GEOLOGIC ASSESSMENT OF A SALMONID SPAWNING HABITAT ON THE FEATHER RIVER, OROVILLE, CALIFORNIA

A Thesis

Presented to the faculty of the Department of Geology

California State University, Sacramento

Submitted in partial satisfaction of
the requirements for the degree of

MASTER OF SCIENCE

in

Geology

by

Jay Edward Heffernan

FALL
2013

GEOLGIC ASSESSMENT OF A SALMONID SPAWNING HABITAT ON THE

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by

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Abstract

of

GEOLOGIC ASSESSMENT OF A SALMONID SPAWNING HABITAT ON THE FEATHER RIVER, OROVILLE, CALIFORNIA

by

Jay Edward Heffernan

Anthropogenic processes have altered the natural state of the Feather River creating unsuitable habitat for spawning salmonids. These processes have restricted the natural flow of the river resulting in an armored river bed. The goal of this study is to identify areas to reduce armoring and enhance salmonid spawning habitat.

This study is sponsored by the California Department of Water Resources and will be conducted for a period of 4 years starting in the Fall of 2011. Three riffle complexes on the Feather River were studied to evaluate the condition of the salmonid spawning habitat prior to restoration. The sites were analyzed for grain size utilizing Wolman pebble counts and bulk samples. Piezometers were installed throughout each riffle complex to measure hyporheic conditions such as dissolved oxygen, electrical conductivity, pH, temperature, and turbidity. Surface water depth, velocity, and direction of flow measurements were made using a Marsh/McBirney current meter affixed to a topset wading rod. Gravel permeability was tested using Barnard-McBain standpipe tests and upwelling was measured using a bubble manometer board and in-river baffle.

The three restoration sites currently have poor salmonid spawning habitat. The gravels at the sites are too large for the salmonids to manipulate and low hydraulic conductivity was prevalent through the sites. Low dissolved oxygen was also present at the proposed restoration sites. The restoration sites lacked significant gravel bars or geomorphic structures. The sites need improvement with the installation of transverse bars, riffles, and the addition of smaller size grains. This will reduce armoring and increase hyporheic flow.

_______________________, Committee Chair
Dr. Timothy Horner

____
Date

DEDICATION

This work is dedicated to the loving memory of my father Captain E.H. Heffernan, U.S.M.C. (RET.) and my mother Nancy J. Heffernan, FNP.

ACKNOWLEDGEMENTS

This thesis project was funded by the California Department of Water Resources, Oroville Field Division.

- Dr. Tim Horner, CSUS
- Ryan Martin, DWR
- Eric See, DWR
- Scott Kennedy, DWR
- Koll Buer, DWR
- Dr. Kevin Cornwell, CSUS
- Margaret K. Janes, CSUS
- Joe Rosenbery, CSUS
- Jessica Bean,CSUS
- Mike O'Connor, CSUS
- Ryan McCoy, CSUS
- Lewis Lummen, CSUS
- Chris Hall, CSUS

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Chapter 1.0

Introduction

1.1 Feather River

The ability for gravel to mobilize in a river system is crucial for the health of that river system and its ecosystem (Kondolf et al, 2008). As a result of gold mining and dam building, the Feather River has lost its ability to mobilize gravel through seasonal flows (Sommer et al, 2002; DWR, 2010). These anthropogenic processes have altered the natural state of the Feather River creating unsuitable habitat for spawning salmonids and have restricted the natural flow of the sediment, resulting in an armored river bed (DWR, 2010). Augmentation of spawning gravel has a positive effect on salmonid habitat and benefits the system by improving water quality indicators and effectively managing the area's watershed (Devries, 2000).

Spawning salmonids need proper hydrologic conditions and gravel bed substrate to build their redd (nests for eggs). Salmonids spawn in freshwater rivers in upstream pool-riffle complexes (Figure 1) and build their redd in the hyporheic zone, the region where groundwater and surface water interact (Geist and Dauble, 1998). Proper-sized gravels and cobbles must be present for the salmonid to manipulate the stream bed into a redd and allow for adequate hyporheic exchange around the redd (Lisle and Eads, 1991; Kondolf et al, 2008; Geist and Dauble, 1998). Upwelling conditions are commonly associated with salmonid redds due to the increased water exchange which delivers oxygen and removes waste (Becker and others, 1983; Malcolmet al, 2003). Vronskiy and

Leman (1991) propose that hyporheic exchange is critical and upwelling and downwelling may not be as vital.

Three riffle complexes on the Feather River were studied to evaluate the condition of the salmonid spawning habitat prior to spawning gravel restoration. This study was sponsored by the California Department of Water Resources and will be conducted for a period of 4 years (started in the Fall of 2011). The CSUS Geology Department has contracted with the Department of Water Resources Oroville Field Division to evaluate a spawning gravel augmentation project. Results described in this thesis are a summary of data collected at each restoration site (Cottonwood/Hatchery Riffle, Upper Auditorium Riffle, and Auditorium Riffle) prior to restoration of each site.

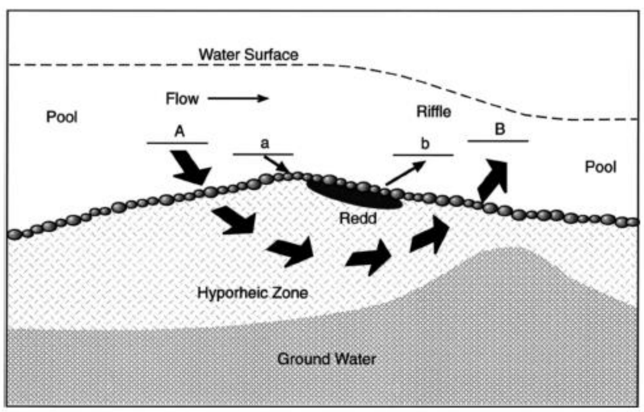


Figure 1: Pool-riffle complex with a salmonid redd showing downwelling(A) and upwelling(B) conditions in the hyporheic zone. Image from Geist and Dauble, 1998.

1.2 Study Objective

The goal of the gravel enhancement was to reduce armoring and enhance salmonid spawning habitat area (DWR, 2010). Tons of clean sorted gravel will be added to each restoration site to replenish the impeded natural sediment supply. Evaluation of the salmonid spawning habitat was conducted using a BACI study design (Smith, 2002). BACI stands for Before, After, Control and Impact , and in this study the focus is on gravel addition and spawning salmonids. This study will cover the "Before" portion of the field work.

Objectives for the salmonid spawning habitat pre-gravel restoration fieldwork and analysis are summarized below:

- Conduct grain size analyses using Wolman pebble counts and bulk samples
- Measure depth, direction, and velocity of surface water
- Measure gravel permeability with Barnard and McBain standpipe tests
- Measure hyporheic pressure head of mini-piezometers vs. surface water (upwelling and downwelling)
- Measure hyporheic water quality parameters (dissolved oxygen, turbidity, electrical conductivity, pH, and temperature) from mini-piezometers
- Create GIS maps from the collected data

Objectives for the post-gravel augmentation fieldwork and analysis are summarized below:

- Conduct grain size analysis using Wolman pebble counts and bulk samples

- Conduct gravel mobility tests and analysis using tracer rocks and scour chains
- Measure depth, direction, and velocity of surface water
- Measure gravel permeability with Barnard McBain stand pipe tests
- Measure hyporheic pressure head of mini-piezometers vs. surface water (upwelling and downwelling)
- Measure temperature data using HOBO temperature loggers
- Measure hyporheic water quality field parameters (dissolved oxygen, turbidity, electrical conductivity, pH, and temperature) from mini-piezometers
- Create GIS maps from the collected data

This post-project assessment will begin in Fall 2014, after the addition of the new gravel. Results will be used to manage the system and compare pre and post restoration conditions.

1.3 Study Area

The Feather River Basin is a major contributor to the California State Water Project and encompasses an area over 6,000 mi^2 (Koczot at al, 2012; USEPA, 2013).The Feather River watershed lies in the northern Sierra Nevada province and flows from the crest (~3778 feet elevation) to the western slope of the Sierra while flowing to the foothills of the Sacramento Valley where it becomes a tributary to the Sacramento River (~10 feet elevation) (Koczot et al, 2012; ICE, 2013). The climate of Oroville, California is Mediterranean, with hot, dry summers coupled with cool, wet winters and an annual precipitation of ~30 inches (City of Oroville, 2013).

The local geology varies considerably in the Feather River Basin. The study sites are composed of resistant metamorphic, volcanic, and plutonic rocks ranging in age from Ordovician to the present, with most basement rocks Middle to Late Mesozoic in age (Buer, 2003; DWR 2010). Above the resistant basement material, Tertiary gold-bearing gravels are overlain by Eocene non-marine rocks, volcanic flows and lahars (Buer, 2003). The Feather River has incised these resistant rocks forming steep canyon walls.

Mining practices of the 19th and 20th century affected the Feather River flora and fauna adversely by removing large swaths of habitat and destroying native vegetation through hydraulic gold mining, dredging for navigation and gold, and through sand/gravel mining. Hydraulic mining in the 1800s introduced over 500 million tons of material into the Feather River Basin and the floods of 1861-1862 swept large amounts of sediment and debris onto the Sacramento Valley floodplain resulting in 7 foot thick sediment deposits (DWR, 2010). Oroville Dam was completed in 1967 to supply water to the state, create power, and irrigate local crops. This furthered the anthropogenic impacts on the river by reducing habitat, altering the natural flow of the river, and by restricting the natural flow of sediment downstream. The river continues to degrade the channel and coarsen the substrate (DWR, 2010). The Feather River Fish Hatchery was installed to help mitigate the resulting reduction in salmonid populations. Previous work done by Koll Buer and others (2003) from DWR has concluded that Feather River spawning gravels have become coarser since the completion of Oroville Dam, which is detrimental to spawning habitats.

Three riffle complexes were chosen by the DWR Oroville Field Division for augmentation due to low salmonid redd counts at these sites (Figures 2 and 3). Three high use spawning control sites consisting of Upstream site, Moe's Ditch, and Downstream site were also chosen for a comparison to the restoration sites because of their large density of salmonid redds present (Figure 10). This will help document the natural conditions that salmon choose for spawning. Field work was started in January 2012 and ceased in November 2012 due to increased flows in the Low Flow Channel of the Feather River. The increase in flows from 600cfs to a peak of 2400cfs, which stayed above 1000cfs for the remainder of the winter, was caused by a fire at the Thermalito Power Plant that required flow to be diverted through the Low Flow Channel. Pre-project monitoring resumed briefly a few weeks in the Summer of 2013 at wadeable locations.

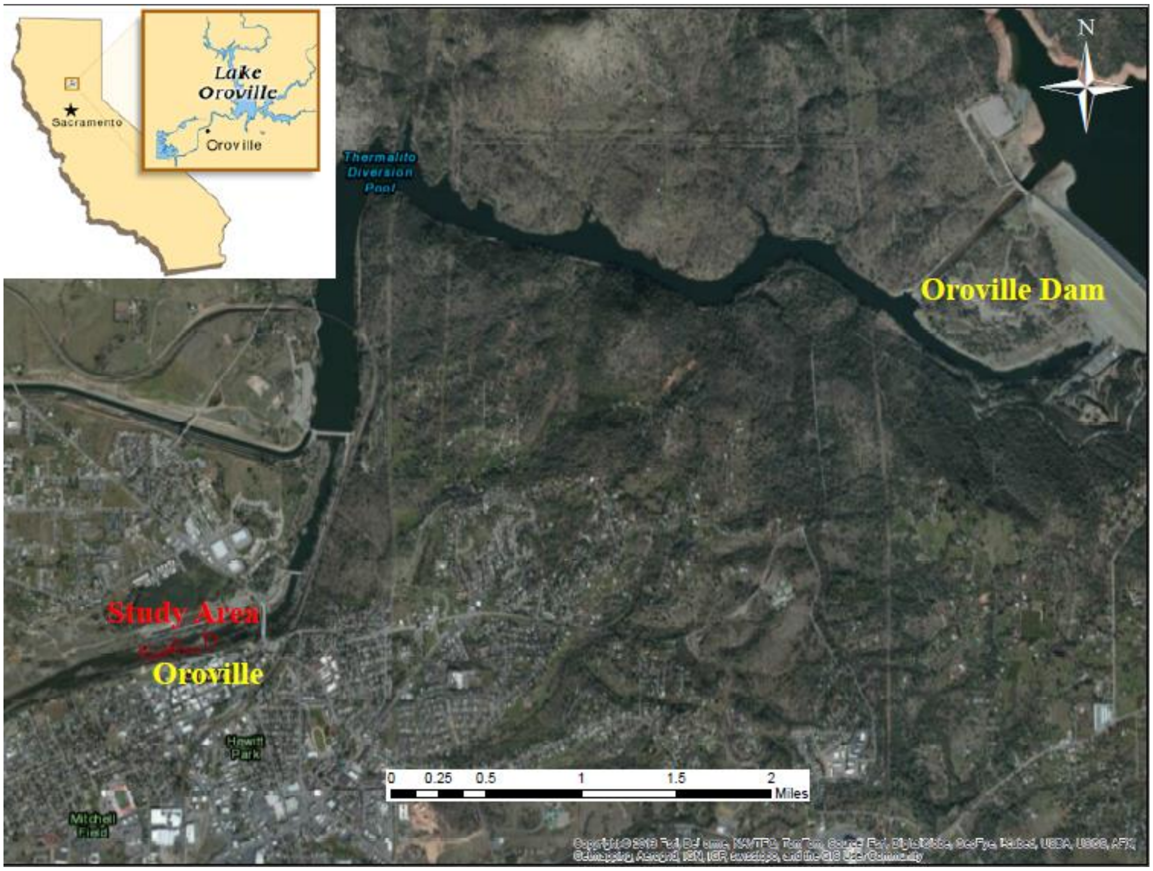


Figure 2: Location map of study area on the Feather River in Oroville, California.

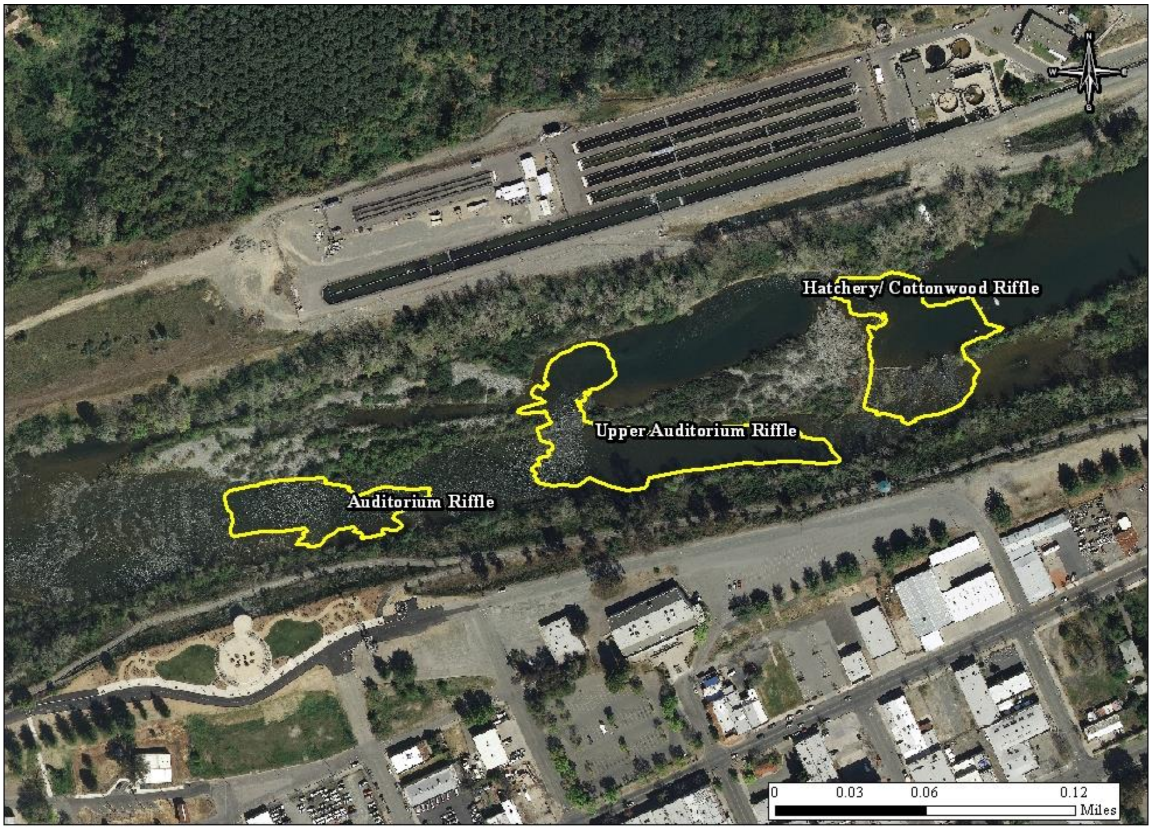


Figure 3: Study sites on the Feather River, Oroville, CA. The three riffle complexes that will be enhanced by gravel addition are the Cottonwood/Hatchery Riffle, Upper Auditorium Riffle, and Auditorium Riffle.

1.3.1 Cottonwood Hatchery Riffle

The Cottonwood Hatchery Riffle (figure 4) has patches of exposed bedrock throughout the site (Figure 5). Upstream from the site is a low velocity deep pool (>10 feet deep) that splits into a high velocity riffle on river right and a low velocity shallow riffle on river left. The high velocity riffle discharges into the pool above Upper Auditorium Riffle, and the low velocity riffle discharges into the main channel (Figure 4). Large cobble-sized grains are present throughout the site (Figure 5a), and fine-grained sands fill the voids between boulders and cobbles. Mini-piezometers were installed at 8 locations (Figure 4) that were accessible by a wading field crew.

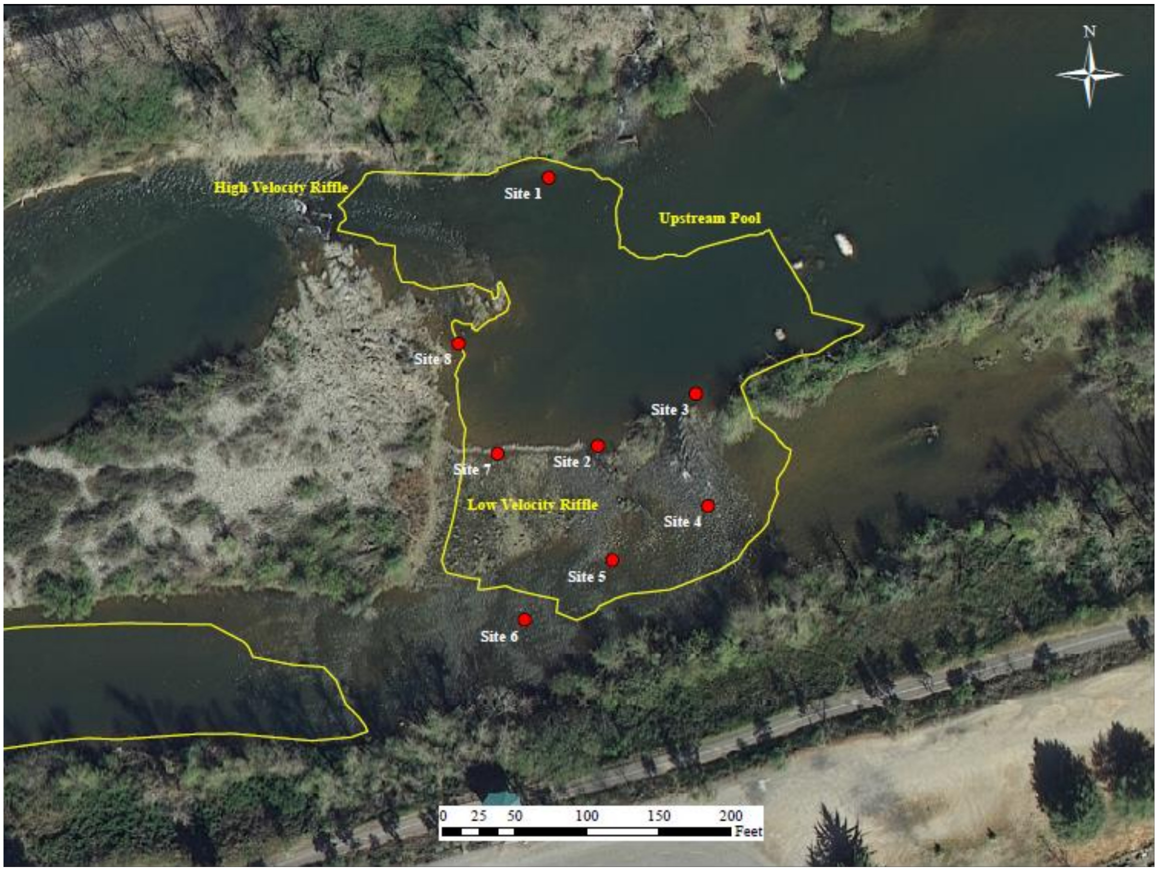


Figure 4: Cottonwood Hatchery Riffle mini-piezometer site locations. Mini piezometers were placed in areas that were "wadeable" and had some gravel over bedrock.

5a)  5b) 

Figure 5: 5a) Photo looking east of Cottonwood Upstream view of the pool and low velocity riffle. 5b) Photo looking north at exposed bedrock downstream from the pool at Cottonwood Hatchery Riffle with the high velocity riffle in the background.

1.3.2 Upper Auditorium Riffle

The Upper Auditorium Riffle complex is dominated by a shallow pool upstream from a high velocity riffle that discharges into the main channel of the Feather River (Figure 6 and 7). Coarse cobble and boulder-sized grains are present throughout the site, with a matrix of fine-grained sand. The coarser grains form an armored surface layer. Mini-piezometers were installed at 9 locations (Figure 6) that were accessible by a wading field crew.

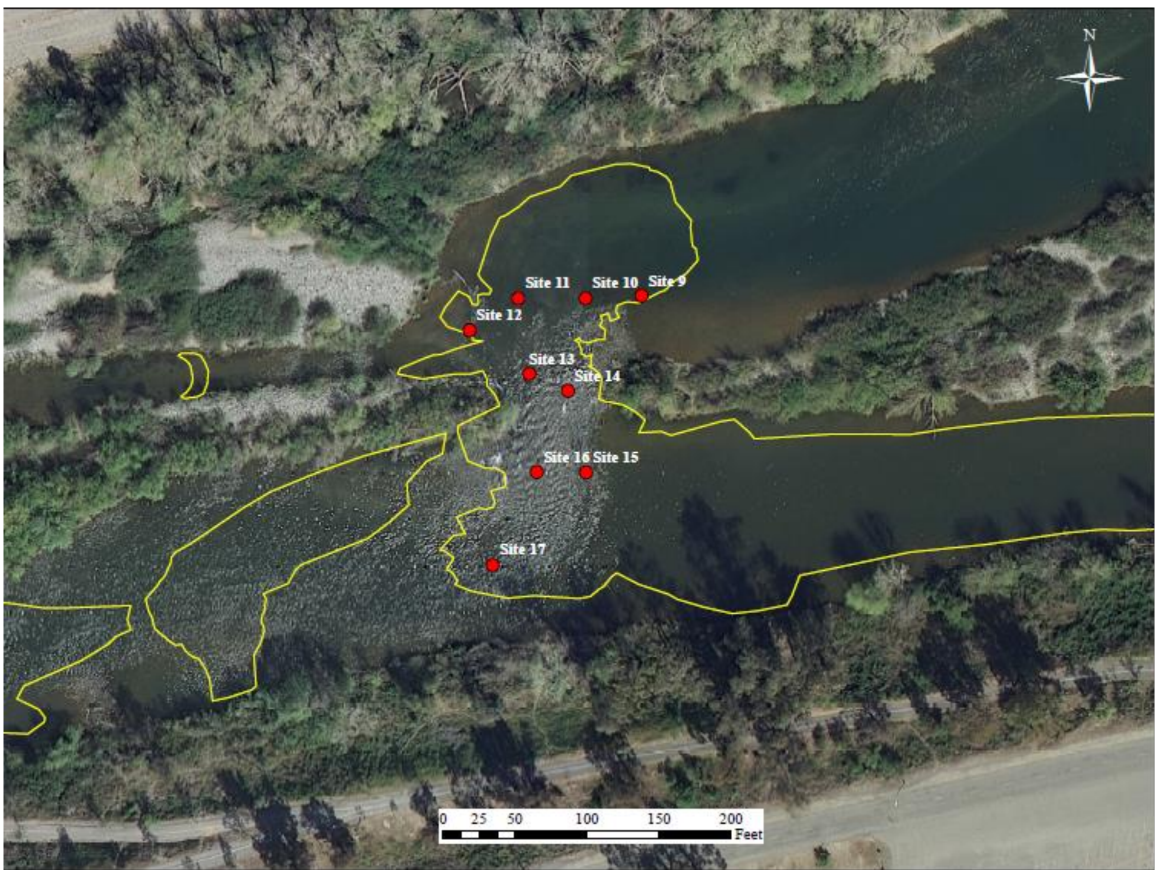


Figure 6: Upper Auditorium Riffle mini-piezometer site locations. Mini piezometers were placed in “wadeable” area where depths are appropriate for spawning.

7a)  7b) 

Figure 7: 7a) View looking east upstream toward the pool of the Upper Auditorium Riffle. 7b) Armored bed of the river at the Upper Auditorium Riffle.

1.3.3 Auditorium Riffle

The Auditorium Riffle site has a straight wide channel with a hummocky riverbed. Geomorphologically it would be called a run or glide, and pools and riffles are absent. (Figure 8 and 9). Bed material consists of cobble-sized grains mixed with fine material. Mini-piezometers were installed at 11 locations (Figure 8) that were accessible by a wading field crew.

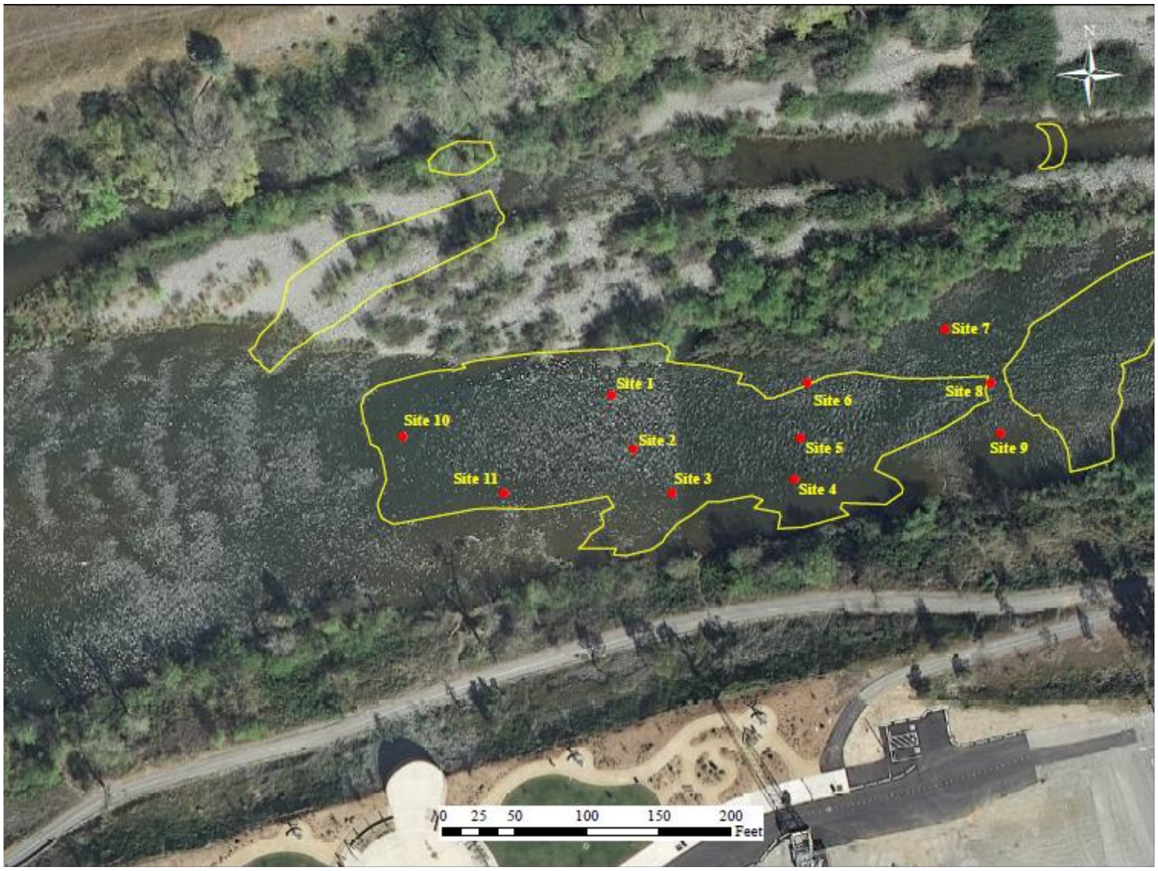


Figure 8: Auditorium Riffle mini-piezometer site locations. Mini piezometers were placed in “wadeable” area that will yield data about spawning site selection.

Figure 9: Downstream view of Auditorium Riffle showing the straight channel and shallow, featureless glide or run.

