Physical and geochemical characteristics of the 2009 Sailor Bar gravel addition

Submitted to the US Bureau of Reclamation, Sacramento office

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1.0 Introduction and Objectives

Results described in this report are a summary of data collected at the Sailor Bar gravel addition before and after restoration work was completed in September 2009. This work was funded by the U.S. Bureau of Reclamation (Sacramento Office), and is part of the overall Central Valley Project Improvement Act (CVPIA) objective to enhance spawning gravels on the American River.

Field work and analyses conducted during the 2009/2010 field season have eight major objectives including an extension of the monitoring duration at the 2008 Sailor Bar gravel addition to provide analysis of changes occurring over time. These objectives were described as tasks in a gravel evaluation proposal submitted to the U.S. Bureau of Reclamation, Sacramento office on August 31, 2009 are summarized below:

- Grain size analysis; Wolman pebble counts
- Measure hyporheic field parameters (dissolved oxygen, pH, electrical conductivity, and temperature) from installed mini piezometers
- Measure upwelling vs. downwelling at each mini piezometer location
- Measure water depth and velocity at mini piezometer locations
- Locate tracer rocks in the 2008 gravel addition
- Conduct salt water tracer tests to measure spawning gravel seepage velocity
- Create GIS maps of the study area with study locations
- Compile a written report for the 2009/2010 season

2.0 Background/Previous Work

The Lower American River (LAR) is 23 miles of unobstructed channel that lie below Nimbus and Folsom Dams approximately 10 miles East of Sacramento, CA. The upper four miles of the river from Sailor Bar to Lower Sunrise produces approximately one third of the salmon in Northern California (IEP, 2008). This area has become the primary spawning ground due to the presence of Nimbus dam as a barrier the fish cannot overcome. The dams have caused the LAR to become sediment-starved due to a lack of annual gravel deposition from historical floods that no longer occur. This lack of sediment replenishment is causing the LAR to lose an average of 50,000 cubic feet per year of gravel (Fairman, 2007) that has not been naturally replaced. The lack of gravel is causing the river to incise from periodic large water releases from the dams, which in turn leads to armoring of the river bed. Salmonids are unable to spawn in many areas below the dam due to grain sizes that are large and cemented together with very fine-grained silt and clay sediment.

Declining salmon populations have caused significant effort to be made to evaluate and restore fish habitat quality (Snider et al., 1992; Merz and Vanicek, 1996; Snider and Vyverberg, 1996; Vyverberg et al., 1997; DFG Technical Report no. 01-2, Morita, 2005). Because of the problems, the Bureau of Reclamation funded a gravel addition in September 2008 across from the Nimbus Fish Hatchery at Sailor Bar. Prior to gravel addition, Sailor Bar was armored with coarse grains that made spawning difficult. The gravel added to the river allowed the salmonids to have nearly ideal spawning gravel. CSUS monitored the gravel addition site before and after restoration to evaluate the gravel addition based upon the previously stated study objectives.

Anthropogenic forces such as dams, artificial levees, and channel modification have altered the natural equilibrium of the river. Previous work (Castleberry et al. 1993; Horner, 2005; Morita, 2005) has shown these changes to be probable causes in the reduction of salmon historically. The declining salmon populations caused significant effort to be made to evaluate and restore fish habitat quality for the past 20 years (Snider et al., 1992; Snider and Vyverberg, 1996; Vyverberg et al., 1997; DFG Technical Report no. 01-2, Morita, 2005).

This report concentrates on the physical and hydrologic conditions that existed at the 2009 gravel site before and after gravel was added. Project objectives for this report include the continued monitoring of the 2008 Sailor Bar gravel addition.

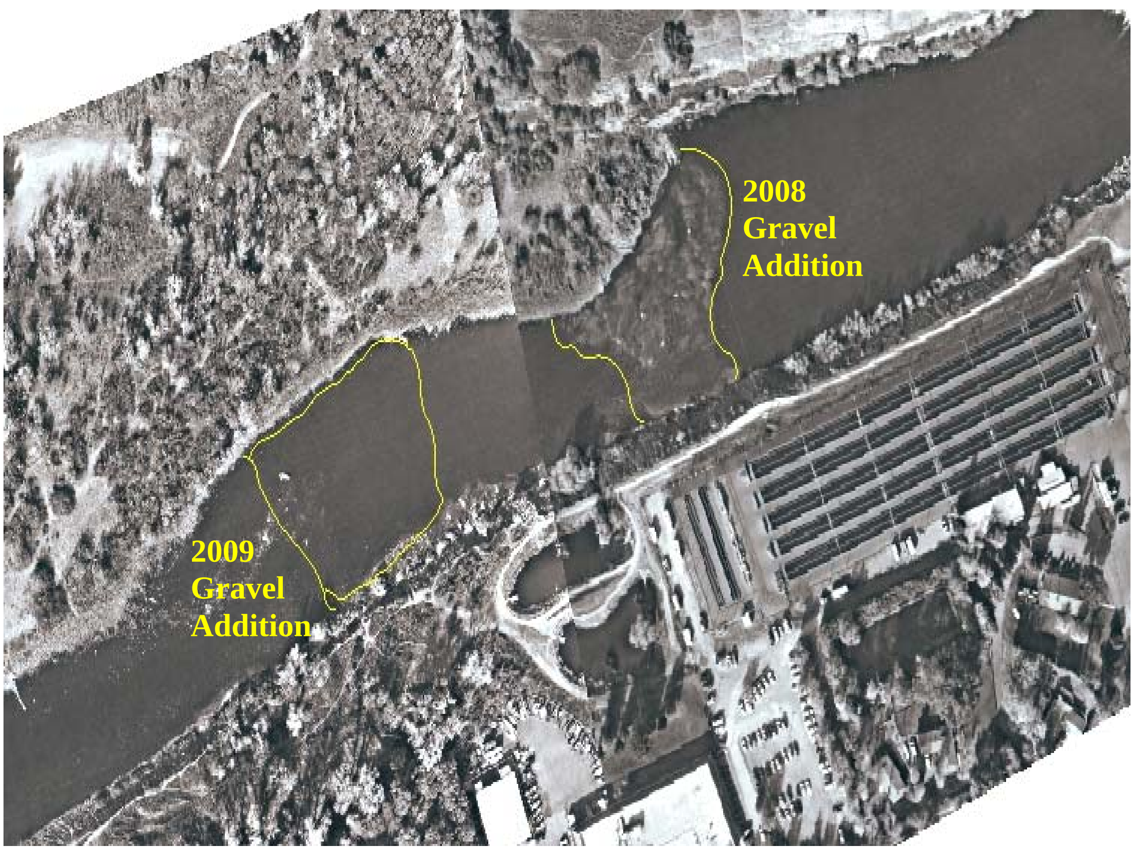

Figure 1: Map showing the outline in yellow of the gravel additions from 2008 and 2009. The Nimbus fish hatchery is in the lower right corner.

3.0 Methods; Grain Analysis

Grain size was measured using the Wolman (1954) pebble count method, but also taking into account Kondolf's (1993) additional comments. Pebble counts were executed by taking a step forward and picking up the rock that is directly below the big toe portion of the field worker's foot. This ensures a random selection of rocks, with the first grain that is touched the grain to be measured. Grains that were selected were than measured with templates of pre-existing size classes from 7 inches in intermediate diameter to 5/16 of an inch diameter.

One hundred rocks were collected per pebble count and transects followed the Kondolf (1993) suggestion of diagonally crossing riffles in a v-shaped pattern. This method was used to collect the 9 pebble counts at Sailor bar prior to gravel addition work. An additional 9 pebble counts were collected after the restoration was completed.

3.1 Gravel Mobility

Tracer rocks were deployed at the 2008 gravel addition in transects across the restoration area (after gravel addition) to better understand the movements of discrete gravel sizes during varying flow conditions. Forty rocks of the three sizes of tracers rocks were used for each transect.

The tracer rocks were placed in transects across the new gravel addition at upstream, mid gravel addition, and downstream locations. The largest rocks (2 ½-3 inch) were painted bright yellow, the medium size rocks (1 ¼ to 1 ¾ inch) were painted blue, and the smallest rocks (5/8- 7/8 inch) were painted red for obvious differentiation from the riverbed. The transect lines were mapped with high resolution GPS to within 50cm horizontal error. The tracer rocks were initially deployed at a flow of 800 cfs. Figures 1 and 2 show pictures of a grouping of the two largest grain sizes used in the tracer rock study.

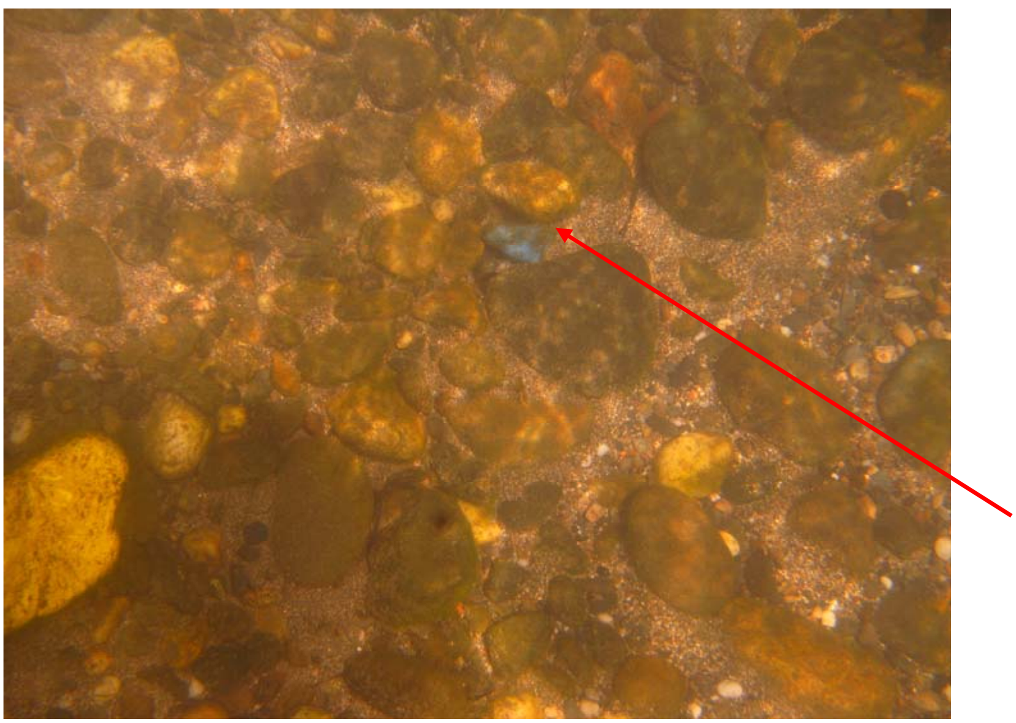

Figure 1: Picture showing the two largest grain sizes used in the tracer rock study.

Figure 2: Arrows are pointing to yellow and blue tracer rocks.

3.2 Water Quality

Mini piezometers were installed throughout the gravel addition area before and after the restoration work was completed to measure changes in water chemistry, temperature, and the vertical pressure gradient. Mini piezometers were installed in August 2009 (before gravel addition) and September 2009 (after gravel addition). Mini piezometers were installed to a depth of 30 cm below the riverbed (ground surface) to create a well. Samples were collected using ¼ inch polyethylene tubing and special 3 cm long stainless steel drive point tips that form the mini piezometers. The mini piezometer tips have a 1cm long screen, that allows sampling from a discrete interval in the subsurface. These tubes were than capped with golf tees to ensure that river water did not mix with the water at the 30 cm depth. Mini piezometers were installed throughout the restoration site at upstream, mid gravel, and downstream locations. Several mini piezometers were installed outside of the restoration area at upstream locations to show natural river conditions and provide a control for the water quality measurements.

This study design is known as a BACI study design, where sites are evaluated Before, After, Control, and Impact of the restoration area. Figure 3 shows the piezometer tip with polyethylene tubing.

Figure 3: Picture of the piezometer tip and ¼ inch tubing used for mini piezometers. The mini piezometer is inside of the drive rod device used for mini piezometer installation.

During hyporheic sampling events, water was pumped from the piezometers into a sealed flow-through chamber where dissolved oxygen (DO), pH, electrical conductivity (EC), turbidity and temperature were measured. When measurements were made using the flow-through chamber, samples were monitored without any interaction with the atmosphere. Figure 4 shows the field setup of the pump and flow-through chamber with the meters used, and GPS. Dissolved oxygen concentrations are particularly susceptible to equilibration with the atmosphere, and care must be taken to ensure that results are as representative of the subsurface as possible. Instrument probes were inserted into each port of a flow-through sampling cell; an airtight seal was obtained by tightening a rubber gasket around the individual probes.

Figure 4: Picture of the field setup for the flow-through cell and water quality equipment.

A peristaltic pump was then used to pump water through the flow-through chamber from each of the mini-piezometers. Water was allowed to circulate through the chamber until each of the parameters had adequately stabilized, typically 3 to 5 minutes. Turbidity was measured with a hand-held DRT turbidity meter that uses back-scattered light to measure the turbidity. An Orion 210 pH meter, YSI 95 DO meter, and an Orion Model 128 Electrical Conductivity (EC) were calibrated within 30 minutes of data collection prior to each sampling event. Water samples were also collected and filtered with a 0.45 micron filter, and samples were immediately frozen for preservation. These samples were used for nutrient analysis. Temperature measurements were made using a Fluke thermocouple temperature probe. The temperature probe was inserted to a depth of 30 cm inside the ¼ inch mini piezometers to measure temperatures in the spawning gravel. The temperature probe was calibrated by immersing the probe in boiling water followed by immersion in an ice bath. Temperatures are within one tenth of a degree Celsius.

3.3 Hyporheic Pressure Head Measurements

A manometer board was used to measure the difference in pressure head between the piezometers and the bottom of the streambed. The manometer board (Zamora, 2006) consisted of a graduated board with a glass tube in the shape of an inverted “U”.

The glass tube was then attached to the piezometer of interest on one side and a baffle bubble on the streambed bottom on the other side. Figure 5 shows the manometer used for measurements. The tubing from the manometer board was then connected to the baffle bubble. The baffle bubble created an environment that easily equilibrated to the pressure of the streambed, but removed the issue of stream flow past the manometer tubing, which can greatly affect readings in the manometer board. At the top of the glass tube, a release valve allowed water to be drawn into the manometer board from the bottom of the streambed and the piezometer. All devices used to measure the hyporheic zone were calibrated within 30 minutes of field usage where applicable.

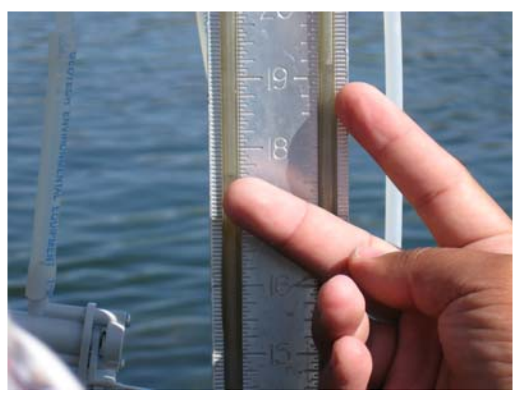

Figure 5: Picture of the manometer used for measuring the upwelling or downwelling for each mini piezometer. The photo to the right shows a close-up view of the different pressure heads from a measurement.

3.4 Water Depth and Velocity

A Price AA flow meter and wading rod was used to measure the water depth and velocity at each mini piezometer location in the gravel addition and control areas. Velocity was measured at the 0.2, 0.6, and 0.8 water depth to obtain a representative (average) velocity. Average velocity can be obtained two ways:

(1) $Vaverage = \frac{V0.2 + V0.8}{2}$

(2) $Vaverage = V0.6$

The average of the 0.2 and 0.8 values are compared with the 0.6 depth for measurement accuracy. The 0.8 depth is also the approximate "snout velocity" for spawning salmonids. Velocity was calculated by counting the revolutions per minute from the flow meter and converting to velocities using the equation: V=2.2048R + 0.0178; where R is the number of revolutions per minute, and V is the velocity in feet per minute (converted to feet per second). Figure 6 shows a picture of the equipment used to measure the velocity and depth of the study area.

Figure 6: Picture showing the Price AA wading rod stream velocity measuring equipment.

3.5 Inter Gravel Velocity Measurements

Inter gravel velocity was measured in the gravel addition area by conducting salt water tracer tests. The inter-gravel velocity of the tracer used was converted to hydraulic conductivity using the following equation:

$$(3)\ v = -\frac{Kdh}{n_e dl}$$

This equation describes the seepage velocity, where n_e is the porosity (porosity value of 20% used for this study) and dh/dl is approximated to be the stream gradient.

In these tests, a main well or injection well of 1 ¾ inch diameter stainless steel pipe was inserted 30 cm into the subsurface. Three 1 ¼ inch diameter stainless steel pipes (monitoring wells) were installed with 30 cm, 60 cm, and 90 cm spacing downstream from the injection well, to a depth of 30 cm. Each well was purged (developed) prior to tracer measurements. Orion electric conductivity meters were inserted into the injection well and the three monitoring wells. The meters were calibrated 30 minutes prior to each field day used. The background conductivity was measured in each well to verify the meter's accuracy prior to testing. Figure 7 shows the monitoring well configuration for salt water tracer tests with a 30cm monitoring well spacing from the injection well.

Figure 7: Picture showing the field set up of the permeability measurements.

During a typical test, two liters of super-saturated saltwater solution were injected into the main well. The saltwater solution was created by the addition of 5 lbs of rock salt to 3 gallons of water. Salt crystals were still visible in the water 12 hours after the solution was created, and provided visual confirmation that the tracer fluid was saturated with sodium chloride. During each test, each EC meter was monitored for an increase in conductivity as time elapsed. Increases in the conductivity readings were recorded with time until the electrical conductivity readings became stable, or greater than 30 minutes of time had elapsed since the original increase. The electrical conductivity readings in the saturated solution were usually several orders of magnitude higher than the background (river) conductivity readings, giving an obvious electrical signal from the salt plume arrival at each well. This tracer test method is used to provide a graph of electrical conductivity versus time at different monitoring points.

The arrival time of the plume at each piezometer along with the distance from the injection source is used to derive the Darcian (inter gravel) velocity for the tracer test area.

3.6 Temperature Analysis

Hobo water Temp Pro v2 data loggers were installed in the river in October 2009. 13 pairs of nested loggers were inserted at the river bottom, and a depth of 30 cm. Two of the pairs were inserted approximately 10 meters upstream of the gravel addition to provide control data. Temperatures will be recorded every hour for at least 10 months prior to data upload, and up to 2 years assuming battery duration. Hobo loggers were calibrated in 0.0 degree Celsius ice –bath prior to insertion to ensure accuracy of the loggers. Temperature loggers were installed in the new gravel to record any variation in temperature between the river bottom and the 30 cm redd depth. Changes in temperature as small as 0.1 degrees Celsius have potential impacts on salmonid spawning success.

4.0 Results; Before Gravel Addition Grain Analysis

8 pebble counts were conducted before gravel addition in August 2009. The before restoration pebble counts showed a range in grain sizes from 5/16 inches to 10 inches in diameter. Figure 8 shows a map of the pebble count locations.

Pebble counts showed a general trend of increasing grain size with depth, grain diameters commonly reached over 10 inches on the deeper end of the pebble count transects. Figure 9 shows the cumulative frequency for the before gravel addition pebble counts. Median grain size diameters (d_{50}) ranged from 2 inches to 4.5 inches.

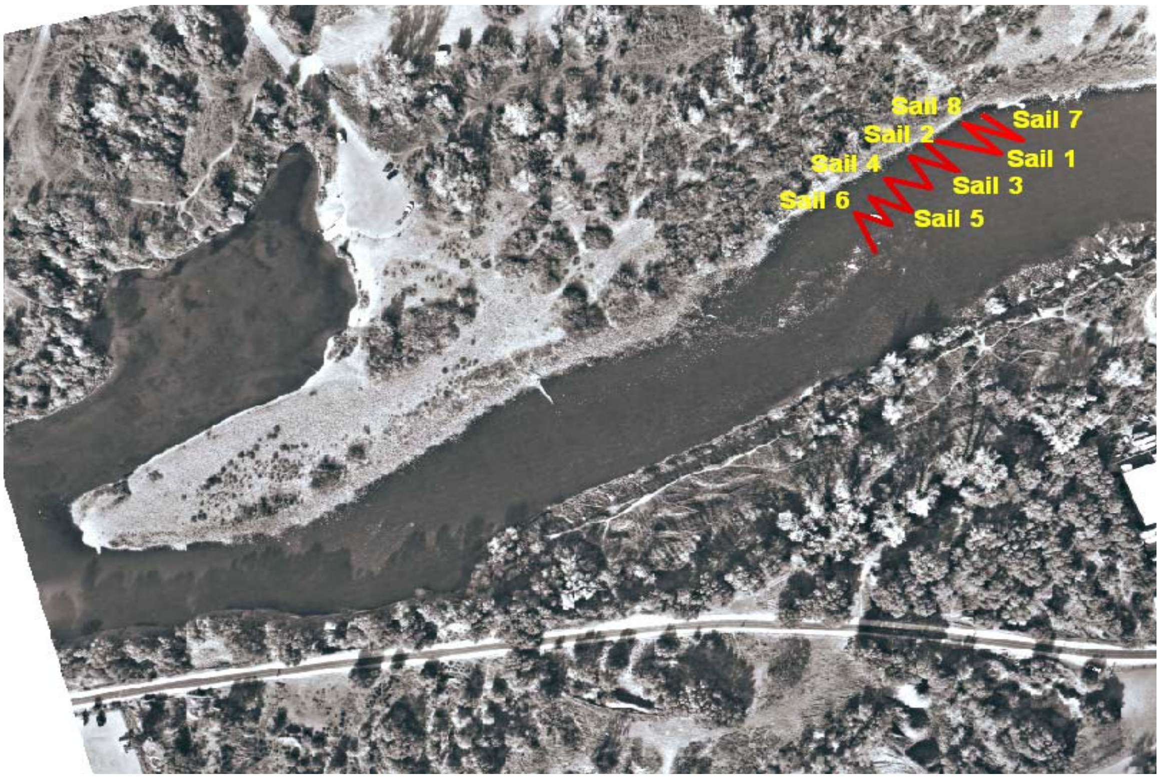

Figure 9: Map showing before gravel addition pebble count locations, August 2009.

Figure 10 shows a graph of the percent of each grain counted for the 8 pebble counts. The graph shows that almost half of the grains sampled are large enough to diminish spawning. Figure 10 shows that more than 90% of the grains counted prior to restoration were greater than 1.25 inches in diameter. 60 percent of the total grains counted were greater than 2.5 inches.

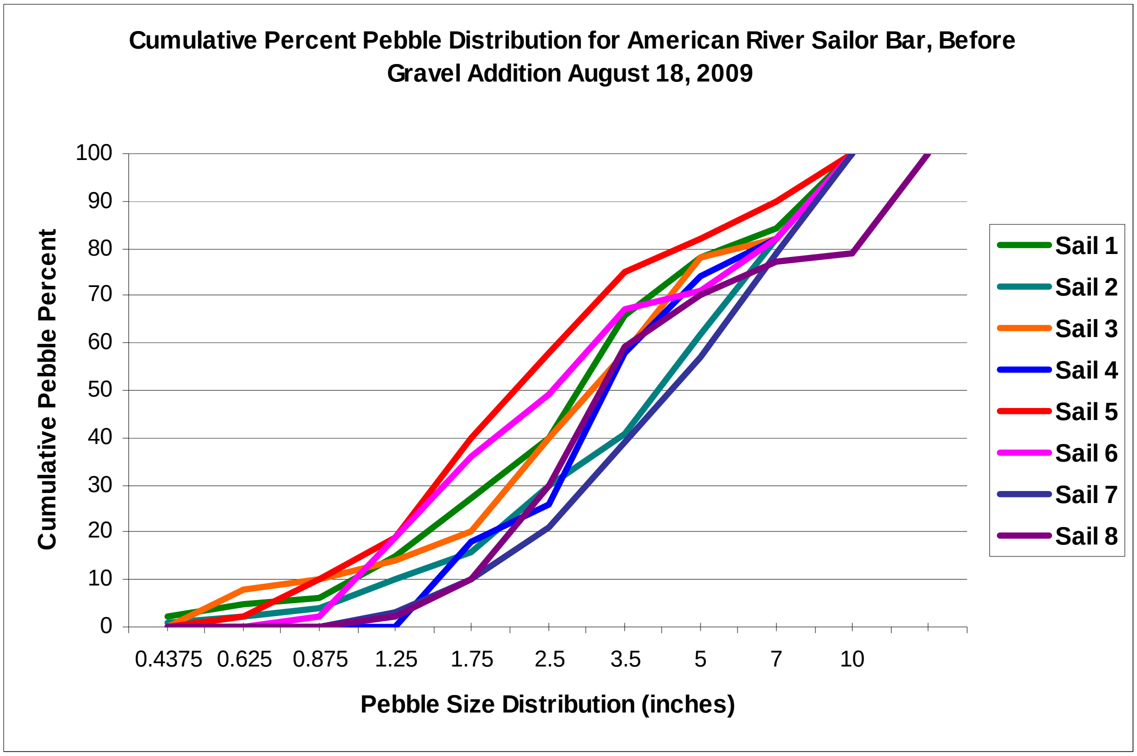

Figure 10: Graph showing the cumulative frequency of each pebble count, before gravel was added, August 2009.

