.09%
	12/1/2009	Immediately after	145	22	15.17%
	11/11/2010	1 year after	359	42	11.70%
	11/21/2011	2 years after	2394	46	1.92%
	11/26/2012	3 years after	3619	63	1.74%
US2010/2011	12/1/2009	Before	145	2	1.38%
	11/21/2011	Immediately after	2394	13	0.54%
	11/26/2012	1 year after	3619	6	0.17%
LSB2012	11/21/2011	Before	2394	64	2.67%
	11/26/2012	Immediately after	3619	220	6.08%

Redd counts are inexact, because redds can be built over one another, it is difficult to distinguish the number of individual redds in a group, and reflections and shadows make counting redds from photos challenging.

It is also clear that the US2010/2011 site is receiving particularly low usage compared to the other sites regardless of the total number of redds on the river. This is the only site to see a decrease in the number of redds during any of the years following restoration (Table 7.4). While the individual parameters measured in this study show optimal conditions for salmonid spawning at US2010/2011, it is still unclear why the salmon are not using the site. Especially, when the natural spit (located a few meters across from US2010/2011 on the south bank of the river) is highly used (130 redds in 2012). It is important to remember that while parameters are measured separately, they are not necessarily independent. Many variables are interrelated, and additional information may be gleaned by assessing the relationships between various parameters. It is, therefore, recommended that multivariable assessment of all four restoration sites be conducted to examine how habitats differ from site to site.

a

b

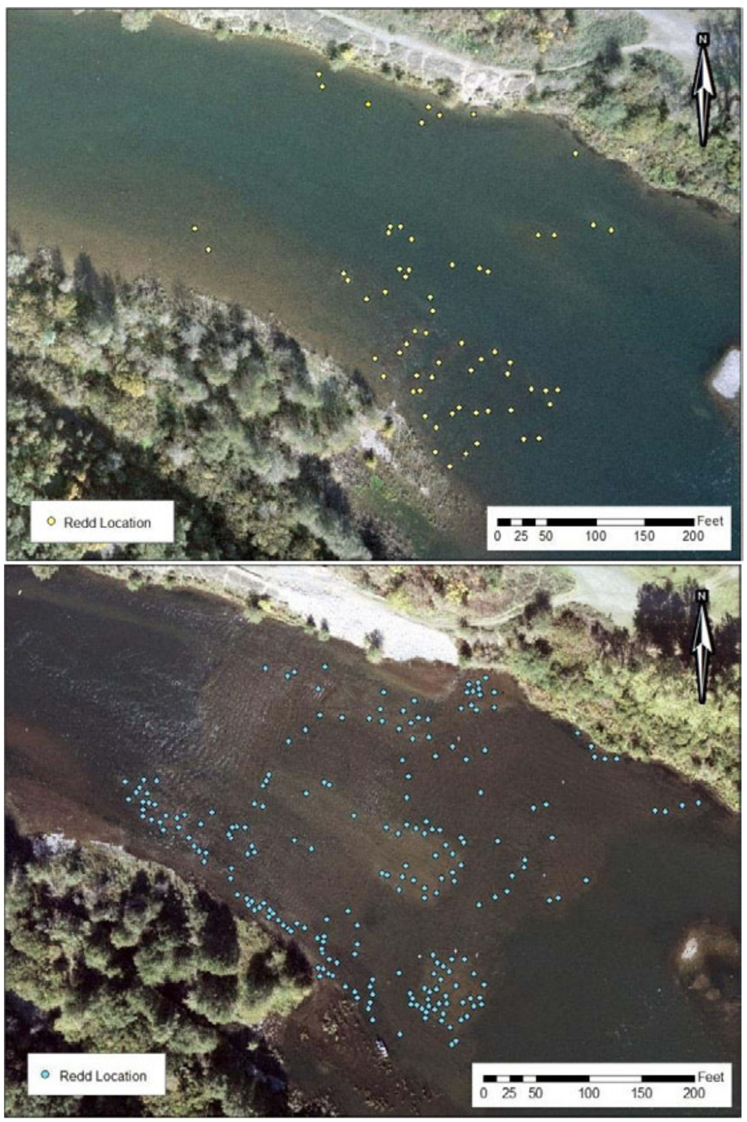


Figure 7.4: Locations of redds at LSB2012 during the (a) 2011 and (b) 2012 Fall-run Chinook salmon spawning seasons.

Summary of Recommendations

Gravel augmentation projects on the Lower American River are improving salmonid spawning habitats. Immediately following restoration, physical parameters measured in this study showed significant improvement when compared to pre-restoration conditions. Over time, these sites are continuing to provide optimal conditions for salmonid spawning, but the sites are changing and showing signs of an eventual return to pre-restoration conditions. The longevity of these restoration projects is still unclear, and further monitoring is necessary to establish the duration of habitat improvement. Furthermore, redd counts are showing that usage of the sites by spawning salmonids varies. To understand why salmon are choosing one site over another, it is important to continue monitoring sites and identify variables that predict fish use or good habitat. The following is a summary of recommendations outlined in this report:

(1) Conduct three to five bulk samples at each site within the next year to quantify current surface and subsurface grain size and evaluate streambed armoring.

(2) Dig out missing scour chains during the next low flow event to determine if deposition or erosion is occurring.

(3) Replace missing scour chains at the USB2009, US2010/2011, and LSB2012 sites and install new scour chains at the USB2008 site.

(4) Use a total station to survey each site within the next year to determine current streambed topography and evaluate how restoration sites have morphed over time.

(5) Consider ending the use of tracer rocks for analyzing gravel mobility.

(6) Conduct higher density permeability measurements at all sites.

(7) Continue monitoring water quality of all sites to determine at what point parameters (D.O. and turbidity) will reach pre-restoration levels.

(8) Conduct higher density grain size analysis, depth and velocity, temperature, and hyporheic pressure head measurements in zones with high use by spawning salmonids.

(9) Conduct hyporheic pressure head measurements at greater depths at all sites.

(10) Implement the use of a thermal imaging camera to find groundwater seeps.

(11) Continue monitoring temperature at the US2010/2011 site and adjacent natural spit, install temperature loggers at the USB2008 and USB2009 sites, and increase the number of loggers the LSB2012 site.

(12) Conduct multivariable assessment of all four restoration sites to examine the interrelation or physical variables and how habitats differ from site to site.

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