1.3.4 Natural Spawning Sites

Natural spawning was documented throughout the low flow channel (Figure 10) (DWR, 2010; Sommer et al, 2002). The restoration sites were chosen for augmentation due to the low density of redds present. Three natural spawning areas were selected near the proposed restoration sites and used as controls. The control sites were the paradigm spawning sites for the Low Flow Channel. Piezometer wells were installed at the control sites. The collected data was compared to the areas scheduled for restoration. Grain size analysis was conducted in these natural spawning areas and limited hyporheic measurements were conducted. An increase in flows in November of 2012 significantly limited access to the sites and the completion of tasks. The three natural spawning sites chosen as background and control sites were Upstream Site, Moe's Ditch, and Downstream Site (Figure 10). These sites were chosen for their dense population of salmonid redds present in the 2012 redd survey conducted by California's Department of Water Resources (Figure 10).

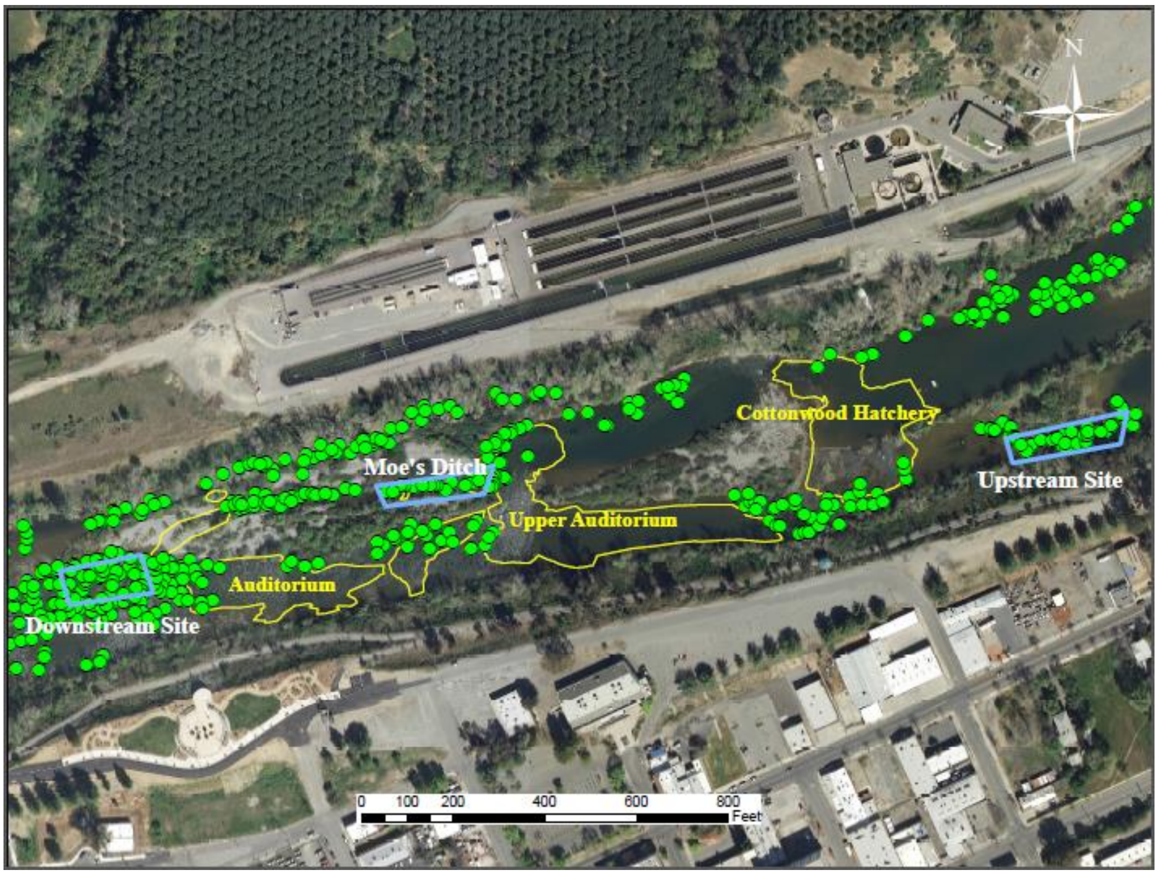


Figure 10: Natural spawning sites are outlined in blue and were identified from 2012 redd count surveys provided by California's Department of Water Resources. The green dots represent salmonid redds counted in 2012.

Upstream Site Control Site

The Upstream Site (Figures 11 and 12) control site is a narrow side channel upstream and river right from Cottonwood Hatchery Riffle. Natural spawning is especilly dense at this site, so it was chosen as a control site. The Upstream Site has coarse grained pebbles and gravels present throughout. Depth and velocity are low, and the channel consists of small riffles and glides. The Upstream Site flows into a flat wide shallow pool before it flows into the main channel of the river.

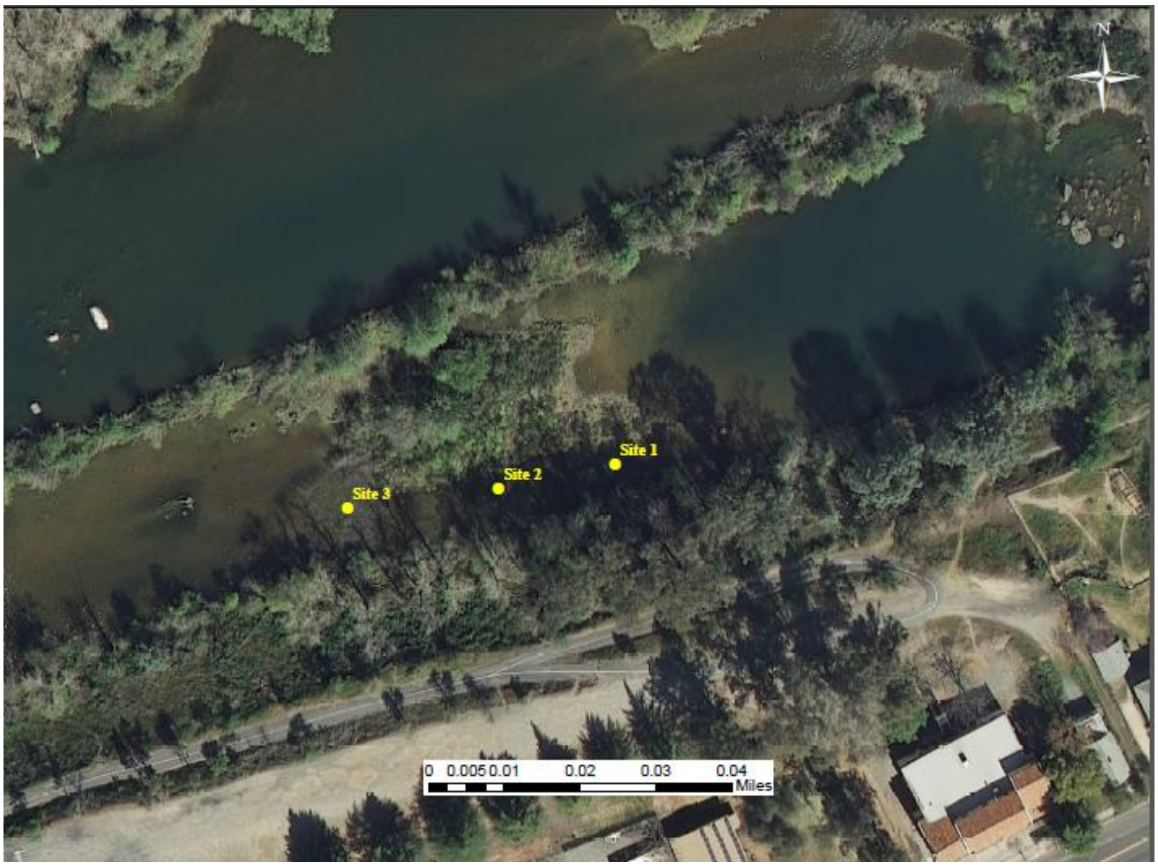


Figure 11: Upstream Site mini-piezometer locations. Mini piezometers were placed in “wadeable” areas that will yield data about spawning site selection.

Figure 12: Upstream Site control site looking east at natural spawning site with small pool riffle sequences.

Moe's Ditch Control Site

The Moe's Ditch control site (Figures 13 and 14) is a straight channel less than 10 feet across in places with significant amounts of woody debris present. This is an un-restored area where a significant amount of natural spawning occurs. A mixture of gravels, pebbles, and boulders comprise the riverbed surface. Moe's Ditch is directly west of and fed by Upper Auditorium Riffle.

Figure 13: Moe’s Ditch control site mini-piezometer site locations. Mini piezometers were placed in “wadeable” area that will yield data about spawning site selection.

Figure 14: Moe’s Ditch control site looking west at featureless narrow channel.

Downstream Control Site

The Downstream Site control site (Figure 15) is similar to Auditorium Riffle with a wide straight river channel and hummocky bed. Natural spawning is common at this control site. The site contains pebbles, gravels, and boulders with a significant amount of fine grain material present and is directly downstream from Auditorium Riffle.

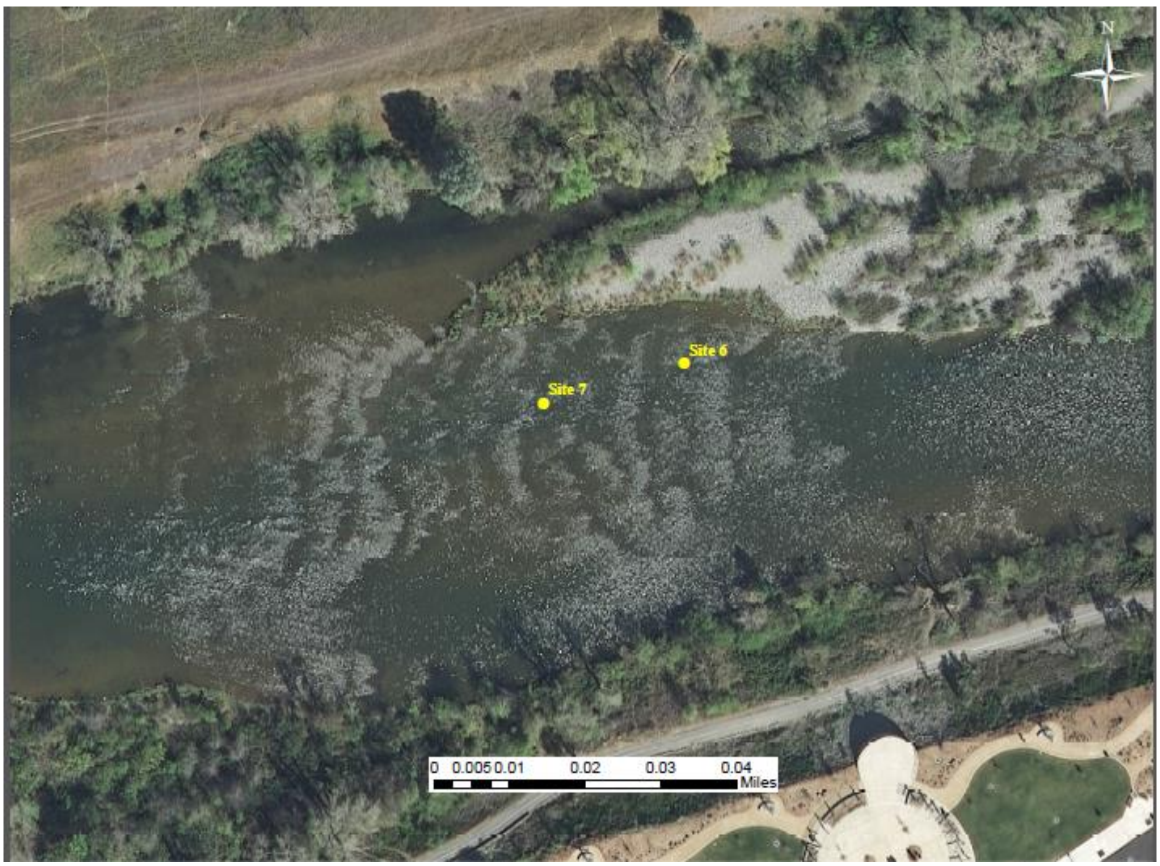


Figure 15: Downstream Site control site mini-piezometer site locations. Mini piezometers were placed in "wadeable" area that will yield data about spawning site selection.

Chapter 2.0

Methods

2.0 Methods

Numerous methods were employed to assess salmonid spawning habitat on the Feather River. They included grain size, surface water depth and velocity, permeability, and hyporheic conditions at Cottonwood/Hatchery Riffle, Upper Auditorium Riffle, and Auditorium Riffle. Field work was started in the Fall of 2011 with the installation of piezometer wells at all site locations. Piezometers are shallow wells that were installed with a drive tube and slide hammer to a depth of 30 cm (Figure 16). The piezometers were used in sampling pore water.

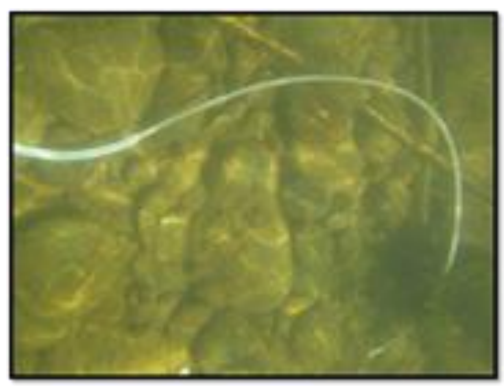
16a)  16b) 

Figure 16: 16a) A handful of mini-piezometer tips is ready for installation in the river. 16b) Mini-piezometer installed at 30cm depth, with plastic tubing that allows sampling of hyporheic conditions from a discrete interval in the subsurface.

2.1 Grain Size

Grain size is an important element in quality salmonid spawning habitat (Kondolf et al, 2008; Merz and Setka, 2004; Geist and Dauble, 1998). A salmonid can only move grains in proportion to its body size. Salmonid spawning gravel needs to be large enough for oxygenated water to be delivered to the redds and remove waste (Youngson et al, 2004; Nawa, 1990) and not too fine to block flows or emergence of fry (Kondolf et al, 2008; Wu, 2000). Observed spawning in the Low Flow Channel occurred in gravels ranging from -7 phi (12.8 cm) to -3.5 phi (1.1cm) (Sommer et al, 2002). Grain size was determined by the Wolman (1954) pebble count method and collection and analysis of bulk samples (Bunte and Abt, 2001; Ettema, 1984).

2.1.1 Wolman Pebble Counts

The Wolman (1954) pebble count method was used to create a size distribution plot of the grain size at each riffle site. The Wolman pebble count method does not account for fine material such as sand and silt but it does describe the distribution of coarser grains (Bunte and Abt, 2001). Wolman pebble counts were conducted by measuring the intermediate axis of a randomly chosen grain. A pebble count was completed by counting 100 random grains along a zigzagging transect. To select grains, the field worker bent at the waist and without looking picked up the first grain their index finger touched. This grain's intermediate diameter was measured with a gravelometer (Figure 17) and then the grain was tossed over the shoulder to ensure that the same grain was not picked up twice. After the grain was chosen, measured, recorded, and returned, the field worker took a step forward and repeated the process until 100 grains were measured. This pebble count distribution was plotted as cumulative frequency percent versus phi scale size to aid in assessing the habitability of each riffle complex. The d_{50},

d_{16}, d_{84}, d_{95}, and d_5 values were taken directly from the grain size distribution graphs. Numerous pebble counts are conducted at each riffle complex and transect locations were documented with GPS coordinates.

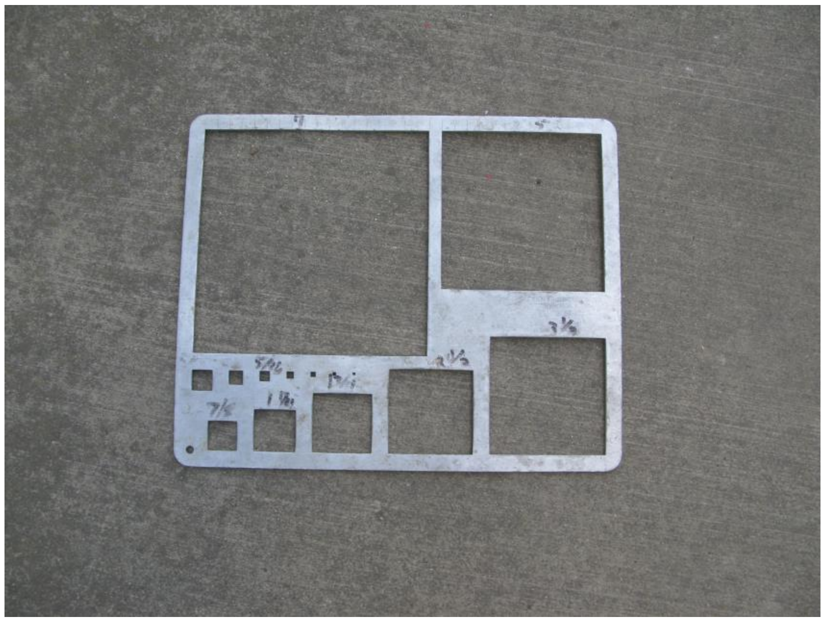


Figure 17: Gravelometer used to measure the intermediate axis of a grain during the pebble count transects.

2.1.2 Bulk Sample

Bulk samples were collected prior to the 2014 restoration. Each bulk sample site was chosen randomly by tossing a marker into the river to locate the center of the bulk sample area. The largest surface grain in the sample area was collected and weighed, and the weight of that grain is compared to the bulk sample chart (Figure 18) to determine the total sample size (Bunte and Abt, 2001). The bulk sample chart from Church (1987) shows the total bulk sample size necessary to reduce the uncertainty rate in size distribution to <5%. Surface and substrate samples were collected separately to identify river bed armoring. An armoring index was calculated by comparing the d_{50} value of surface grains to the d_{50} of subsurface grains (Ettema, 1984). The depth of the surface sample was defined as the diameter of the largest surface grain. Bulk samples were collected with a shovel. A 3 foot diameter corrugated metal tube (Figure 19) was installed in the sample area to prevent the finest materials from escaping downstream. Five gallon buckets were used to transport the sample material to shore, where samples were drained and then weighed. Grains were split into size classes using rocker sieves. Seven rocker sieves (Figure 20) from less than 5/16 inch to greater than 3.5 inches in size were used to separate the grains. Sieve openings were 5/16, 5/8, 7/8, 1.25, 1.75, 2.5, and 3.5inches in size. Grains larger than 3.5 inches were measured manually with a template. The grains from each size class were then weighed on a digital scale. The fraction with grains less than 5/16 of an inch in diameter were collected in steel cans and sealed for further detailed analysis (sieving) in the lab. The weight of each grain size was compared with the total weight of the sample to determine the percent weight distribution. Grain sizes were also converted from inches to millimeters and phi scale size (Figure 21). The bulk sample distribution was plotted as a cumulative weight percent versus phi scale size of grains to aid in assessing the habitability of each riffle complex (Boggs, 2006). The d_{50}, d_{16}, d_{84}, d_{95}, and d_5 values were obtained from the grain size distribution graphs.

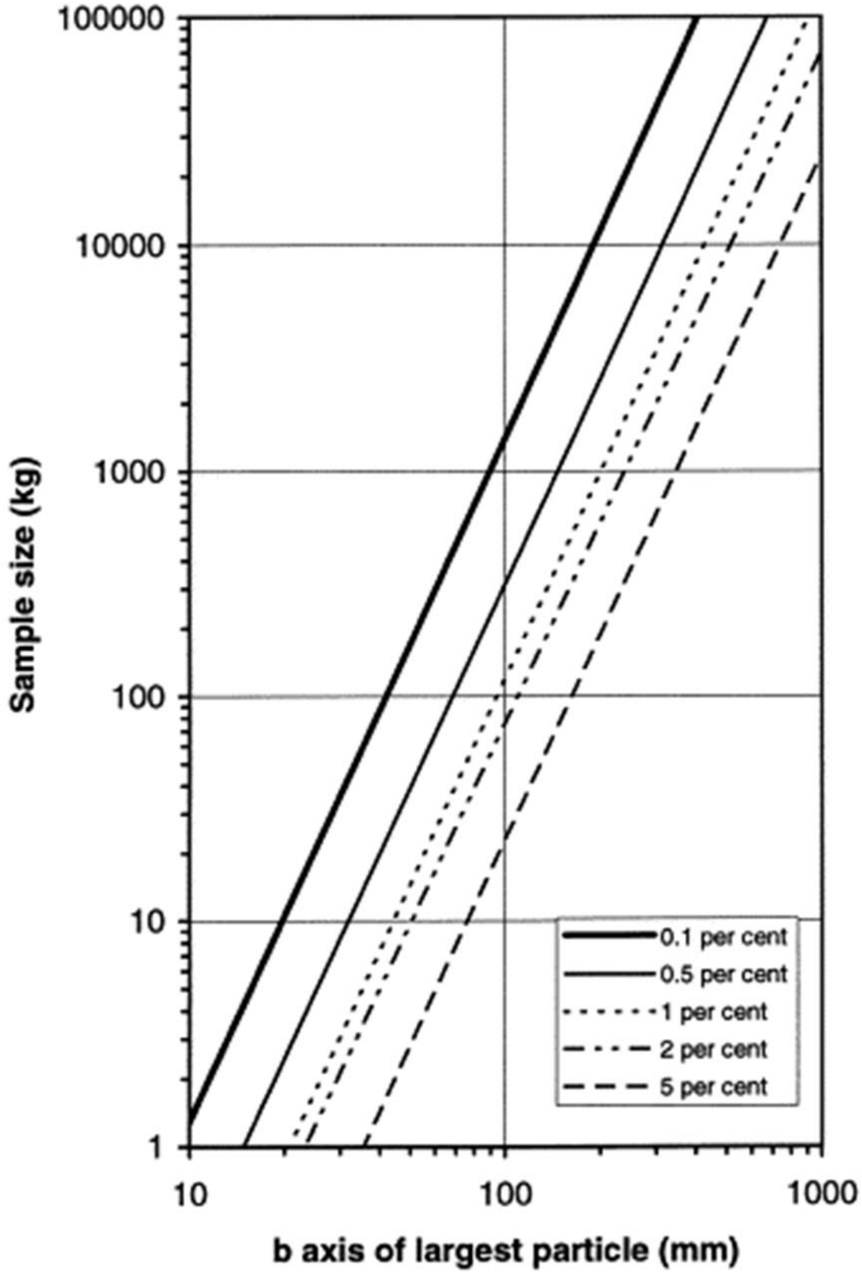


Figure 18: Bulk sample collection size chart. The intermediate (b-axis) size of the largest grain in the sample was measured and compared to this chart to yield a sample collection size and percentage of error. The larger the sample size, the smaller the percent error. From Church, et al (1987).

Figure 19: Bulk sample collection technique using corrugated metal tube and 5 gallon bucket. The metal tube prevents the loss of fine material.

Figure 20: Bulk sample sieve line. The dried gravel was sorted by grain size with rocker sieves and size fractions were stored in 5 gallon buckets for individual weight measurements.

Millimeters		µm	Phi (ϕ)	Wentworth size class	
			-20		
	4096		-12	Boulder (-8 to -12ϕ)	
	1024		-10		
	256		-8	Pebble (-6 to -8ϕ)	
	64		-6		
	16		-4	Pebble (-2 to -6ϕ)	
	4		-2		Gravel
	3.36		-1.75		
	2.83		-1.50	Gravel	
	2.38		-1.25		
	2.00		-1.00		
	1.68		-0.75		
	1.41		-0.50	Very coarse sand	
	1.19		-0.25		
	1.00		-0.00		
	0.84		0.25		
	0.71		0.50	Coarse sand	
	0.59		0.75		
1/2	0.50	500	1.00		
	0.42	420	1.25		
	0.35	350	1.50	Medium sand	Sand
	0.30	300	1.75		
1/4	0.25	250	2.00		
	0.210	210	2.25		
	0.177	177	2.50	Fine sand	
	0.149	149	2.75		
1/8	0.125	125	3.00		
	0.105	105	3.25		
	0.088	88	3.50	Very fine sand	
	0.074	74	3.75		
1/16	0.0625	63	4.00		
	0.0530	53	4.25		
	0.0440	44	4.50	Coarse silt	
	0.0370	37	4.75		
1/32	0.0310	31	5	Medium silt	
1/64	0.0156	15.6	6	Fine silt	
1/128	0.0078	7.8	7	Very fine silt	
1/256	0.0039	3.9	8		Mud
	0.0020	2.0	9		
	0.00098	0.98	10		
	0.00049	0.49	11	Clay	
	0.00024	0.24	12		
	0.00012	0.12	13		
	0.00006	0.06	14		

Figure 21: Wentworth scale of grain sizes from Boggs (2006).

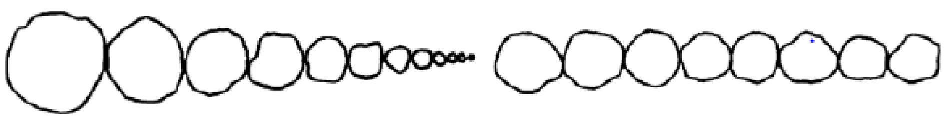
Bulk sample grain size data was plotted on a graph of phi size versus cumulative weight percent and statistical analysis was applied to determine sediment properties (Boggs, 2006). Sample grain size data was converted into phi size according to the Wentworth scale (Figure 21) and results were applied to the statistical equations in Boggs

(2006). The mean grain size, sorting (Table 1 and Figure 22), skewness (Table 2), and armoring index were derived from the pebble count and bulk sample graphs. Graphs created from the grain size sampling were used to determine mean grain size, sorting, skewness, and an armoring index based on the equations in Boggs (2006). The mean grain size is the average size of sediment particles in the sample. Sorting is the standard deviation of the particle size and is the range of grain sizes in a sediment sample and how scattered these are about the mean grain size (Boggs, 2006). Another measure of grain size distribution is skewness, which accounts for the coarse and fine tails of the distribution plot. The armoring index is a ratio of mean surface grain size to mean subsurface grain size, and the larger the ratio the greater the armoring present. The results from the sorting and skewness equations were classified based on Tables 1 and 2 from Boggs (2006). The equations are as follows:

Mean Grain Size	$\frac{d16+d50+d84}{3}=Mz$	equation 1
Sorting	$\frac{d84-d16}{4}+\frac{d95-d5}{6.6}=S$	equation 2
Skewness	$\frac{d84+d16-2d50}{2(d84-d16)}+\frac{d95+d5-2d50}{2(d95-d5)}=Sk$	equation 3
Armoring Index	$\frac{d50surf}{d50sub}=Ai$	equation 4

σ_ϕ	sorting
< 0.35 ϕ	very well sorted
0.35 – 0.50 ϕ	well sorted
0.50 – 0.71 ϕ	moderately well sorted
0.71 – 1.00 ϕ	moderately sorted
1.00 – 2.00 ϕ	poorly sorted
2.00 – 4.00 ϕ	very poorly sorted
> 4.00 ϕ	extremely poorly sorted

Table 1: Values for sorting showing the range of grain sizes in a sediment sample and how far they are from the mean. Sorting and standard deviation are the same calculation. From Boggs (2006).



Poorly Sorted Well Sorted

Figure 22: Example of poorly sorted grains versus well sorted grains. The poorly sorted sample represents a greater diversity in size of material available. The well sorted sample is uniform in size. From Boggs (2006).

sk_ϕ	skewness
> +0.3	strongly fine skewed
+0.3 – +0.1	fine skewed
+0.1 – - 0 .1	near symmetrical
-0.1 – -0.3	coarse skewed
< -0.3	strongly coarse skewed

Table 2: Values for skewness show whether the sample is skewed toward tails of fine or coarse sediment on the grain size distributions. From Boggs (2006).

2.2 Depth and Velocity

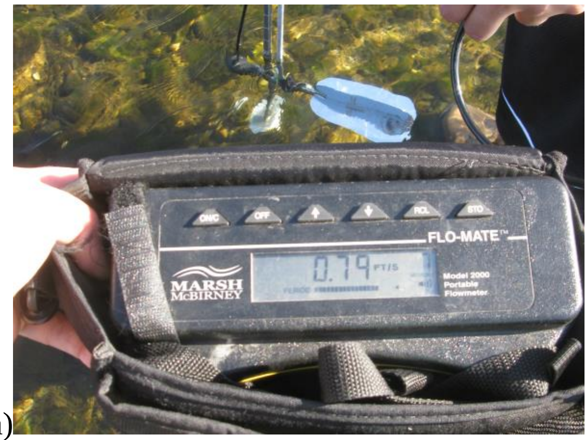
Surface water depth and velocity are key variables in redd site selection (Merz et al, 2004; DWR, 2010; Kondolf et al, 2008). Spawning salmonids require high enough surface water velocities to allow oxygenated water to flush through the gravel (Figure 1), and higher dissolved oxygen in the subsurface results in decreased egg mortality rates

(Malcolm, et al, 2003; Wu, 2000)). Chapman and others (1986) estimate that surface water velocities between 0.5-2.0 m/s are optimal for spawning. Lower surface water velocities decrease the volume of water flowing in the subsurface, which reduces the amount of dissolved oxygen in the gravel pore waters (Silver et al, 1963; Greig et al, 2007). Higher surface water velocities add stress to the spawning females by making them work harder to stay on the redd, thus reducing their normal 10-14 day stay on the redd (Chapman et al, 1986; Kondolf et al, 2008). Salmonid spawning has been reported at depths greater than 7 meters (Chapman et al, 1986) although observed depths and velocities for salmonids spawning in the Low Flow Channel range from 1.6-2.6 feet deep and velocities range from 1.5- 2.7 ft/s (Sommer et al, 2002).