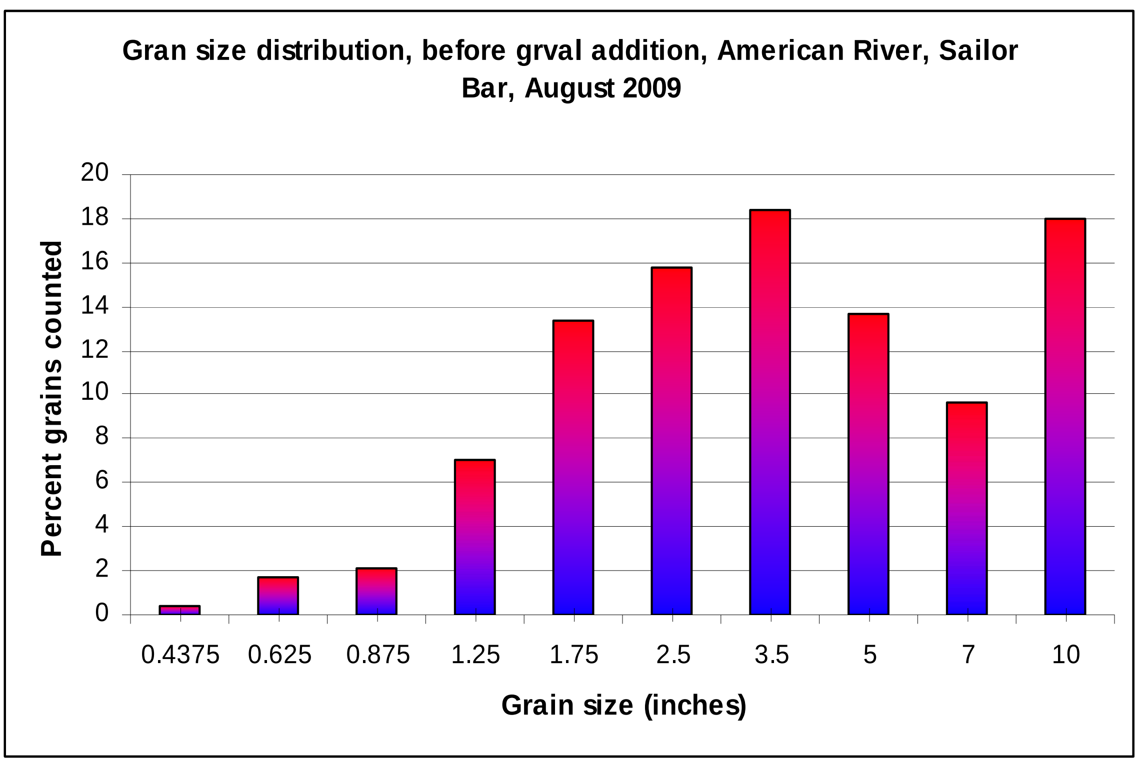

Figure 11: Graph showing the percent of the total grains counted from all pebble counts before gravel addition, August 2009.

4.01 Before Gravel Addition Water Quality

A total of 12 mini piezometers were installed before the gravel addition in August 2009. Figure 12 shows the location of the mini piezometers before gravel addition, mini piezometers Up 1 and Up 2 are the control piezometers. Data was collected in September 2009. Table 1 shows the before gravel addition water quality data.

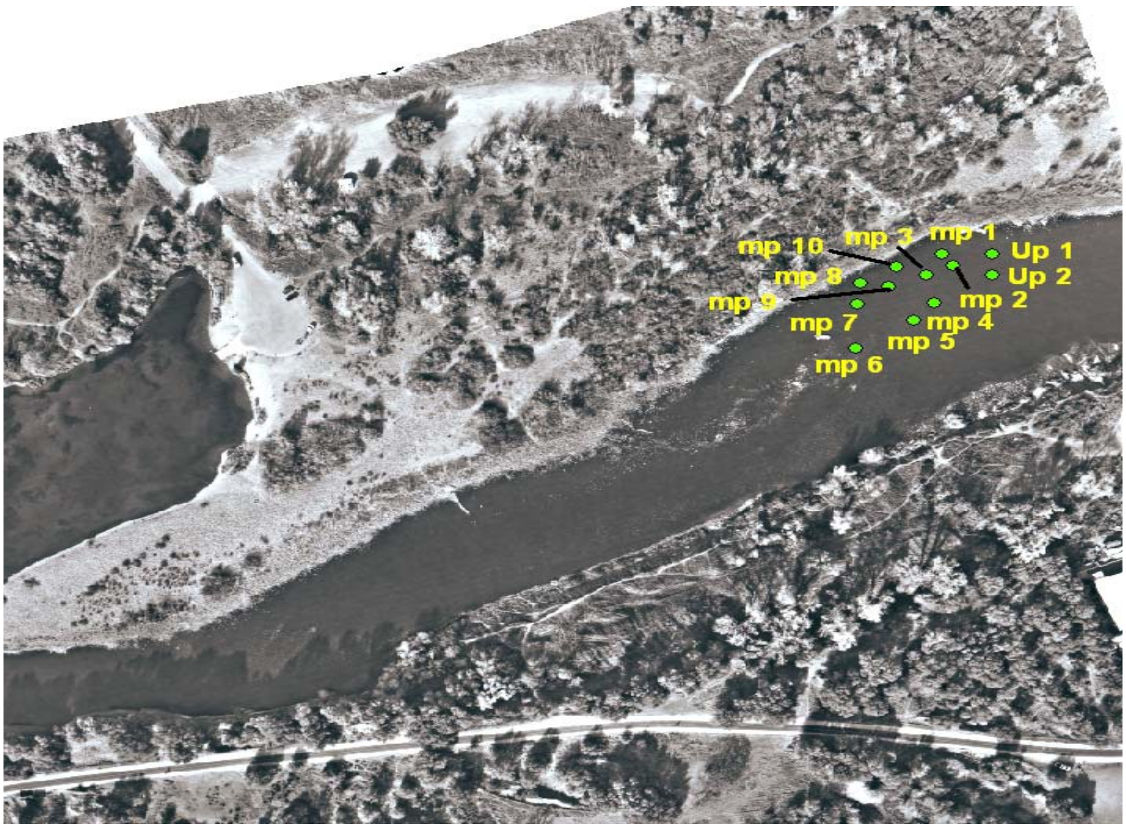

Figure 12: Map of the mini piezometer locations before gravel addition, September 2009.

Dissolved Oxygen values are significantly lower in the gravel prior to (marked in red on table one) restoration. The D.O. from table 1 show mean D.O. value of 3.5 mg/L for the study area. The control D.O. mean was 3.8 mg/L and the mean of the surface water samples was 7.7 mg/L. Figure 13 shows a map with the before gravel addition D.O. values.

The mean D.O values before gravel addition were low enough to reduce the possibility of spawning due to oxygen deprivation. This is due to the very fine grain material in the river collecting in the pore spaces and cementing the up to 10 inch boulders together.

Location	**Temp (River)**	**Temp (well)**	**EC (ms)**	**pH**	**D.O.**	**Turbidity (NTU)**
MP-1	19.2	19.2	56.8	6.7	3.0	35
MP-2	18.8	18.9	51.8	6.7	3.7	25
MP-3	18.8	18.9	56.1	6.5	1.5	13.5
MP-4	18.8	18.8	52.3	6.6	3.6	12.8
MP-5	18.8	18.8	54.3	6.6	3.3	8.41
MP-6	18.6	18.6	56.2	6.7	3.6	35.1
MP-7	18.9	18.9	54.7	6.5	3.3	7.3
MP-8	18.6	18.6	54.5	6.7	3.8	25
MP-9	18.9	18.9	60.4	6.8	2.1	58.8
MP-10	19.2	19.2	49.9	7.0	7.4	23.1
Mean	**18.9**	**18.9**	**54.7**	**6.7**	**3.5**	**24.2**
Up-1	18.9	18.9	54.1	6.8	4.6	34.3
Up-2	18.8	18.8	57.1	6.83	3.0	17.2
Surface 1	18.6	N/A	42.1	6.6	7.9	1.57
Surface 2	18.5	N/A	46.5	6.8	7.5	5.5

Table 1: Before gravel addition water quality data, September 2009.

The data from table 1 shows abnormally high Turbidity values. This is a result of the mini piezometers installation occurring in an armored area of the river. Sand and silt infiltrated between the larger grain sizes (cobbles), forming a less permeable matrix. The larger grain sizes (greater than 3 inch diameter) covered the surface forming an armored layer. The pumping action disturbed the very fine grains and they remained in suspension even after the water appeared to be free of any grains.

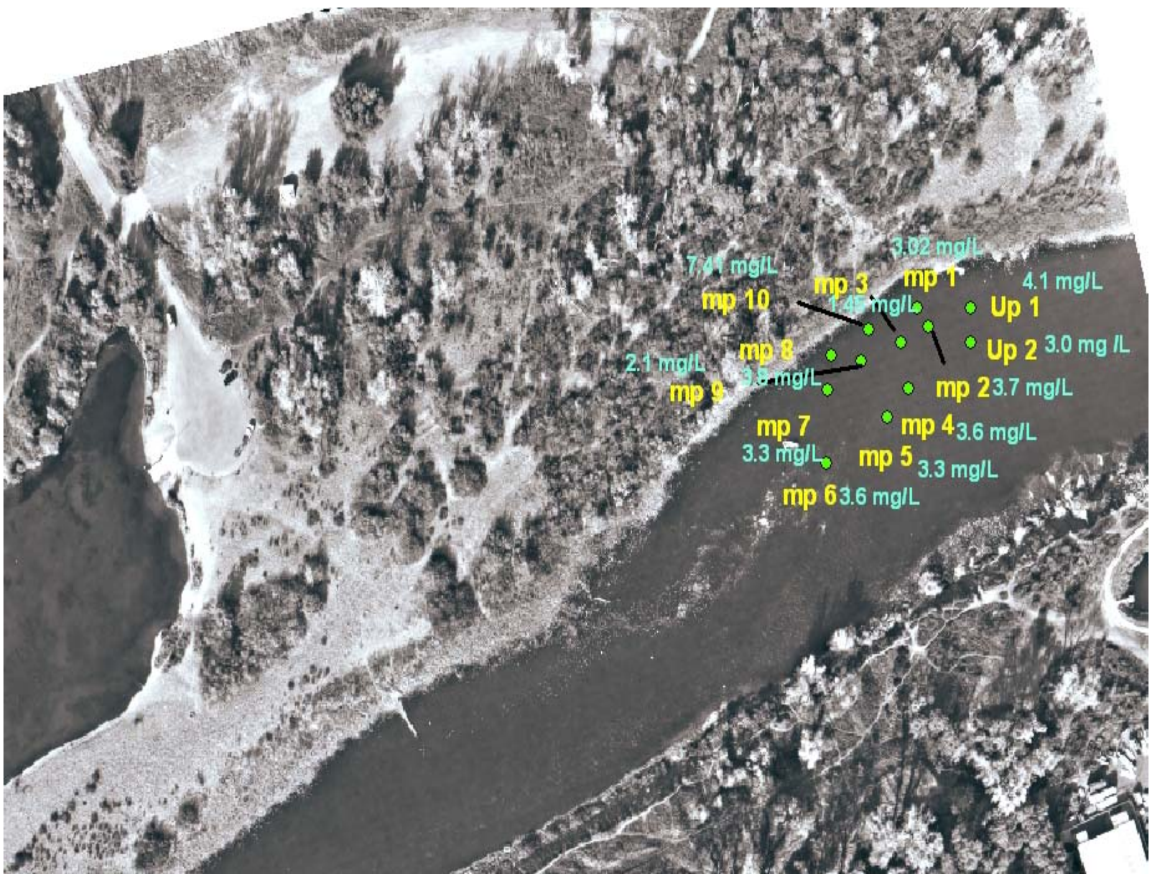

Figure 13: Map showing the distribution of the D.O. measurements before gravel addition, September 2009.

Mean pH for the before gravel addition study area was 6.7. The mean electrical conductivity was 54.7 micro Siemens/cm. Mini piezometers 2 and 3 showed a 0.1 temperature increase from the river water temperature.

4.02 Before Gravel Addition Hyporheic Pressure Head Measurements

The pre gravel addition upwelling and downwelling measurements all showed downwelling conditions. Figure 14 shows a map of the before gravel addition upwelling and downwelling measurements. Table 2 shows the gradient values measured.

Figure 14: Before gravel addition map showing the downwelling measurements, September 2009.

4.11 After Gravel Addition Grain Size

8 pebble counts were conducted after gravel addition in May 2010. The before gravel addition pebble counts were replicated using high resolution GPS. The after gravel addition pebble counts showed a range in grain sizes from less than 7/16 inches to 7 inches in diameter. Figure 15 shows a map of pebble count locations. After gravel addition pebble counts showed a smaller range in grain size and no grains of 10 inches or grater observed. Figure 16 shows the cumulative frequency for after gravel addition pebble counts. Median grain size diameters (d_{50}) ranged from 7/8 inches to 1 3/4 inches.

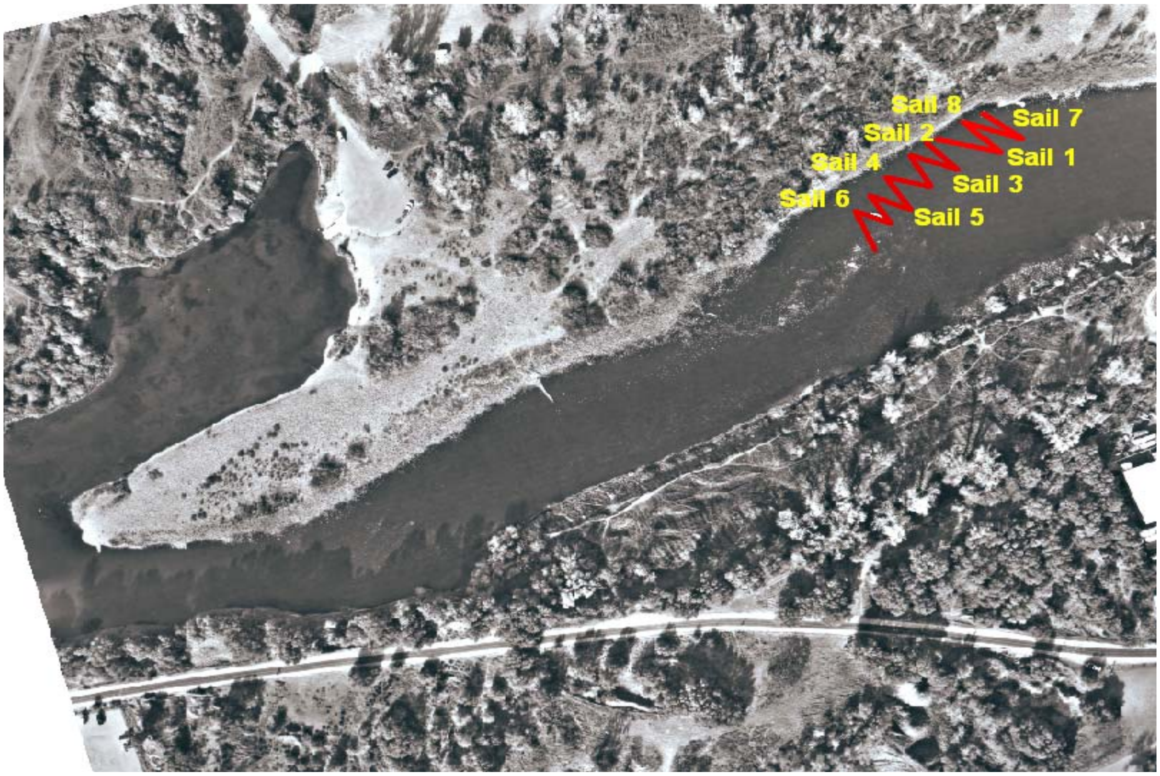

Figure 15: Map showing before gravel addition pebble count locations, August 2009.

Figure 17 shows a graph of the percent of each grain counted for the 8 pebble counts. The graph shows the majority of the gravel (75%) to be suitable for spawning. Figure 17 shows that 10% of the grains counted after gravel addition were greater than 2 1/2 inches in diameter.

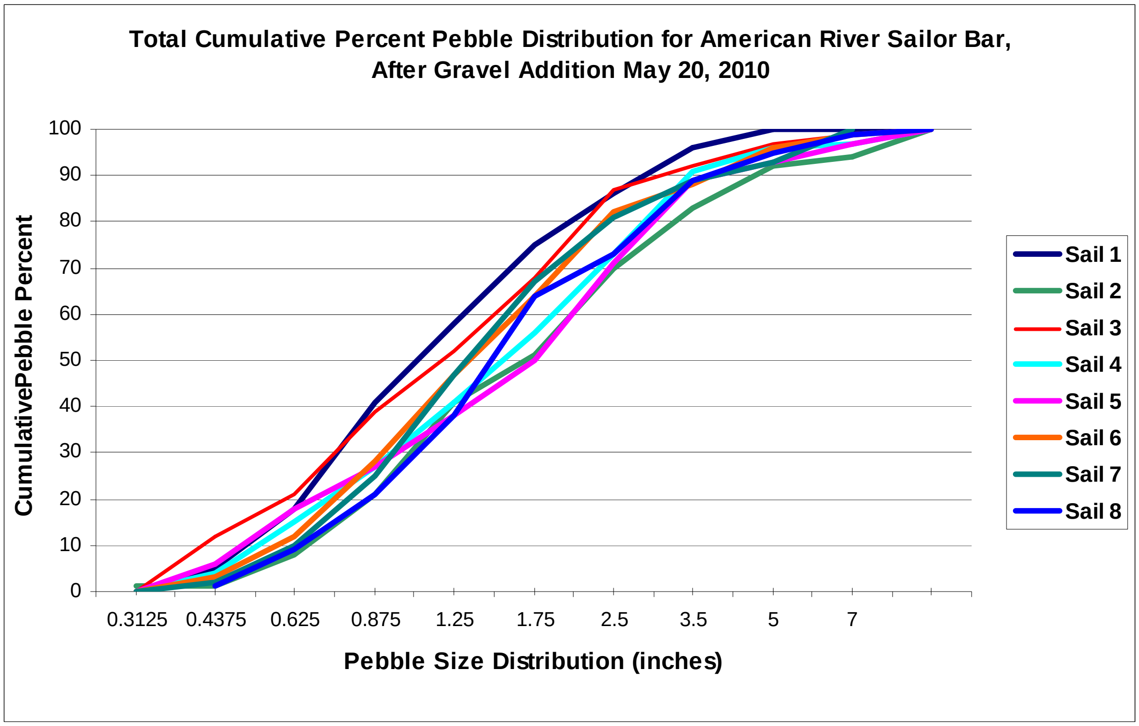

Figure 16: Graph showing the cumulative frequency of each pebble count, after gravel was added, May 2010.

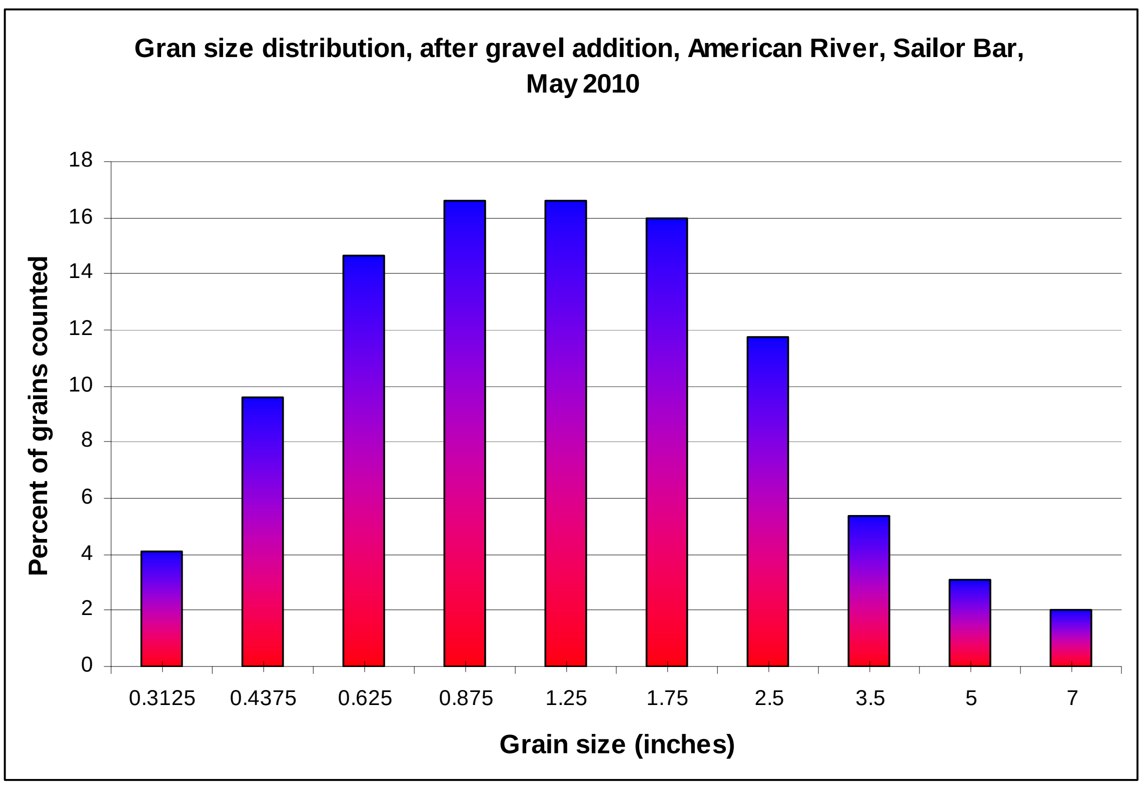

Figure 17: Graph showing the percent of the total grains counted from all pebble counts after gravel addition, May 2010.

4.12 After Gravel Addition Water Quality

Figure 18 shows the distribution of the mini piezometers after gravel addition. The mini piezometers installed in September 2009, were sampled in November 2009 and January 2010. Table 2 shows the water quality data from November 2009. Table 3 shows the water quality data from January 2010.

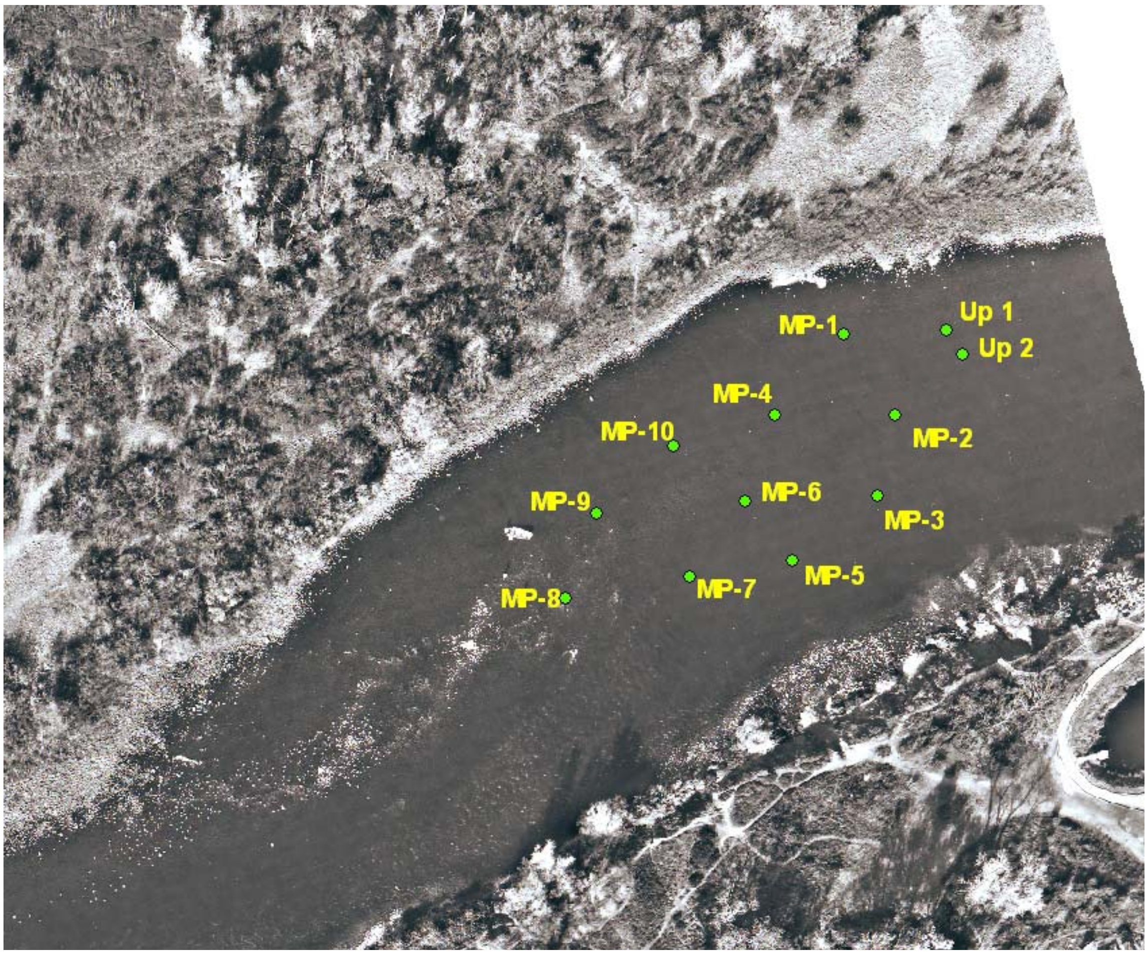

Figure 18: Map of the after gravel addition mini piezometer locations, installed September 2009.