2.2.1 Depth, Direction, and Velocity Methods

Surface water velocity measurements were conducted following USGS stream gaging procedures (USGS, 1980). Surface water depth and velocity were measured using a Marsh/McBirney current meter (Figure 23) attached to a topset wading rod. Surface water depth and velocity measurements were taken at random sites covering the study area and recorded to decimeter level with a high resolution GPS. A single depth measurement was made at each site, at a depth of 60% from the surface. The 60% depth measurement was used to represent the average velocity of the column of water. 30 to 50 measurements of depth and velocity were made at each site, and a Brunton compass was used to measure the direction of flow at each location point. The direction of flows was incorporated into depth and velocity maps created in GIS for the Cottonwood/Hatchery

Riffle (Figure 60), Upper Auditorium Riffle (Figure 61), and Auditorium Riffle (Figure 62).

23a) 

23b) 

Figure 23: 23a) Marsh McBirney current meter used to measure flow velocity in the river. 23b) Sacramento State student demonstrating use of the current meter.

2.3 Permeability

2.3.1 Permeability Measurements

The Barnard and McBain (1994) standpipe test method was utilized to measure permeability in river gravels. A one inch diameter stainless steel pipe 1 meter long with well screen perforations at the closed end (Figure 24) was driven into the river bed to a depth of 30 cm. The well was developed by pumping a minumum volume of 6 liters to begin the test. This cleaned silt and clay from the perforated interval. The test consists of maintaining a one inch drawdown inside the well while pumping. The backpack pump removed and stored the water from the well (Figure 24) and the time of the test was measured with a stopwatch until it reached a given volume. The volume of water stored in the backpack was measured with a graduated cylinder and recorded. The volume and time for each test were compared to permeability value on an empirically derived chart (Figure 25). This test was performed numerous times at each study site and locations of the measurements were recorded with GPS. A GIS map of each site was created to compare trends in the data.

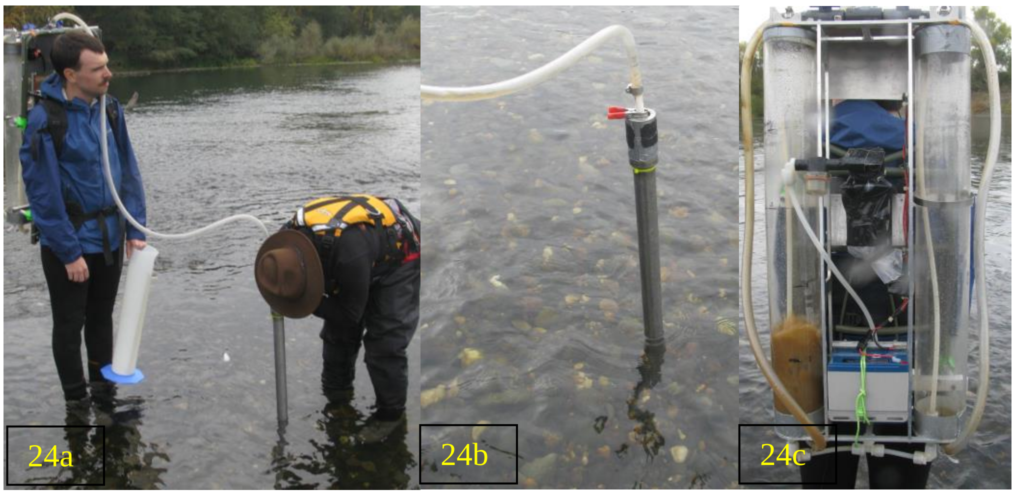


Figure 24: Barnard McBain standpipe test. 24a) Listening for the “slurping” sound to establish a depth to water. 24b) Standpipe with 1 inch drawdown test being conducted. 24c) Backpack pump with reservoirs for collecting the sample volume.

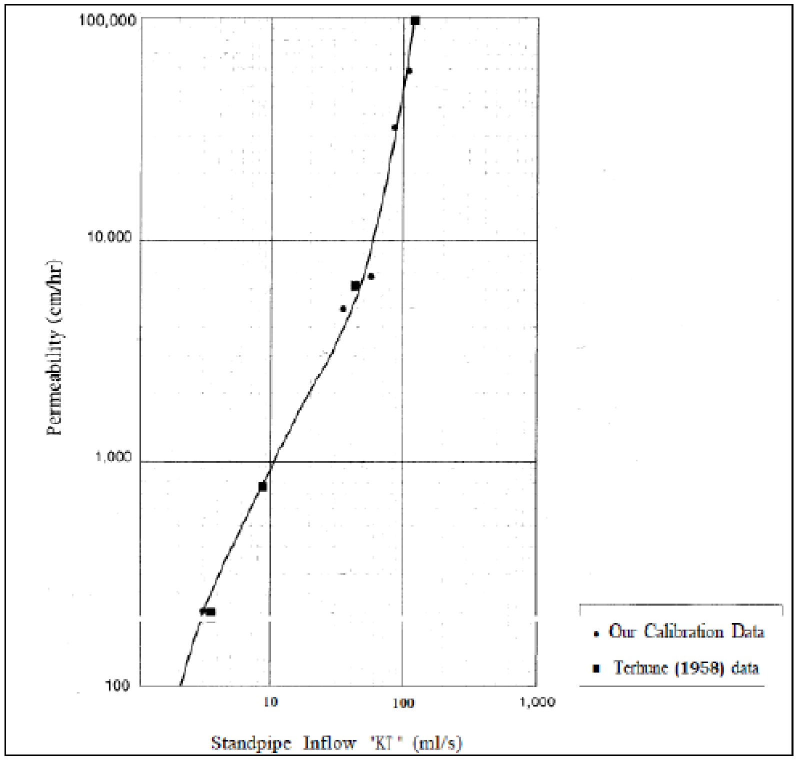


Figure 25: Permeability vs. standpipe inflow rate calibration curve. The collected standpipe inflow rate from a particular test is compared to the chart to reveal a permeability value. Image from Barnard McBain (1994).

2.4 Hyporheic Conditions

Water quality conditions are a good indicator of the health of a river's ecosystem (Kondolf et al, 2008). Spawning salmonids need adequate hyporheic flow and oxygen to ensure the viability of their eggs (Wu, 2000; Greig, 2007). Quantifying conditions in spawning areas will lead to a greater understanding of the spawning salmonids' habitat.

Figure 26: CSUS river crew students measuring up/downwelling conditions with boat, peristaltic pump, in-stream baffle (not pictured), 30cm deep well, and manometer board.

2.4.1 Hyporheic Sampling Methods

Water quality parameters were collected at multiple sites in the Feather River study area for the purpose of evaluating salmonid spawning habitat. All meters were calibrated at the study site before every outing using proper guidelines and field procedures. Hyporheic conditions were measured by sampling each mini-piezometer that was installed in the riffle complex sites. A small pontoon boat was outfitted as a sampling boat (Figure 27). During sampling events a surface water sample was collected first to establish baseline conditions. Then subsurface conditions were measured in each piezometer. Piezometers were connected to a flow through cell which housed a YSI 95 dissolved oxygen meter and an YSI model pH meter. Water was pumped from the piezometer, with a peristaltic pump connected to a motorcycle battery. Water from the subsurface was isolated, and never exposed to the atmosphere. A DRT turbidity meter was used to determine the amount of suspended material in the subsurface water sample and an YSI model electrical conductivity meter was used to indicate the abundance of dissolved ions present in the pumped sample. Temperature was recorded from the dissolved oxygen meter and dissolved oxygen was recorded as both a percent and in mg/l. All information was recorded into field books and a final surface sample was taken at the end of the day to account for any meter drift experienced through the field day. A GIS map was created from the dissolved oxygen data to locate and compare emerging trends.

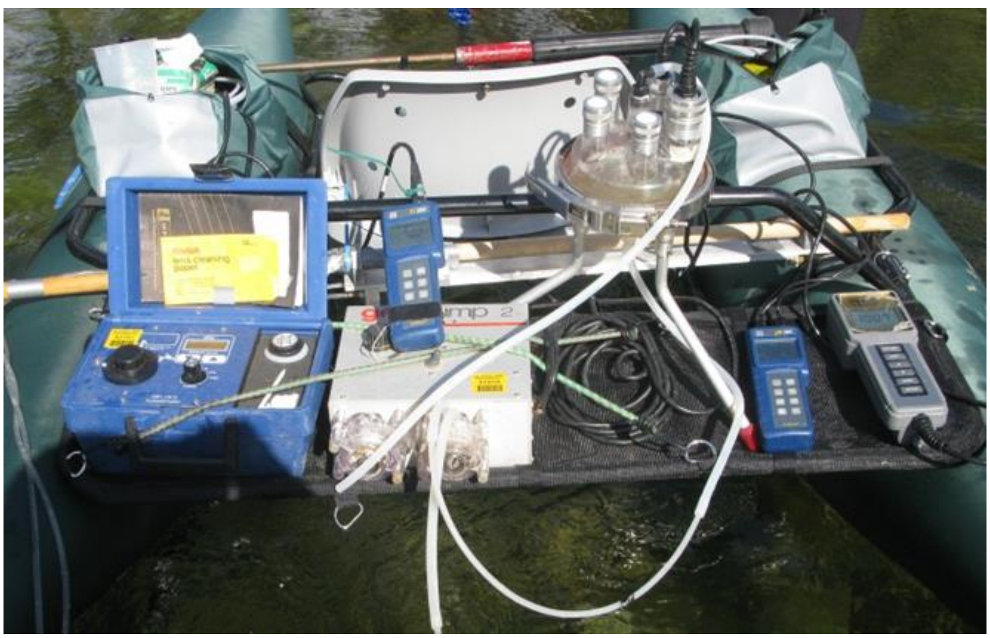


Figure 27: Sampling boat and equipment consisting of (from left to right) a DRT turbidity meter, an YSI model electrical conductivity meter atop the peristaltic pump, a flow thru cell, an YSI model pH meter, and a YSI 95 dissolved oxygen meter.

2.4.2 Upwelling/Downwelling

Strong upwelling or downwelling conditions are commonly associated with salmonid spawning site selection (Becker et al, 1983; Malcolm et al,2003). In this project upwelling and downwelling were determined by measuring differences in hyporheic head which influence the direction of subsurface flow. These differences could be a deciding factor in salmonid spawning site selection.

Measuring hyporheic pressure head reveals upwelling and downwelling conditions in the subsurface. A bubble manometer board (Figure 28a) (Zamora, 2006) attached to an in-river baffle (Figure 28b) was used to compare pressure head differences between the river and 30cm gravel depth (Figure 28a). Every site location was recorded with GPS. Higher pressure heads in the river vs. the gravel subsurface indicates a downwelling (losing) condition where surface water is seeping into the subsurface. Higher pressure heads in the gravel subsurface vs. the river indicates an upwelling (gaining) condition where the subsurface water is discharging into the stream. Subsurface flow in the hyporheic zone is controlled by the differences in pressure head and may be a key factor in salmonid redds site selection (Geist and Dauble, 1998). Data was plotted on a spatial map to compare trends across the site.

28a) 

28b) 

Figure 28: 28a): Manometer board showing pressure head differences between the 30cm deep well and the in-stream baffle. The left (well) side is higher pressure than the right (baffle) side indicating upwelling conditions. 28b): In-stream baffle used during up/downwelling measurements to compare the pressure of the river to the pressure at 30cm deep in the subsurface. The baffle removes the effect of surface flow.

Chapter 3.0

Introduction

3.0 Results

Work began at the three restoration sites with the installation of piezometers in the Spring of 2013. Hyporheic information and grain size distribution data were collected to determine trends at the restoration sites that pertain to salmonid spawning habitat. During the Summer of 2013, three additional natural spawning sites were identified and studied for comparison to the restoration sites.

The Low Flow Side Channel of the Feather River flowed at a steady rate of ~600cfs until the Fall of 2012. These levels were wadeable by field crews. In Fall 2012 flows periodically increase to over 2000cfs (Figure 29) because of a fire at the Thermalito power plant. The fire at the Thermalito power plant shut down the facility and the daily influx of water had to be diverted into the Low Flow Channel. From that time onward work was limited by the higher flow in the channel. Increases in flow limited access to the sites and prohibited the completion of some monitoring tasks.

A summary of tasks that have been accomplished as of July 2013 is presented in Table 3. 31 pebble counts were completed with: 10 at Cottonwood/Hatchery Riffle, 7 at Upper Auditorium Riffle, 7 at Auditorium Riffle, and 7 at natural spawning sites near the proposed restoration areas. A total of 35 mini-piezometer wells were installed at the three proposed restoration sites. The wells were sampled in Spring and Fall of 2012 to document background conditions in the gravel. Surface water and groundwater were sampled for water quality and hyporheic pressure head measurements and gravel permeability tests were conducted at each proposed restoration site. High resolution depth, direction, and velocity maps were created for each site.

Spring 2012 through Summer 2013 Work accomplished prior to restoration

Completed:	31 pebble counts 17 bulk samples Barnard McBain Standpipe Tests Hyporheic Pressure Measurements
Installed:	35 Piezometers Installed, replaced missing piezometers
Sampled:	All sites sampled for dissolved oxygen, electrical conductivity, pH, turbidity, and temperature
Data Analysis:	Create: Site maps in GIS Pebble count and bulk sample distribution graphs Depth, direction, and velocity maps for each site dissolved oxygen and permeability results site maps Upwelling/downwelling site maps

Table 3: Summary of work completed in 2012 and 2013 on the proposed restoration sites at Cottonwood Hatchery, Upper Auditorium, and Auditorium Riffles.

Due to delays in project planning and a fire at the Thermalito Afterbay Power Plant in November of 2012, the gravel addition was postponed until 2014. An increase in flows in the side channel (Figure 29) limited access to the sites and prohibited some tasks from being completed. Table 4 summarizes tasks that will be completed after restoration. The same tasks that occurred prior to restoration will be implemented post restoration, and new tasks will be added; scour chains and tracer rocks will be used to measure gravel mobility and temperature loggers will be installed to profile the temperature gradient in the new gravels.

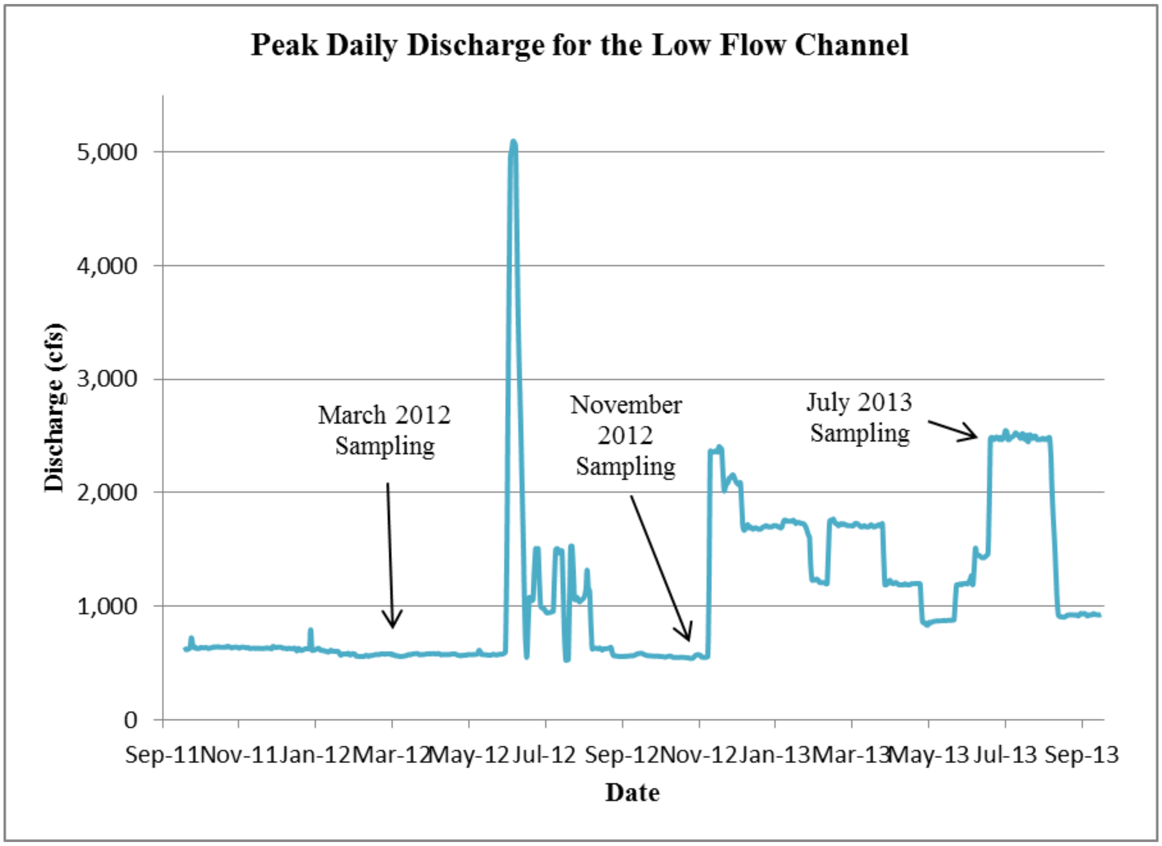


Figure 29: Hydrograph of the Low Flow Side Channel of the Feather River near Oroville, CA.

Post-restoration Work

Post Gravel Addition Work	24 pebble counts 7 bulk samples Barnard McBain standpipe tests

	Create depth, direction, and velocity maps Install 20+ piezometers Install 20 scour chains Add and track tracer rocks Install temperature loggers Create GIS maps Sample all sites

Table 4: Summary of tasks to be completed after gravel is added to the restoration sites.

3.1 Grain Size

Grain size is an important element in evaluating salmonid spawning habitat. The grains need to be small enough for the adult salmonids to manipulate during spawning and redd construction but not so fine as to block the emergence of fry or the delivery of oxygen and nutrients (Geist and Dauble, 1998). Grain size was evaluated at all three proposed restoration sites and three nearby natural spawning sites that served as control sites. The data from the grain size analysis is presented in tables (5-11) showing the d_{50}, d_{16}, d_{84}, d_{95}, and d_5 all taken from the grain size distribution graphs. The mean grain size, sorting, skewness, (Tables 1 and 2) and armoring index were calculated for each site using equations from Boggs (2006). The Boggs (2006) equations are not valid for the analysis of pebble count data because pebble counts produce a frequency distribution instead of a mass distribution.

3.1.1 Wolman Pebble Counts

Pebble counts were conducted at all three riffle complexes (Figures 30, 32, and 34). In this results section pebble count transect colors on the map correspond with colored lines on the grain size distribution graphs. The d_{50} represents the median grain size for a given transect, and d_{50} values were compared between spawning sites.

Cottonwood Hatchery Riffle Pebble Counts

Figure 30: Transect paths of the pebble counts collected at Cottonwood/Hatchery Riffle. The colored transects correspond to the colored lines on the Cottonwood Hatchery Riffle Pebble Count Distribution.

Results from pebble counts at the Cottonwood Hatchery Riffle show a narrow range of grain sizes and are plotted in Figure 31. The median grain size was -5.75 on the phi scale (5.4 cm), and grains up to -7 on the phi scale (12.8 cm) were abundant. The shape of the curves indicates a poorly sorted riverbed surface with a dominance of coarse grains >-5 phi (3.2 cm).

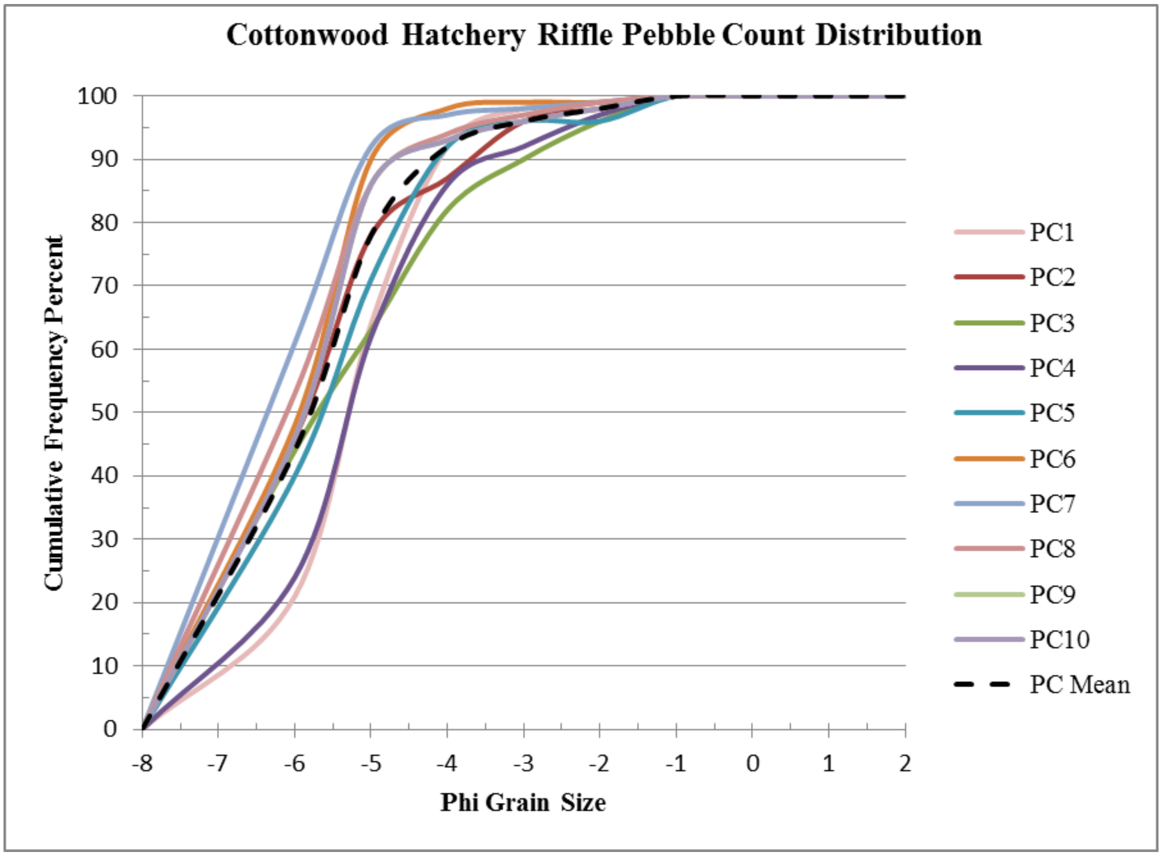


Figure 31: Pebble count distribution chart for the Cottonwood/Hatchery Riffle. Ten pebble counts were conducted in January of 2012 and their mean is shown with the blue dashed line.

Site	d_{50}	d_{16}	d_{84}	d_{95}	d_5
Cottonwood Hatchery	-5.75 (5.4 cm)	-7.25 (15.2 cm)	-4.75 (2.7 cm)	-3.50 (1.1 cm)	-7.75 (21.5 cm)

Table 5: Cottonwood Hatchery pebble count data summary taken from PC Mean in figure 31. Values are in phi scale.

Upper Auditorium Riffle Pebble Counts

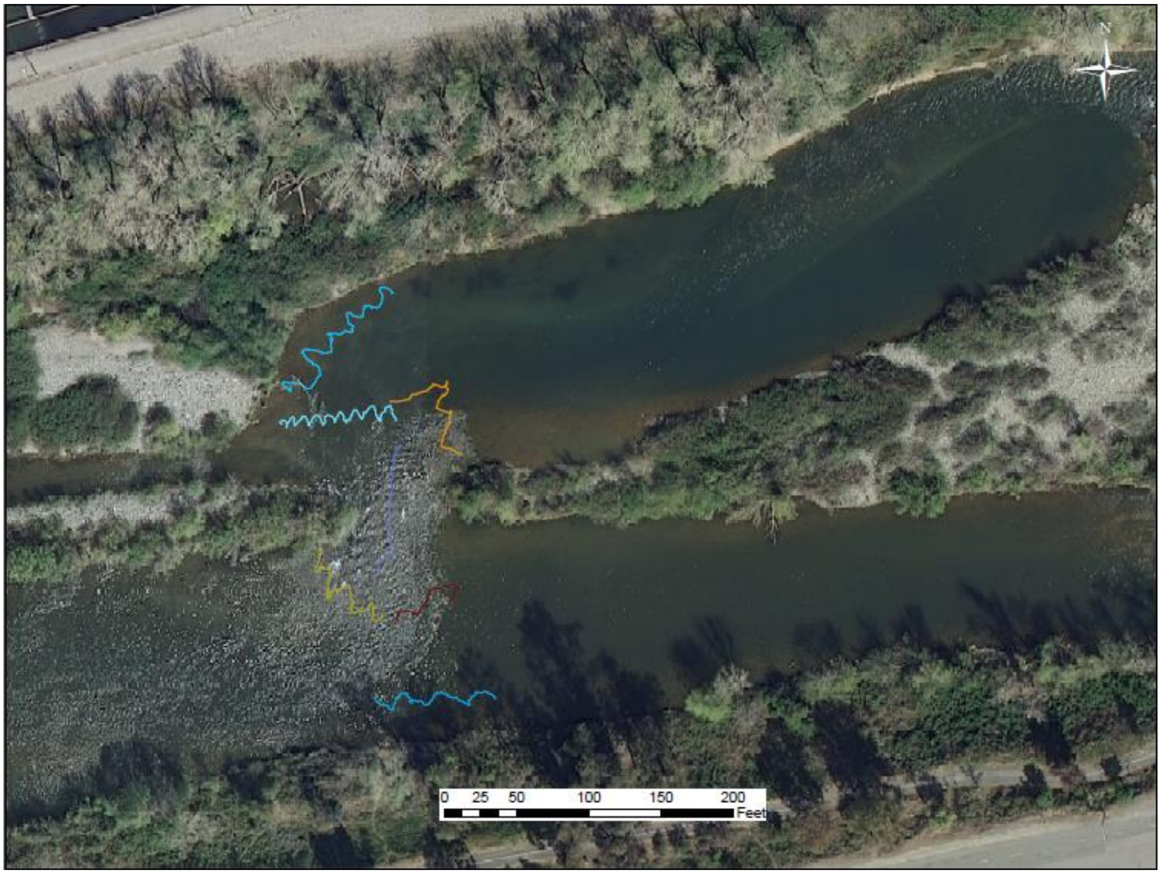


Figure 32: Transect paths of the pebble counts collected at Upper Auditorium Riffle. The colored transects correspond to the colored lines on the Upper Auditorium Riffle pebble count distribution.

Pebble counts from the Upper Auditorium Riffle show a wider range of grain sizes (Figure 33). The median grain size was -5.50 on the phi scale (4.5 cm), and many transects had excess fine material less than -3.00 on the phi scale (0.8 cm). The shape of the curves indicates that the riverbed surface is poorly sorted.

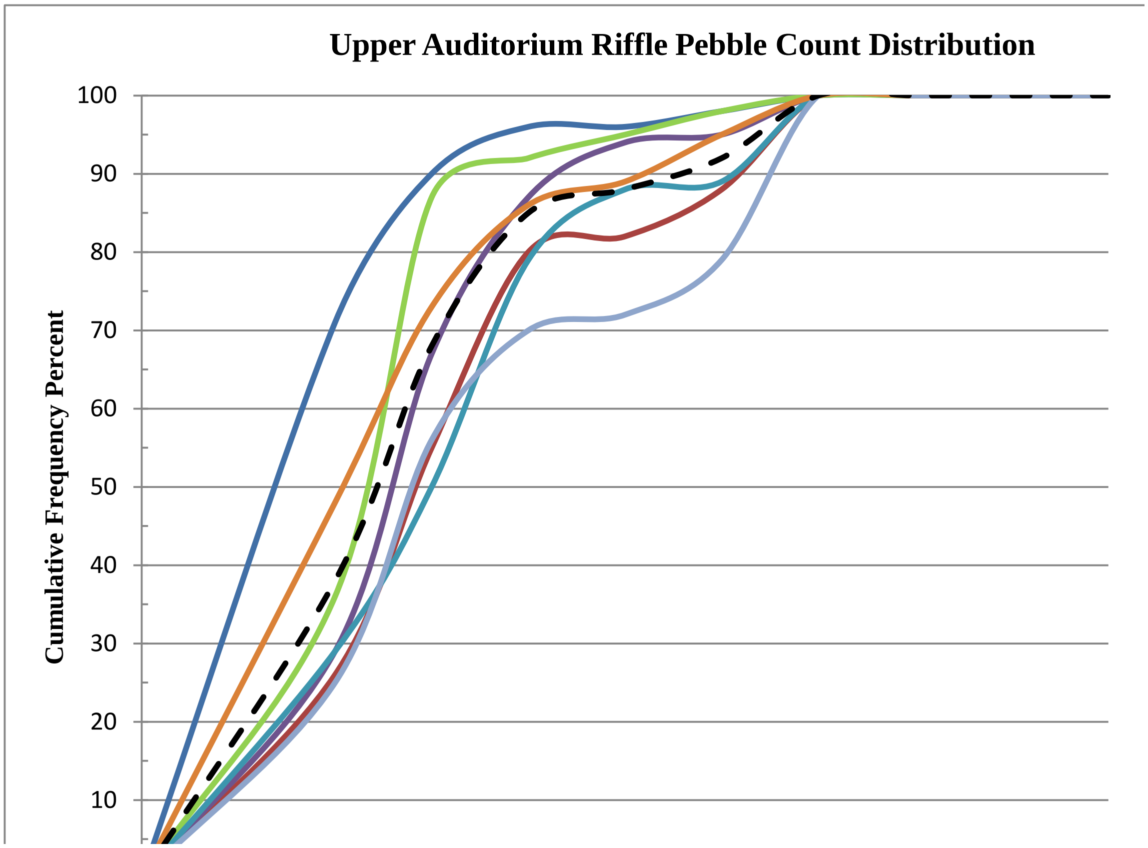


Figure 33: Pebble count distribution chart for the Upper Auditorium Riffle. Seven pebble counts were conducted in January of 2012 and their average is shown with the mauve dashed line.

Site	d_{50}	d_{16}	d_{84}	d_{95}	d_5
Upper Auditorium	-5.50 (4.5 cm)	-7.00 (12.8 cm)	-4.00 (1.6 cm)	-1.50 (0.3 cm)	-7.75 (21.5cm)

Table 6: Upper Auditorium pebble count data summary taken from PC Mean in figure 33. Values are in phi scale.

Auditorium Riffle Pebble Counts

Figure 34: Transect paths of the pebble counts collected at Auditorium Riffle. The colored transects correspond to the colored lines on the Auditorium Riffle pebble count distribution .

Pebble counts from Auditorium Riffle showed relatively consistent grain sizes (Figure 35). The median grain size of -6.00 on the phi scale (6.4cm) is coarse, and many grains larger than-5.50 on the phi scale (4.5cm) are present. The shape of the curves indicates that the riverbed surface is poorly sorted. Two transects (PC21 and PC22) showed an abundance of fine material smaller than -3 on the phi scale (0.8cm).

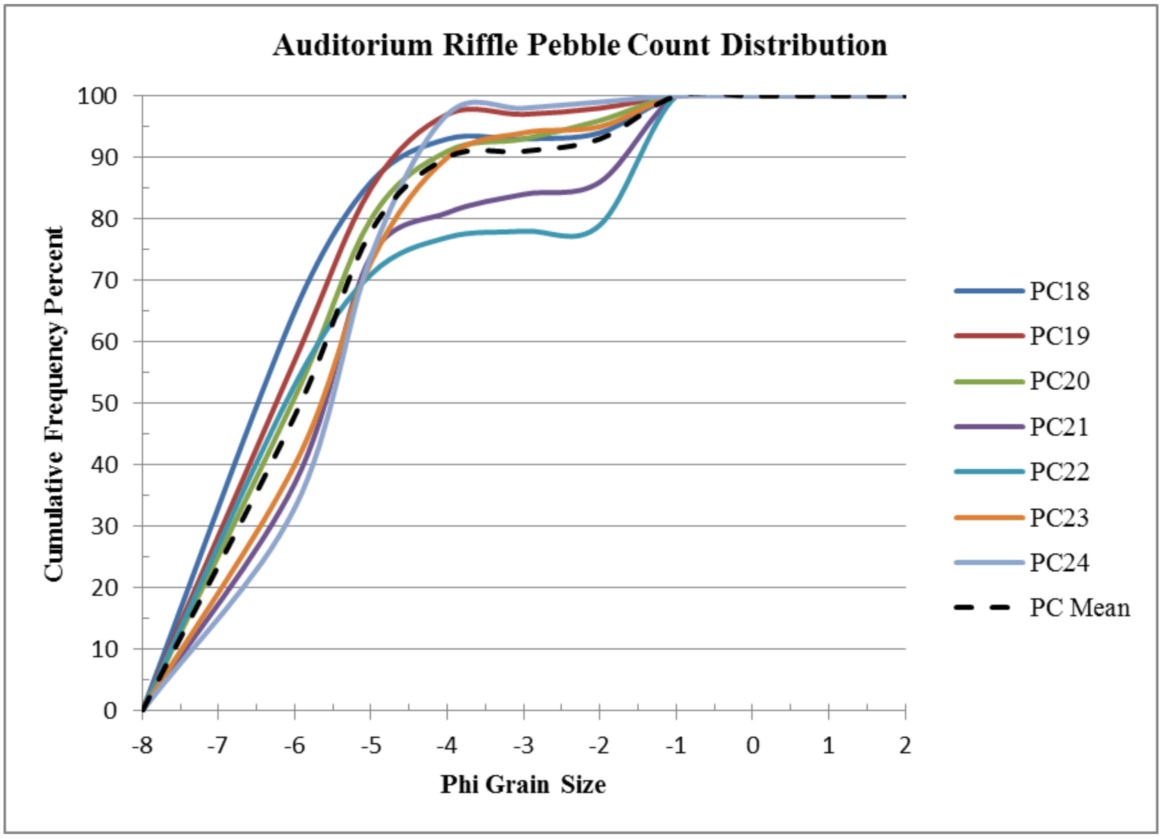


Figure 35: Pebble count distribution chart for Auditorium Riffle. Seven pebble counts were conducted in January of 2012 and their average is shown with the mauve dashed line labeled PC Mean.

Site	d_{50}	d_{16}	d_{84}	d_{95}	d_5
Auditorium	-6.00 (6.4 cm)	-7.40 (16.8 cm)	-4.75 (2.7 cm)	-2.00 (0.4 cm)	-7.75 (21.5 cm)

Table 7: Auditorium pebble count data summary from PC Mean in figure 35. Values are in phi scale.

Summary of Restoration Sites Pebble Count Data

A comparison of the median grain size of each site reveals a significant amount of similarity among the sites (Figure 36). All sites possess coarse average grain sizes in excess of -5.5 on the phi scale (4.5cm) and are all poorly sorted.

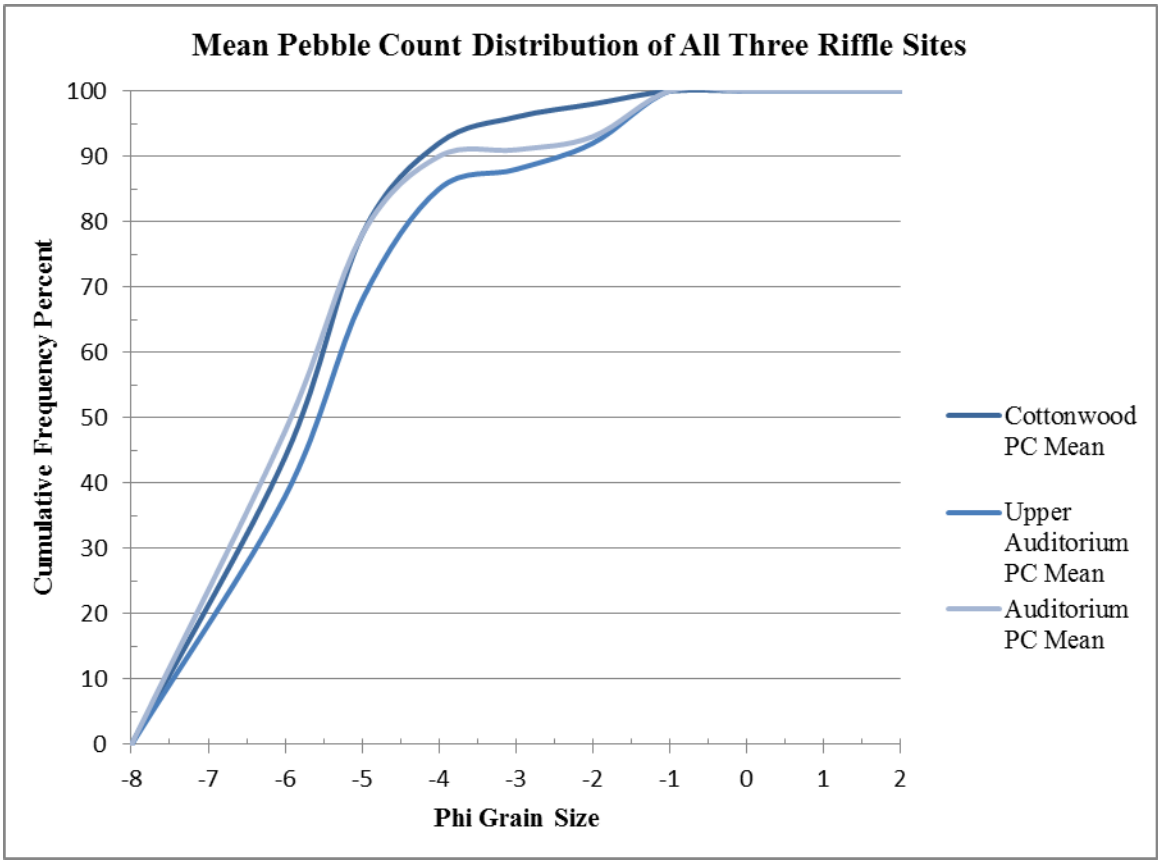


Figure 36: Pebble count distribution graph showing the mean pebble count line for each restoration site.

Site	d_{50}	d_{16}	d_{84}	d_{95}	d_5
Cottonwood Hatchery	-5.75 (5.4 cm)	-7.75 (21.5 cm)	-4.75 (2.7 cm)	-3.50 (1.1 cm)	-7.75 (21.5 cm)
Upper Auditorium	-5.50 (4.5 cm)	-7.00 (12.8 cm)	-4.00 (1.6 cm)	-1.50 (0.3 cm)	-7.75 (21.5 cm)
Auditorium	-6.00 (6.4 cm)	-7.40 (16.8 cm)	-4.75 (2.7 cm)	-2.00 (0.4 cm)	-7.75 (21.5 cm)

Table 8: Comparison pebble count of all riffle complex sites based on figure 36. Values are all in phi scale.

Natural Spawning Sites Pebble Counts

Pebble counts were also conducted at nearby high-use spawning areas. These sites are not scheduled for gravel addition, but may be useful for identifying conditions that are naturally suited for spawning. Two sites were selected for these background studies. The Upstream Site from Cottonwood Hatchery has high spawning use, and Moe’s Ditch also shows high use during the spawning season (Figure 37).

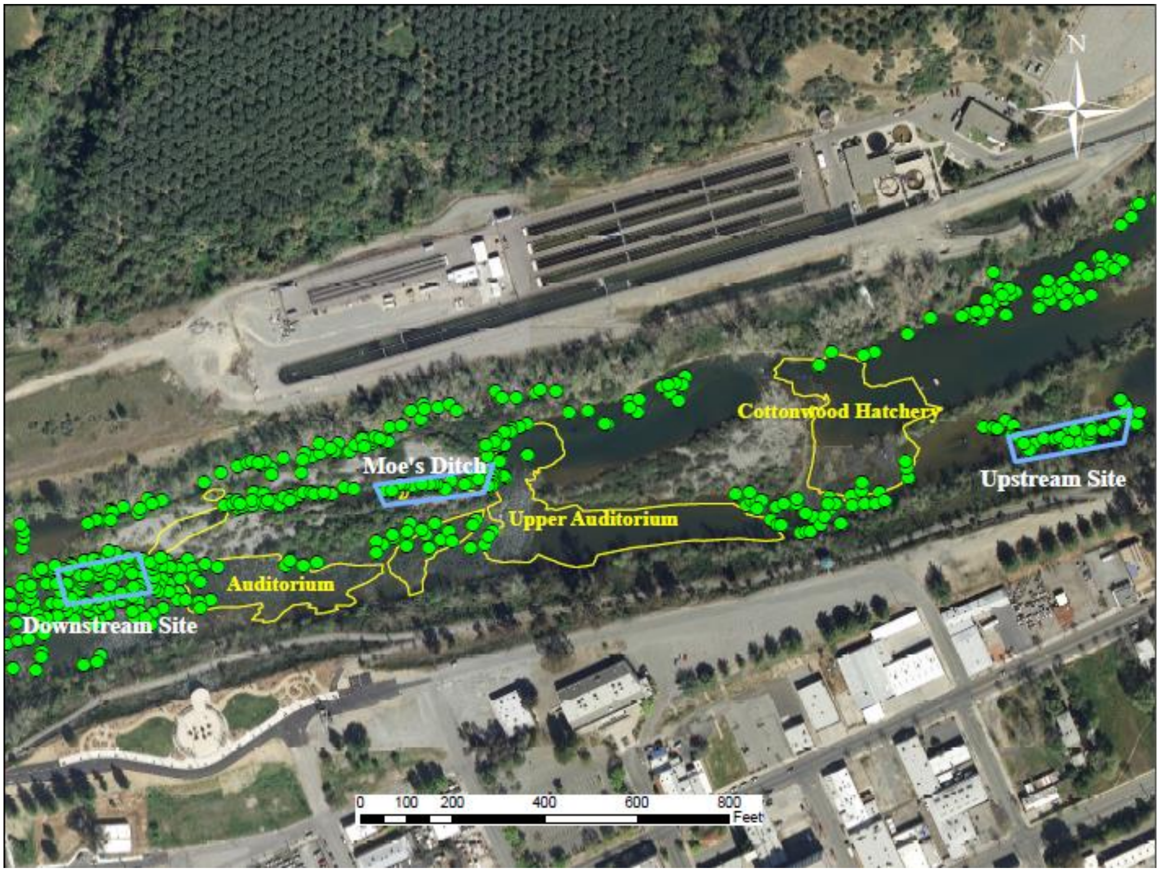


Figure 37: Site map showing the natural spawning sites (Upstream, Moe’s Ditch, and Downstream) adjacent to the proposed restoration sites. The green dots represent a salmonid redd counted in 2012.

Upstream Site Pebble Counts

Figure 38: Transect paths of the pebble counts collected at Upstream Site. The colored transects correspond to the colored lines on the Upstream Site Pebble Count Distribution graph.

Pebble counts from the Upstream Site show a uniform range of grain sizes (Figure 39). The median grain size was -5.25 on the phi scale (3.8cm) which is finer than the proposed restoration sites. The shape of the curves indicates that the riverbed surface is poorly sorted.

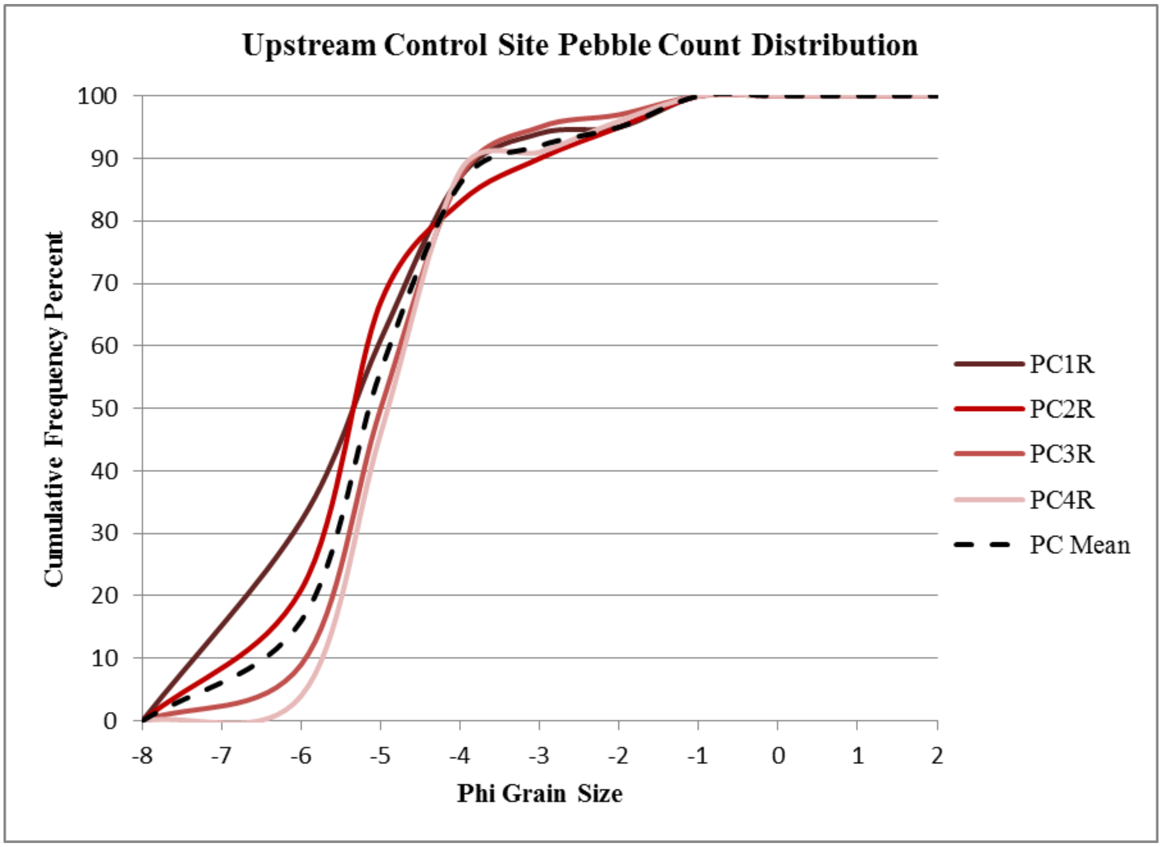


Figure 39: Pebble count distribution from the Upstream control site. Four pebble counts were conducted at this site in June of 2012.

Site	d_{50}	d_{16}	d_{84}	d_{95}	d_5
Upstream Site	-5.25 (3.8 cm)	-6.00 (6.4 cm)	-4.00 (1.6 cm)	-2.50 (0.5 cm)	-7.00 (12.8 cm)

Table 9: Upstream Site pebble count averages taken from figure 39. Values are in phi scale.

Moe's Ditch Pebble Counts

Figure 40: Transect paths of the pebble counts collected at Moe's Ditch. The colors of the transect lines corresponds to the colored lines on the Moe's Ditch pebble count distribution graph (Figure 41).

Pebble counts from the Moe's Ditch high use spawning site showed moderate range of grain sizes (Figure 41). The median grain size was -5.00 on the phi scale (3.2cm) which is finer than the proposed restoration sites. The shape of the curves shows that the riverbed surface is poorly sorted.

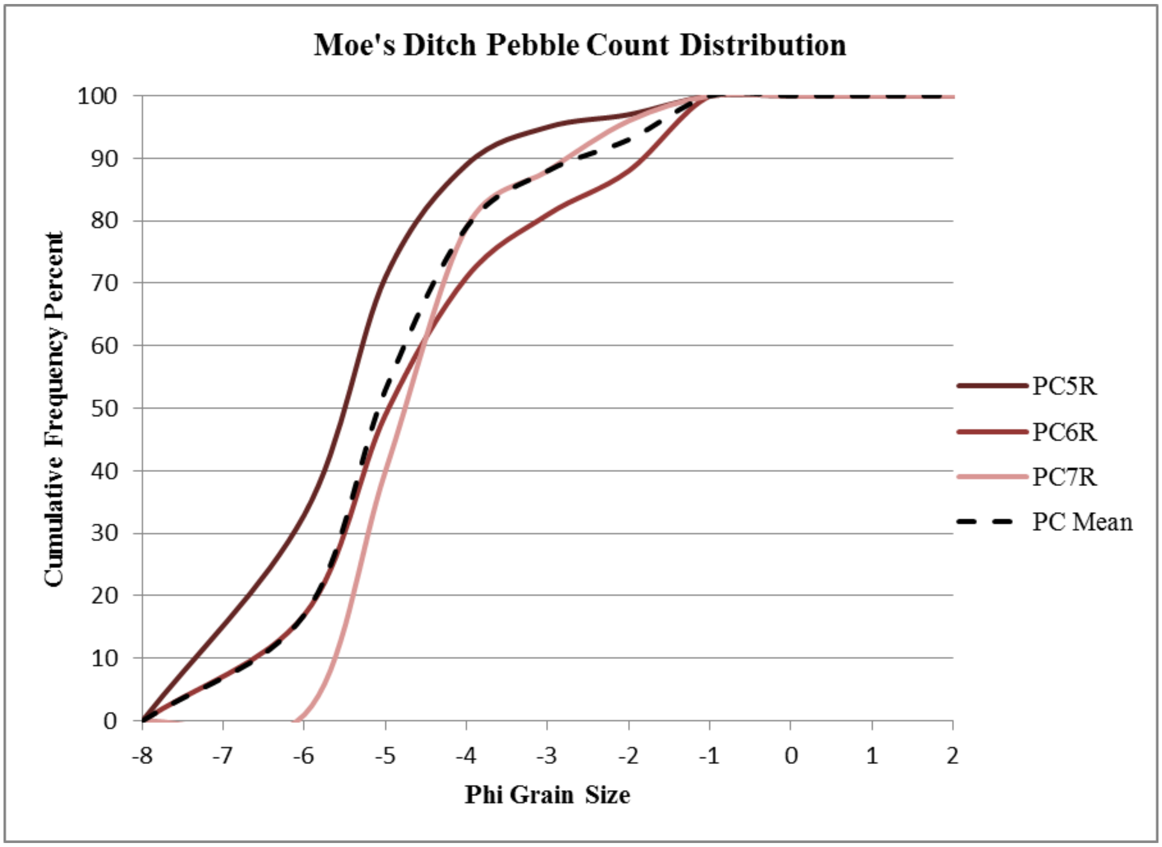


Figure 41: Pebble count distribution for Moe's Ditch. Three pebble counts were conducted in June of 2012.

Site	d_{50}	d_{16}	d_{84}	d_{95}	d_5
Moe's Ditch	-5.00 (3.2 cm)	-6.25 (7.6 cm)	-3.50 (1.1 cm)	-2.00 (0.4 cm)	-7.25 (15.2 cm)

Table 10: Moe's Ditch pebble count averages taken from figure 41. Values are in phi scale.

Pebble Count Data Comparison

Figure 42 shows the mean pebble count distributions for the three restoration sites in blue and the natural high use spawning sites in red. The restoration sites had an average grain size of -5.5 to -6.1 on the phi scale (4.5cm -6.9cm) and the natural spawning site had an average grain size of -5.1 on the phi scale (3.4cm) (Table 11). The commonality among all sites is that they are poorly sorted riverbed gravels.

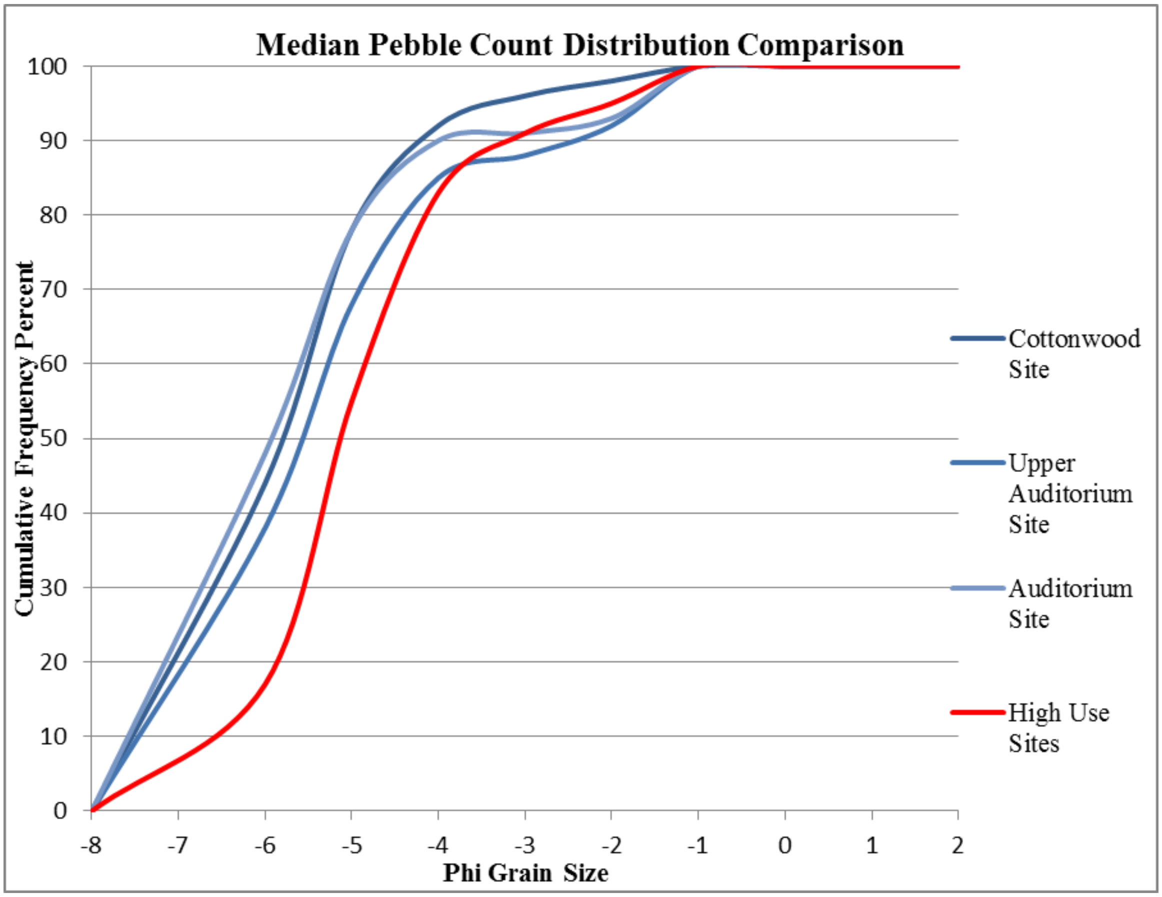


Figure 42: Pebble count distribution comparison of the means of all three restoration sites and the mean of the natural spawning site.

Site	Mean d_{50}	Sorting
Cottonwood Hatchery	-5.9 (5.9 cm)	Poorly sorted
Upper Auditorium	-5.5 (4.5 cm)	Poorly sorted
Auditorium	-6.1 (6.8 cm)	Poorly sorted
Natural Spawning Sites	-5.1 (3.4 cm)	Poorly sorted

Table 11: Comparison of the means of all three restoration sites and the mean of the natural spawning site taken from figure 43.

3.1.2 Bulk Samples

Bulk samples were collected from three sites in the Cottonwood Hatchery riffle complex (Figure 43), 2 sites in Upper Auditorium Riffle (Figure 45), and two sites in Auditorium Riffle (Figure 47). The samples were segregated into surface and subsurface fractions and plotted on a cumulative weight percent versus phi size graph. Additional bulk samples were collected from high use spawning areas Upstream control site (Figure 49), in Moe's Ditch (Figure 51), and downstream from Auditorium Riffle (Figure 53). Subsurface samples were not collected from the spawning sites due to high flows and limited access. All quantitative data were taken from the grain size distribution plots.

Cottonwood Hatchery Bulk Sample Data

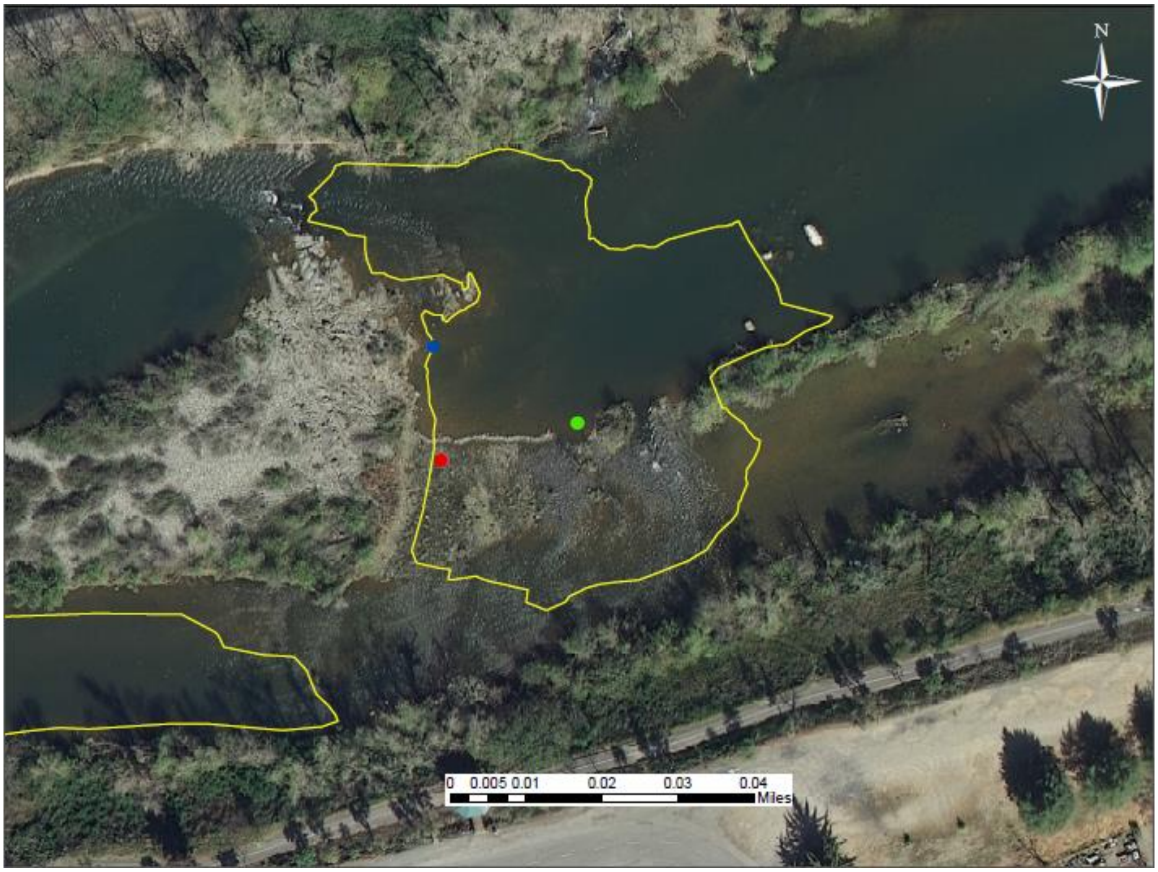


Figure 43: Bulk sample locations for Cottonwood Hatchery Riffle. The colored dots correspond to the colored lines on the bulk sample totals from the Cottonwood Hatchery Riffle graph (Figure 44). Three bulk samples were conducted during the Summer of 2012.