Location	Temp (River)	Temp (well)	EC (ms)	pH	D.O. (mg/L)	Turbidity (NTU)
MP-1	14.6	14.6	50.0	7.2	10.9	7.2
MP-2	14.4	14.5	50.0	7.3	10.6	5.2
MP-3	14.8	14.9	49.8	7.2	11.02	5.3
MP-4	14.4	14.4	49.6	7.1	11.18	3.4
MP-5	14.3	14.3	49.8	7.2	11.06	6.8
MP-6	N/A	N/A	N/A	N/A	N/A	N/A
MP-7	14.2	14.2	50.3	7.3	11.76	4.8
MP-8	14.3	14.3	56.4	7.2	11.59	2.4
MP-9	N/A	N/A	N/A	N/A	N/A	N/A
MP-10	14.3	14.3	61.5	7.3	11.7	4.4
Mean	**14.5**	**14.5**	**52.2**	**7.2**	**11.2**	**4.9**
Up-1	14.3	14.3	64.9	7.2	11.6	3.8
Up-2	15.0	15.0	50.2	7.2	10.8	3.6
Surface 1	14.3	N/A	50.2	7.3	11.6	3.5
Surface 2	14.3	N/A	46.7	7.2	11.8	3.1

Table 2: Water quality data for the 2009 gravel addition after restoration work occurred. Data was collected November 2009.

Mean D.O. for the after gravel addition area was 11.2 mg/L. The upstream controls were inundated with gravel and became part of the gravel addition data. The values measured from both November and January both show very high levels of oxygen saturation in the mini piezometers. Discrepancies of 0.1 degrees Celsius were measured at MP-2 and MP-3. This location also showed increased temperature at 30 cm depths compared to the river water temperature in the before gravel addition measurements.

Location	Temp (River)	Temp (well)	EC (ms)	pH	D.O. (mg/L)	Turbidity (NTU)
MP-1	9.4	9.4	57.5	7.1	10.98	5.4
MP-2	9.3	9.3	57.5	7.03	10.93	4.6
MP-3	9.3	9.3	57.5	7.2	11.3	5.7
MP-4	9.4	9.4	57.8	7.2	11.56	4.0
MP-5	9.3	9.3	57.3	7.1	11.04	6.2
MP-6	9.3	9.4	57.4	7.1	12.2	4.8
MP-7	9.3	9.4	60.5	7.3	11.8	5.3
MP-8	N/A	N/A	N/A	N/A	N/A	N/A
MP-9	9.4	9.5	57.4	7.1	11.62	5.3
MP-10	9.3	9.3	62.1	7.2	11.67	4.1
Mean	**9.3**	**9.4**	**58.3**	**7.2**	**11.45**	**5.0**
Up-1	9.4	9.4	57.4	7.1	11.78	5.9
Up-2	N/A	N/A	N/A	N/A	N/A	N/A
Surface 1	9.3	N/A	57.5	6.9	10.85	2.86
Surface 2	9.3	N/A	58.7	7.1	12.1	2.91

Table 3: Water quality data for the 2009 gravel addition after gravel addition. Data was collected January 2010.

Parameters measured in January are similar to the measured values from November suggesting little change in the water quality of the gravel 4 months after the restoration work occurred. The D.O. values from table 3 are slightly over estimated due to colder temperatures during measurements in January. Mean pH (7.2) did not change; mean turbidity increased slightly from 4.9 to 5.0 NTU. Mean E.C. values ranged from 52.2 in

November to 58.3 in January. January data shows a slight temperature increase at different locations than the November sampling event.

4.13 After Gravel Addition Hyporheic Pressure Head Measurements

Hyporheic pressure was measured after gravel addition in November 2009 and January 2010. Figure 19 shows the November 2009 measurements. Figure 20 shows the January 2010 measurements. The majority of the mini piezometers showed upwelling conditions in both sampling events. Only MP-4 and MP-7 Showed downwelling conditions. Hyporheic gradient measurements ranged from 0.01 to 0.09 for upwelling and 0.03 for downwelling. Table 4 shows the hyporheic gradient data.

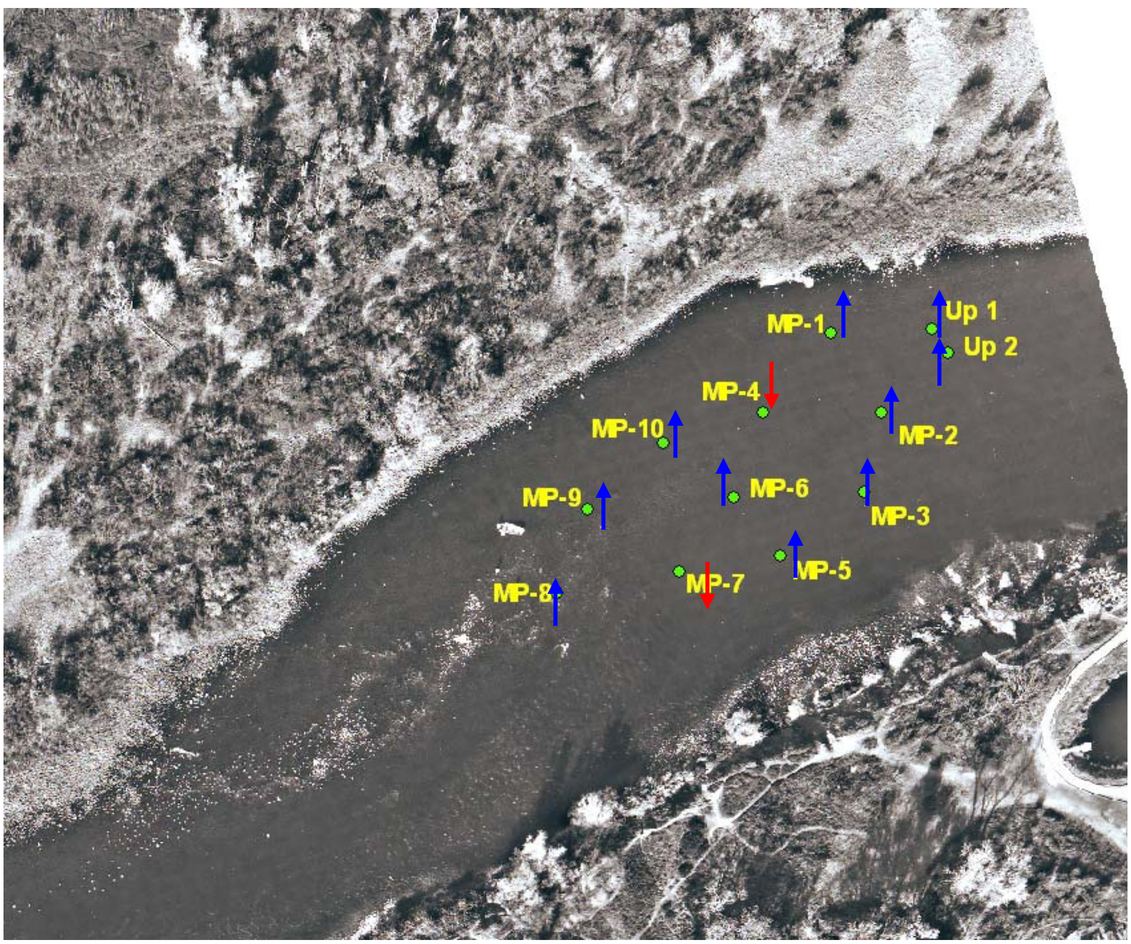

Figure 19: After gravel addition map showing the upwelling/downwelling conditions for the 2009 gravel addition. Data was collected November 2009.

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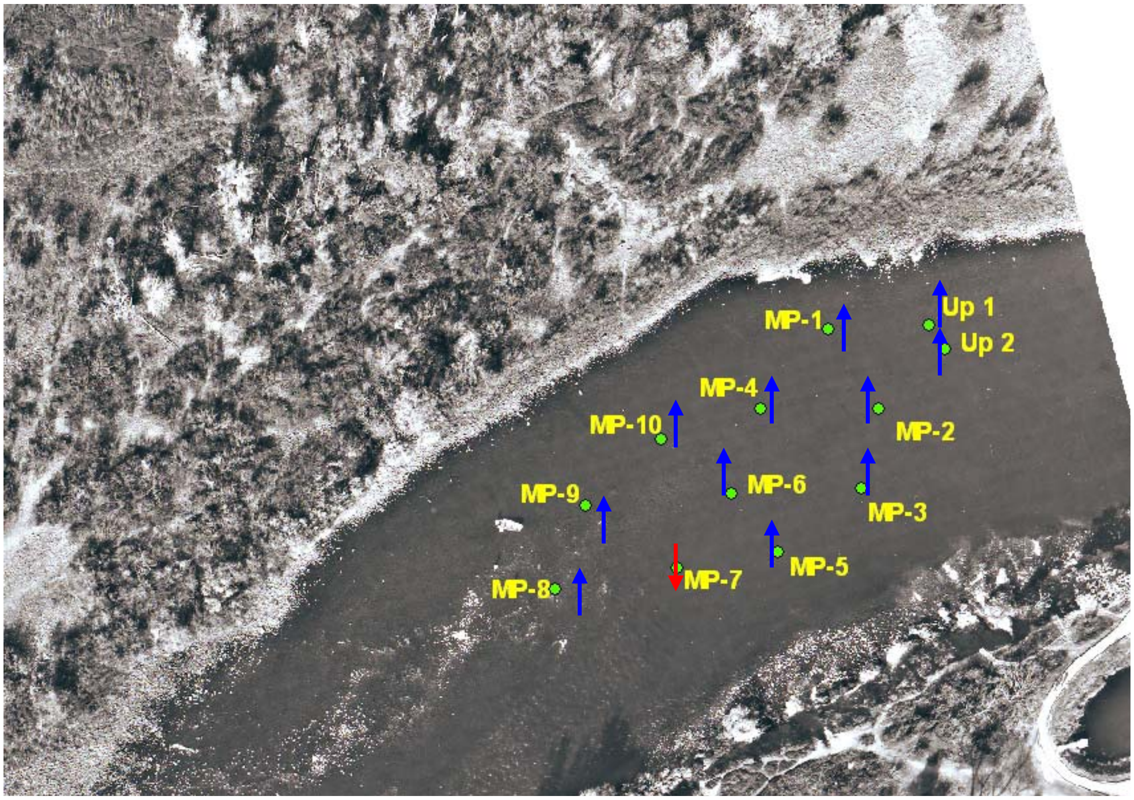


Figure 20: After gravel addition map showing the upwelling/downwelling conditions for the 2009 gravel addition. Data was collected January 2010.

Location	**Up/Down (November)**	**Gradient**	**Up/Down(January)**	**Gradient**
MP-1	upwelling	0.04	upwelling	0.02
MP-2	upwelling	0.04	upwelling	0.03
MP-3	upwelling	0.03	upwelling	0.02
MP-4	downwelling	-0.04	upwelling	0.01
MP-5	upwelling	0.03	upwelling	0.02
MP-6	upwelling	0.02	upwelling	0.02
MP-7	downwelling	-0.01	downwelling	-0.03
MP-8	upwelling	0.02	upwelling	0.01
MP-9	upwelling	0.09	upwelling	0.05
MP-10	upwelling	0.01	upwelling	0.02
Up-1	upwelling	0.02	upwelling	0.03
Up-2	upwelling	0.03	upwelling	0.01

Table 4: After gravel addition hyporheic gradient data, November 2009, and January 2010. Negative values indicate upwelling conditions.

4.14 After Gravel Addition Water Depth/Velocity

Water depth and velocity were measured after gravel addition in November 2009 and January 2010. River flows for the sampling events were 1600 cfs and 1900 cfs respectively. Table 5 shows the data recorded in November 2009. Table 6 shows the data recorded from January 2010. Mean depths were 1.6 feet for November and 1.5 feet for January. Velocity calculations show the mean velocity at the 0.6 depth for the November data to be 2.6 feet per second. The mean velocity at the 0.6 depth for the January data was 2.5 feet per second.

Location	**Depth (ft)**	**Velocity 0.6 ft (ft/sec)**	**Velocity 0.8 ft (ft/sec)**	**Velocity 0.2 ft (ft/sec)**
MP-1	1.5	2.92	3.51	2.15
MP-2	2.2	2.74	2.55	3.14
MP-3	1.7	3.66	4.13	2.74
MP-4	1.8	3.33	2.81	3.91
MP-5	1.7	0.16	0.16	0.09
MP-6	2.2	3.84	2.96	4.91
MP-7	1.2	1.49	1.34	1.38
MP-9	0.8	2.15	0.94	2.70
Up-1	1.8	2.30	3.88	1.49
Up-2	1.2	3.18	1.45	3.88
Mean	**1.6**	**2.6**	**2.4**	**2.7**

Table 5: After gravel addition depth and velocity data. November 2009, river flow was 1900 cfs.

Location	Depth (ft)	Velocity @ 0.6 ft (cfs)	Velocity @ 0.8 ft (cfs)	Velocity @ 0.2 ft (cfs)
MP-1	1.4	2.72	3.31	2.02
MP-2	2.0	2.67	2.43	3.03
MP-3	1.6	3.58	4.06	2.65
MP-4	1.6	3.22	2.77	3.83
MP-5	1.5	0.12	0.13	0.10
MP-6	2.0	3.69	2.88	4.83
MP-7	1.1	1.40	1.30	1.37
MP-9	0.7	2.11	0.92	2.64
Up-1	1.7	2.21	3.78	1.46
Up-2	1.1	3.11	1.38	3.82
Mean	**1.5**	**2.5**	**2.3**	**2.6**

Table 6: After gravel addition depth and velocity data. January 2010, river flow was1600cfs.

4.15 After Gravel Addition Inter Gravel Velocity

Five Salt water tracer tests were conducted in March 2010 and April 2010. Figure 21 shows the location of the tracer tests. All of the tests conducted showed immediate responses from the injected sodium chloride at 10cm distances from the injection well. Figures 22 and 23 show graphs of electrical conductivity versus time for tests 1 and test 2 . Appendix XX shows the data collected and additional E.C. versus time graphs.

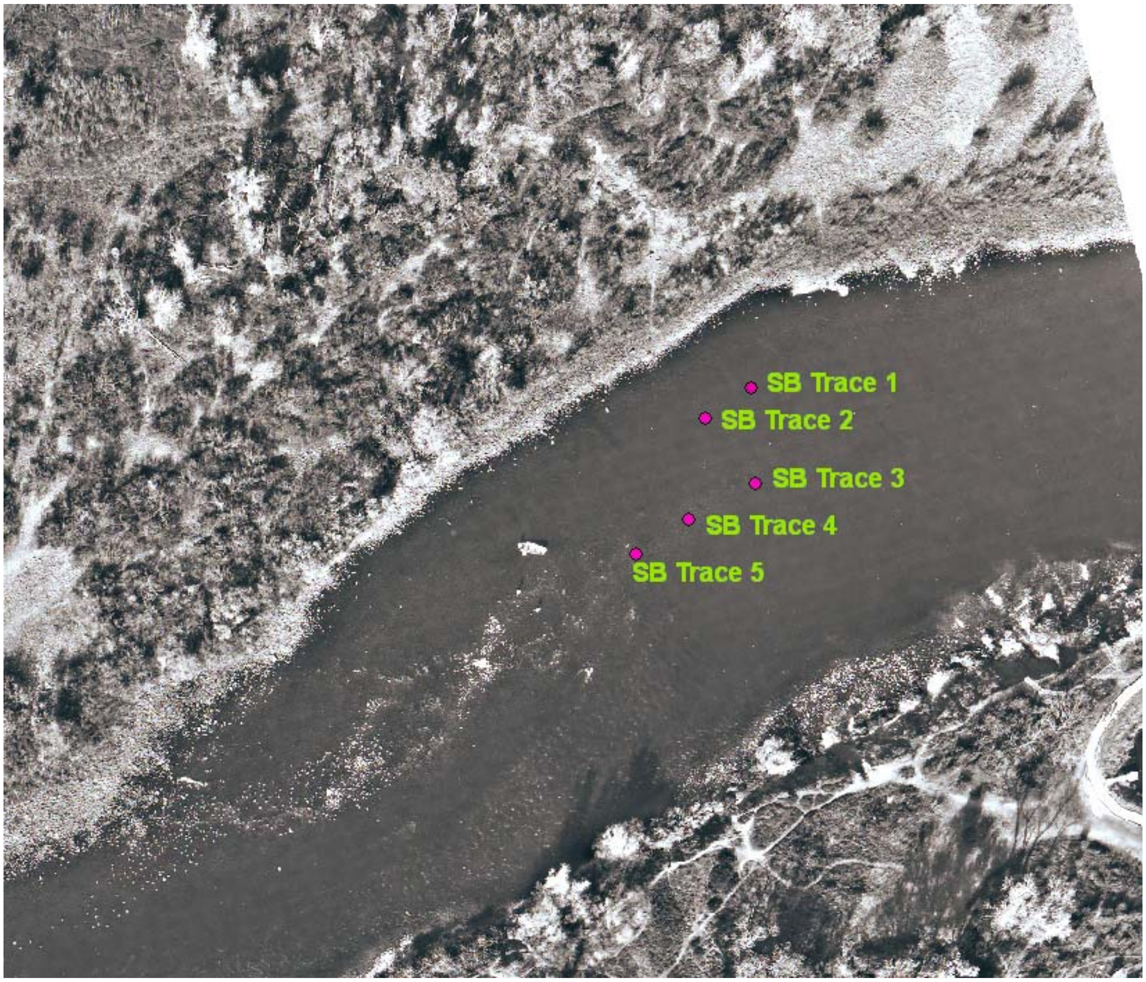


Figure 21: After gravel addition map of inter gravel velocity locations. SB Trace 1 and SB Trace 2 were conducted March 2010. SB Trace 3-5 were conducted April 2010.

Figures 22 and 23 show two of the tracer tests conducted in March 2010. Inter gravel velocities ranged from 8 cm/min to 36 cm/min for the first four tests. Test 5 showed velocity values ranging from 3 cm/min to 10cm/min. Tracer tests 1-4 showed an immediate response to the injected sodium chloride 10 cm from the injection well. Distances 50 cm or greater from the injection well showed a response to the sodium chloride in two of the five tests. Test 5 showed a monitoring well 80 cm from the injection well with elevated electrical conductivity levels.

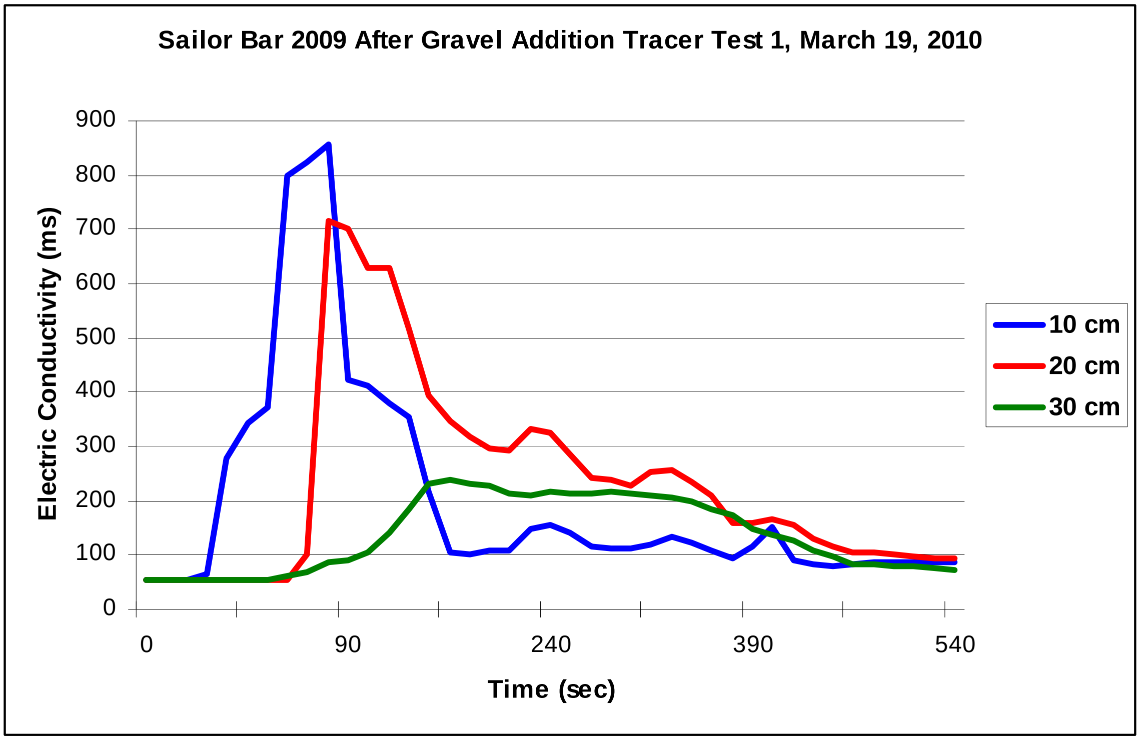


Figure 22: After gravel addition graph of electrical conductivity and time, March 2010.

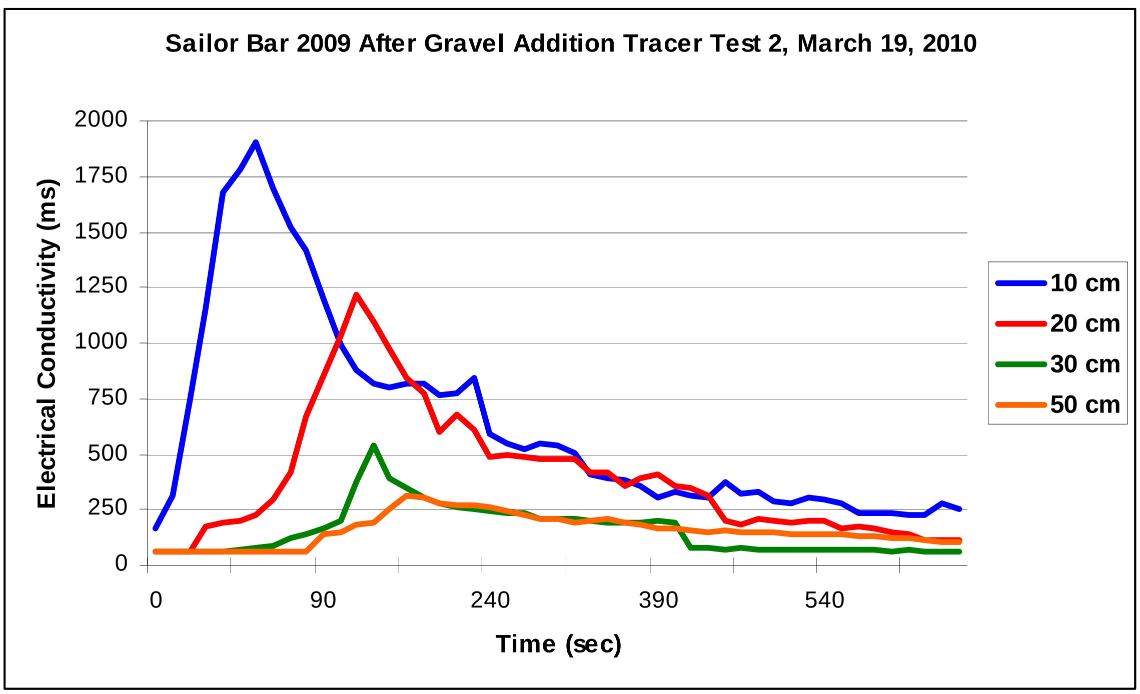


Figure 23: After gravel addition graph of electrical conductivity and time, March 2010.