Bulk sample results for the Cottonwood Hatchery Riffle are compiled in Figure 44. This Figure shows surface samples as solid lines and the dash lines for subsurface samples. The surface and subsurface samples were similar in size. The average grain size for the surface was -6.60 on the phi scale (9.7cm) and the subsurface was -5.10 on the phi scale (3.4cm) (Table 13). The surface samples were negatively (coarse) skewed, meaning that there was excess fine material. The subsurface samples were nearly symmetrical, indicating no skewness toward coarse or fine material was present. The surface was classified as moderately sorted and the subsurface was poorly sorted with an armoring index of 1.3 (Table 13). Bulk samples from Cottonwood Hatchery Riffle show an armored river bed (armoring index = >1.0) and excess coarse material (mean grain size= -6.60 phi).

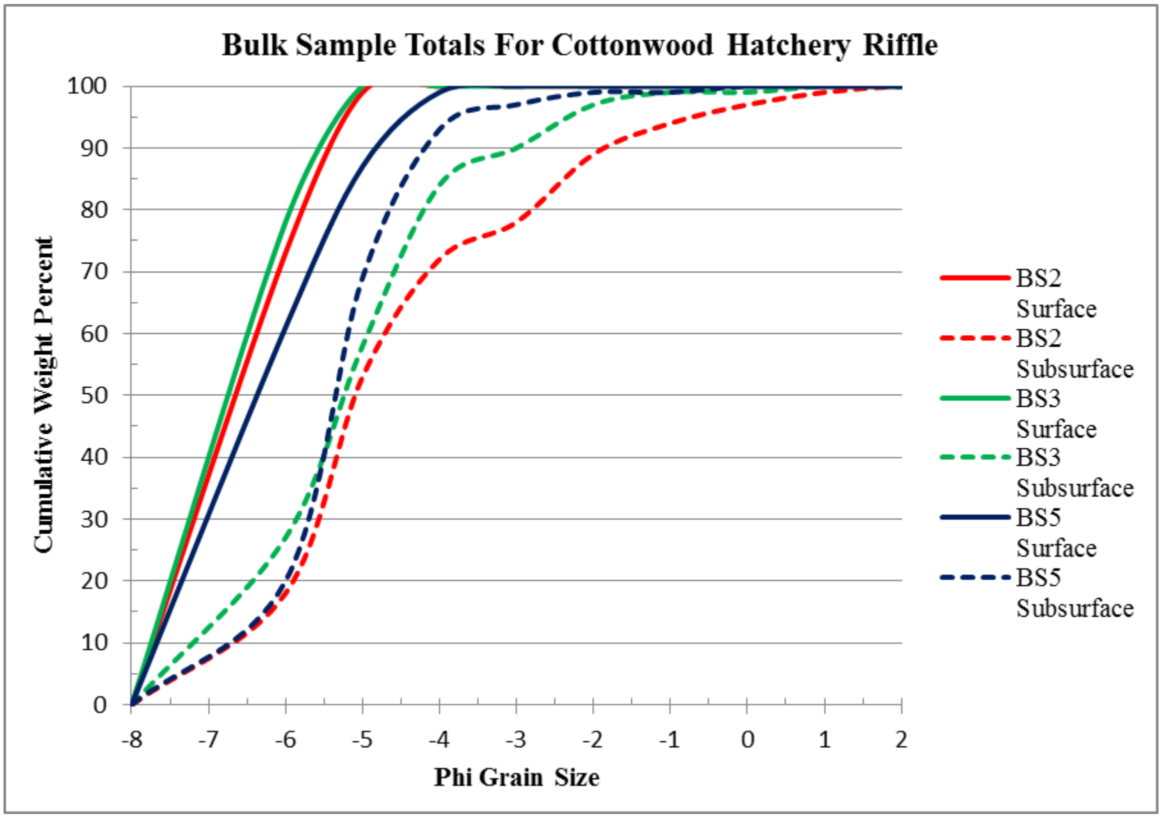


Figure 44: Bulk sample distribution chart for Cottonwood/Hatchery Riffle. Three bulk samples were conducted at the riffle complex and were separated into surface and subsurface sample sizes. The colored lines correspond to the colored dots on Figure 44.

Cottonwood Hatchery	d_{50}	d_{16}	d_{84}	d_{95}	d_5
Surface	-6.50 (9.1 cm)	-7.50 (18.1 cm)	-5.75 (5.4 cm)	-5.50 4.5 cm)	-7.80 (22.2 cm)
Subsurface	-5.00 (3.2 cm)	-6.50 (9.1 cm)	-3.75 (1.3 cm)	-2.50 (0.5 cm)	-7.50 (18.1 cm)

Table 12: Comparison table of the averages for the surface and subsurface samples at Cottonwood Hatchery Riffle taken from Figure 44.

The d_{50}, d_{16}, d_{84}, d_{95}, d_5 were taken from the bulk sample size distribution graphs and used in equations 1-4 to determine mean grain size, sorting, skewness, and an armoring index for the site. Cottonwood/Hatchery Riffle bulk sample surface calculations are shown to illustrate the calculations:

Mean grain size $$\frac{d16+d50+d84}{3} = Mz$$ equation 1

$$\frac{-7.50+(-6.50)+(-5.75)}{3} = Mz$$

-6.60 = *Mz*

Sorting $$\frac{d84-d16}{4} + \frac{d95-d5}{6.6} = S$$ equation 2

$$\frac{-5.75-(-7.50)}{4} + \frac{-5.50-(-7.80)}{6.6} = S$$

0.79 = *S*

Skewness $$\frac{d84+d16-2d50}{2(d84-d16)} + \frac{d95+d5-2d50}{2(d95-d5)} = Sk$$ equation 3

$$\frac{-5.75+(-7.50)-2(-6.50)}{2(-5.75-(-7.50))} + \frac{-5.50+(-7.80)-2(-6.50)}{2(-5.50-(-7.80))} = Sk$$

-0.14 = *Sk*

Armoring index $$\frac{d50surf}{d50sub} = Ai$$ equation 4

$$-\frac{6.60}{-5.10} = Ai$$

$1.30 = Ai$

Cottonwood Hatchery	Mean Grain Size	Sorting	Armoring Index	Skewness
Surface	-6.60 (9.7 cm)	0.79 Moderately sorted	1.30	-0.14 Negatively skewed
Subsurface	-5.10 (3.4 cm)	1.45 Poorly sorted		-0.05 Near symmetrical

Table 13: Calculated average of values from the three Cottonwood/Hatchery Riffle bulk samples from Table 12.

Upper Auditorium Riffle Bulk Sample Data

Figure 45: Bulk sample locations for Upper Auditorium Riffle. The colored dots correspond to the colored lines of the bulk sample distribution graphs (Figure 46). Two bulk samples were conducted during the Summer of 2012.

The bulk samples collected at Upper Auditorium Riffle were very distinct from one another. The BS4 (blue dot) sample is located directly above a riffle in shallow (< 2ft deep) swift moving water and the BS1 (red dot) sample is located in a pool of slack water upstream from the riffle.

Bulk sample results for Upper Auditorium Riffle are compiled in Figure 46. The average grain size for the surface sample BS4 was -6.80 on the phi scale (11.1cm) and the subsurface sample was -4.5 on the phi scale (2.2 cm) (Table 15). The surface and subsurface were strongly fine (positive) skewed meaning the grains are skewed toward coarse material. The surface is moderately sorted, the subsurface is very poorly sorted, and the armoring index is 1.5 (Table 15). The BS4 (blue line) samples had an armoring index of 1.51. The bulk samples from the Upper Auditorium Riffle sample BS1 (red line) are compiled in figure 46, and show a solid line for the surface sample and the dash line for subsurface sample. The calculated mean grain size for the surface was -4.35 on the phi scale (2.0 cm) and the subsurface was -4.10 on the phi scale (1.7 cm) (Table 15). The surface is strongly positively skewed (indicating an abundance of coarse material) and the subsurface is positively skewed. The surface and subsurface are both very poorly sorted with an armoring index of 1.06 (Table 15). The BS1 sample shows a slightly armored river bed (>1.0) with similar grain sizes (Mean Grain Size= -4.35 and -4.10 phi, 2.0 cm and 1.7 cm).

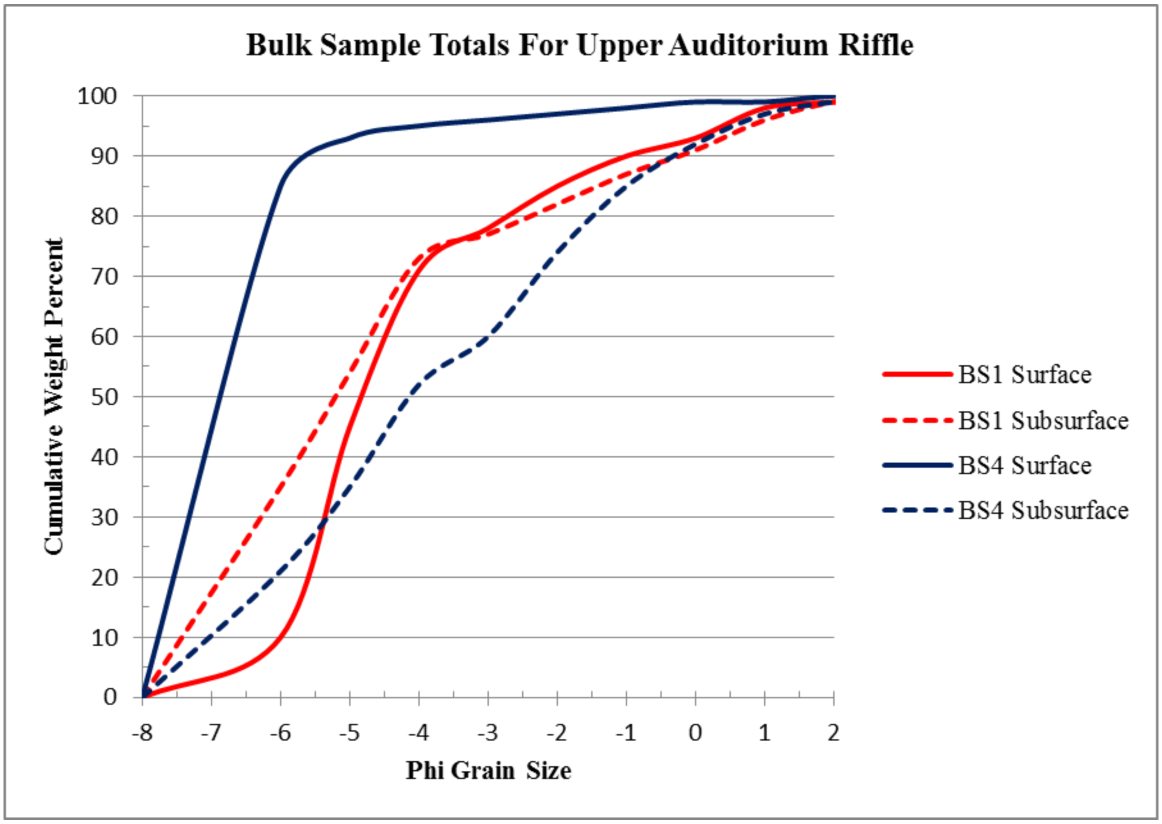


Figure 46: Bulk sample distribution chart for the Upper Auditorium Riffle Complex. Two bulk samples were collected at the riffle complex and are separated into surface and subsurface sample sizes.

Upper Auditorium	d_{50}	d_{16}	d_{84}	d_{95}	d_5
BS4 Surface	-7.00 (12.8 cm)	-7.50 (18.1 cm)	-6.00 (6.4 cm)	-4.00 (1.6 cm)	-7.80 (22.2 cm)
BS4 Subsurface	-5.50 (4.5 cm)	-6.50 (9.0 cm)	-1.50 (0.3 cm)	0.50 (0.07 cm)	-7.50 (18.1 cm)
BS1 Surface	-5.00 (3.2 cm)	-5.75 (5.4 cm)	-2.00 (0.4 cm)	0.50 (0.07 cm)	-6.50 (7.6 cm)
BS1 Subsurface	-4.25 (1.9 cm)	-7.00 (12.8)	-1.00 (0.2 cm)	0.50 (0.07 cm)	-7.50 (18.1 cm)

Table 14: Comparison table of the Upper Auditorium results from the surface and subsurface samples taken from figure 46.

Upper Auditorium	Mean Grain Size	Sorting	Armoring Index	Skewness
BS4 Surface	-6.80 (11.1 cm)	0.95 Moderately Sorted	1.51	0.46 Strongly Positively

				Skewed
BS4 Subsurface	-4.50 (2.2 cm)	2.50 Very Poorly Sorted		0.53 Strongly Positively Skewed
BS1 Surface	-4.35 (2.0 cm)	2.00 Very Poorly Sorted	1.06	0.59 Strongly Positively Skewed
BS1 Subsurface	-4.10 (1.7 cm)	2.71 Very Poorly Sorted		0.14 Positively Skewed

Table 15: Comparison table of calculated results from the Upper Auditorium bulk sample taken from Table 14.

Auditorium Riffle Bulk Sample Data

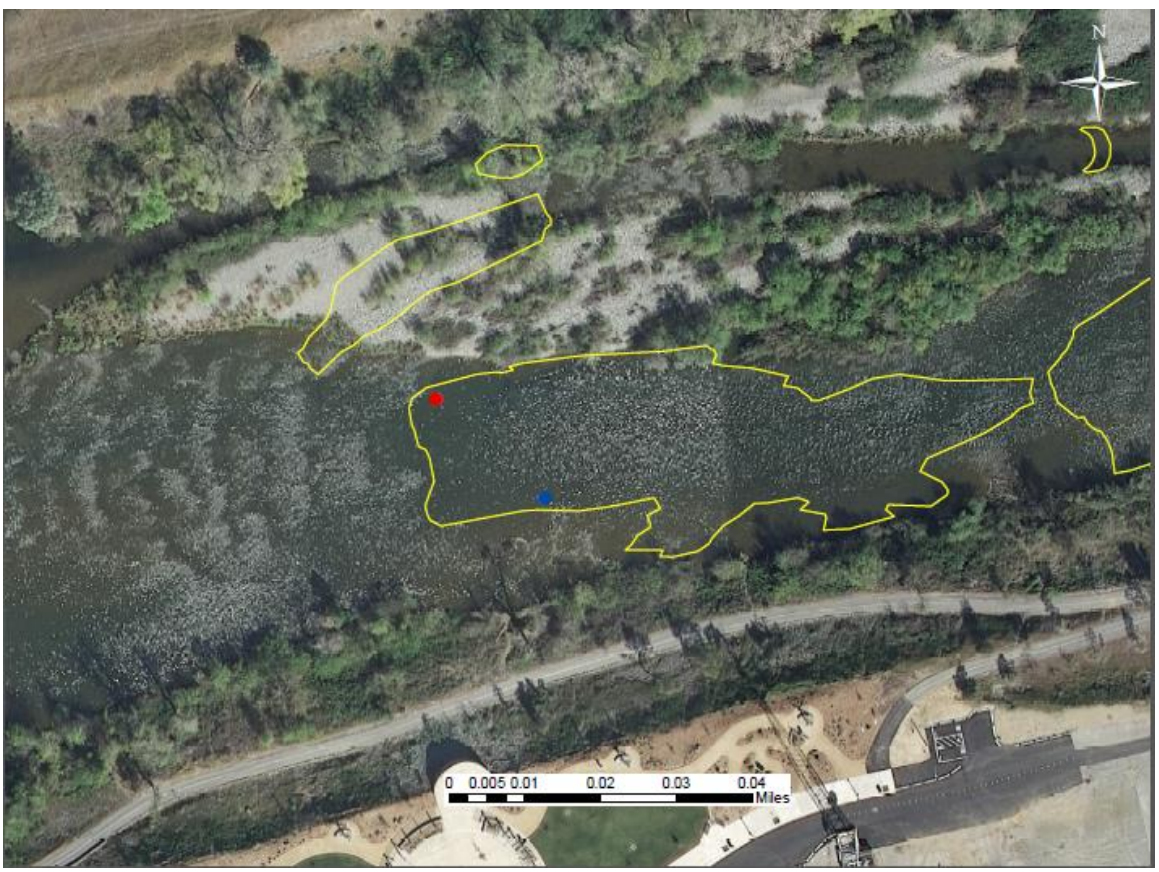


Figure 47: Bulk sample locations for the Auditorium Riffle. The colored dots correspond to the colored lines of the bulk sample graphs (Figure 48). Two bulk samples were conducted in the Summer of 2012.

Bulk sample results for the Auditorium Riffle were compiled in Figure 48 showing the solid line surface samples and the dash line subsurface samples. The surface and subsurface plots were similar to one another. The average grain size for the surface was -6.40 on the phi scale (8.4 cm) and the subsurface was -4.80 on the phi scale (2.7 cm) (Table 17). The surface and subsurface were strongly positively skewed indicating an abundance of coarse material. The surface was classified as poorly sorted and the subsurface was very poorly sorted with an armoring index of 1.33 (Table 17). The samples from Auditorium Riffle show an armored river bed (>1.0) with excess coarse surface material (mean grain size= -6.40 phi, 8.4 cm) and a large amount of fine material (< 2.0 phi) present in the subsurface.

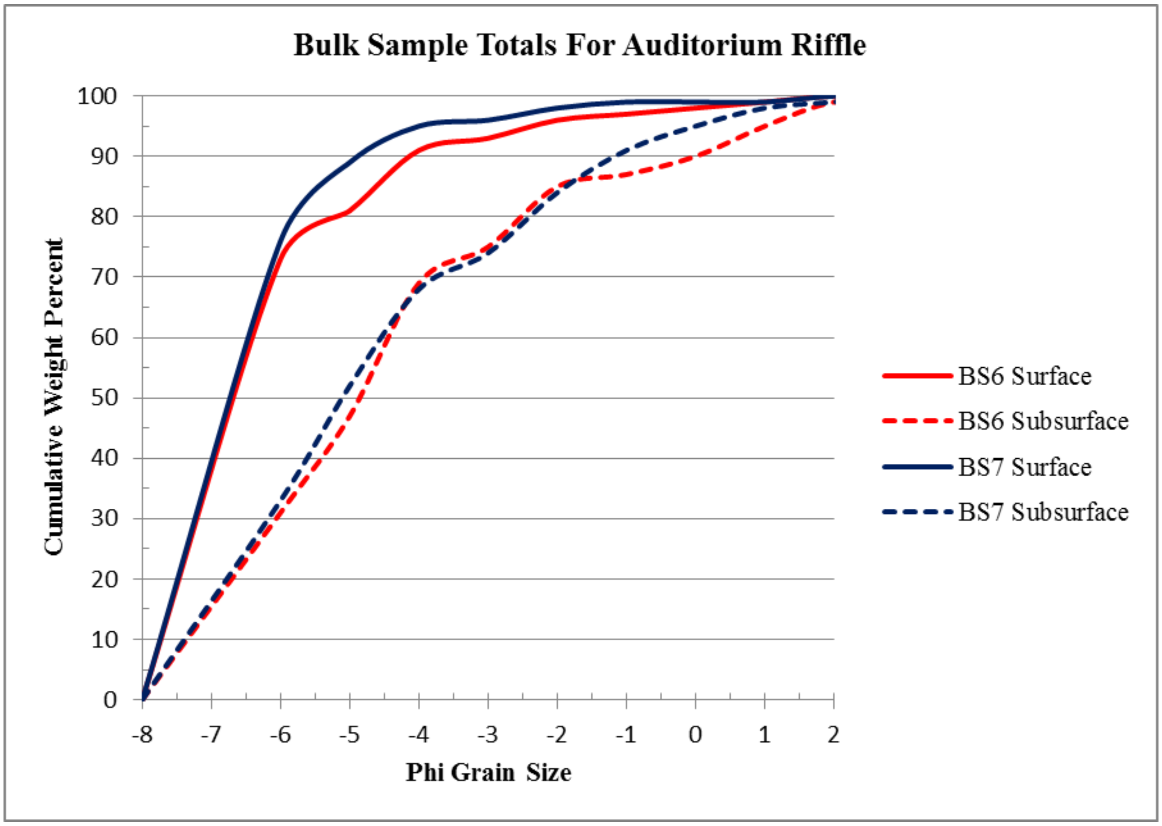


Figure 48: Bulk sample distribution chart for the Auditorium Riffle. Two bulk samples were conducted at the riffle complex and are separated into surface and subsurface sample sizes.

Auditorium	d_{50}	d_{16}	d_{84}	d_{95}	d_5
Surface	-6.75 (10.7 cm)	-7.50 (18.1 cm)	-5.00 (3.2 cm)	-2.50 (0.5 cm)	-7.80 (22.2 cm)
Subsurface	-5.25 (3.8 cm)	-7.00 (12.8 cm)	-2.00 (0.4 cm)	0.50 (0.07 cm)	-7.50 (18.1 cm)

Table 16: Comparison table of the averages for the surface and subsurface samples at Auditorium Riffle taken from Figure 48.

Auditorium	Mean Grain Size	Sorting	Armoring Index	Skewness
Surface	-6.40 (8.4 cm)	1.84 Poorly Sorted	1.33	0.50 Strongly Positively Skewed
Subsurface	-4.80 (2.7 cm)	2.46 Very Poorly Sorted		0.37 Strongly Positively Skewed

Table 17: Calculated results average for the two Auditorium Riffle bulk samples taken from Table 16.

Natural Spawning Control Sites Bulk Sample Data

Bulk samples were collected from three high-use natural spawning areas. These sites were used to determine grain size conditions in areas that fish selectively choose for spawning, and may be used as a guideline for restoration projects. A subsurface sample was not collected and an armoring index was not calculated.

Upstream Site Bulk Sample Data

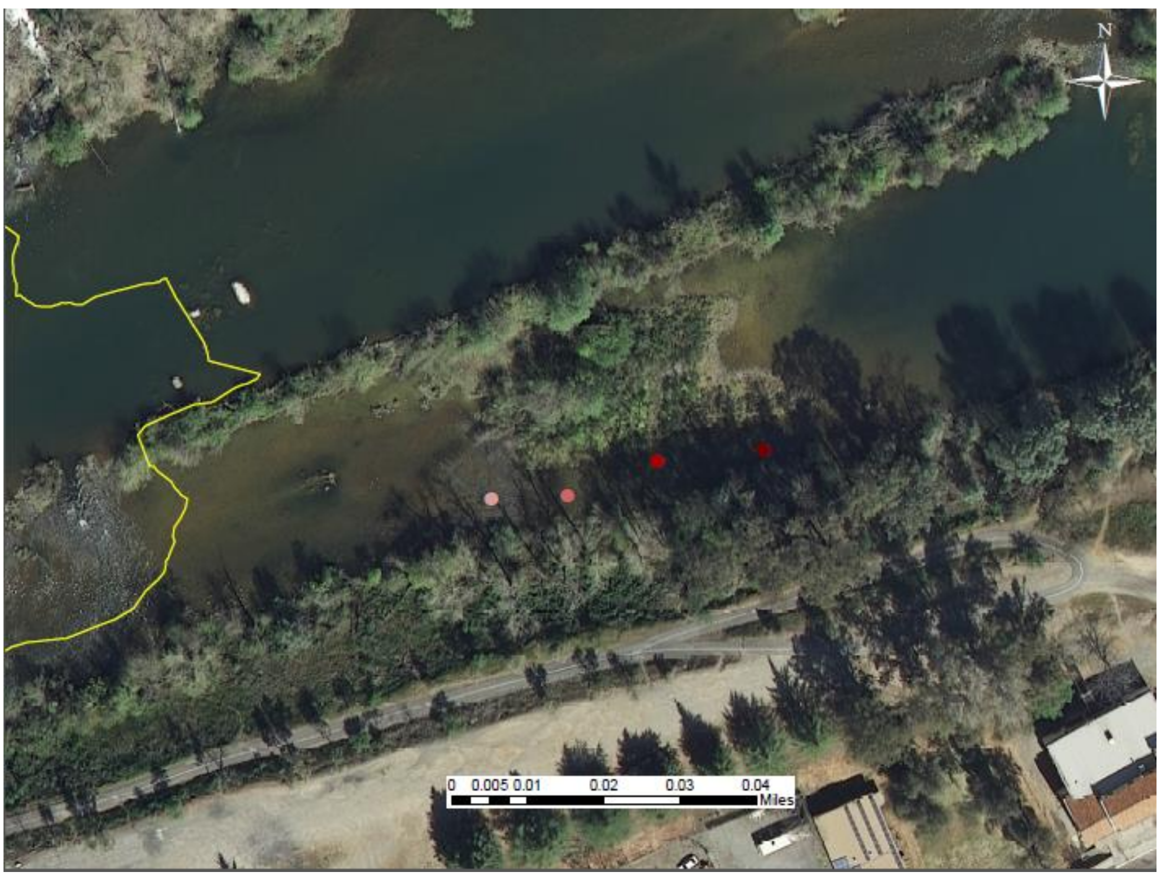


Figure 49: Bulk sample locations for the Upstream Site. The colored dots correspond to the colored lines of the bulk sample distribution graphs (figure 50).

Bulk sample results from the Upstream Site show a uniform range of grain sizes (Figure 50). The mean grain size was -4.75 on the phi scale (2.7cm), which is finer than the restoration sites, and an abundance of fine material present. The sample was strongly positively skewed, indicating an abundance of coarse material, and was poorly sorted (Table 19).

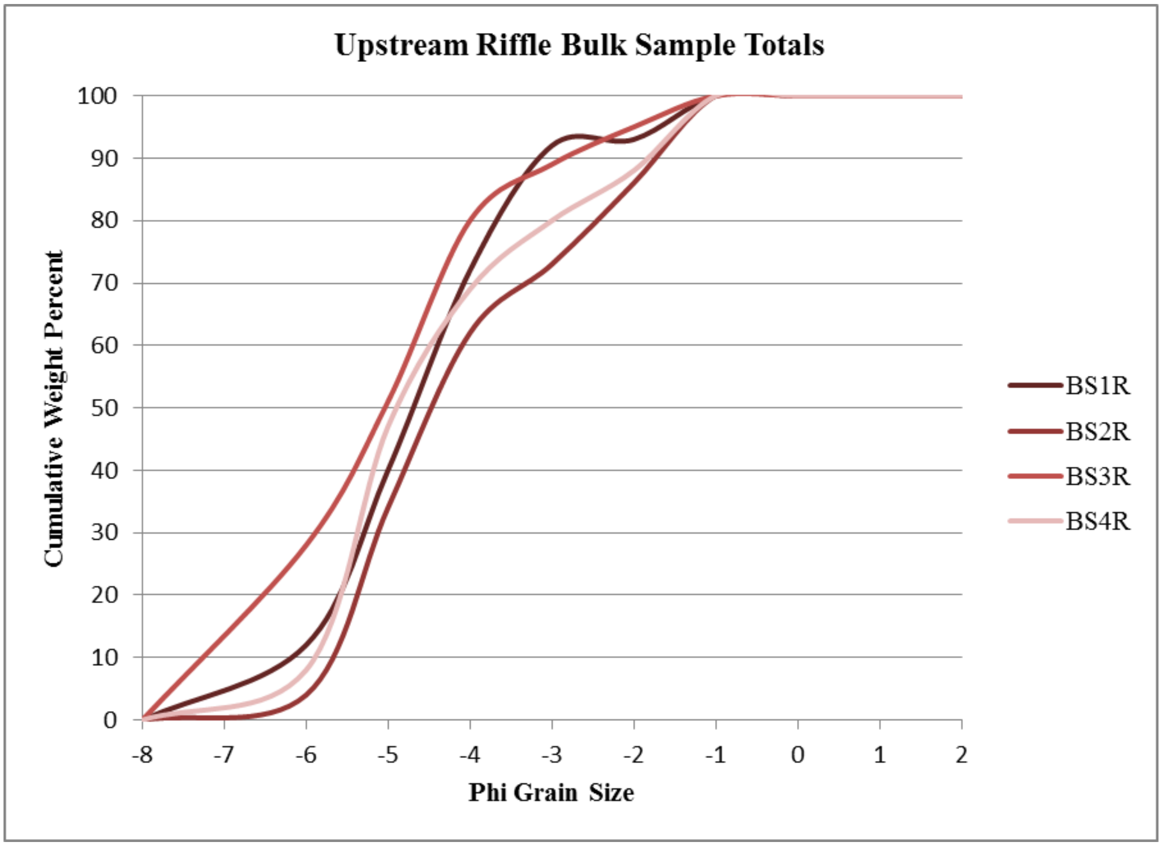


Figure 50: Bulk sample distribution graph of the Upstream Site. Four bulk samples were conducted the Summer of 2012.

Upstream Site	d_{50}	d_{16}	d_{84}	d_{95}	d_5
	-5.00 (3.2 cm)	-6.00 (6.4cm)	-2.50 (0.5 cm)	-1.50 (0.3 cm)	-7.00 (12.8 cm)

Table 18: Comparison table of the averages for the surface and subsurface samples at Upstream control site taken from Figure 50.

Upstream Site	Mean Grain Size	Sorting	Skewness

	-4.50 (2.2 cm)	1.71 Poorly sorted	0.35 Strongly Positively skewed

Table 19: Calculated results average from Upstream control site bulk samples taken from Table 18

Moe's Ditch Bulk Sample Data

Figure 51: Bulk sample locations for Moe's Ditch. The colored dots correspond to the colored lines on the bulk sample distribution graphs (Figure 52).

Bulk sample results from Moe's Ditch show a wide range of grain sizes (Figure 52). The mean grain size was -5.0 on the phi scale (3.2 cm) which is less coarse than the restoration sites with an abundance of fine material present. The sample was strongly finely skewed, indicating an abundance of coarse material, and was poorly sorted (Table 21).

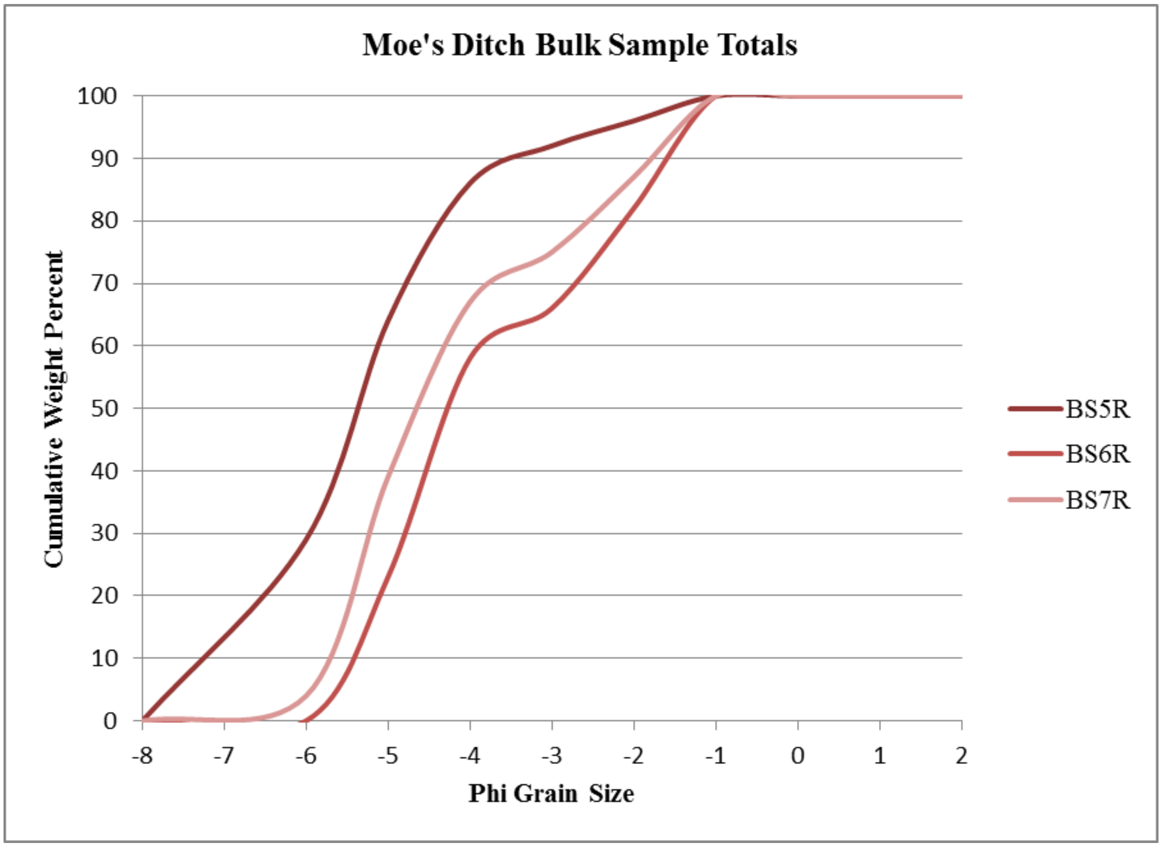


Figure 52: Graph of bulk samples from Moe's Ditch.

Moe's Ditch	d_{50}	d_{16}	d_{84}	d_{95}	d_5
	-5.00 (3.2 cm)	-5.75 (5.4 cm)	-2.25 (0.45 cm)	-1.50 (0.3 cm)	-6.75 (10.7 cm)

Table 20: Comparison table of the averages for the surface and subsurface samples at Moe's ditch taken from Figure 52.

Moe's Ditch	Mean Grain Size	Sorting	Skewness
	-4.33 (2.0 cm)	1.67 Poorly sorted	0.45 Strongly Positively skewed

Table 21: Calculated results average from Moe's Ditch samples taken from Table 20

Downstream Site Bulk Sample Data

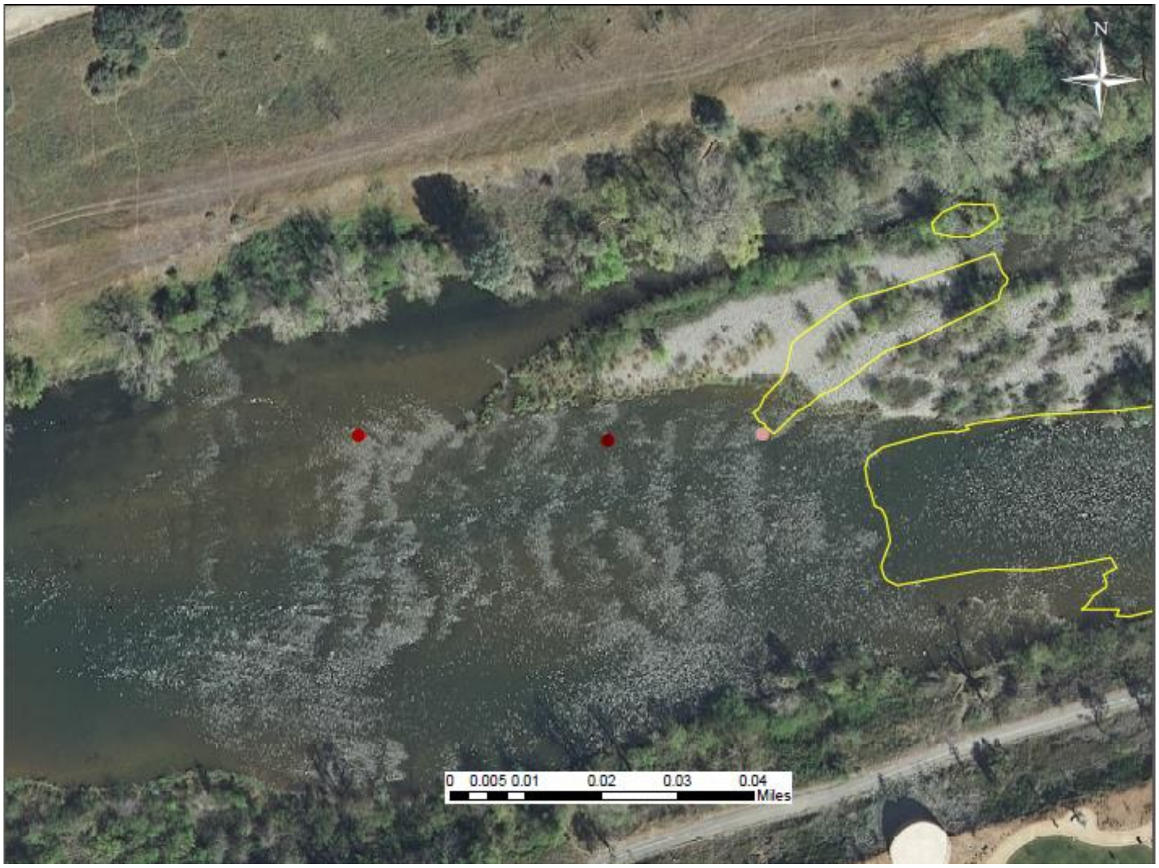


Figure 53: Bulk sample locations for the Downstream Site. The colored dots correspond to the colored lines on the bulk sample distribution graph (Figure 54).

Bulk sample data from the Downstream Site show a uniform range of grain sizes (Figure 54). The mean grain size was -4.5 on the phi scale (2.3cm) which is less coarse than the restoration sites with an abundance of fine material present. The sample was strongly finely skewed, indicating an abundance of coarse material, and was poorly sorted (Table 23).

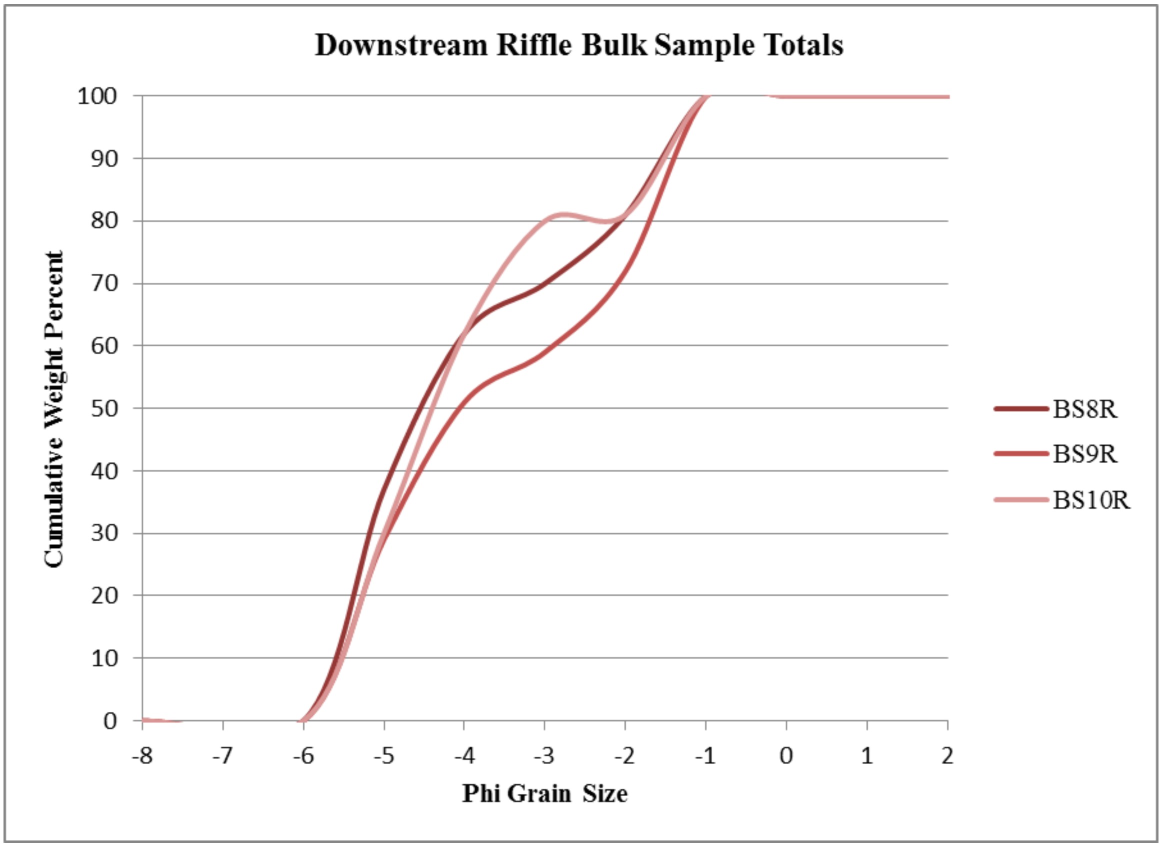


Figure 54: Graph of bulk sample distribution of Downstream Site.

Downstream Site	d_{50}	d_{16}	d_{84}	d_{95}	d_5
	-4.50 (2.2 cm)	-5.50 (4.5cm)	-1.80 (0.34 cm)	-1.40 (0.26 cm)	-5.75 (5.4 cm)

Table 22: Comparison table of the averages for the surface and subsurface samples at Downstream control site taken from Figure 54.

Downstream Site	Mean Grain Size	Sorting	Skewness
	-3.93 (1.5 cm)	1.58 Poorly sorted	0.44 Strongly Positively skewed

Table 23: Calculated results average from Downstream control site taken from Table 22.

Bulk Sample Results Comparison

The surface bulk sample results from all three restoration sites and the three spawning sites were compiled in Figure 55. The natural spawning sites (red lines) show a finer grain size distribution than the restoration sites (blue lines). The natural spawning control sites are consistently finer than the restoration sites. The average grain size for the natural spawning site is -4.1 phi compared with a range of -4.5 to -5.1 phi for the restoration sites (Table 24).

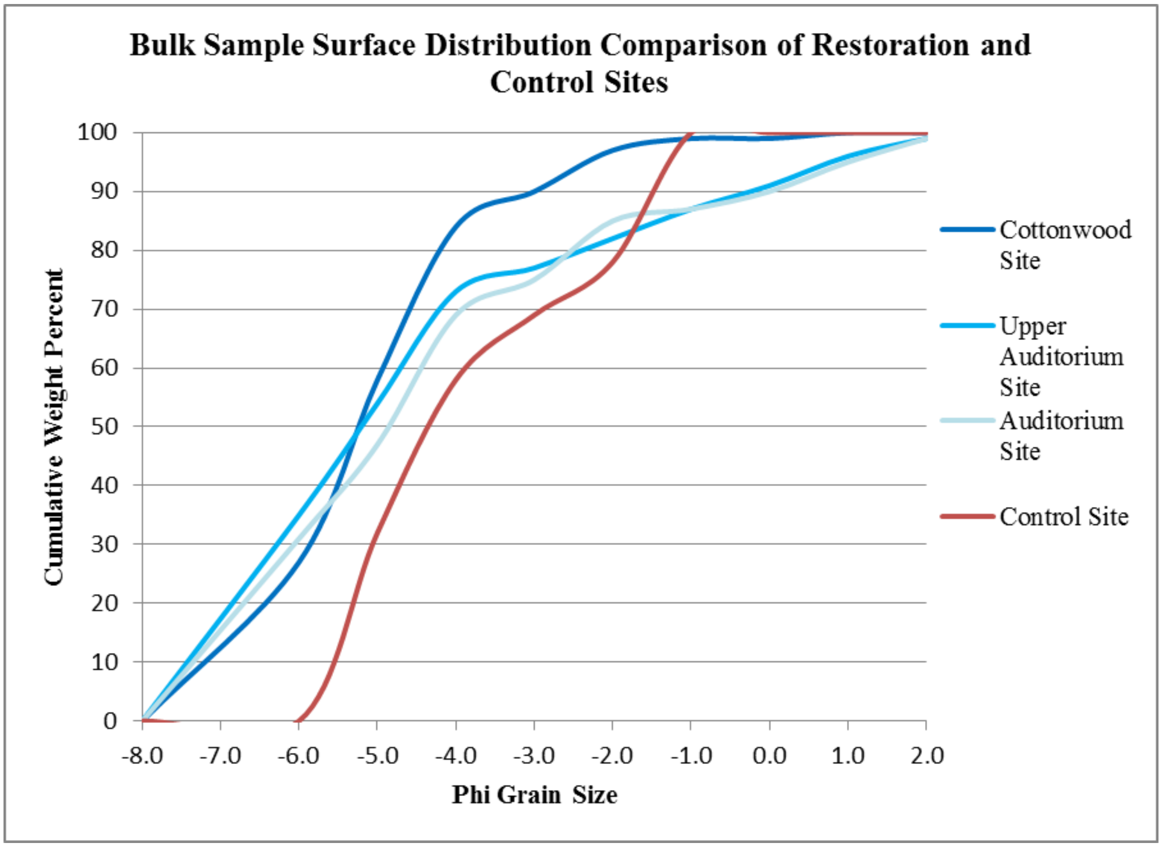


Figure 55: Comparison graph of the mean surface bulk sample data from all sites studied.

Site	Mean Grain Size	Sorting	Skewness
Cottonwood Hatchery	-6.60 (9.7 cm)	Poorly sorted	Near Symmetrical
Upper Auditorium	-4.38 (2.1 cm) and -6.80 (11.1 cm)	Very poorly sorted	Positive Skewed
Auditorium	-6.40 (8.4 cm)	Very poorly sorted	Strongly Positively

			Skewed
Natural Spawning Sites	-3.93 (1.5 cm) to -4.50 (2.2 cm)	Poorly sorted	Strongly Positively Skewed

Table 24: Comparison Table of the surface bulk sample calculated averages for each site studied.

3.2 Depth and Velocity

Depth and velocity are important variables in salmonid spawning site selection (Chapman et al, 1986). Salmonids spawn in stretches of rivers with pool riffle complexes and require adequate surface water velocities to flush nutrients and oxygen through the gravel. When surface water velocities are low, less dissolved oxygen is available in the subsurface and less surface water flows through the redds. Surface water depth, direction, and velocity measurements were taken at numerous locations within each of the restoration sites (Figures 56, 57, and 58).

Cottonwood Hatchery Surface Water Depth, Direction, and Velocity

The results of surface water measurements for Cottonwood Hatchery Riffle are displayed in Figure 56. The upstream pool is more than 6 feet deep. This pool and the high velocity riffle shown in Figure 56 were inaccessible to a wading crew. The low velocity riffle is shallow and has low surface water velocity. The site has an upstream pool that flows west into a high velocity riffle and the upstream pool spills into the main channel via low and moderate velocity riffles. This site shows heterogeneity in flow with varying magnitudes and direction of flow in a pool and two riffle sequences.

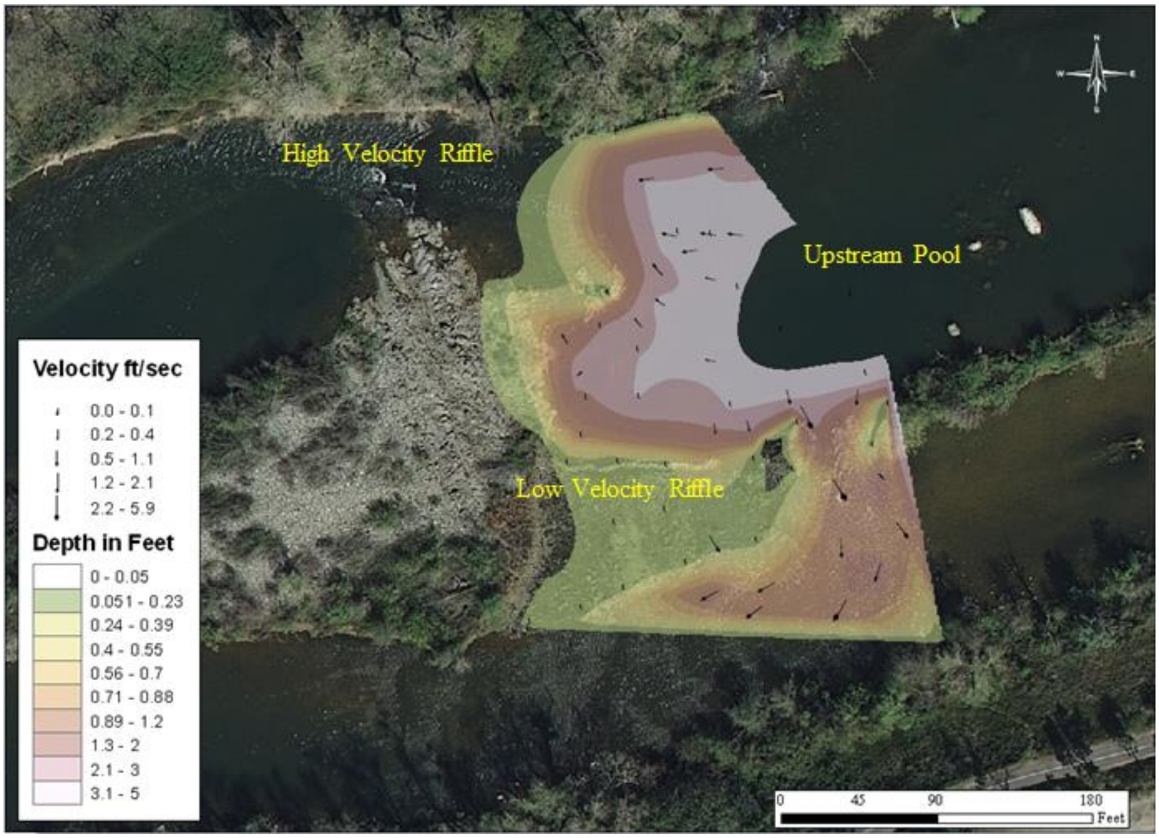


Figure 56: Depth, velocity, and direction of flow map for the Cottonwood/Hatchery Riffle. The brown colors indicate an increase in depth and the green and yellow colors indicate shallow water. The size of the arrow and orientation indicates the magnitude and direction of flow.

Upper Auditorium Depth, Direction, and Velocity

Figure 57 show for the Upper Auditorium Riffle the depth of the surface water and the magnitude and direction of flow. This riffle/pool complex has an upstream shallow pool (< 6ft deep) that flows slowly west into Moe’s Ditch and turns sharply south into the main channel through a high velocity chute. The site has a pool-riffle complex with minimal change in the magnitude and direction of flow.

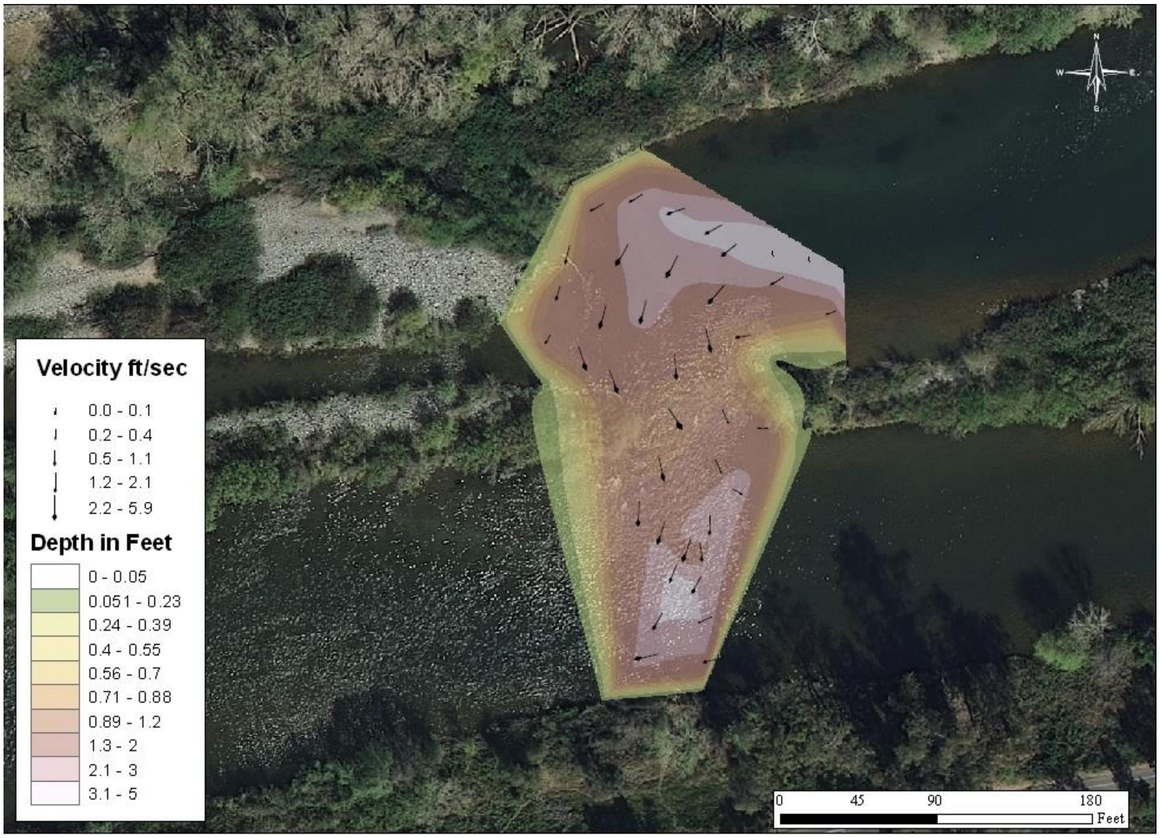


Figure 57: Depth, velocity, and direction of flow map for the Upper Auditorium Riffle. The warm colors indicate an increase in depth and the orientation and size of the arrow indicates velocity and direction of flow.

Auditorium Depth, Direction, and Velocity

Figure 58 shows results for surface water depth, velocity, and direction of flow at the Auditorium Riffle. The site is a homogenous straight run lacking of pool or riffle structures.

Figure 58: Depth, velocity, and direction of flow map for the Auditorium Riffle. The brown colors indicate an increase in depth and the green and yellow colors indicate shallow water. The size of the arrow and orientation indicates the magnitude and direction of flow.

3.3 Permeability

Permeability is important in groundwater surface water interactions, and the higher the permeability the faster fluids can flow through gravels. Permeable gravels allow for oxygen delivery and waste removal in shallow stream gravel and can be a key indicator of the health of a river system.

3.3.1 Barnard and McBain Permeability Tests

Numerous Barnard and McBain standpipe tests were conducted at each of the study sites: Cottonwood Hatchery Riffle, Upper Auditorium Riffle, and the Natural Spawning sites. Increased flow conditions in the Low Flow Channel prevented any standpipe tests from being conducted at the Auditorium Riffle. The data gathered from the tests were compared to Figure 59 to extract the hydraulic conductivity (K) in cm/hr for each test. Two tests were conducted at each test site, and results were averaged. The data were plotted on maps with green dots representing high K values (>10,000 cm/hr), yellow dots representing moderate K values (7,000-10,000 cm/hr), red dots representing low K values (< 7,000 cm/hr), and blue triangles represent wells that did not recover when pumped (Calver, 2001).

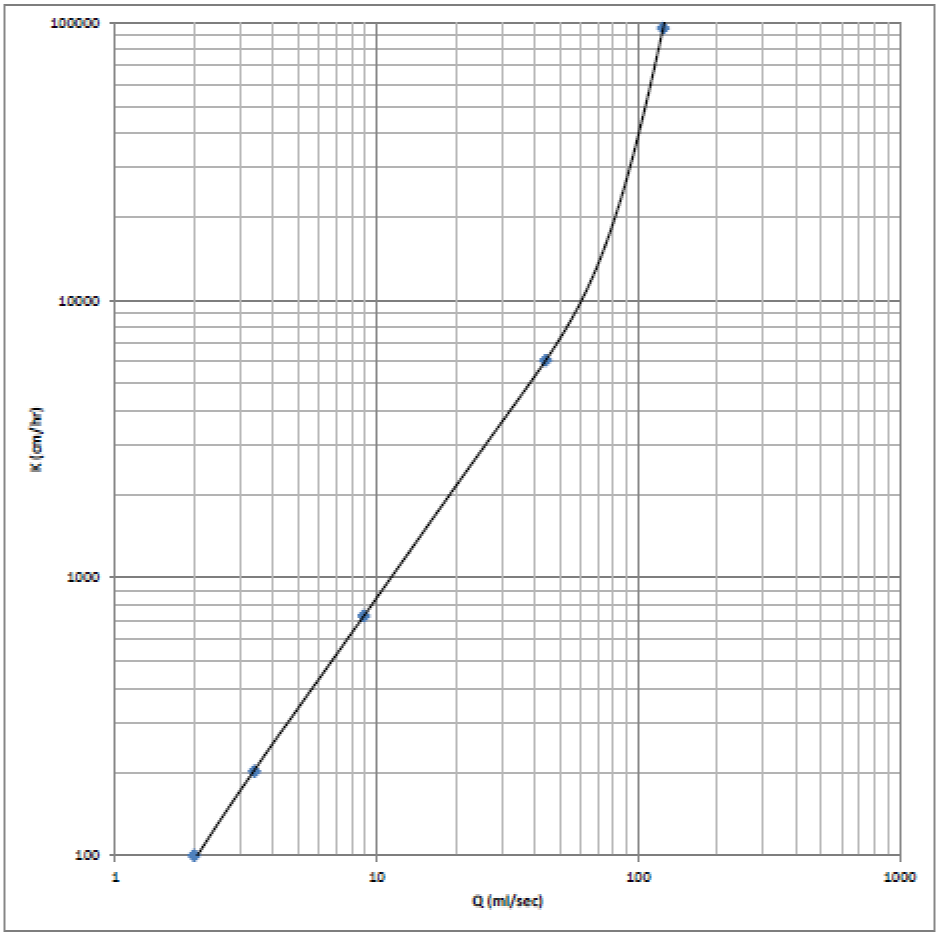


Figure 59: Permeability vs. standpipe inflow rate calibration curve. The collected standpipe inflow rate is compared to the chart to reveal a permeability value. Image from Barnard McBain (1994).