4.16 After Gravel Addition Temperature Analysis

13 pairs of temperature loggers were deployed at the river bottom and 30cm into the gravel addition, and two additional pairs were installed upstream of the gravel addition to provide control data in October 2009. Figure 24 shows the location of the temperature loggers in the gravel addition. 6 pairs of loggers and the control loggers were uploaded in January 2010. Figures 25 and 26 show graphs from T-3 and T-9 showing a deviation of 0.05 degrees Celsius from the T-3 logger and variability up to 0.1 degrees Celsius for the T-9 logger between the 30 cm depth and the river bottom. Three (Up1, T-9, and T-10) of the loggers uploaded showed differences between the 30 cm depth and river bottom greater than 0.1 degrees Celsius.

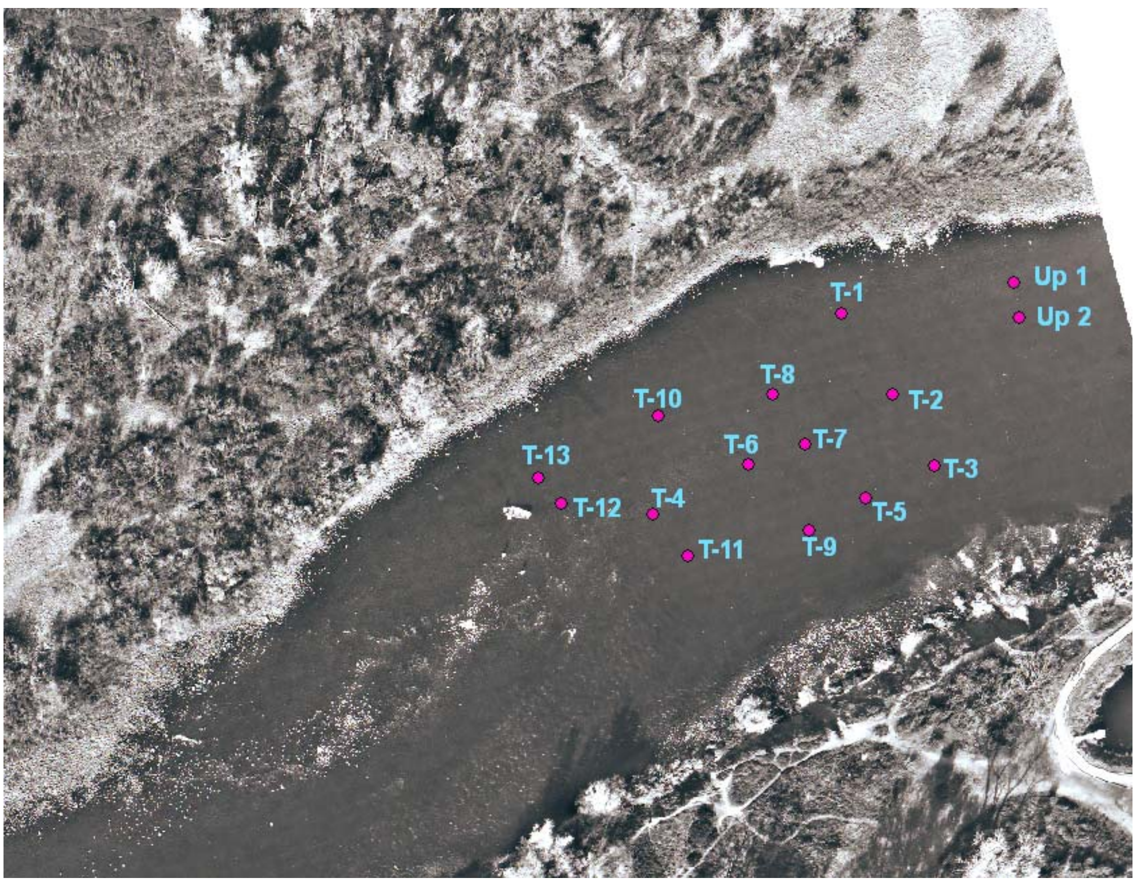


Figure 24: After gravel addition map of the temperature logger locations. Loggers were deployed in October 2009.

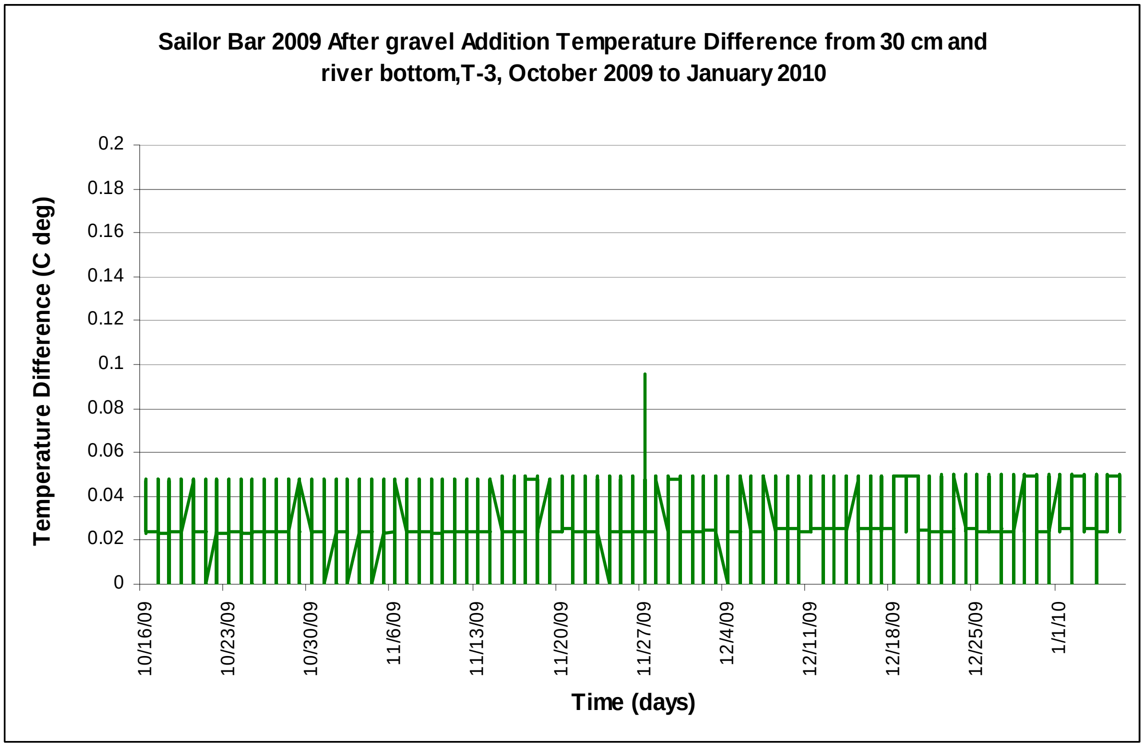


Figure 25: After gravel addition graph showing temperature differences between the 30 cm depth and the river bottom. Loggers were deployed in October 2009, uploaded in January 2010.

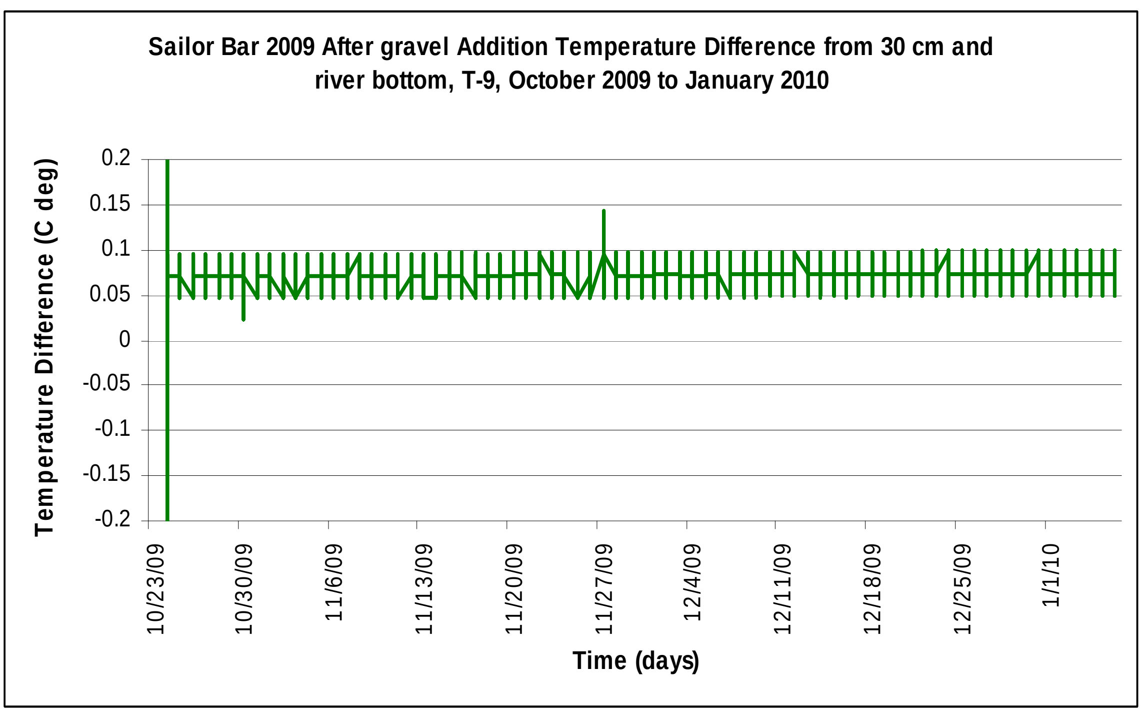


Figure 26: After gravel addition graph showing temperature differences between the 30 cm depth and the river bottom. Loggers were deployed in October 2009, uploaded in January 2010.

4.20 2008 Gravel Addition Gravel Mobility

Figure 27 shows the tracer rock transects installed after gravel addition in September 2008. Tracer rocks were located in Feb 2009, June 2009, and June 2010. The furthest downstream transect lost the southern 1/3 of the tracer rocks, almost immediately to a blowout or loss of gravel. The middle and upper transects also lost considerable rocks to either burial or movements by fish during the salmon redd building process during the 2008, and 2009 fall Chinook salmon runs. This was witnessed on multiple occasions by the field crew. Substantial numbers of yellow and blue rocks were located 18 months after the gravel addition was completed. The upper transect recovered 11 large (yellow, 2 ½ -3 inch) rocks, 2 intermediate-sized (blue, 1 ¼ - 1 ¾ inch) and 1 small-sized (red, 5/8 – 7/8 inch) rocks. The middle transect recovered 11 large rocks, 3 blue rocks and 1 red rocks. Only 4 rocks from the lower transect were located.

After 18 months, and flows up to 5000 cfs. Most of the yellow rocks did not move. There was minor movement of yellow rocks in the high velocity portion of the gravel addition. The middle transect showed a similar pattern, and the downstream transect was either buried or washed out. Few rocks were located from the downstream transect. Blue tracer rocks were mobile in the upper and middle transects, moving up to 20 meters. Red tracer rocks moved the furthest and yielded the smallest number of rocks located due to burial or removal from the area. Figure 27 shows that only a few of the tracer rocks located in June 2010 had moved from the previous June. 26 out of 120 yellow rocks were located, 4 out of 120 blue rocks, and 2 out of 120 red rocks were located.

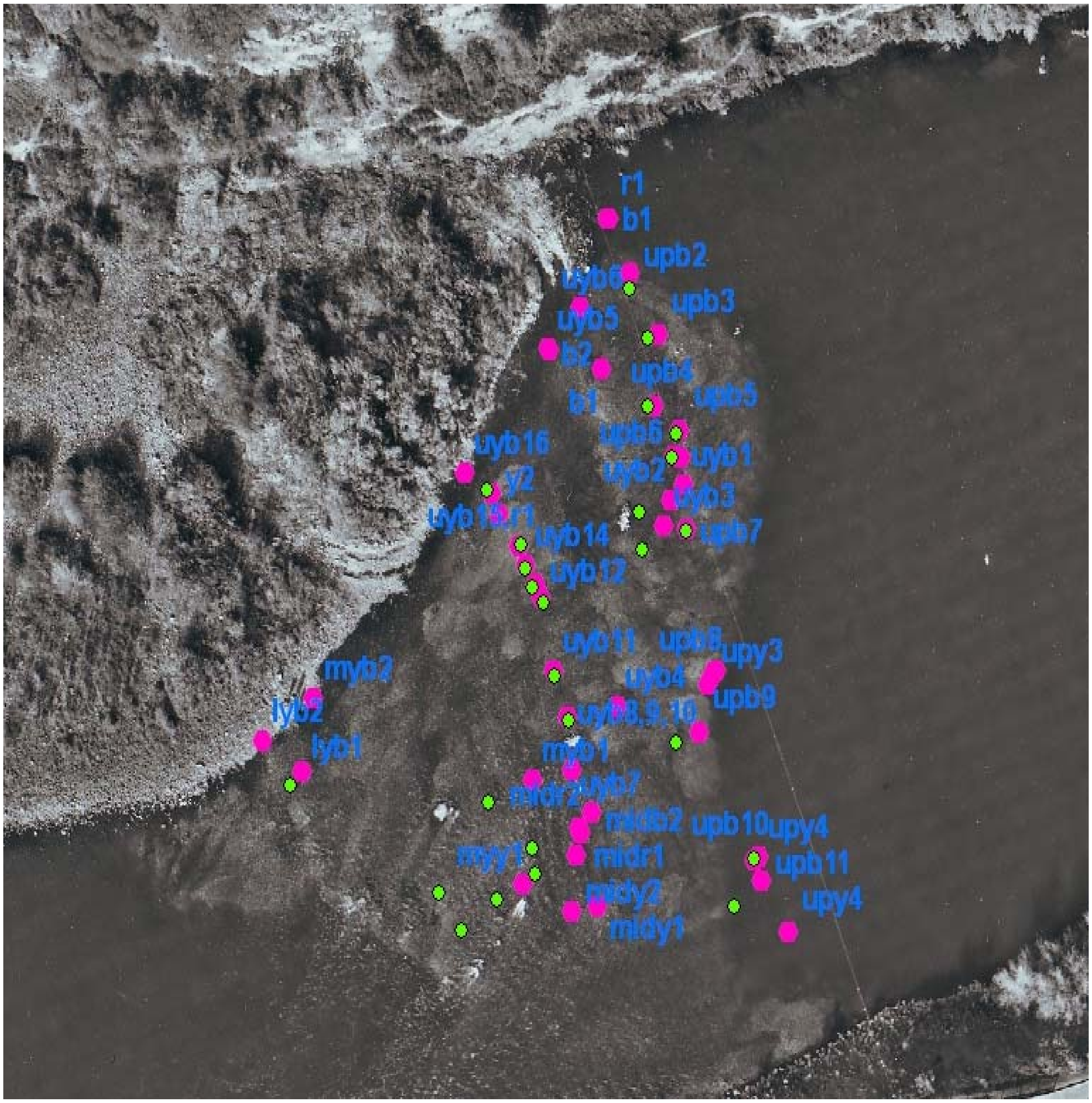


Figure 27: After gravel addition map showing the tracer rock transects from June 2009 in pink. Green points indicate tracer rocks identified in June 2010.

4.21 2008 Gravel Addition Water Quality

Figure 28 shows a map of the mini piezometer locations from the 2008 gravel addition. Mini piezometers were sampled in November 2009 and January 2010. Tables 7 and 8 show the data from November and January respectively. Mean D.O. from November 2009 was 7.4 mg/L. Mean E.C. was 47.1 ms/cm, mean pH was 6.9, and mean turbidity was 9.1 NTU. Mean D.O. from the January sampling event was 11.1 mg/L. D.O. values are slightly inflated from colder water temperatures. Mean E.C. from the January 2010 sampling event was 57.7 ms/cm, mean turbidity was 4.95 NTU, and mean pH was 7.1.

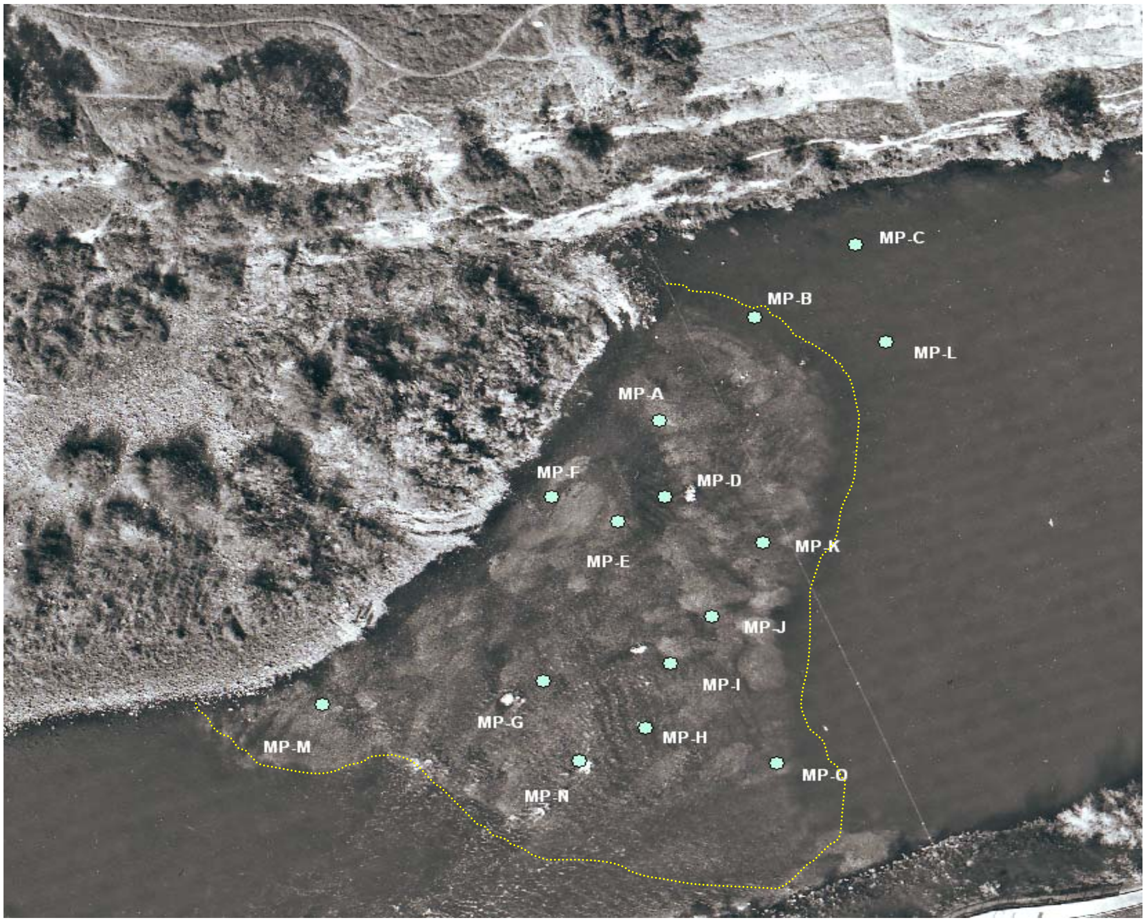


Figure 28: After gravel addition map showing the gravel addition area. Points indicate mini piezometer locations. MP C and MP L are upstream of the gravel to provide control measurements.

Location	Temp (River)	Temp (well)	EC (ms)	pH	D.O. (mg/L)	Turbidity (NTU)
MP-A	16.1	16.2	46.2	6.84	7.0	2.4
MP-B	16.1	16.1	46.9	6.85	8.02	2.6
MP-C	16.1	16.1	47.6	6.72	8.83	13.5
MP-D	15.8	15.9	46.6	6.98	7.05	4.17
MP-E	15.5	15.5	44.8	6.81	8.11	4.2
MP-F	16.1	16.1	48.5	6.96	6.7	6.5
MP-G	15.6	15.6	46.8	6.98	8.04	4.03
MP-H	15.8	15.8	46.6	7.11	8.34	5.6
MP-I	15.7	15.7	49.6	7.07	8.74	3.6
MP-J	16.0	16.0	46.5	6.99	6.01	22.0
MP-K	16.1	16.1	48.1	6.61	8.3	33.2
MP-L	16.3	16.3	47.1	7.32	3.8	15.6
MP-M	16.0	16.0	46.4	6.96	7.72	1.56
MP-N	N/A	N/A	N/A	N/A	N/A	N/A
Mean	**15.9**	**15.9**	**47.1**	**6.9**	**7.4**	**9.1**
Surface 1	16.1	N/A	46.2	6.95	8.73	2.5
Surface 2	16.0	N/A	46.4	6.93	8.7	2.71

Table 7: Water quality data for the 2008 gravel addition. Data was collected November 2009.

Location	Temp (River)	Temp (well)	EC (ms)	pH	D.O. (mg/L)	Turbidity (NTU)
MP-A	9.3	9.3	57.6	6.98	11.53	4.4
MP-B	Too many redds	Too many redds	Too many redds	Too many redds	Too many redds	Too many redds
MP-C	9.1	9.1	57.8	6.94	12.1	2.6
MP-D	N/A	N/A	N/A	N/A	N/A	N/A
MP-E	9.3	9.3	57.7	7.1	11.64	7.4
MP-F	9.2	9.2	57.2	7.1	10.62	6.0
MP-G	9.2	9.2	57.8	7.06	10.55	5.6
MP-H	N/A	N/A	N/A	N/A	N/A	N/A
MP-I	9.2	9.2	58.0	7.2	11.02	4.2
MP-J	9.2	9.2	57.5	7.06	9.00	5.2
MP-K	9.2	9.2	58.0	7.13	11.70	5.8
MP-L	N/A	N/A	N/A	N/A	N/A	N/A
MP-M	9.2	9.2	57.5	7.03	11.77	3.4
Mean	**9.2**	**9.2**	**57.7**	**7.1**	**11.1**	**4.95**
Surface 1	9.3	N/A	57.8	7.05	11.77	3.4
Surface 2	9.3	N/A	58.7	7.1	12.1	2.9

Table 8: Water quality data for the 2008 gravel addition. Data was collected January 2010.

4.22 2008 Gravel Addition Hyporheic Pressure Head Measurements

Figure 28 shows a map of the upwelling and downwelling conditions measured in November 2009 and January 2010. Table 9 shows the gradient values measured from each location.

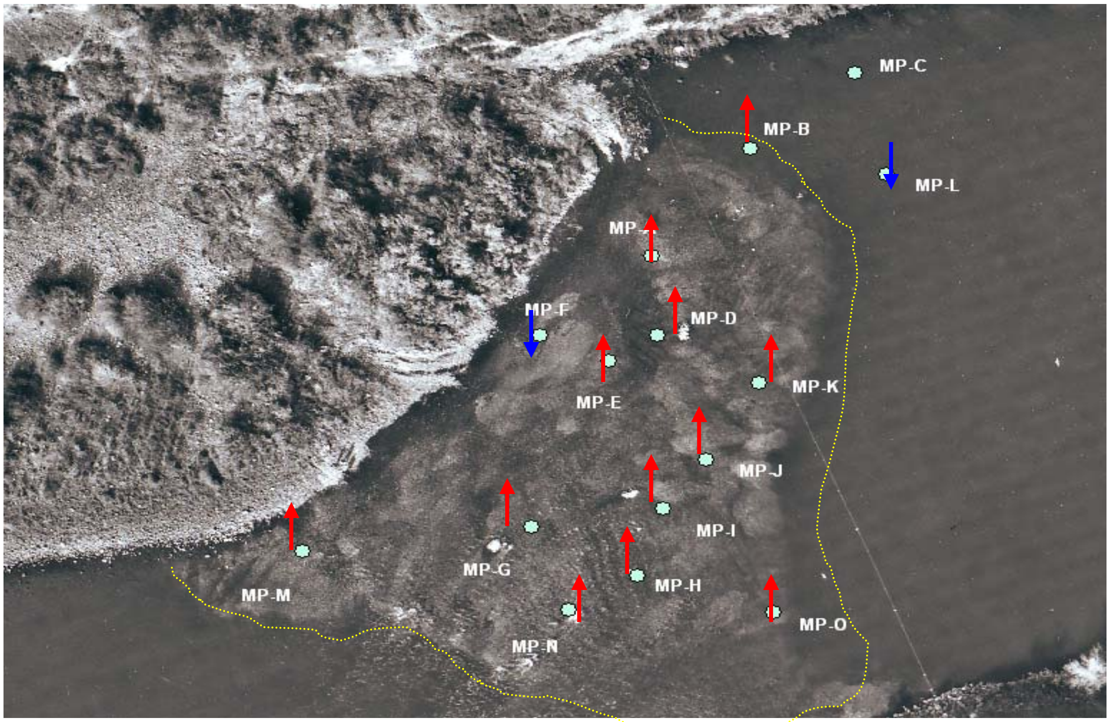


Figure 29: 2008 Gravel Addition map showing upwelling and downwelling measurements from November 2009 and January 2010.