Cottonwood Hatchery Permeability Data

A total of nine permeability tests were conducted at Cottonwood Hatchery Riffle (Figure 60). All test sites had low K values except sites four and eight. Site four had a high K value and site 8 had a moderate K value.

Figure 60: Permeability test locations at the Cottonwood Hatchery Riffle. Red dots are low K values, yellow dots are moderate K values, and green dots are high K values.

Site	Test 1 (ml/sec)	Standpipe Inflow	Test 2 (ml/sec)	Standpipe Inflow	K Value cm/hr	K Value ft/day
1	3200/138	23	3250/108	30	3600	2800
2	3100/133	23	3300/111	29	3600	2800
3	3250/107	30	3750/114	33	3700	2900
4	3450/35	98	3750/35	107	55000	43000
5	700/396	1.8	750/336	2.2	<100	<79
6	2800/250	11	2850/275	10	850	670
7	2500/170	15	2450/175	14	1400	1100
8	3350/65	51	3250/60	54	8500	6700
9	3100/171	18	3050/152	20	2200	1700

Table 25: Table of results for the Cottonwood Hatchery permeability tests.

Upper Auditorium Permeability Data

A total of ten permeability tests were conducted at Upper Auditorium Riffle (Figure 61). Six test sites had low K values and two sites did not recover when pumped, (indicating very low permeability). Site 3 had a high K value and Site 1 had a moderate K value.

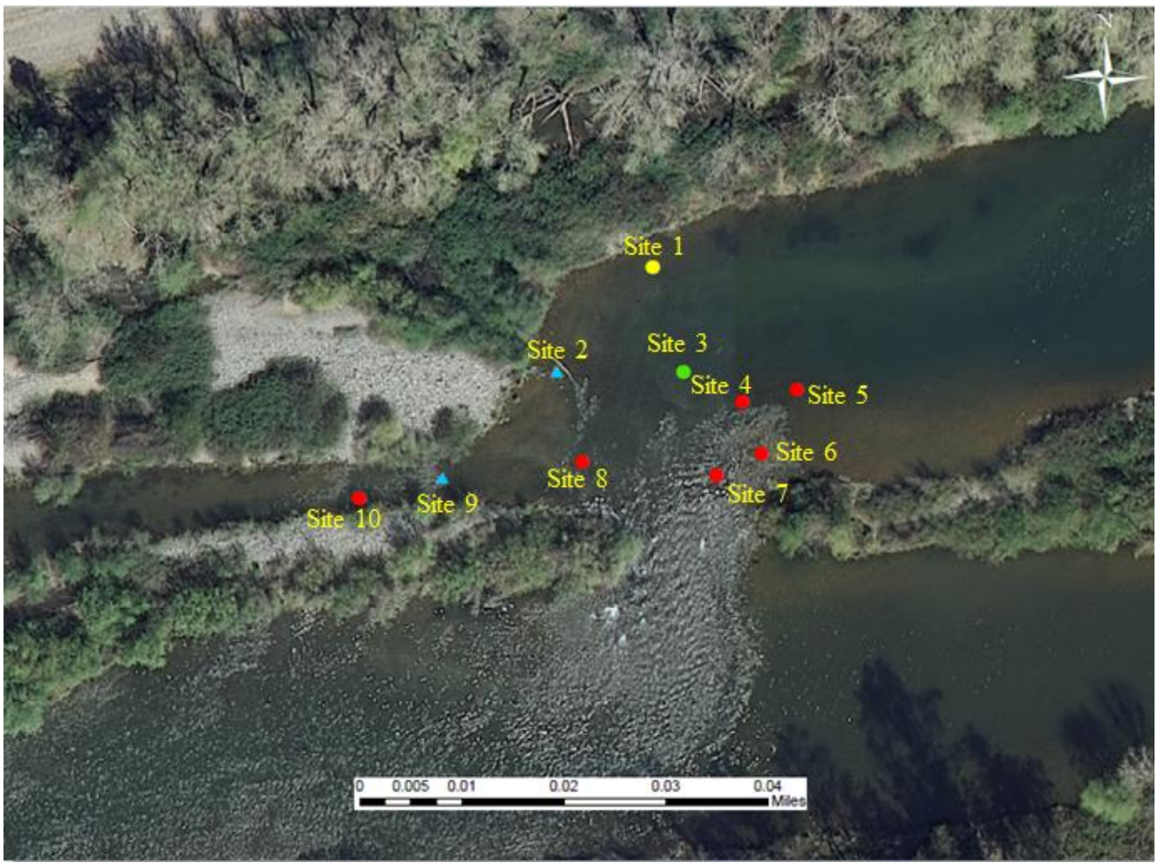


Figure 61: Locations of the standpipe tests at the Upper Auditorium Riffle. Red dots are low K values, yellow dots are moderate K values, green dots are high K values, and the blue triangles are wells that did not recover when pumped (very low permeability).

Site	Test 1 (ml/sec)	Standpipe Inflow	Test 2 (ml/sec)	Standpipe Inflow	K value cm/hr	K Value ft/day
1	3300/70	47	3100/56	55	8600	6700
2	No Recovery		No Recovery			
3	3100/43	72	3200/40	80	19000	15000

4	1900/194	10	1700/175	10	850	670
5	3100/70	44	2900/69	42	5500	4300
6	1300/120	11	1200/120	10	850	670
7	2400/120	20	2300/120	19	2100	1600
8	3200/107	30	3000/93	32	3900	310
9	No Recovery		No Recovery			
10	1500/120	12.5	1500/120	12.5	1100	870

Table 26: Table of results for the Upper Auditorium permeability tests.

Natural Spawning Upstream Site Permeability Data

A total of four permeability tests were conducted at the Upstream Site where natural spawning is common (Figure 62). Two of the sites tested had a low K value and Sites 1 and 2 both had high K values.

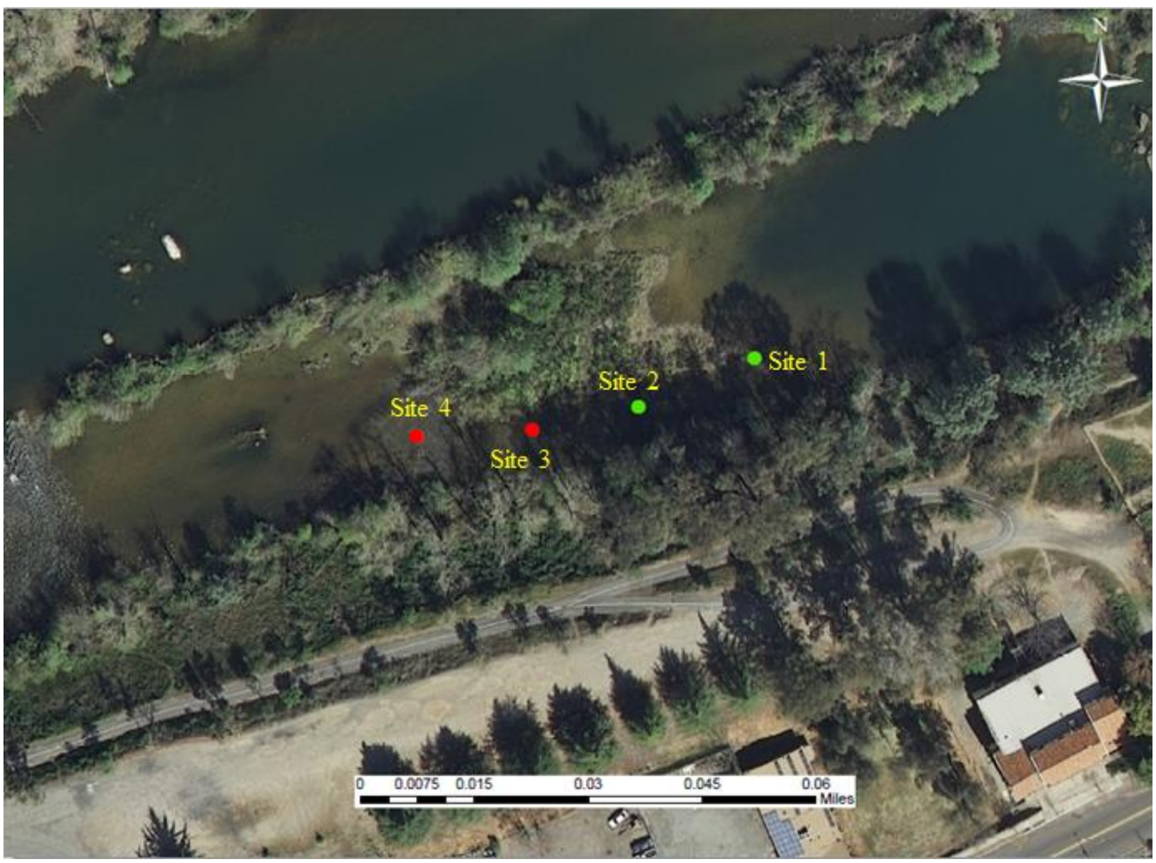


Figure 62: Locations of permeability tests for the Upstream Site. Red dots are low K values and green dots are high K values.

Site	Test 1 (ml/sec)	Standpipe Inflow	Test 2 (ml/sec)	Standpipe Inflow	K Value cm/hr	K Value ft/day
1	3350/60	56	3100/54	57	8800	7000
2	3100/60	52	3200/55	58	9000	7100
3	2700/100	27	3100/110	28	3300	2600
4	2000/100	20	2100/100	21	2300	1800

Table 27: Table of results for the Upstream Site permeability tests.

Natural Spawning Moe's Ditch Permeability Data

A total of three permeability tests were conducted at Moe's Ditch (Figure 63), where natural spawning is common. Site one had a low K value, the second site had a moderate K value, and the third site had a high K value.

Figure 63: Locations of permeability tests at Moe's Ditch. Red dots are low K values, yellow dots are moderate K values, and green dots are high K values.

Site	Test 1 (ml/sec)	Standpipe Inflow	Test 2 (ml/sec)	Standpipe Inflow	K Value cm/hr	K Value ft/day
1	1100/189	6	1200/185	6	430	400
2	3200/67	48	3400/69	49	7300	5800
3	3300/44	75	3200/40	80	19000	15000

Table 28: Table of results for the Moe's Ditch permeability tests.

3.4 Hyporheic Conditions

Water quality in the hyporheic zone can be a quality indicator of a river's health. Salmonid need adequate hyporheic flow through their redd for successful egg development. Measuring water quality conditions in the subsurface aid in the qualitative analysis of the restoration sites.

3.4.1 Sampling Parameters

Hyporheic (pore water) samples were collected at the piezometer wells of all three restoration sites (Figures 64, 67, and 70) in March of 2012 and November of 2012 to measure conditions that would be encountered during salmonid spawning and egg development. The natural spawning Upstream Site was sampled in July of 2013 when the flows temporarily went down to a workable level. Disappearing wells were a common occurrence at some sites and were classified as missing. Missing wells were replaced prior to next sampling event. Some wells did not pump during the sampling events due to sediment clogged in the tube or an installation in fine (low permeable) material.

Cottonwood Hatchery Riffle

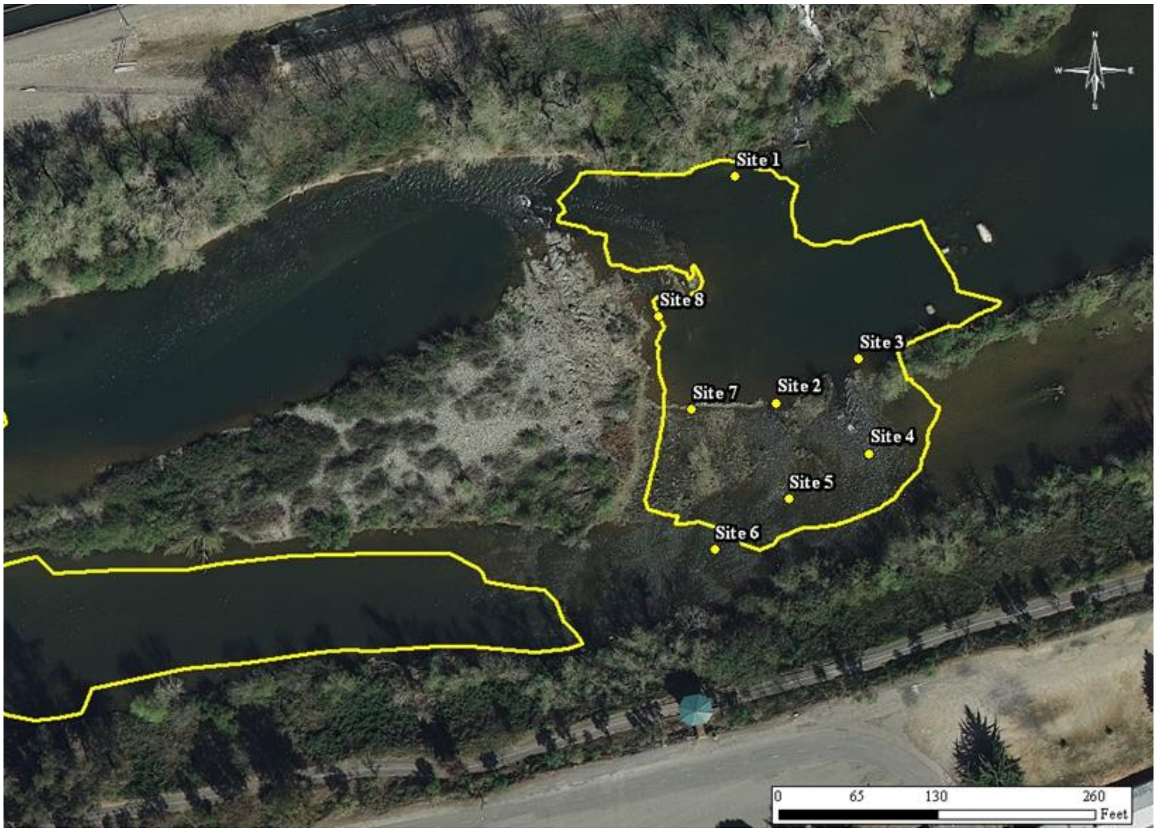


Figure 64: Location map of Cottonwood Hatchery piezometer wells.

Cottonwood Hatchery Riffle Parameters March 21, 2012 at a flow of 559 cfs.

The results of the March 2012 surface water and subsurface pore water parameter sampling at Hatchery/Cottonwood Riffle are compiled in Table 29. Figure 65 shows the locations of the missing wells, no flow wells, high D.O. wells (>85% saturation), and low D.O. wells (<65%). The two wells that show high D.O. were located in high velocity shallow water whereas the one well with low D.O. was located in low velocity deep water. Of the eight piezometers installed: two were missing, three did not produce water or were located in areas of extreme low permeability, and three wells yielded data. An initial surface sample is taken to compare subsurface water to surface water. Two of the three data producing wells had high dissolved oxygen content (>90% saturation) while one of the wells showed low dissolved oxygen content (<50% saturation) (Figure 65).

The high percentage of "no flow" wells is an indicator of poor hyporheic conditions. Loose, permeable gravels have high hyporheic flow. The lack of flow is caused by low permeability.

Figure 65: Site map of Cottonwood Hatchery Riffle showing dissolved oxygen (D.O.) results for March 2012. The green dots represent areas of high D.O. (>85%) saturation and the red dots represent areas of low D.O. (<65%).The blue dots are wells that did not flow and white triangles represent missing wells.

Site	D.O. (%)	E.C. (µS)	pH	Temperature (°C)	Turbidity (NTU)

Surface1	98%	57.7	7.5	10.1	5
1	40%	70.9	6.8	10.2	16
2	97%	59.6	7.6	10.6	22
3	No Flow				
4	91%	62	7.4	11.1	25
5	Missing				
6	Missing				
7	No Flow				
8	No Flow				

Table 29: Table of results from the March 2012 sampling of Cottonwood Hatchery Riffle.

Cottonwood/Hatchery Riffle Parameters November 9, 2012 at a flow of 543 cfs.

Four wells produced some results, and half of these wells had low dissolved oxygen in the subsurface (Figure 66). Electrical conductivity was higher in the wells with low dissolved oxygen. This probably indicates long residence times and ion exchange with pore water. pH was variable, subsurface temperature was relatively consistent and turbidity was highly variable.

Figure 66: Site map of Cottonwood Hatchery Riffle showing dissolved oxygen (D.O.) results for November 2012. The green dots represent areas of high D.O. (>85% saturation), the yellow dots represent areas of moderate D.O. (65-85%), and the red dots represent areas of low D.O. (<65%).The blue dots are wells that did not flow and white triangles represent missing wells.

Site	D.O. (%)	D.O. (mg/l)	E.C. (µS)	pH	Temperature (°C)	Turbidity (NTU)
Surface1	99%	10.5	68.0	6.8	12.8	0.1
1	No Flow					
2	91%	9.66	68.0	7.6	12.7	22
3	Missing					
4	68%	7.3	66	6.4	12.4	17
5	Missing					
6	Missing					
7	Missing					
8	38%	4.8	90	6.8	12.2	1

Table 30: Table of results from the November 2012 sampling of Cottonwood Hatchery Riffle.

Upper Auditorium Riffle

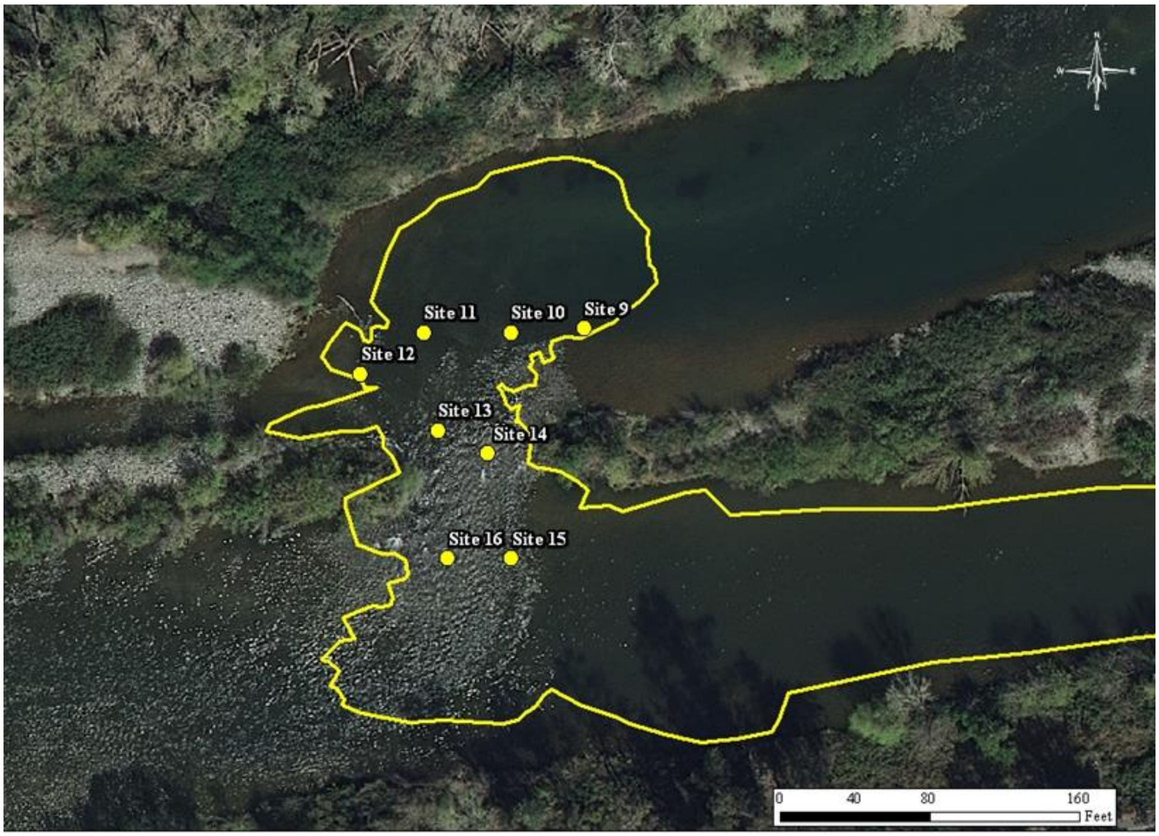


Figure 67: Site map of piezometers installed at Upper Auditorium Riffle.

Upper Auditorium Riffle Parameters March 21, 2012 at a flow of 559 cfs.

Eight piezometers were installed at Upper Auditorium Riffle, and six produced some results (Figure 68). Two piezometers were missing. The Table of results for the March 2012 parameter sampling at Upper Auditorium Riffle are compiled below (Table 31). Of the eight piezometers installed: two were missing and six yielded data. An initial surface sample was taken to compare subsurface water to surface water. Five of the data producing wells had high dissolved oxygen content while one of the wells showed low dissolved oxygen content (Figure 68).

Figure 68 shows the locations of the missing wells, high D.O. wells, and low D.O. wells. The five wells that show high D.O. were located in high velocity shallow water whereas the one well with low D.O. is located in low velocity moderately deep water.

Site	D.O. (%)	E.C. (μS)	pH	Temperature (°C)	Turbidity (NTU)
9	96%	59	7.6	10.2	30
10	92%	60	7.4	10.2	61
11	94%	60	7.6	10.3	3
12	Missing				
13	98%	62	7.7	10.1	8
14	90%	61	7.6	10.4	51
15	50%	62	6.9	10.2	7
16	Missing				
Surface2	97%	57	7.7	10.4	2

Table 31: Table of results from the March 2012 sampling of Upper Auditorium Riffle.

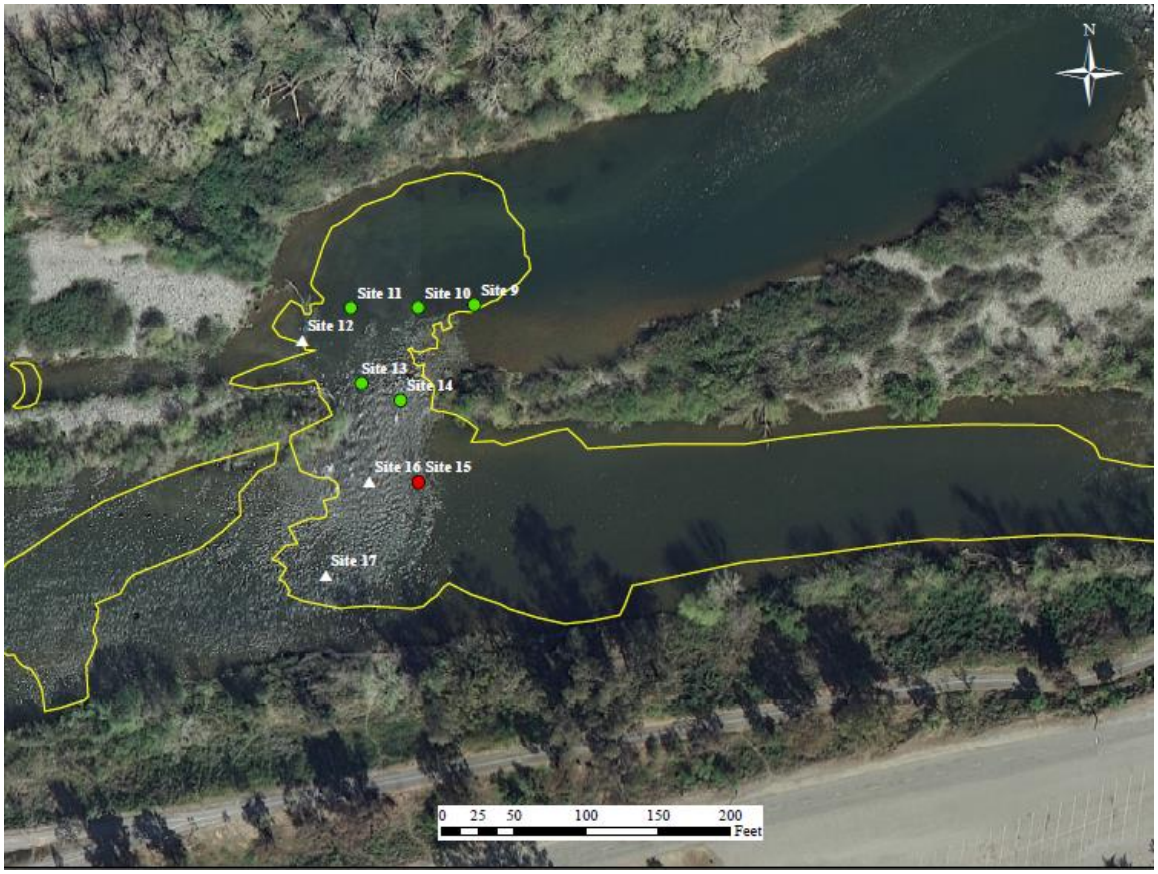


Figure 68: Site map of Upper Auditorium Riffle showing dissolved oxygen(D.O.) results for March 2012. The green dots represent areas of high D.O. (>85% saturation), and the red dots represent areas of low D.O. (<65%).The white triangles represent missing wells.

Upper Auditorium Riffle Parameters November 10, 2012 at a flow of 543 cfs

The results of the November 2012 surface water and subsurface pore water parameter sampling at Upper Auditorium Riffle are compiled in Table 32. Figure 69 shows the locations of the missing wells, moderate D.O. wells (85-65%), high D.O. wells (>85%), and low D.O. wells (<65%). Of the nine piezometers installed: one was missing and eight wells yielded data. An initial surface sample is taken to compare how similar the subsurface water is to the surface water. Seven of the eight data-producing wells had high dissolved oxygen content (>90%) while one of the wells showed moderate dissolved oxygen content (65-85%) (Figure 69).

Site	D.O. (%)	D.O. (mg/l)	E.C. (µS)	pH	Temperature (°C)	Turbidity (NTU)
9	98%	10.3	71.5	7.6	13.2	2
10	90%	9.8	69	7.4	12.3	46
11	96%	10.1	70	7.5	12.8	38
12	82%	8.5	71	7.6	13.9	5
13	95%	10.2	71	7.6	13.0	12
14	95%	10.1	70	7.6	12.9	81
15	79%	8.4	69	7.2	12.7	90
16	96%	10.2	70	7.5	12.8	8
Surface	99%	10.2	70	7.6	13.1	0.2

Table 32: Table of results for the November 2012 sampling of Upper Auditorium Riffle.

Figure 69: Site map of Upper Auditorium Riffle showing dissolved oxygen (D.O.) results for November 2012. The green dots represent areas of high D.O. (>85% saturation) and the yellow dots represent areas of moderate D.O. (65-85%). The white triangles represent missing wells.

Auditorium Riffle

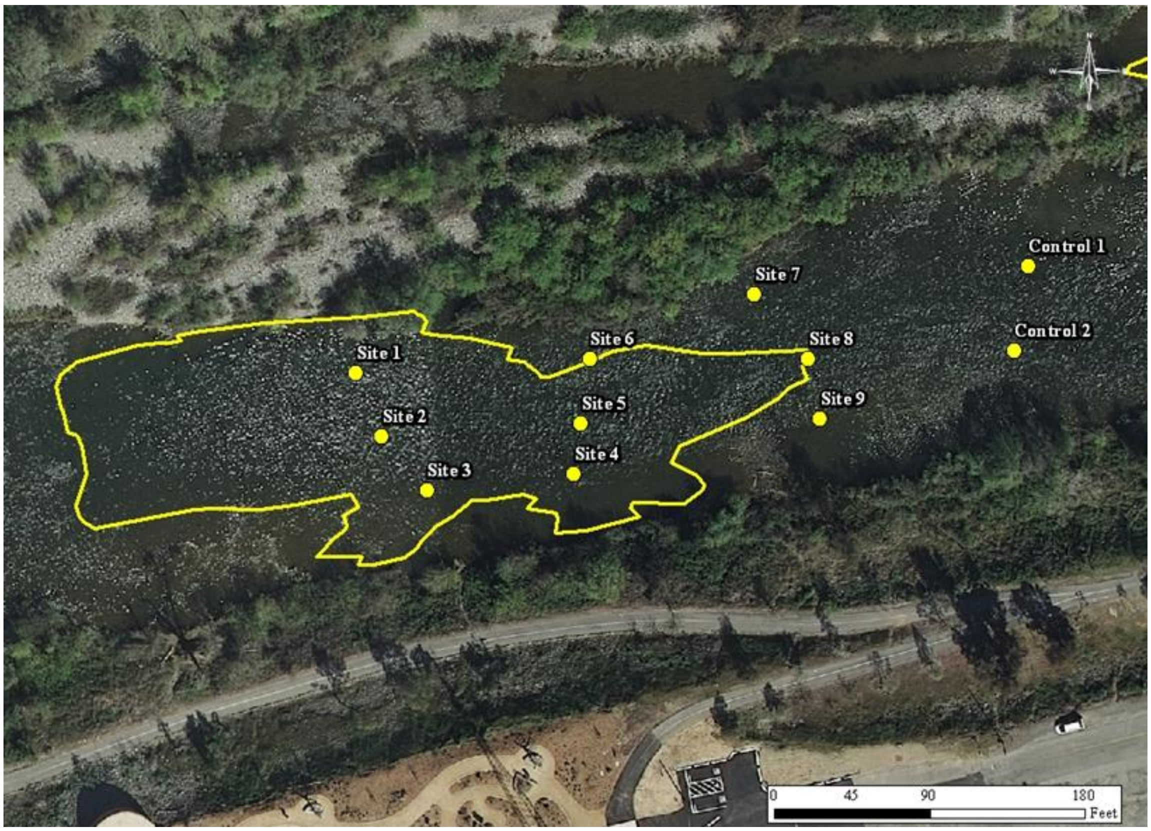


Figure 70: Site map of piezometers installed at Auditorium Riffle.