Location	Up/Down	Gradient
MP A	Up	.02
MP B	Up	.01
MP C	Even	0
MP D	Up	.02
MP E	Up	.06
MP F	Down	-02
MP G	Up	.02
MP H	Up	.05
MP I	Up	.06
MP J	Up	.05
MP K	Up	.03
MP L	Down	-01

Table 9: Gradient values from November 2009 January 2010, negative values indicate downwelling.

4.23 2008 Gravel Addition Water Depth/Velocity Measurements

Table 10 shows the water depth and velocity measurements for the 2008 gravel addition measured in November 2009 and January 2010. The river flow in November 2009 was 199 cfs, river flow in January 2010 was 1620 cfs.

Location	**Depth (ft)**	**Velocity 0.6ft (ft/sec)**	**Velocity 0.8ft (ft/sec)**	**Velocity 0.2ft (ft/sec)**
MP-A	1.7	1.26	1.09	1.30
MP-B	1.8	1.11	0.75	1.51
MP-C	1.6	0.93	0.77	1.28
MP-E	2.3	2.47	2.24	2.60
MP-F	2.0	2.55	2.20	2.54
MP-G	3.4	2.92	2.27	3.08
MP-I	2.6	3.31	2.45	2.99
MP-J	2.3	2.52	1.99	2.79
MP-K	1.7	3.39	2.41	3.34
MP-L	3.3	0.75	0.57	1.02
MP-M	3.1	1.89	1.49	2.29
Mean	**2.3**	**2.1**	**1.7**	**2.3**

Table 10: Depth and velocity data for the 2008 gravel addition mini piezometers.
Data was collected in November 2009, river flow was 1900 cfs.

Location	Depth (ft)	Velocity 0.6ft (ft/sec)	Velocity 0.8ft (ft/sec)	Velocity 0.2ft (ft/sec)
MP-A	1.5	1.19	1.05	1.23
MP-B	1.8	1.05	0.68	1.45
MP-C	1.5	0.86	0.72	1.19
MP-E	2.1	2.33	2.19	2.52
MP-F	1.9	2.48	2.15	2.44
MP-G	3.2	2.77	2.19	2.92
MP-I	2.5	3.03	2.41	2.85
MP-J	2.2	2.44	1.93	2.63
MP-K	1.5	3.29	2.33	3.10
MP-L	3.2	0.72	0.50	0.86
MP-M	2.9	1.78	1.38	2.11
Mean	**2.2**	**2.0**	**1.6**	**2.1**

Table 11: Depth and velocity data for the 2008 gravel addition mini piezometers. Data was collected in January 2010, river flow was 1620 cfs.

The data from table 9 shows a mean depth of 2.3 feet and an average velocity at the 0.6 depth of 2.1 feet per second for the November 2009 sampling event. The January sampling event showed a mean depth of 2.2 feet and an average velocity at the 0.6 depth of 2.0 feet per second.

4.24 2008 Gravel Addition Inter Gravel Velocity

Two salt water tracer tests were conducted in April 2010 at the 2008 gravel addition. Figure 29 shows the location of tracer tests conducted. Figures 30 and 31 show graphs of conductivity versus time for the tracer tests. Inter gravel velocities ranged from 5 cm/min to 33 cm/min. Test 2 showed monitoring well response 48 cm from the injection well. The 10 cm monitoring wells showed a response to the sodium chloride immediately following injection.

Figure 30: Map showing the 2008 gravel addition with April 2010 inter gravel velocity test locations.

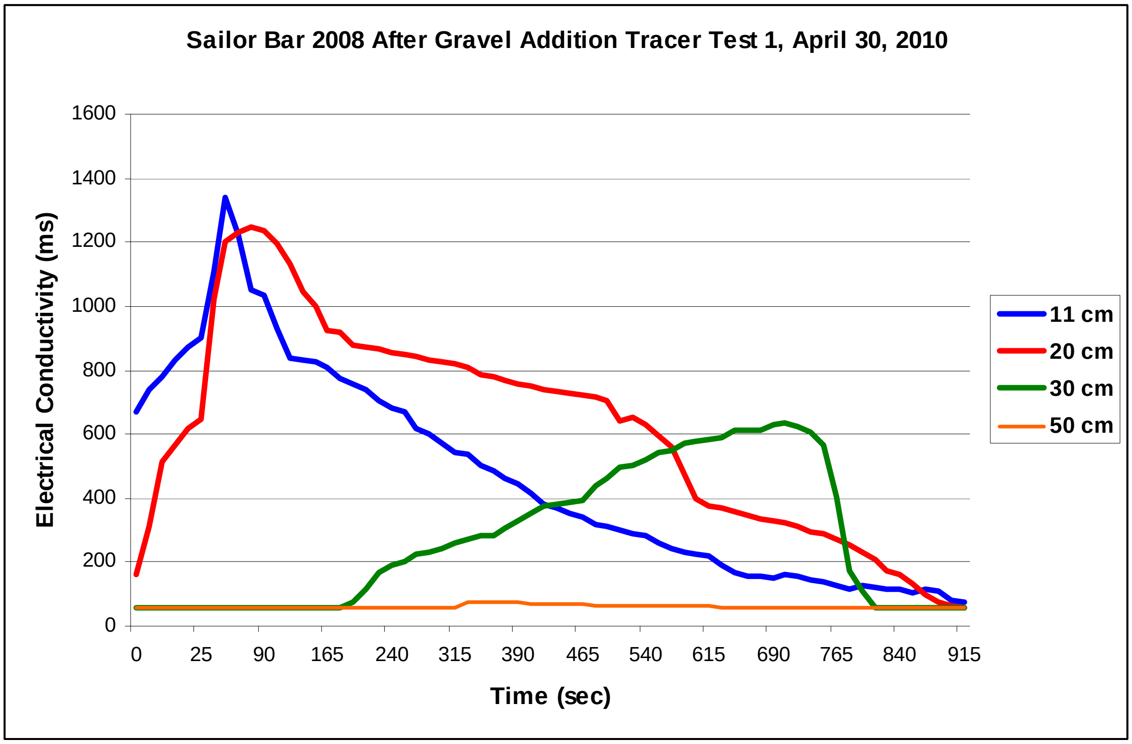


Figure 31: Electrical conductivity versus time graph of a salt water tracer test from Sailor Bar 2008 gravel addition, April 2010.

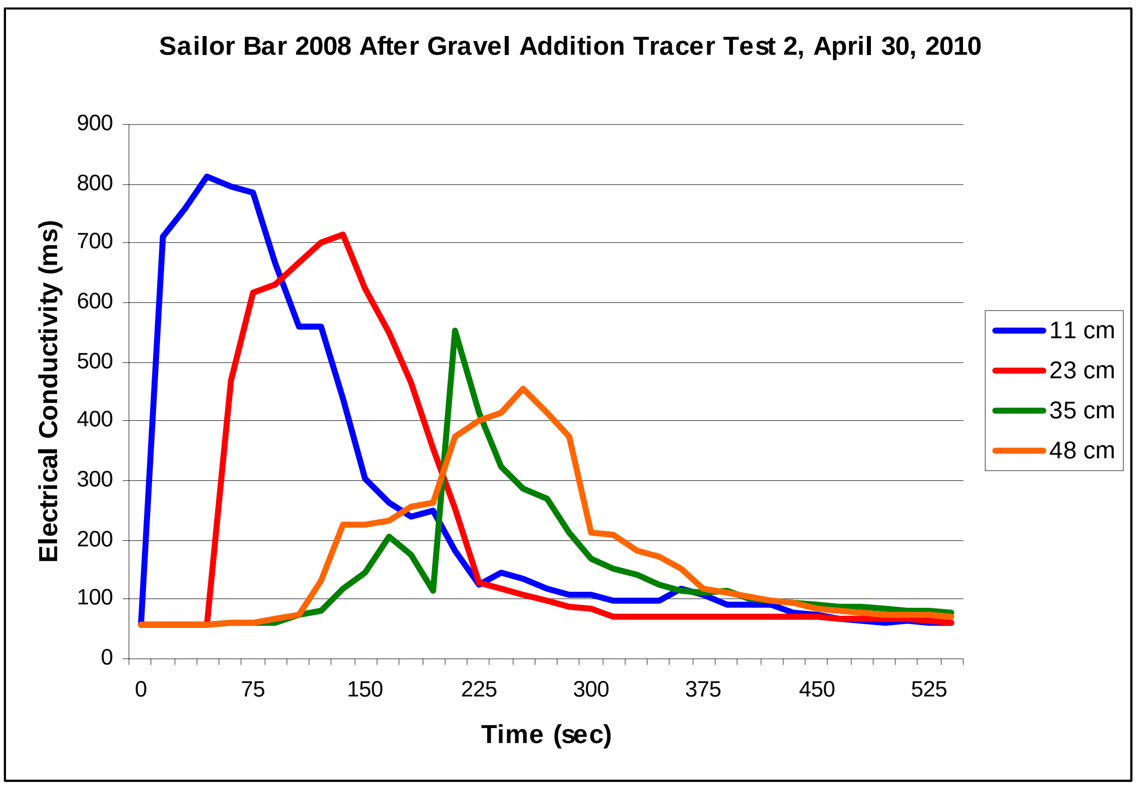


Figure 32: Electrical conductivity versus time graph of a salt water tracer test from Sailor Bar 2008 gravel addition, April 2010.

5.0 Discussion

All of the parameters studied in this report changed as a result of the addition of the gravel at the Sailor Bar location. Several of these changes had significant impacts on the spawning habitat. The most significant changes were the changes associated with a more uniform gravel size of 80% less than 1.25 inch gravel from the previous grains sizes that ranged from .325 inches to over 12 inches intermediate diameter. The improvement in the consistency of the dissolved oxygen measurements in the gravel area are another improvement to spawning habitat.

The D.O. measurements increased by a factor of 10 at some locations in the study area with the pH and Electrical conductivity becoming more uniform with less than 1% deviation in the measurements for E.C. and 15% for the pH.

Tracer rocks showed that the smallest tracer rocks inserted into the gravel addition were washed away from the study area from this year's maximum flow of 5000 cfs. Many of the middle and largest size rocks were able to be found inside of the gravel area 8 months after the rocks were inserted.

Preliminary work with salt water tracer tests has shown the up stream portion of the gravel addition to be highly permeable with values of 1.2 feet/min to 2.5 feet/min. These times indicate rapid movement of water between the pore spaces in the tested locations.

The physical and hydrologic measurements conducted at the Sailor Bar gravel addition site indicate a positive affect in terms of improving spawning habitat and the hydrologic conditions that govern the movement of water and oxygen through the pore spaces in the gravel addition. The gravel addition has also had a stabilizing affect on the pH, electrical conductivity, and temperature.

Personal observation during field work in the gravel addition during spawning times showed that over 70% of the gravel addition area was being used for spawning purposes. The salmon were able to move the gravel to build redds with relative ease compared to previous years with embedded rocks with possibly much larger grain sizes. Improved geochemical conditions will give the salmon an improved chance of spawning success.

References

Bush, N.J. 2006. Natural water chemistry and vertical hydraulic gradient in the hyporheic zone of the Cosumnes River near Sacramento, CA. M.S. thesis. CSUS.

Castleberry, D.T., J.J. Cech, Jr., M.K. Saiki, and B.A. Martin. 1993. Growth, condition and physiological performance of juvenile salmonids from the American River. US. Fish and Wildlife Service, Dixon, CA.

Fairman, D. 2007. A gravel budget for the Lower American River. M.S. thesis. CSUS.

Horner, T.C. 2005. Physical and geochemical characterization of American River spawning gravels. Report to the US Bureau of Reclamation, Sacramento Office.

Horner, T.C., R. Titus, and M. Brown. 2004. Phase 3 gravel assessment on the lower American River: Report to the US Bureau of Reclamation Sacramento Office.

Kondolf. G. M.. M. J. Sale and M, G. Wolman. 1993. Modification of gravel size by spawning salmonids. Water Resources Research 29:2265-2274.

Kondolf, G. M.. and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29:2275-2285.

Morita, E. 2005. The relationship between streambed topography, hyporheic flow, and pore water geochemistry in salmon spawning gravels of the American River, Sacramento. Master's thesis, California State University Sacramento.

Merz, J.E. and Vanicek C.D. 1996. Comparative feeding habitats of juvenile Chinook salmon , steelhead, and Sacramento squawfish in the lower American River, California.

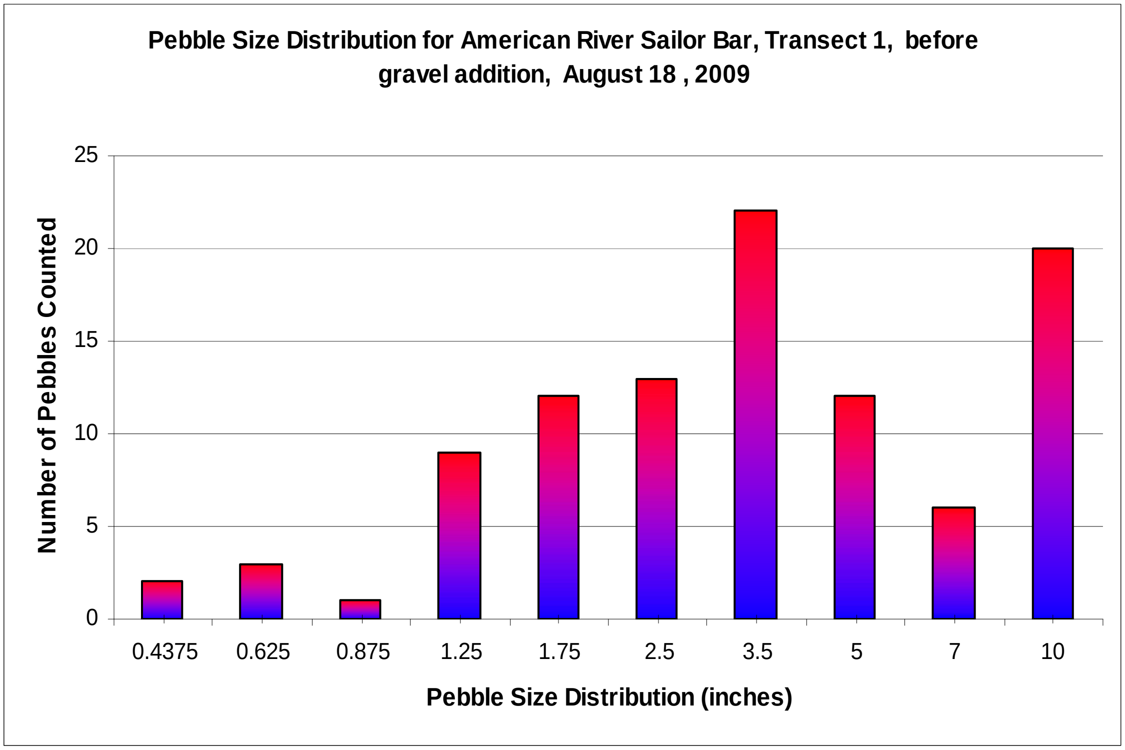
Snider, B., Christophel, D.B., Jackson, B.L., and Bratovitch, P.M., 1992, Habitat characterization of the Lower American River, California Department of Fish and Game, Environmental Services Division in cooperation with Beak Consultants and the county of Sacramento, California, Unpublished report, 20 p.

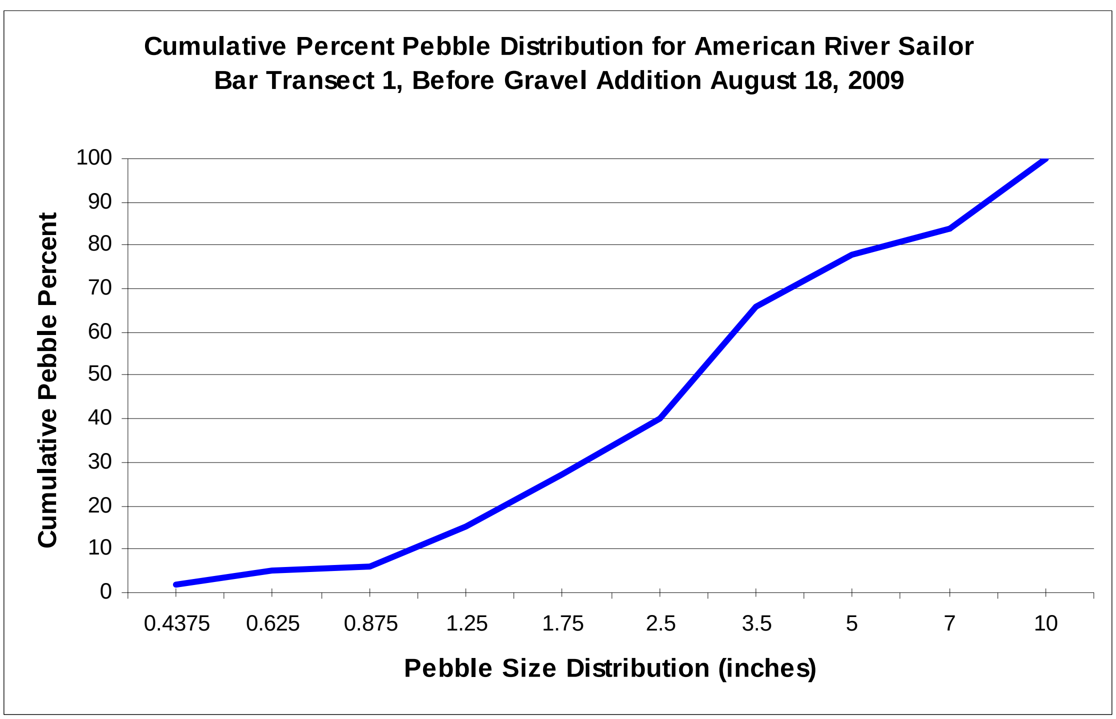
Wolman, M. G. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union 35:951-956.

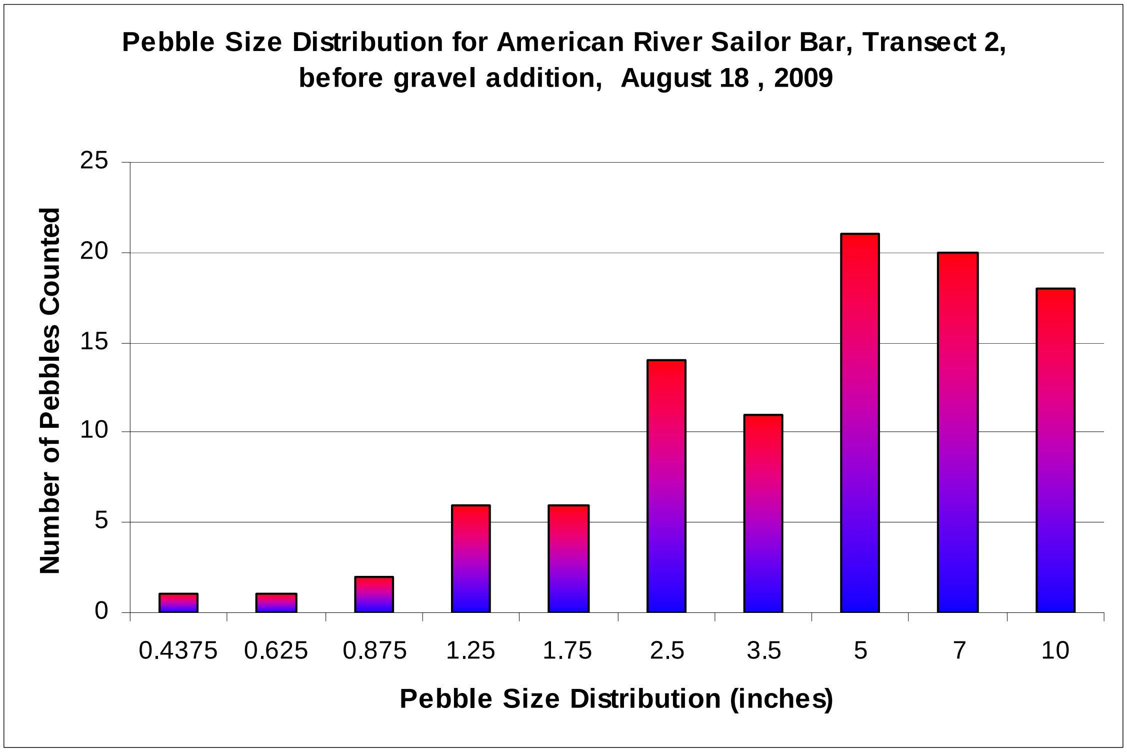
Vyverberg, K., Snider, B., and Titus, R.G., 1997, Lower American River Chinook Salmon spawning habitat evaluation October 1994: California Department of Fish and Game Environmental Services Division Technical Report Number 97-2, 112 p.

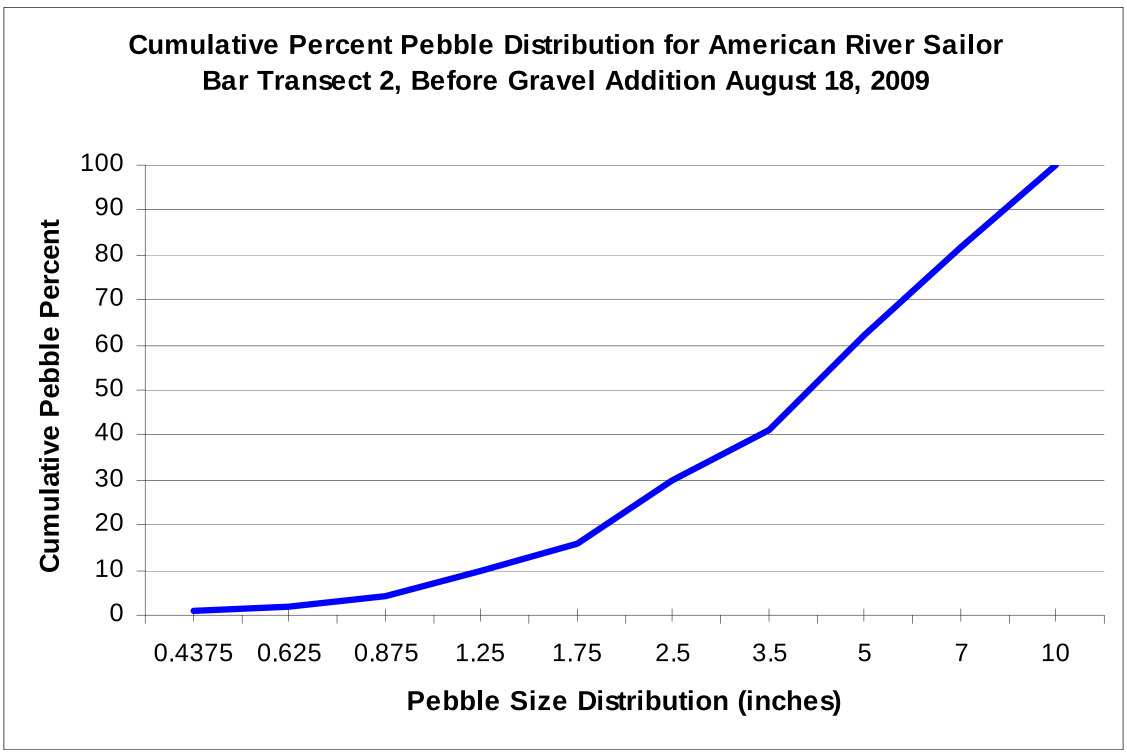
Zamora, C. 2006. Estimating rates of exchange across the sediment/water interface in the lower Merced River, CA. M.S. thesis. CSUS.

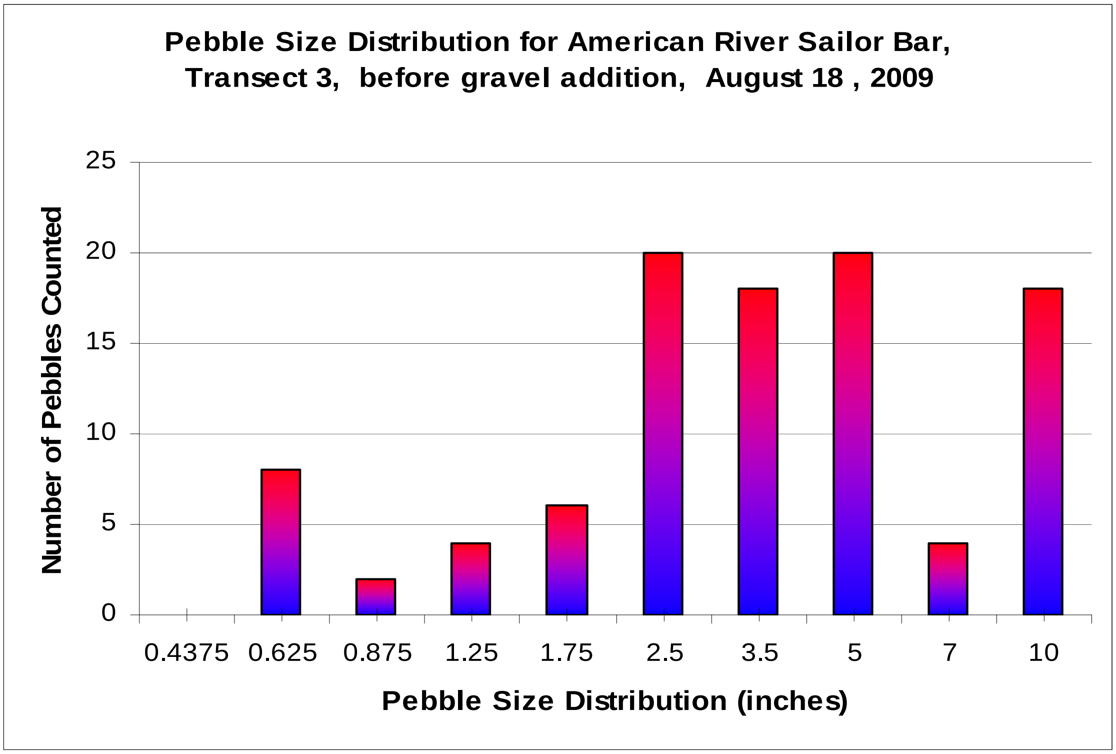
Appendix A: Before gravel addition pebble counts

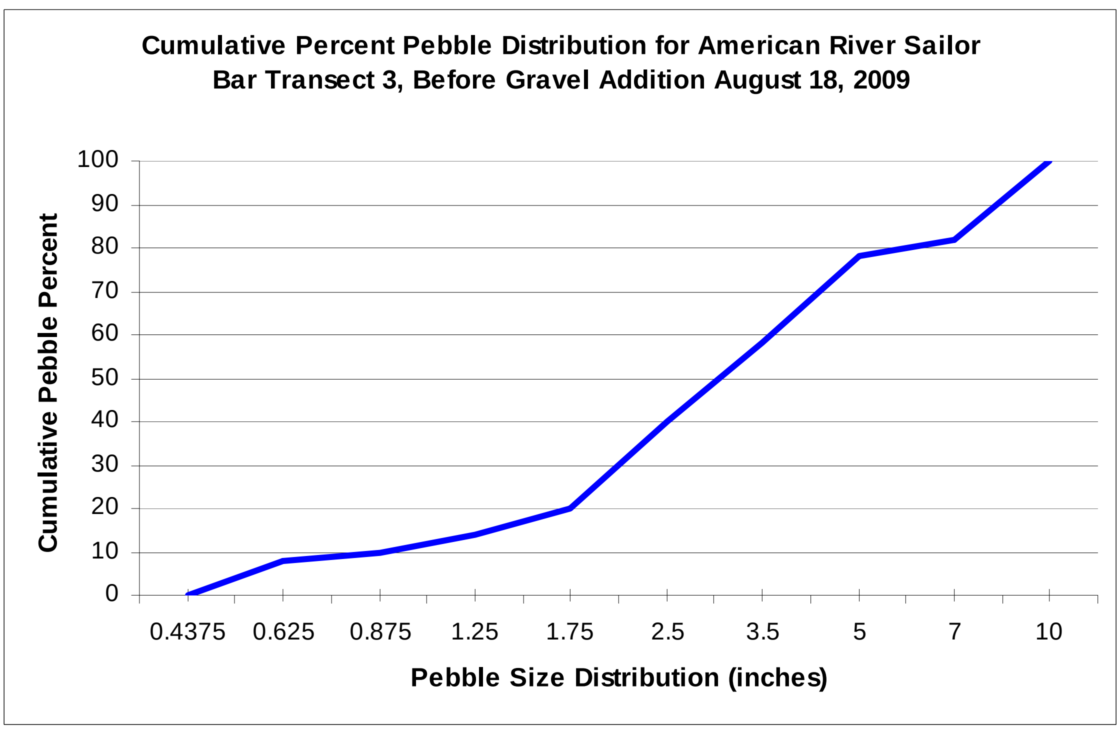

Pebble Size Distribution for American River Sailor Bar, Transect 1, before gravel addition, August 18 , 2009
Number of Pebbles Counted
0
5
10
15
20
25
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

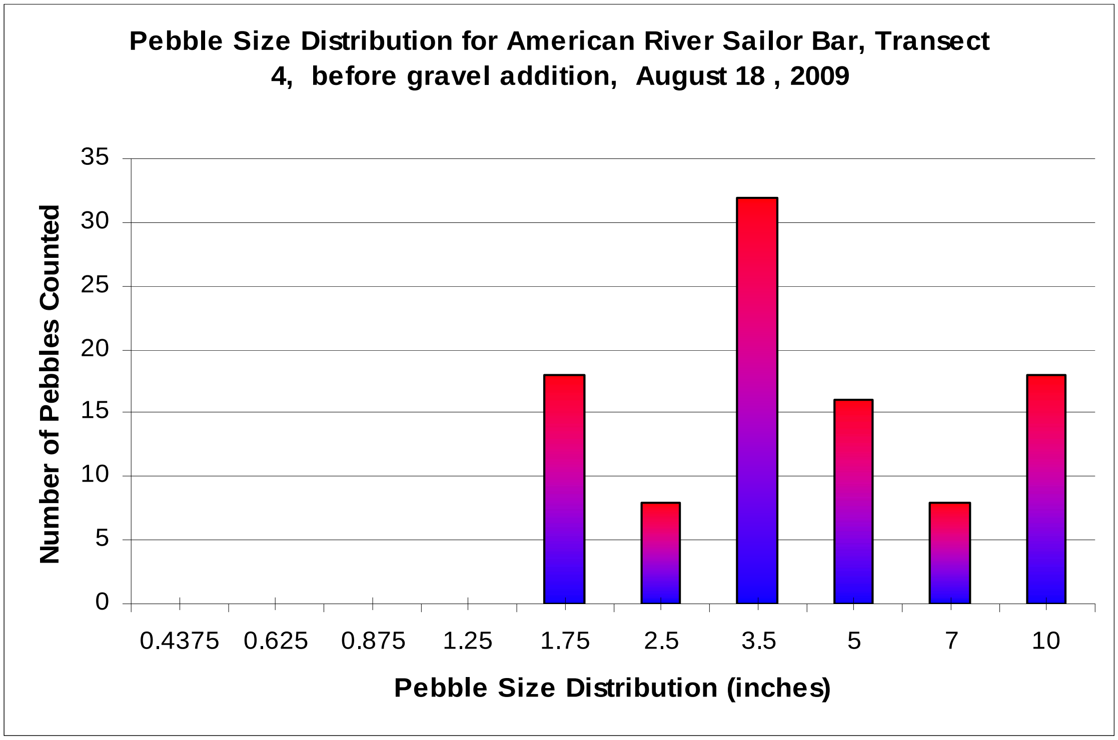

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 1, Before Gravel Addition August 18, 2009
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

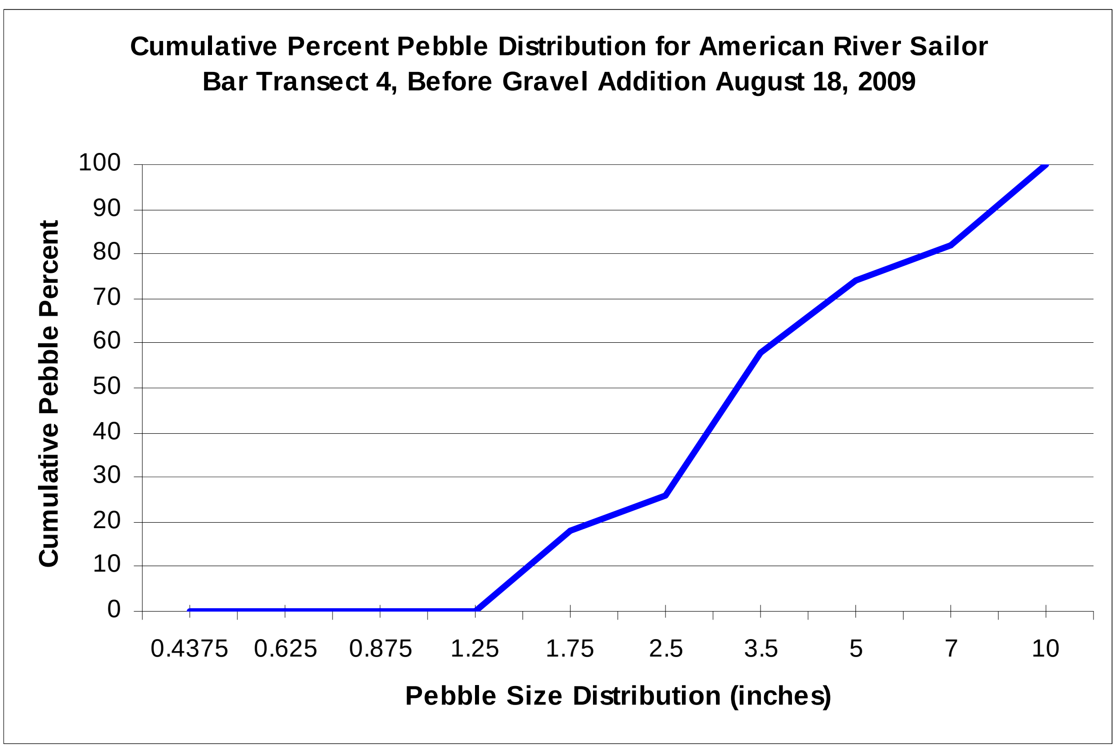

Pebble Size Distribution for American River Sailor Bar, Transect 2, before gravel addition, August 18 , 2009
Number of Pebbles Counted
25
20
15
10
5
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

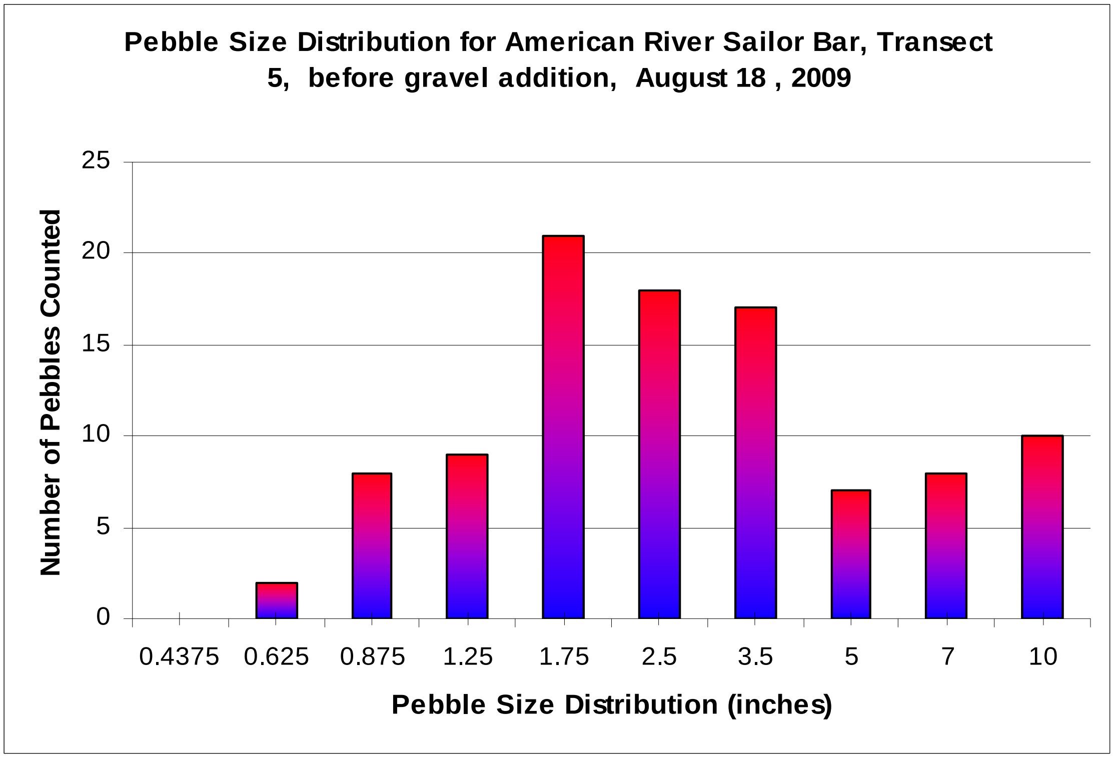

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 2, Before Gravel Addition August 18, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

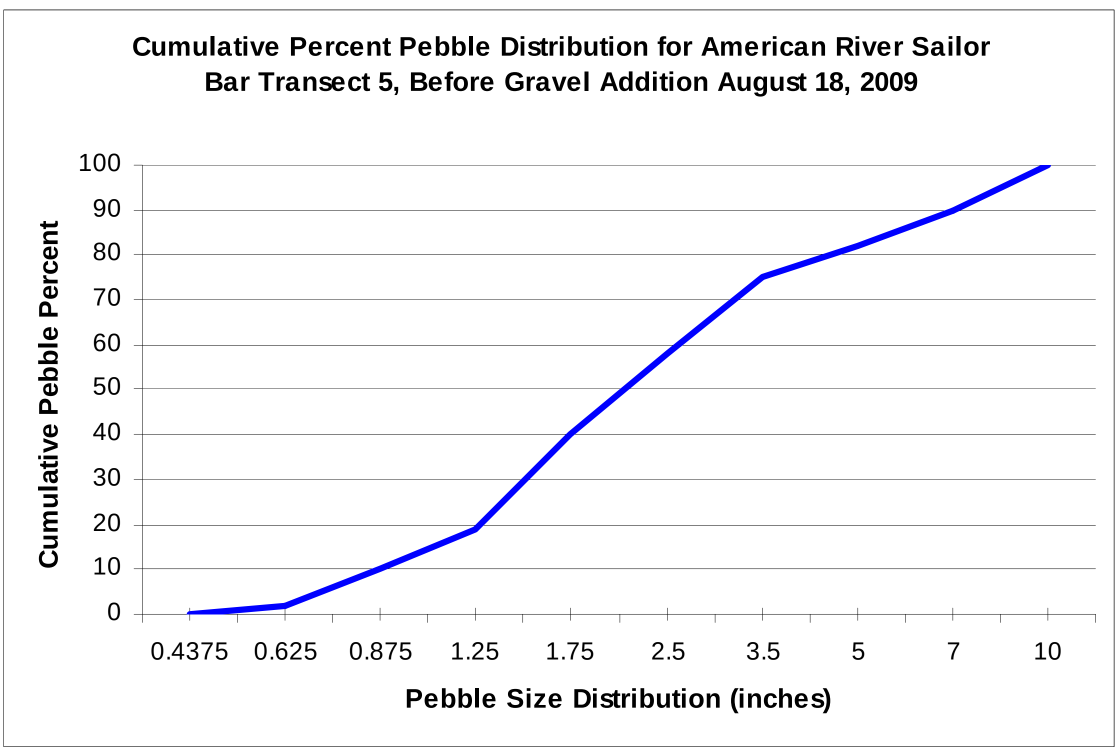

Pebble Size Distribution for American River Sailor Bar,
Transect 3, before gravel addition, August 18 , 2009
Number of Pebbles Counted
25
20
15
10
5
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

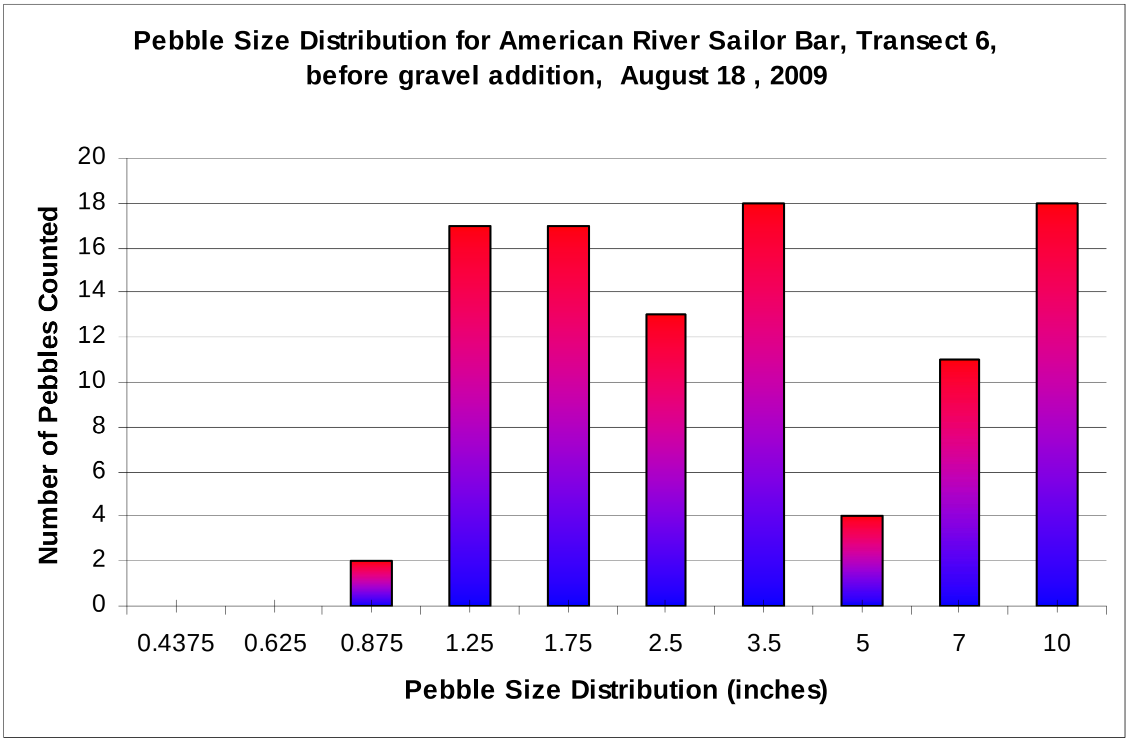

Cumulative Percent Pebble Distribution for American River Sailor
Bar Transect 3, Before Gravel Addition August 18, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

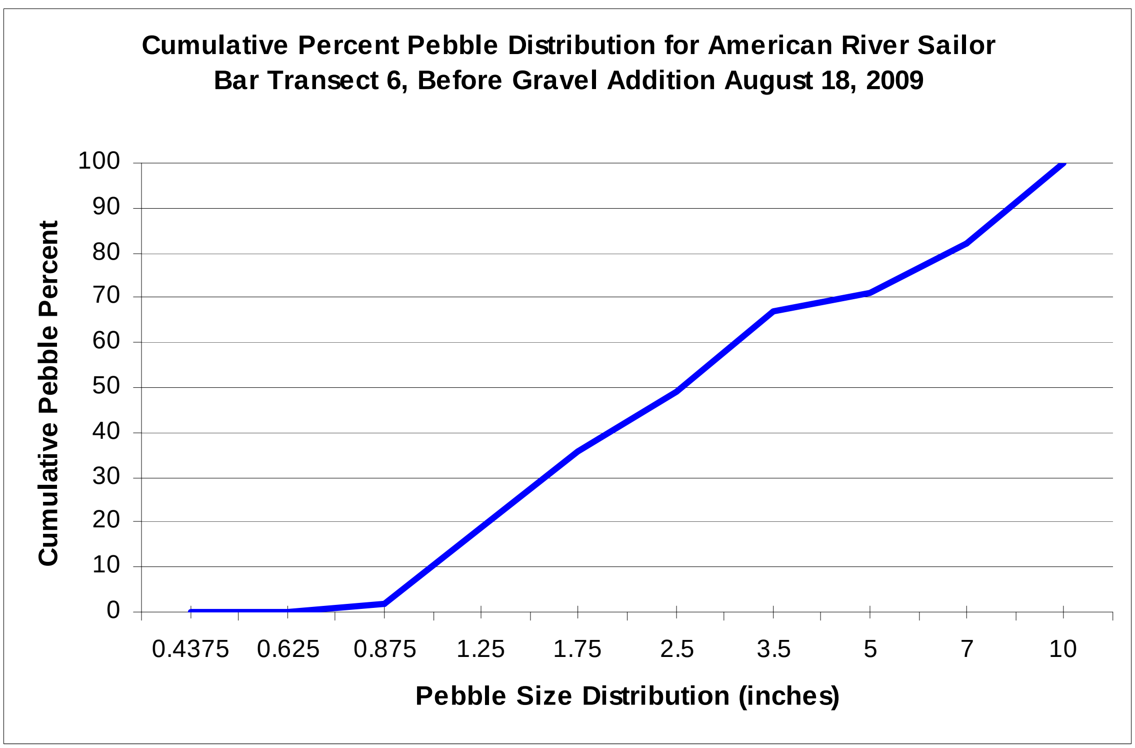

Pebble Size Distribution for American River Sailor Bar, Transect 4, before gravel addition, August 18 , 2009
Number of Pebbles Counted
35
30
25
20
15
10
5
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

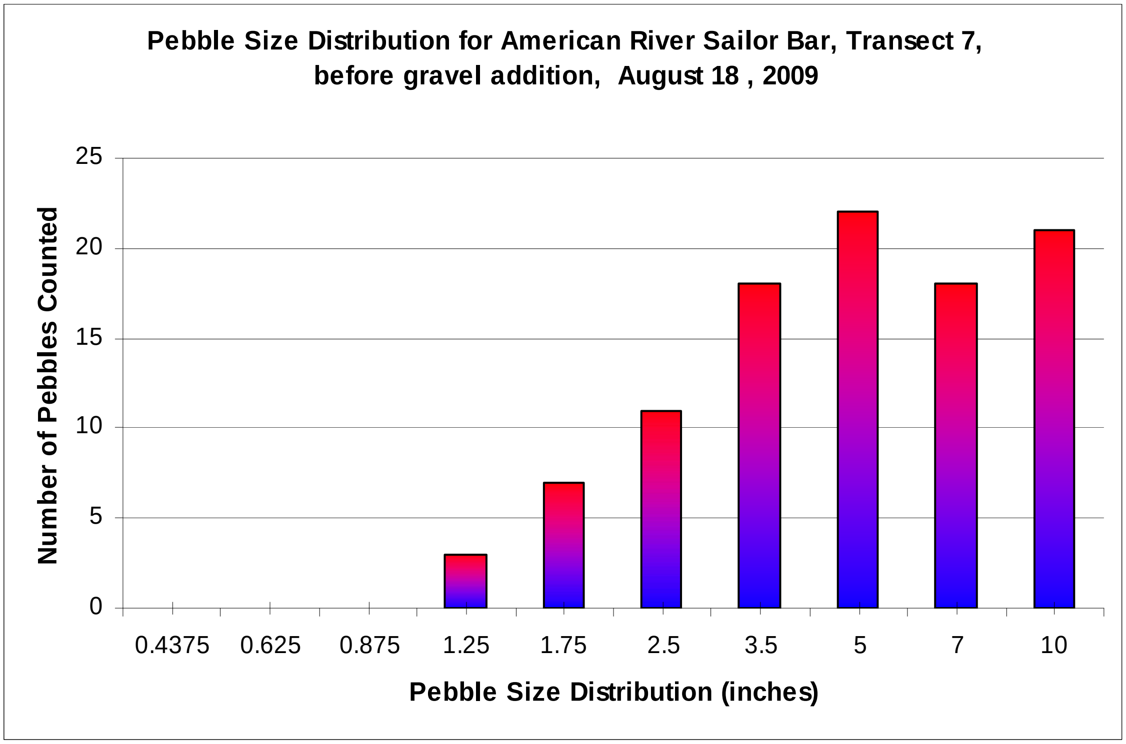

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 4, Before Gravel Addition August 18, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