Auditorium Riffle March 29, 2012 at a flow of 559 cfs.

The results of the March 2012 parameter sampling at Auditorium Riffle are compiled in Table 33. Of the eleven piezometers installed: three were missing, three did not produce water or were located in areas of extremely low permeability, and five wells yielded data. An initial surface water sample was taken to compare how similar the subsurface water is to the surface water. Two of the three data-producing wells had high dissolved oxygen content while two of the wells showed low dissolved oxygen content and one showed moderate dissolved oxygen content (Figure 71).

Figure 71 shows the locations of the missing wells, no flow wells, high D.O. wells, moderate D.O. wells, and low D.O. wells. All sites were located in high velocity moderately deep water.

Site	D.O. (%)	E.C. (µS)	pH	Temperature (°C)	Turbidity (NTU)
Surface1	99%	60	7.7	9.9	16
C1	Missing				
C2	75%	62	7.4	10.1	51
1	Missing				
2	52%	71	6.9	10.3	3
3	Missing				
4	No Flow				
5	85%	66	7.2	10.1	6
6	48%	72	6.9	10.4	2
7	95%	63	7.6	10.2	16
8	No Flow				
9	No Flow				

Table 33: Table of results for the March 2012 sampling of Auditorium Riffle.

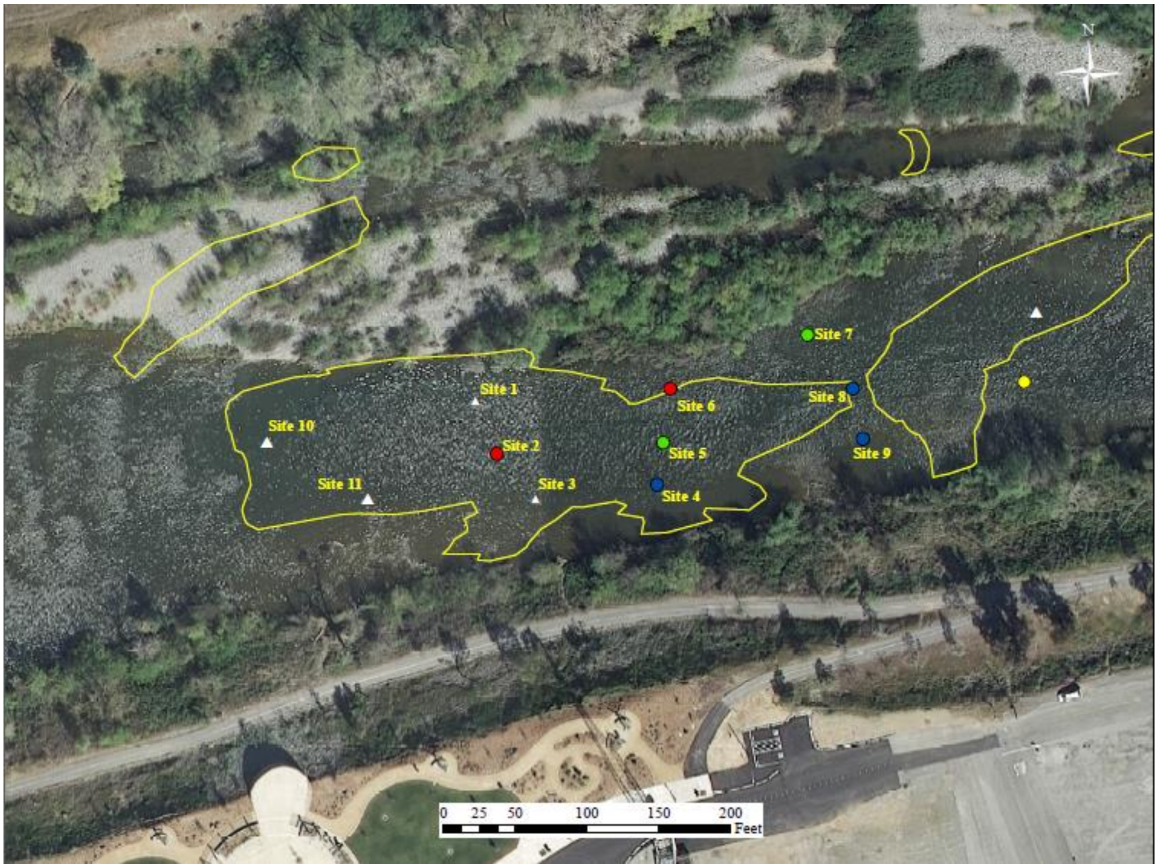


Figure 71: Site map of Auditorium Riffle showing dissolved oxygen (D.O.) results from March 2012. The green dots represent areas of high D.O. (>85% saturation), the yellow dots represent areas of moderate D.O. (65-85%), and the red dots represent areas of low D.O. (<65%).The blue dots are wells that did not flow and white triangles represent missing wells.

Auditorium Riffle Parameters November 17, 2012 at a flow of 543 cfs.

The results of the November 2012 surface water and subsurface pore water parameter sampling at Auditorium Riffle are compiled in Table 34. Figure 72 shows the locations of the missing wells, no flow wells, high D.O. wells (>85% saturation), and low D.O. wells (<65%). Of the thirteen piezometers installed: three were missing, one did not produce water or were located in areas of extreme low permeability, and nine wells yielded data. An initial surface sample is taken to compare the subsurface water to surface water. Three of the nine data producing wells had high dissolved oxygen content (>90%), three of the wells showed moderate dissolved oxygen content (65-85%), while three of the wells showed low dissolved oxygen content (<50%) (Figure 72).

The "no flow" well and low D.O. wells are an indicator of poor hyporheic conditions. Loose, permeable gravels have high hyporheic flow. The lack of flow is caused by low permeability.

Site	D.O. (%)	D.O. (mg/l)	E.C. (μS)	pH	Temperature (°C)	Turbidity (NTU)
Surface1	97%	10.5	72	7.6	12.3	3
C1	Missing					
C2	83%	8.9	72	7.4	12.1	91
1	83%	8.8	77	7.1	12.7	68
2	44%	4.6	83	6.9	12.6	3
3	No Flow					
4	50%	5.4	78	6.9	12.6	12
5	71%	7.6	78	6.8	12.3	16
6	36%	3.8	85	6.8	12.8	42
7	78%	8.4	73	7.2	12.1	6
8	76%	8.1	74	7.3	12.1	15
9	94%	10.1	73	7.5	12.3	21

Table 34: Table of results for the November 2012 sampling of Auditorium Riffle.

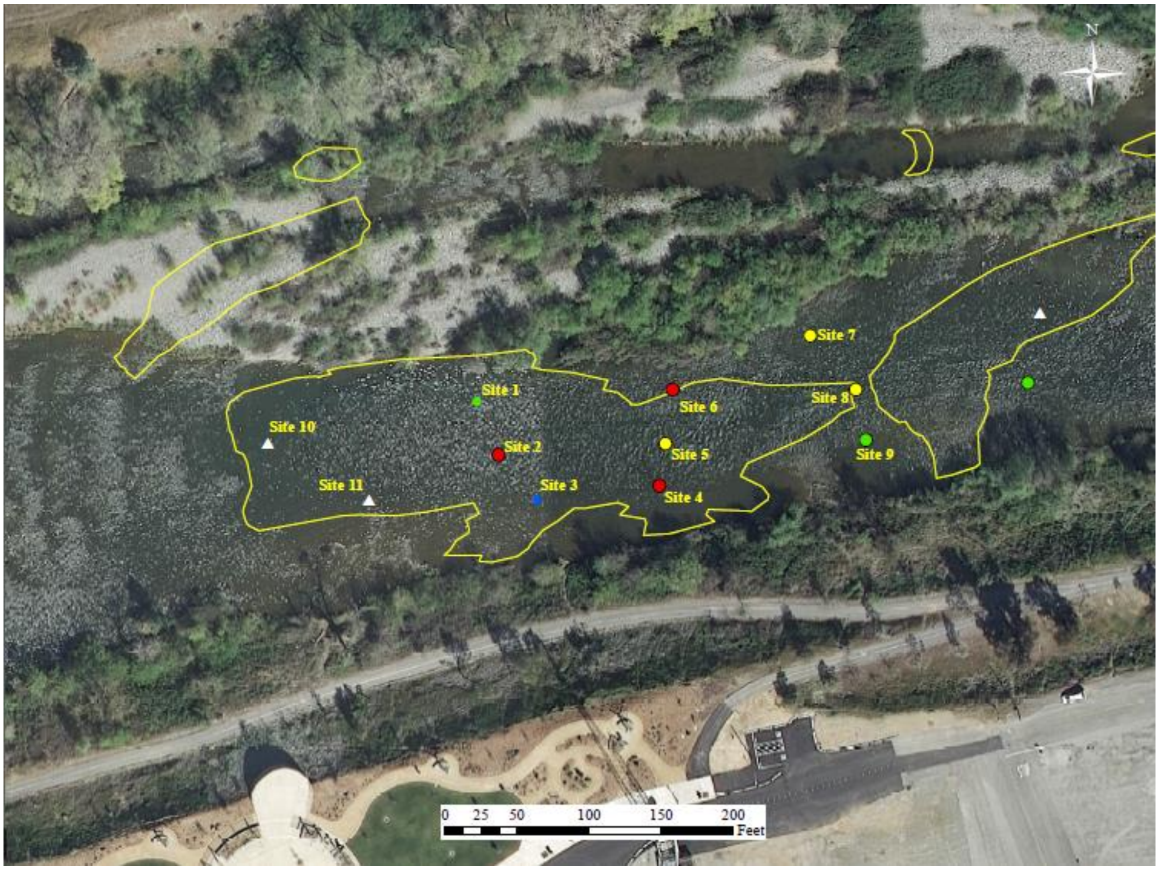


Figure 72: Site map of Auditorium Riffle showing dissolved oxygen (D.O.) results from November 2012. The green dots represent areas of high D.O. (>85% saturation), the yellow dots represent areas of moderate D.O. (65-85%), and the red dots represent areas of low D.O. (<65%).The blue dots are wells that did not flow and white triangles represent missing wells.

Natural Spawning Sites

The natural spawning Upstream Site was sampled in July of 2013. Other sites were not accessible during this period of increased flow. This natural spawning site serves as a control area to document conditions that are preferred during redd site selection.

Upstream Site Parameters July 2013 at a flow of 2490 cfs.

The results of the July 2013 surface water and subsurface pore water parameter sampling at Upstream Site are compiled in Table 35. Figure 73 shows the locations of the missing wells, no flow wells, high D.O. wells (>85%), and low D.O. wells (<65%). Of the three piezometers installed: none were missing and three wells yielded data. An initial surface sample is taken to compare the subsurface water to surface water. All three data producing wells had relatively low dissolved oxygen content (>65%) (Figure 73).

The high percentage of "no flow" wells is an indicator of poor hyporheic conditions. The lack of flow is caused by low permeability.

Site	D.O. (mg/L)	D.O. (%)	E.C. (µS)	pH	Temperature (°C)	Turbidity (NTU)
Surface1	9.7	100	77	7.7	17	5
1	4.0	42	105	7.0	15	130
2	3.9	41	77	6.8	17	4
3	6.1	64	80	7.2	16	5
Surface2	9.1	96	78	7.5	17	3

Table 35: Table of results for the July 2013 sampling of Upstream Site.

Figure 73: Site map of Upstream Site showing dissolved oxygen (D.O.) results from July 2013. Thered dots represent areas of low D.O. (<65%).

Hyporheic Conditions Comparison of All Sites

Table 36 is a comparison of sampling parameters for each site during both the Spring and Fall sampling runs. Electrical conductivity was consistent and uniform for the locations with rare spikes accompanied by low D.O. values. pH was consistent and uniform throughout the sampling events, and turbidity was uniformly low in pore water. The temperature in the gravel was consistent and uniform with the exception of the July 2013 sampling event, which recorded hotter than average temperatures.

The site averages for dissolved oxygen are a little misleading due to the small numbers of site data points available. The Cottonwood Hatchery Riffle had high D.O. in two out of three wells in March and one out of three wells in November. The Upper Auditorium Riffle had high D.O. in five out of six wells in March and six out of eight wells in November. The Auditorium Riffle had high D.O. in two out of five wells in March and three out of nine wells in November. The Upstream natural spawning site had no wells with high D.O., higher than average electrical conductivity, and higher average temperature (Table 36).

Site	Average D.O. and range (%)	Average E.C. and range (µS)	Average pH and range	Average Turbidity and range (NTU)	Average Temperature and range (C°)
Cottonwood Hatchery Riffle March 2012	76% 40-97%	63 59-70	7.3 6.8-7.6	21 16-25	10.6 10.2-11.1
Cottonwood Hatchery Riffle November 2012	65% 38-91%	74 66-90	6.9 6.4-7.6	13 1-22	12.4 12.2-12.7
Upper Auditorium Riffle March 2012	86% 50-98%	61 59-62	7.5 6.9-7.7	26 7-61	10.2 10.1-10.4
Upper Auditorium Riffle November	91% 79-98%	70 69-70	7.5 7.2-7.6	35 2-90	13.0 12.3-13.9

2012					
Auditorium Riffle March 2012	71% 48-95%	67 60-72	7.2 6.9-7.6	16 2-51	10.2 10.2-10.4
Auditorium Riffle November 2012	63% 36-94%	77 72-85	7.1 6.8-7.5	30 6-91	12.4 12.1-12.8
Upstream Site sampled in July 2013	49% 41-64%	87 77-105	7.0 6.8-7.2	46 4-130	16.0 15.0-17.0

Table 36: Comparison table of average results from sampling of all study sites.

3.4.2 Upwelling/Downwelling Conditions

Pressure head differences between surface and shallow subsurface water reveal the direction of flow in the hyporheic zone. Upwelling conditions are commonly associated with salmonid spawning habitat.

Upwelling/downwelling measurements were made at numerous locations throughout the Upper Auditorium Riffle, Auditorium Riffle, and Upstream Site. Measurements were not made at the Cottonwood Hatchery Riffle due to the armored riverbed and increased flow.

Upper Auditorium Upwelling/Downwelling Conditions

The Upper Auditorium Riffle (Figure 74) has significant upwelling throughout most the middle and lower part of the riffle, with downwelling measurements clustered at the head of the riffle. The site results show a downwelling sequence at the head of the riffle in the pool flowing through the subsurface into a zone of upwelling in the riffle's chute.

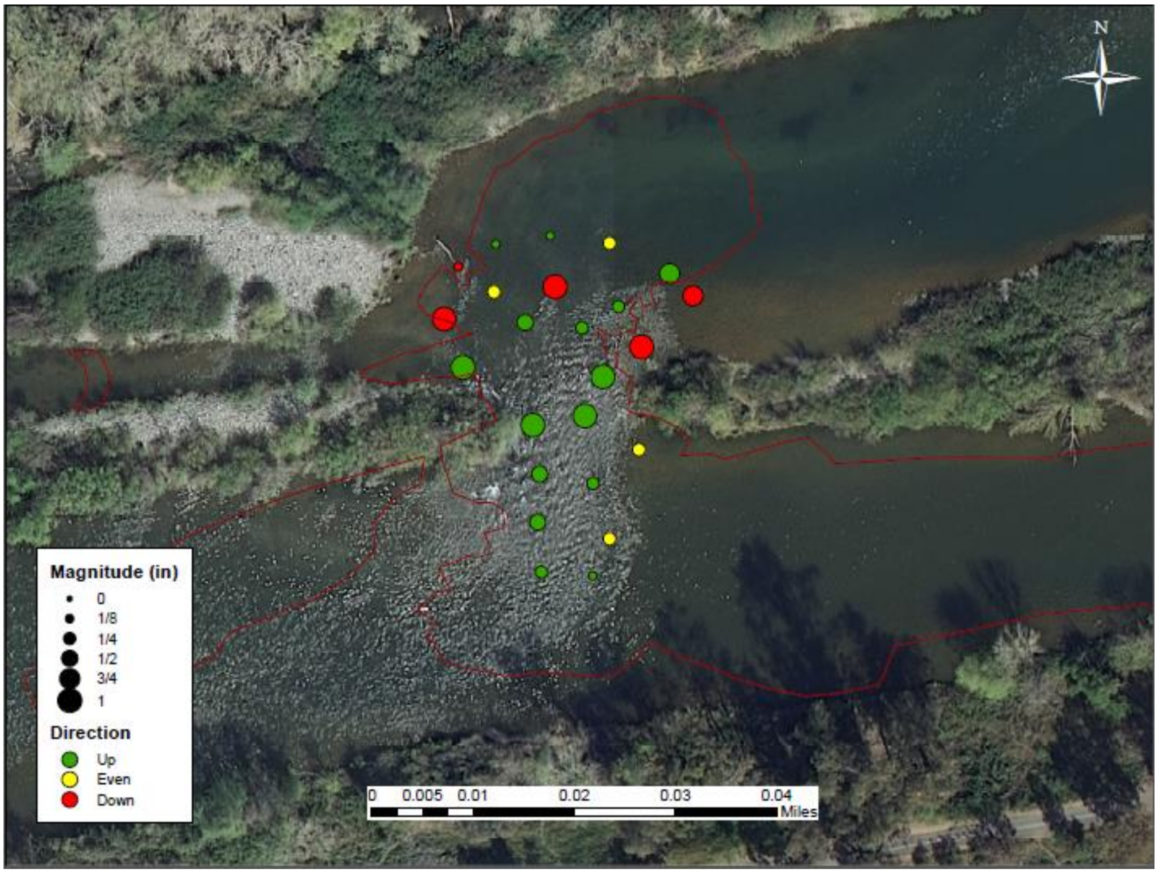


Figure 74: Upwelling/Downwelling map of the Upper Auditorium Riffle.

Auditorium Upwelling/Downwelling Conditions

The upwelling/downwelling data results for the Auditorium Riffle (Figure 75) shows few discernible patterns. The site does have localized upwelling near the head of the riffle and more downwelling near the bottom, but these trends are generally weak and may not be related to geomorphic features.

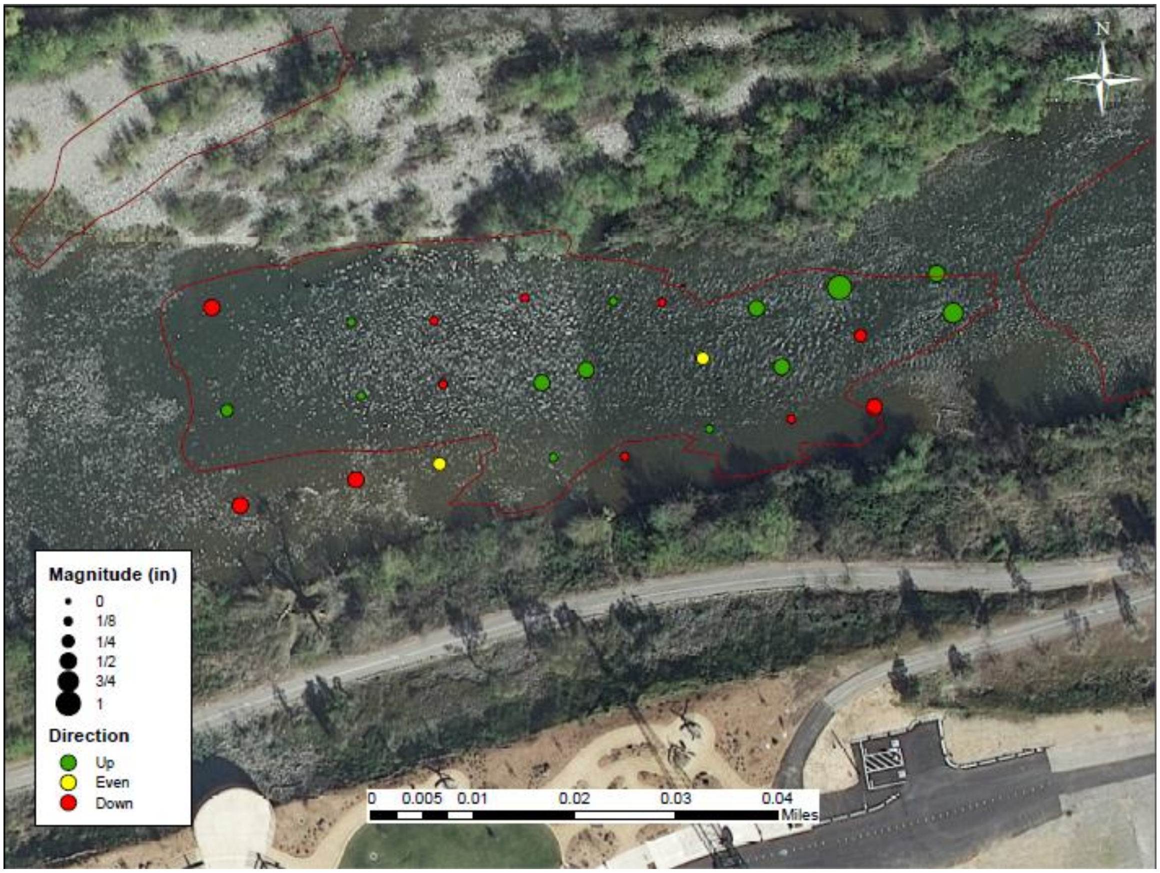


Figure 75: Upwelling/Downwelling map of the Auditorium Riffle.

Upstream Control Site Upwelling/Downwelling Conditions

The Upstream control site (Figure 76) shows moderate upwelling through much of the riffle with downwelling present at some sample locations. This could be upwelling and downwelling on a scale of 10’s of meters horizontally as surface water interacts with the shallow gravel.

Figure 76: Upwelling/Downwelling map of the Upstream control site.

Chapter 4.0

Discussion

4.0 Discussion

The Feather River has carved its way through the resistant meta-volcanics of the Oroville area for millions of years. The river mobilized gravel until anthropogenic events of the 19th century affected natural flows. 19th century gold dredging and sand and gravel mining depleted the river's sediment supply significantly. The construction of Oroville Dam in the mid-20th century further affected the river's ability to mobilize sediment, and resulted in an armored, sediment-starved river system. Flood events mobilized sediment even after construction of the dam, removing fine material, and reducing hyporheic flow. Oroville Dam also altered the natural seasonal flow of the river by eliminating historic seasonal high and low discharges. Salmonids need a dedicated source of permeable gravels of adequate size and a natural flow regime to produce spawning habitat with sufficient hyporheic flow.

The three restoration sites scheduled for gravel augmentation and three control (natural spawning) areas were studied to document existing conditions. Several methods were incorporated to evaluate the spawning gravel conditions qualitatively and quantitatively. Grain size, water depth and velocity, dissolved oxygen content, permeability, and geomorphic characterization were all used to evaluate the sites. The three restoration sites each displayed poor salmonid spawning habitat. The grains are too coarse, the riverbed is armored, the sites lack transverse gravel bars and emergent vegetation, low K values are present throughout, and zones of low D.O. were present at all sites.

Grain size is a fundamental and potentially limiting factor for salmonid spawning habitat. The grains at all proposed restoration sites are too coarse for spawning gravel according to the standards put forth by the California Department of Fish and Game (DWR, 2010). These guidelines state that that 80% of the salmon spawning gravel should be less than -6.2 phi (7.6cm) and 80% of the steelhead habitat should be less than -5.2 phi (3.8 cm) (DWR, 2010; Sommer et al, 2002). Bulk grain size at the proposed restoration sites had an average of 80% of the grains less than -7.0 phi (12.8 cm) while at the control sites showed that 80% of the grains were less than -5.5 phi (4.5 cm). This 80% criteria shows that restoration sites are too coarse, and natural spawning sites are more appropriate for salmon and steelhead spawning.

The mean grain size, sorting, and armoring index are statistics that also help evaluate these sites. The proposed restoration sites had mean grain sizes in the range of -4.5 to -5.1 phi (2.2 cm to 3.4 cm), and natural spawning sites had mean grain size that averaged -4.1 phi (1.7 cm). The proposed restoration sites were very poorly sorted and armored, with an armoring index that ranges from 1.3 to 1.5. The mean grain size at all proposed restoration sites is relatively high, and reflects transport energy as a result of dam releases and periods of high energy transport. Sorting shows variation in transport energy and the Feather River has experienced highly variable flows since construction of Oroville Dam. Proposed restoration sites are all very poorly sorted, and natural spawning areas are poorly to very poorly sorted. Lag deposits are common at the proposed restoration sites. In general the restoration sites are too coarse and too armored to support spawning salmonids, while the control sites are closer to the optimal grain size distribution.

The depths and velocities measured at the restoration sites were not ideal for spawning salmonids. A majority of the observed spawning in the Low Flow Channel occurred at depths between 1.6- 2.6 feet deep and velocities ranging from 1.5-2.7 ft/s (Sommer et al, 2002). Cottonwood Hatchery Riffle had adequate velocities but was too deep (> 3 feet deep) when compared to these ideal spawning conditions. Upper Auditorium Riffle had adequate surface water depths but the velocities were too swift (>3 ft/s) to support spawning. Auditorium Riffle had adequate velocities but was too deep to support spawning. Gravel restoration should address these depth and velocity issues at all of the proposed restoration sites.

The lack of geomorphic features or bedforms is another significant issue at all proposed restoration sites. Transverse gravel bars force surface water through the gravel, and promote hyporheic flow. This also occurs on a reach scale when pools and riffles are present. Boulders, woody debris and other channel obstructions have a similar effect on a small scale. All restoration sites lacked significant bedforms or structures that would lead to enhanced hyporheic flow. The control site in Moe’s Ditch has overhanging vegetation and higher channel complexity that is closer to ideal conditions. Pools may have an unseen benefit to spawning salmonids, because they provide resting or hiding places. Two proposed restoration sites had significant pools (Cottonwood Hatchery Riffle and Upper Auditorium Riffle), and these pools should be preserved during the gravel addition.

The hyporheic zone at the proposed restoration sites is dominated by low hydraulic conductivity (K) values, and this implies that low permeability is a significant issue. The range of hydraulic conductivity values from the three restoration sites resembles values published by Calver (2001) from river deposits of variable sand and gravel content that had clogged, armored, and immobile beds. Hydraulic conductivity values were highly variable at the natural spawning sites, so we assume that fish are modifying these sites to produce appropriate permeability near the redd or egg pocket.

Dissolved oxygen concentrations at the proposed restoration sites were usually adequate for spawning habitat (> 6.5 mg/l), but pockets of low dissolved oxygen were present and could affect egg survivability due to oxygen depletion in the subsurface. Studies by Silver and others (1963) indicate dissolved oxygen levels become lethal for salmonid embryos at < 3 mg/l, and embryo survival drops significantly when levels are < 6.5 mg/l (McMahon, 1983; Carter, 2005). When dissolved oxygen levels are > 8 mg/l the mortality rate is severely diminished (Silver at al, 1963; McMahon, 1983). Low dissolved oxygen values (<6.5 mg/l) affect spawning salmonids by reducing sustained migration swimming speed and they also avoid areas of low dissolved oxygen altogether (McMahon, 1983). When fish create natural redds in these areas, the increase in hydraulic conductivity probably leads to an increase in hyporheic flux and higher dissolved oxygen content. All proposed restoration areas would benefit from increased permeability and higher and more consistent dissolved oxygen content in gravel pore waters.

Upwelling was dominant at all sites except Auditorium Riffle, and small scale changes from upwelling to downwelling were common at all sites. This variability in hyporheic flux is good for habitat, and indicates short flow paths and a high degree of exchange in the shallow subsurface. Restoration efforts should create diverse bedforms that lead to a variety of upwelling and downwelling conditions.

In summary the restoration sites need geomorphic and physical improvement with the creation of transverse bars, riffles, insertion of woody debris, and the addition of smaller sized grains. The armored surface layer is too coarse for salmonids to build redds, permeability is often low, dissolved oxygen and hyporheic flux are variable and sometimes low, and depth and velocity are not always within the desired ranges. The control sites reflected conditions that were closer to the optimal spawning habitat described by Sommer et al (2002) and are a good model for many aspects of the new gravel addition.

The gravel addition will create transverse gravel bars, allow for manipulation of the substrate by salmonids, and structures in the river that will increase the amount of water flowing through the subsurface. This increase in flow will improve hyporheic exchange around redds, increase permeability and raise dissolved oxygen content. The finer substrate will enable salmonids to manipulate a greater percentage of the gravel than they can today. Gravel additions will bring the restorations sites closer to conditions that occur at the natural spawning (control) sites. The new gravel should not impede access to the existing pools and calm areas that adults need for refuge during spawning, and the emergent fry need as safe haven from predatory species. The result of improvement to the existing spawning habitat will be an increase in site use by salmonids.

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