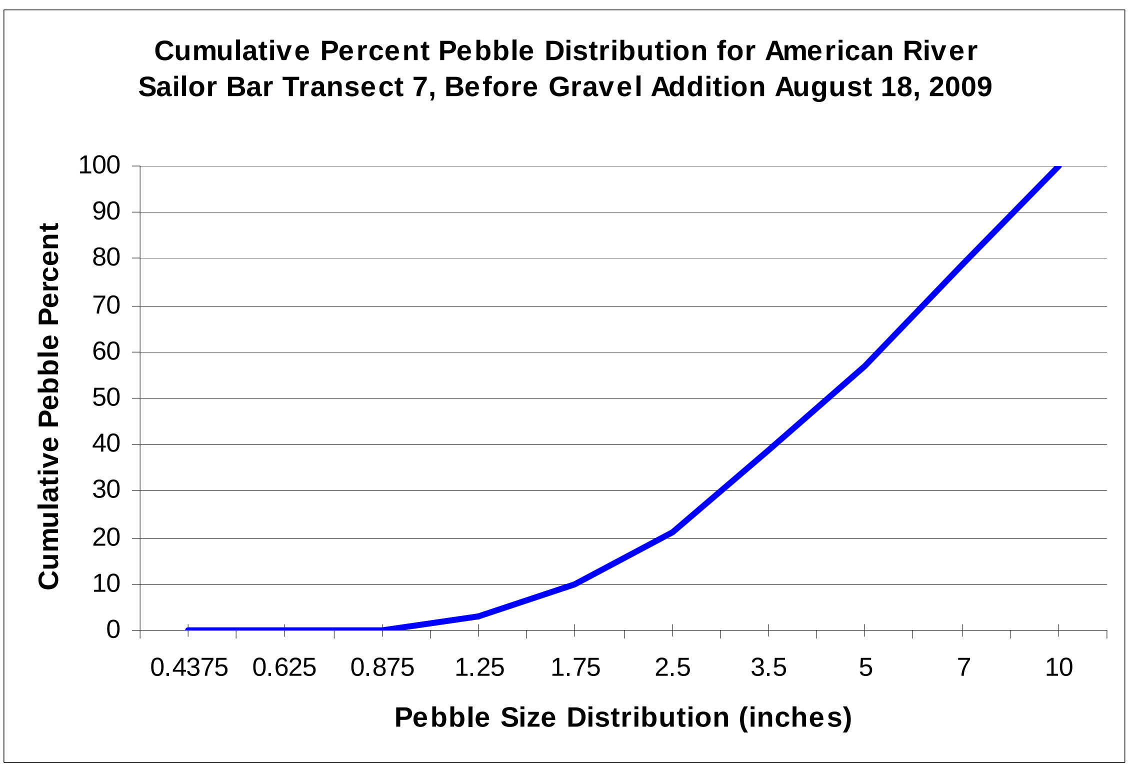

Pebble Size Distribution for American River Sailor Bar, Transect 5, before gravel addition, August 18 , 2009
Number of Pebbles Counted
25
20
15
10
5
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

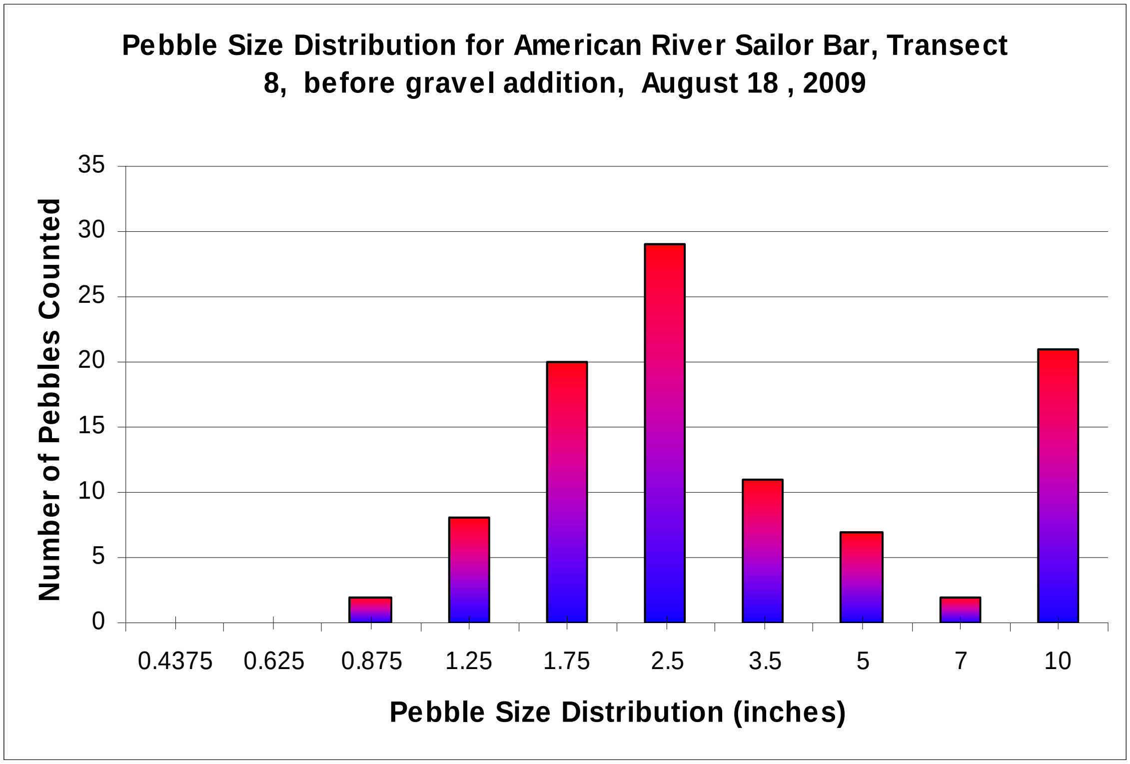

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 5, Before Gravel Addition August 18, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

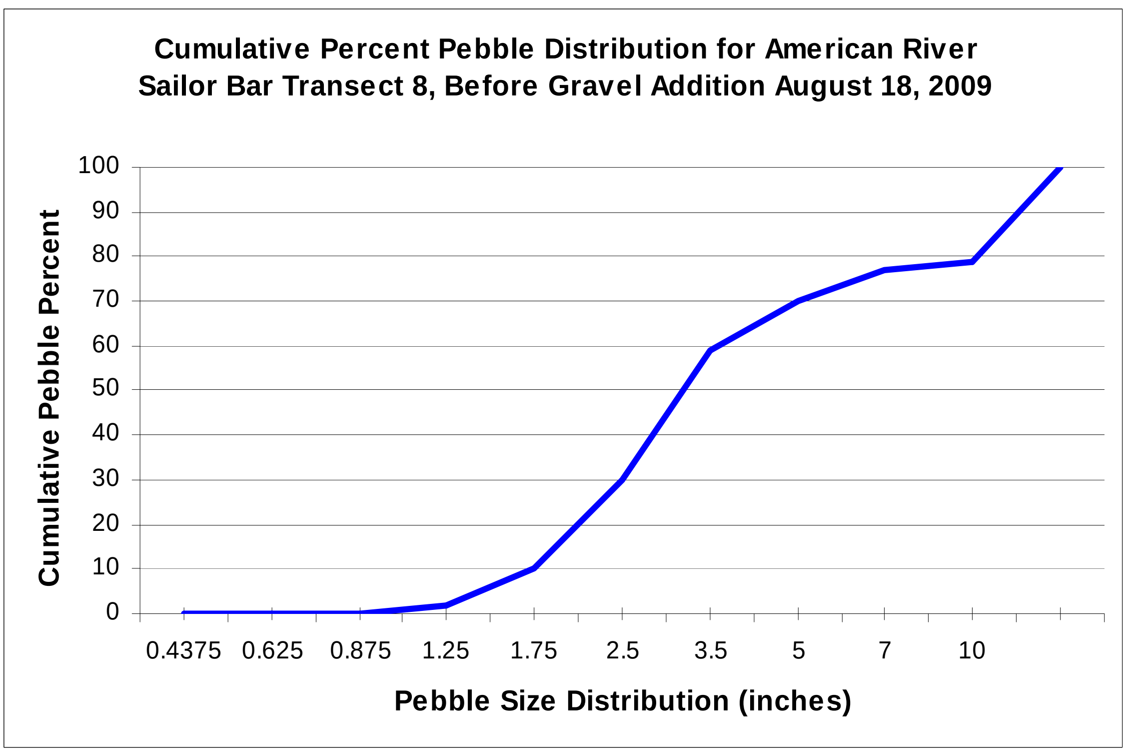

Pebble Size Distribution for American River Sailor Bar, Transect 6, before gravel addition, August 18 , 2009
Number of Pebbles Counted
20
18
16
14
12
10
8
6
4
2
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)


Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 6, Before Gravel Addition August 18, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

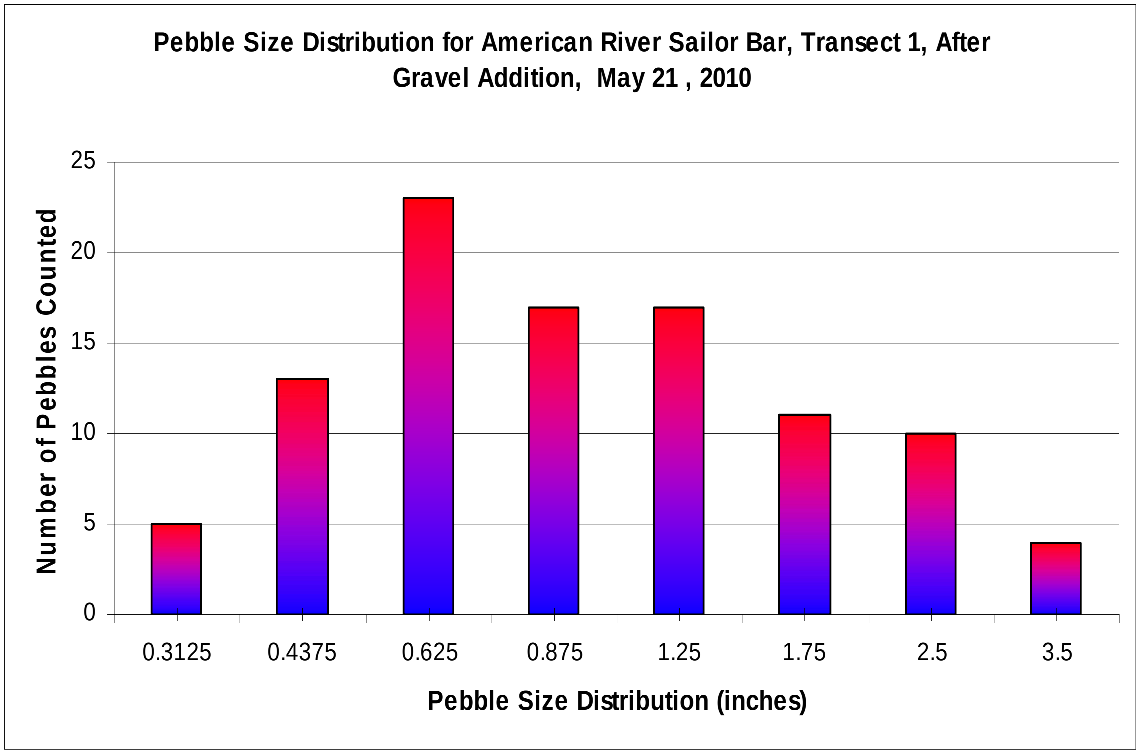

Pebble Size Distribution for American River Sailor Bar, Transect 7, before gravel addition, August 18 , 2009
Number of Pebbles Counted
25
20
15
10
5
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

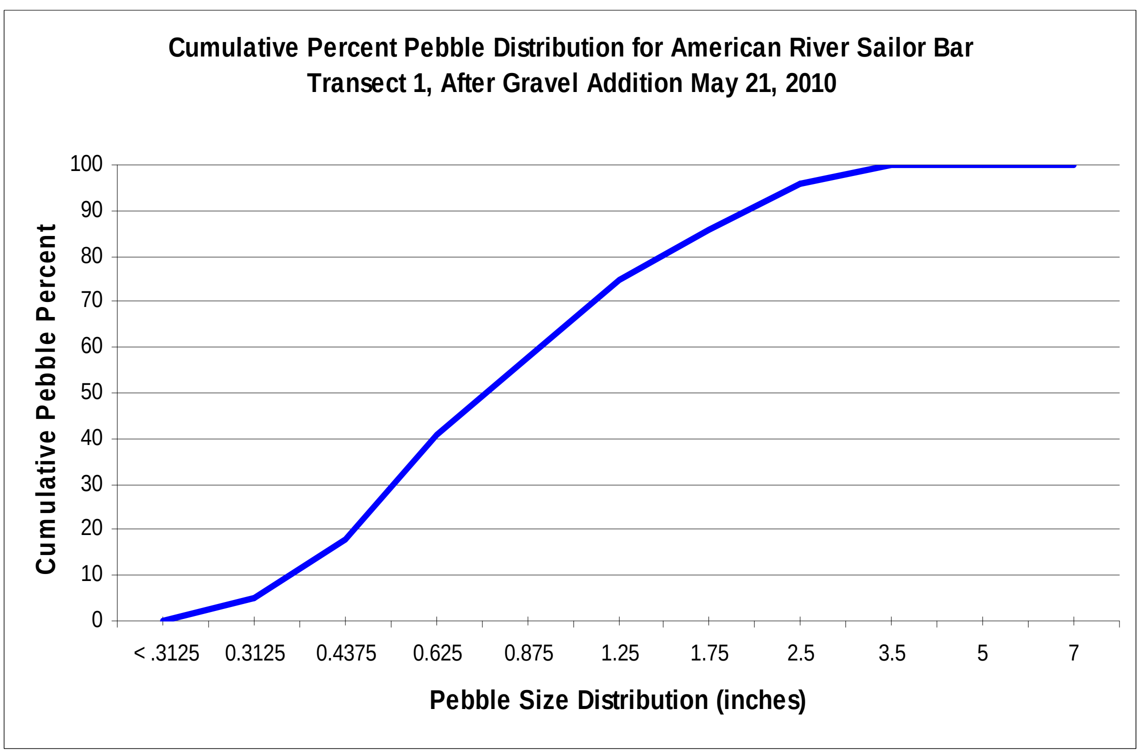

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 7, Before Gravel Addition August 18, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

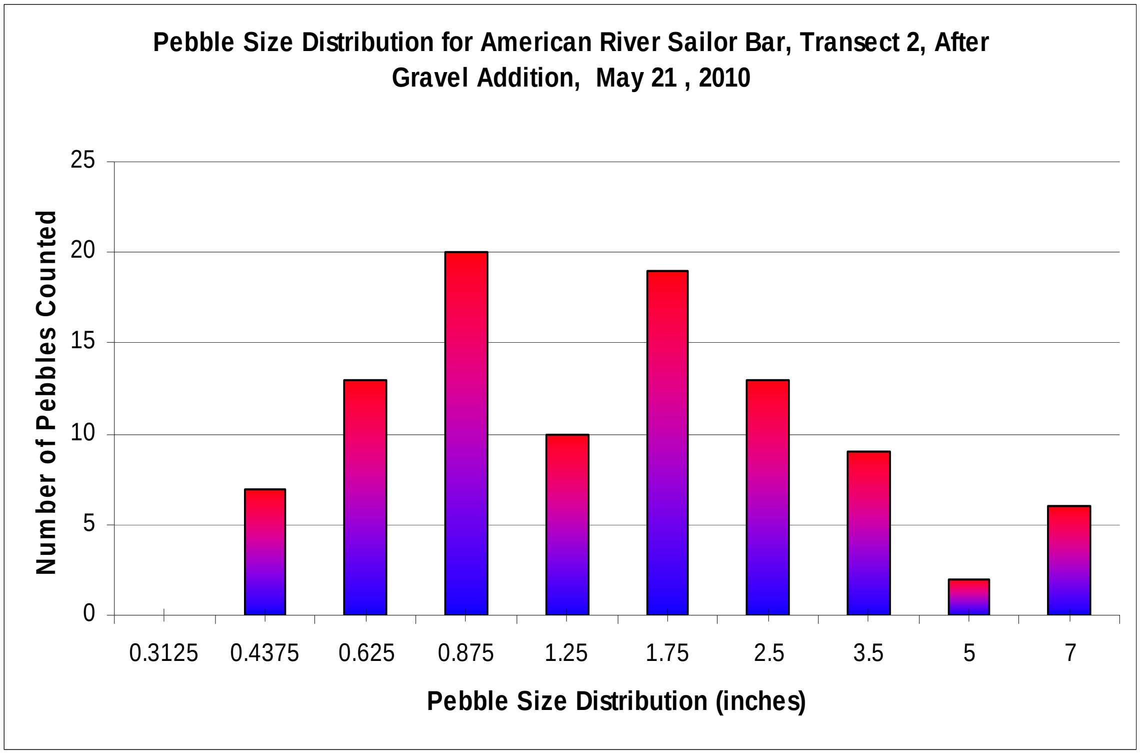

Pebble Size Distribution for American River Sailor Bar, Transect 8, before gravel addition, August 18 , 2009
Number of Pebbles Counted
35
30
25
20
15
10
5
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

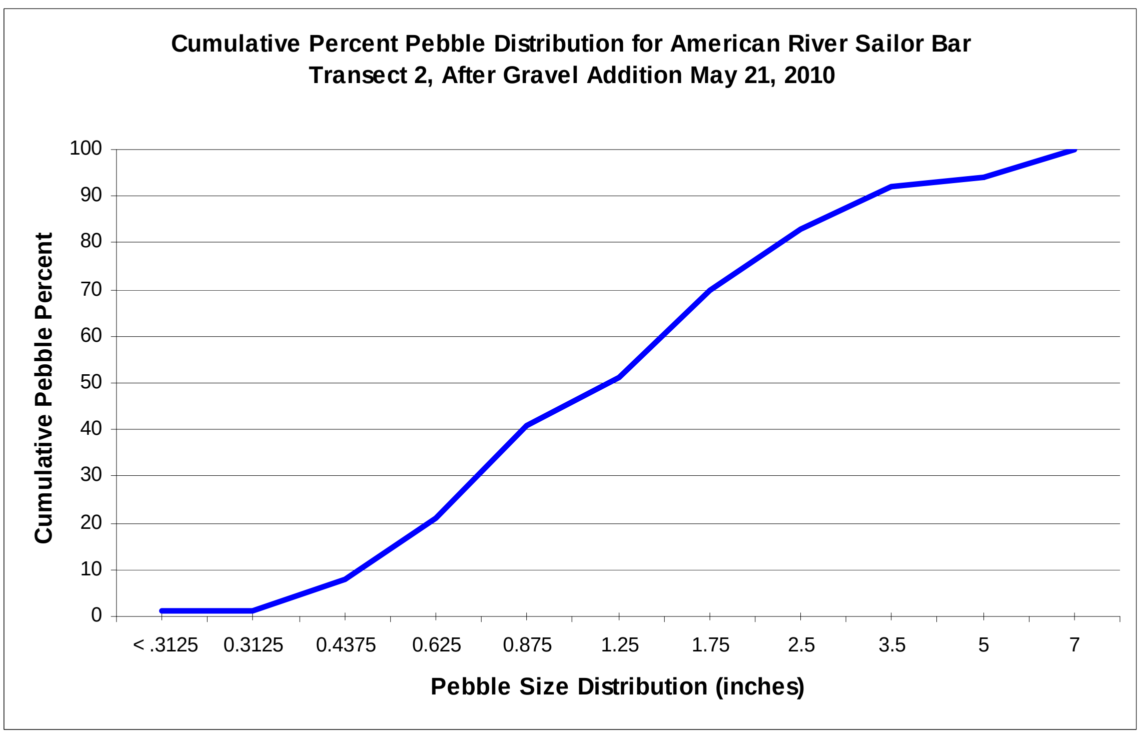

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 8, Before Gravel Addition August 18, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

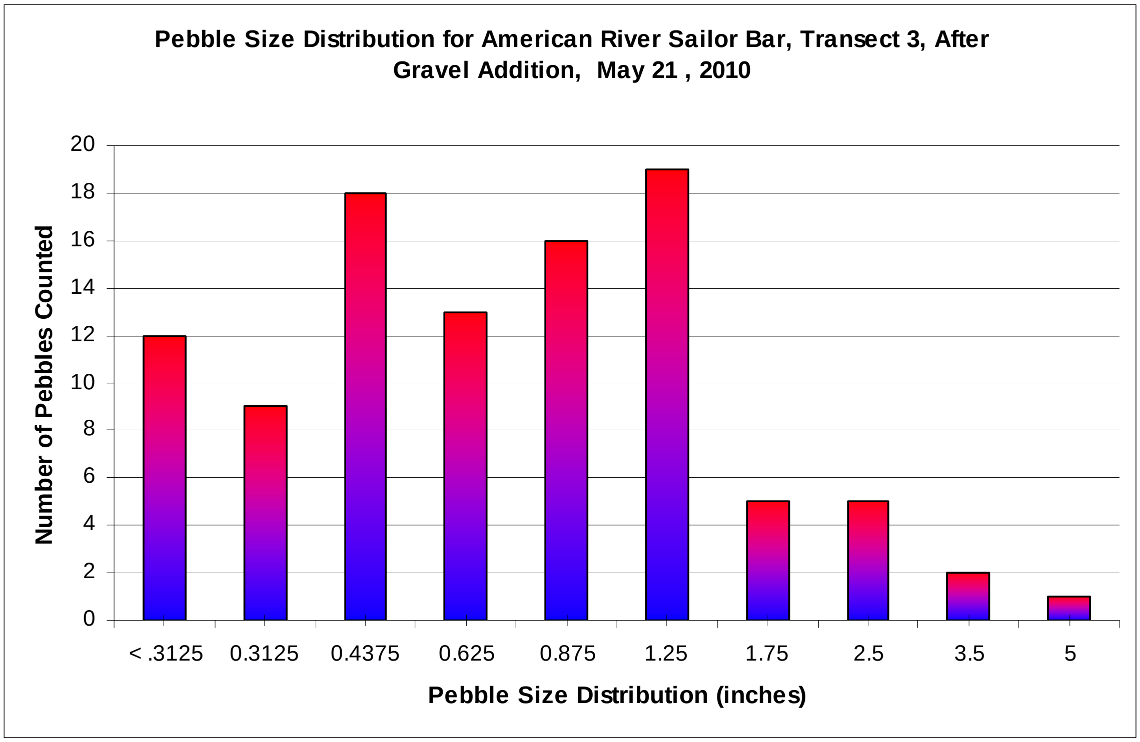
Appendix B: After gravel addition pebble counts

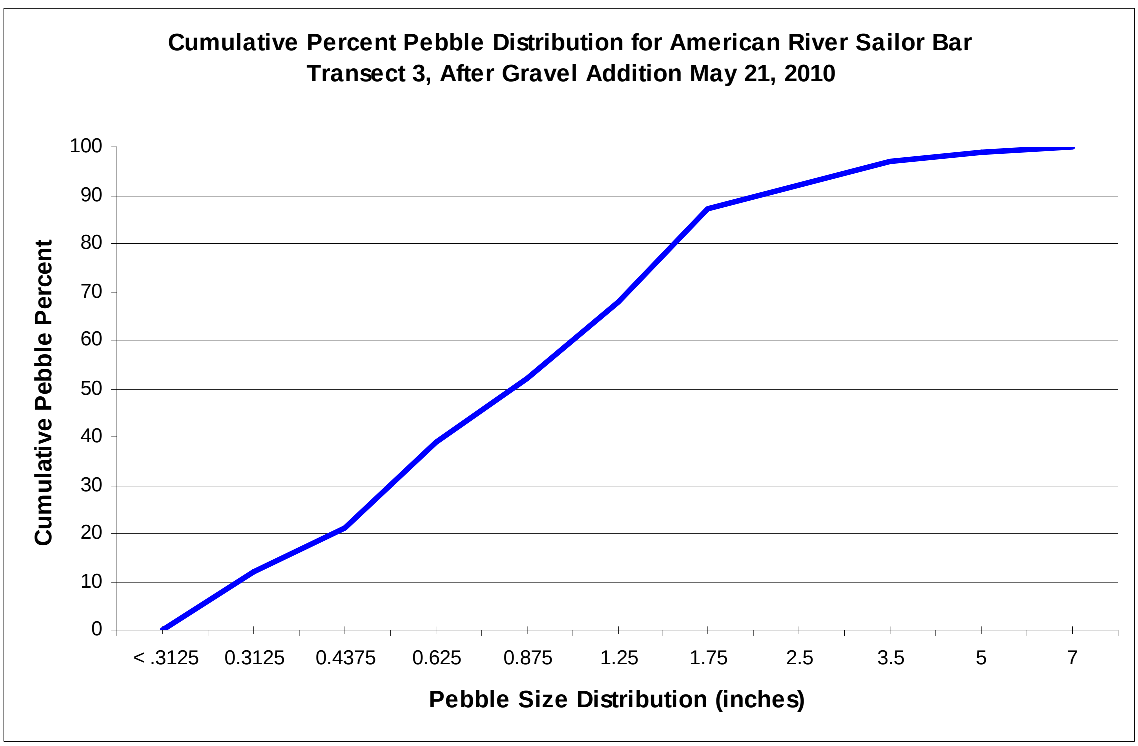

Pebble Size Distribution for American River Sailor Bar, Transect 1, After Gravel Addition, May 21 , 2010
Number of Pebbles Counted
0
5
10
15
20
25
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
Pebble Size Distribution (inches)

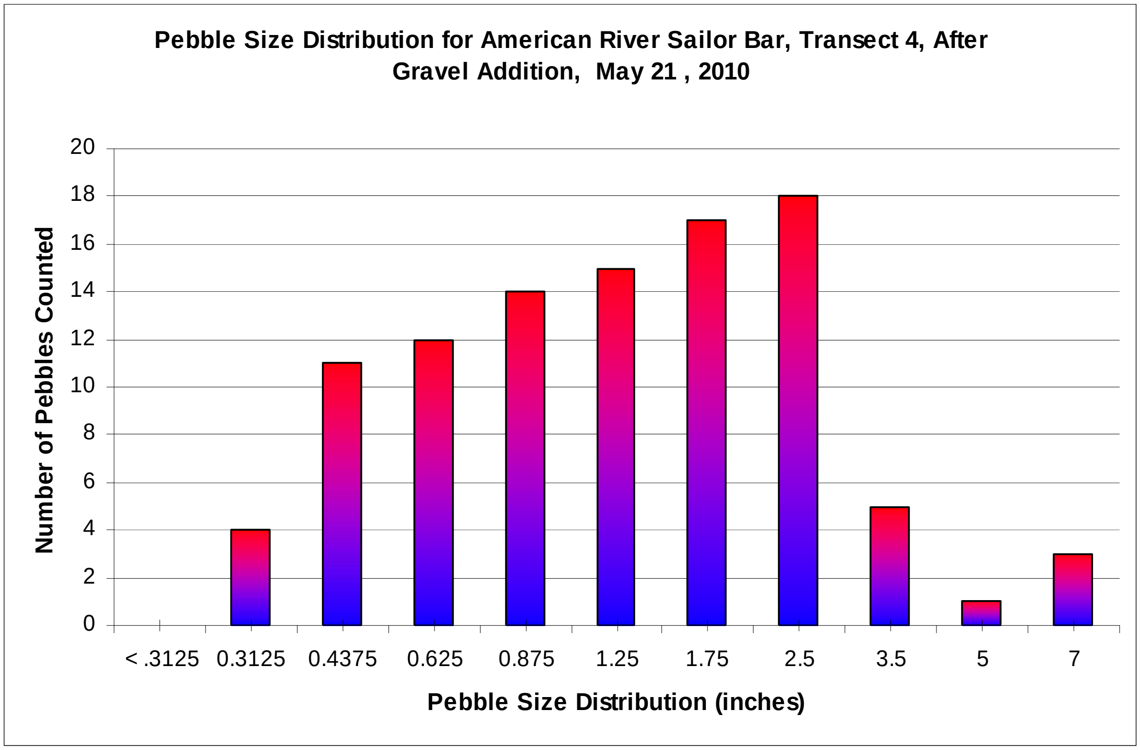

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 1, After Gravel Addition May 21, 2010
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)

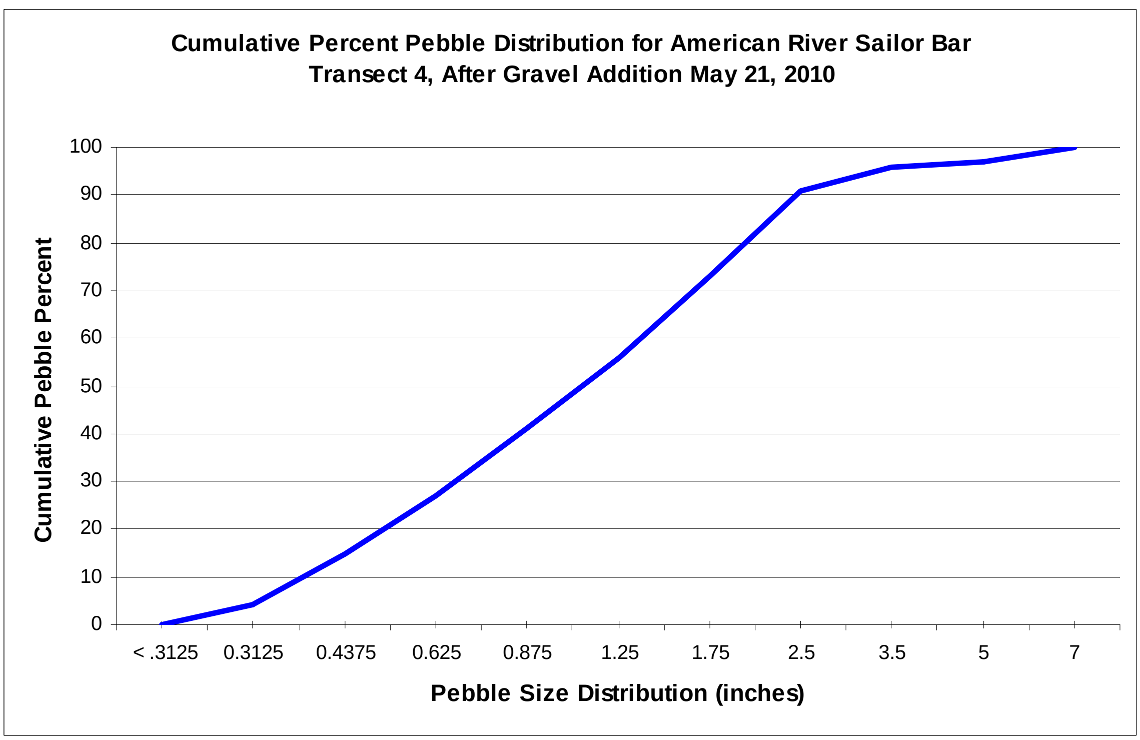

Pebble Size Distribution for American River Sailor Bar, Transect 2, After Gravel Addition, May 21 , 2010
Number of Pebbles Counted
25
20
15
10
5
0
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)

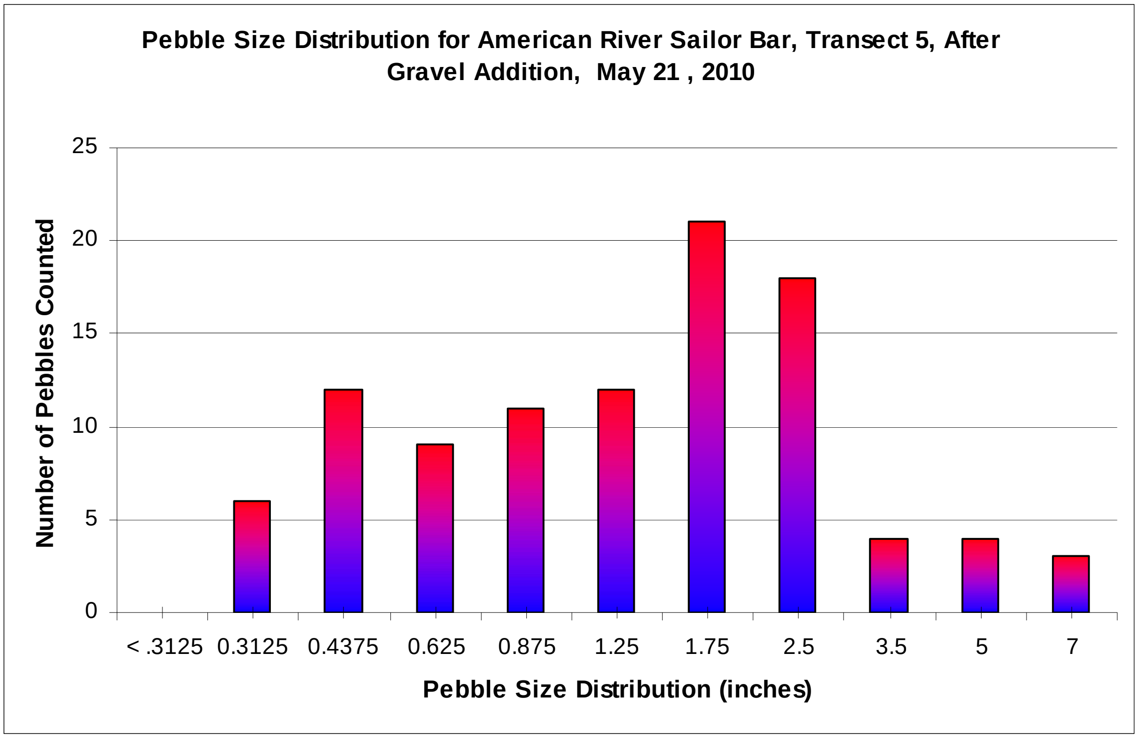

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 2, After Gravel Addition May 21, 2010
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)

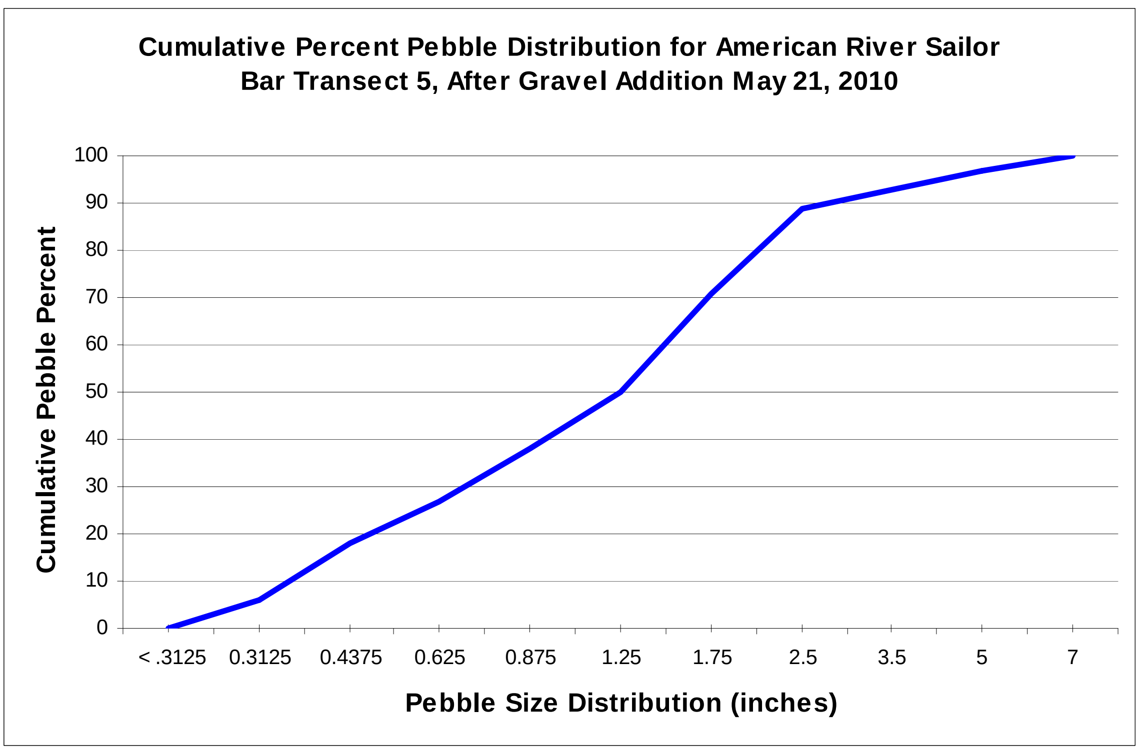

Pebble Size Distribution for American River Sailor Bar, Transect 3, After Gravel Addition, May 21 , 2010
Number of Pebbles Counted
0
2
4
6
8
10
12
14
16
18
20
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

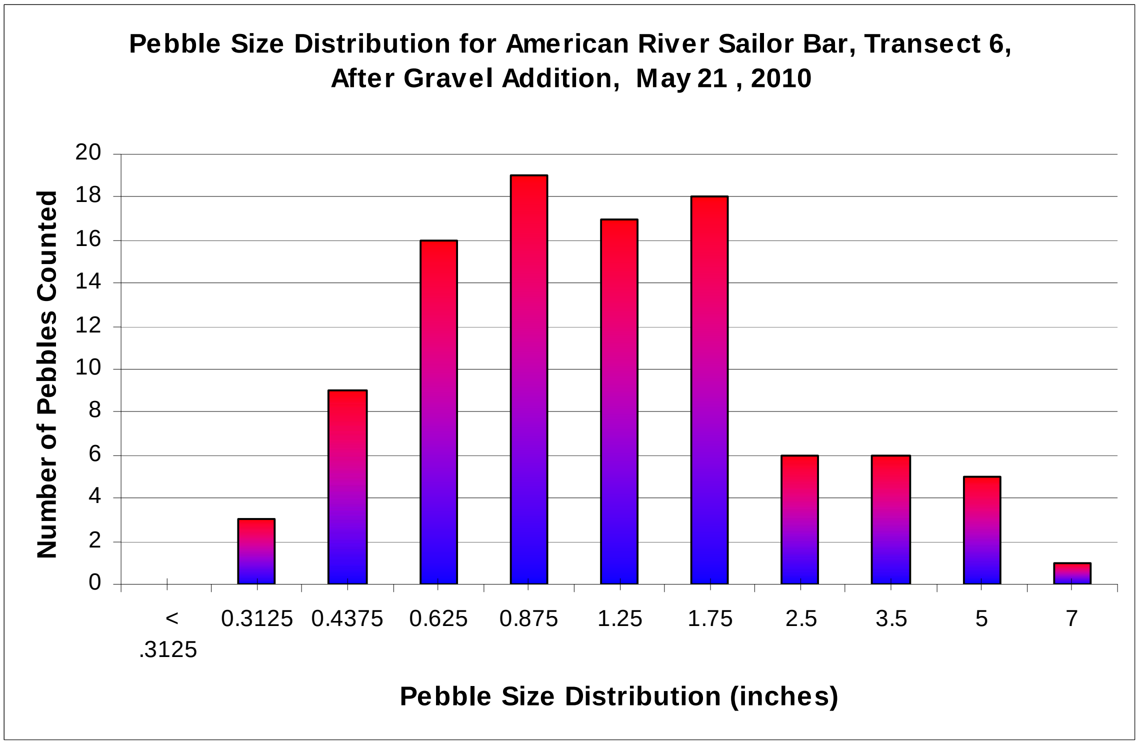

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 3, After Gravel Addition May 21, 2010
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)

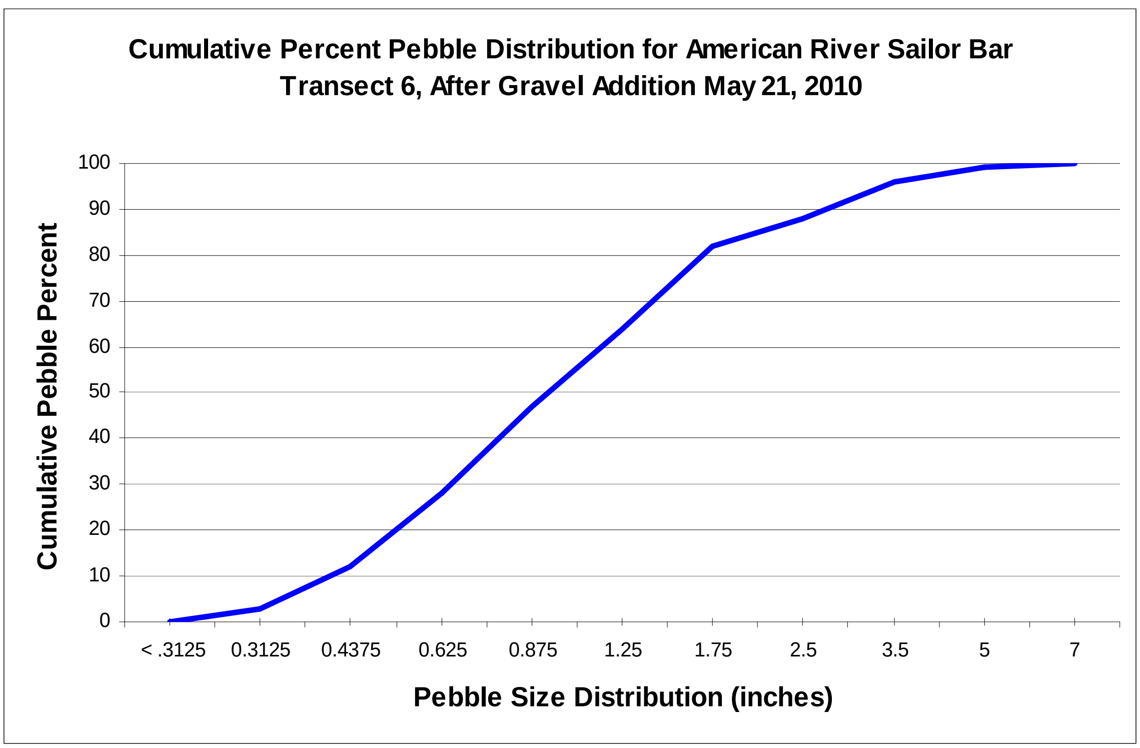

Pebble Size Distribution for American River Sailor Bar, Transect 4, After Gravel Addition, May 21 , 2010
Number of Pebbles Counted
0
2
4
6
8
10
12
14
16
18
20
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)

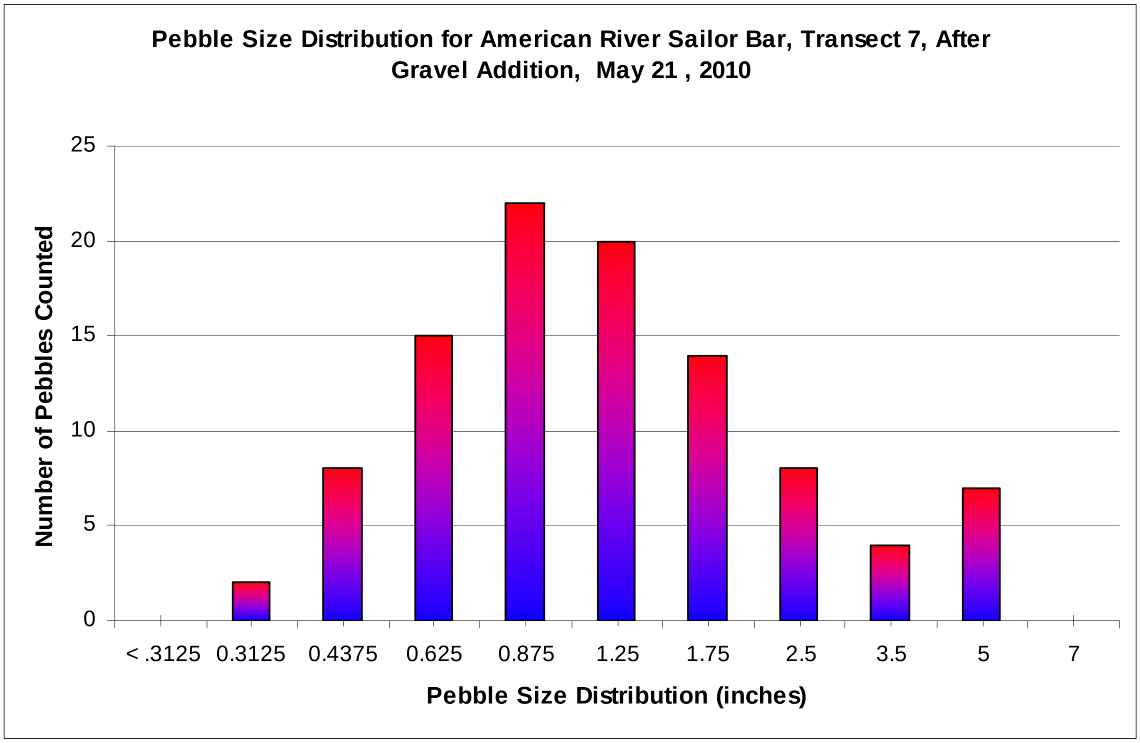

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 4, After Gravel Addition May 21, 2010
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)

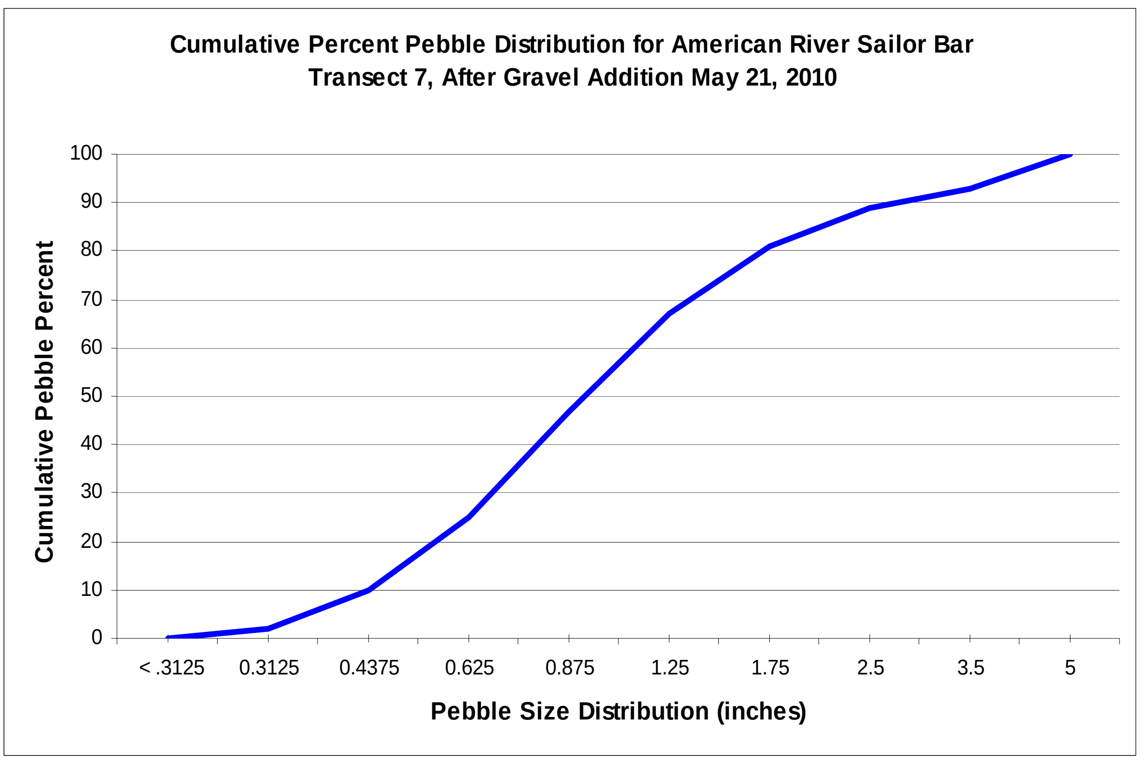

Pebble Size Distribution for American River Sailor Bar, Transect 5, After Gravel Addition, May 21 , 2010
Number of Pebbles Counted
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)

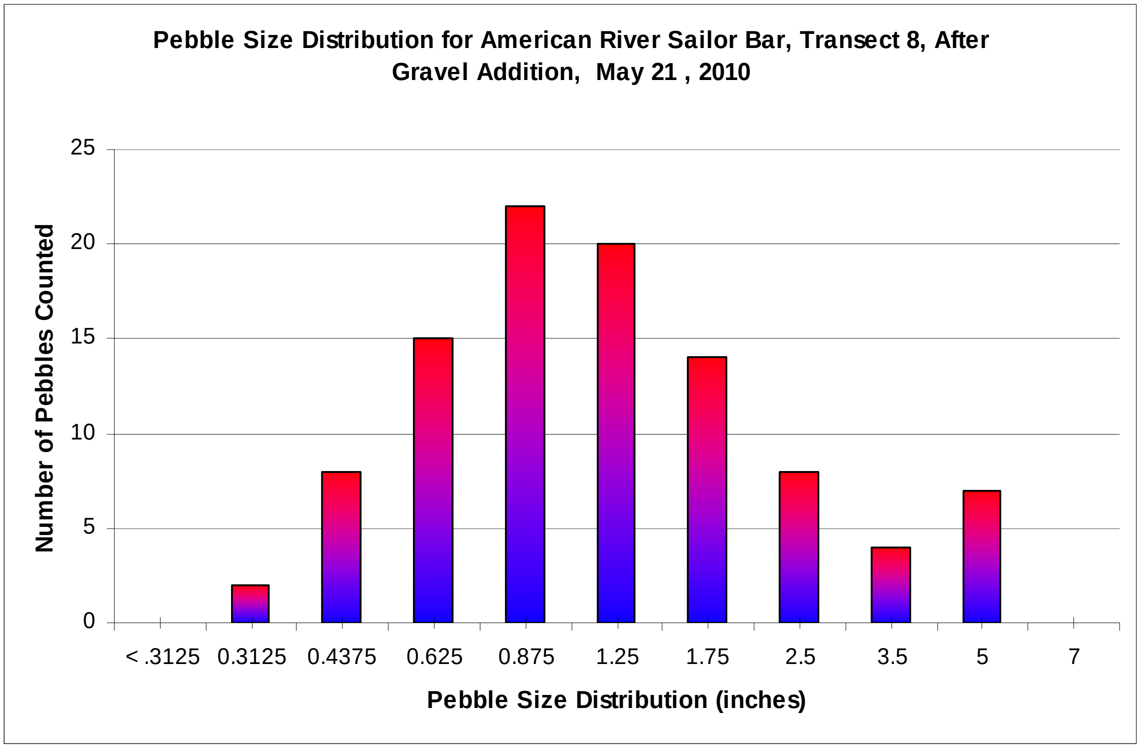

Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 5, After Gravel Addition May 21, 2010
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)

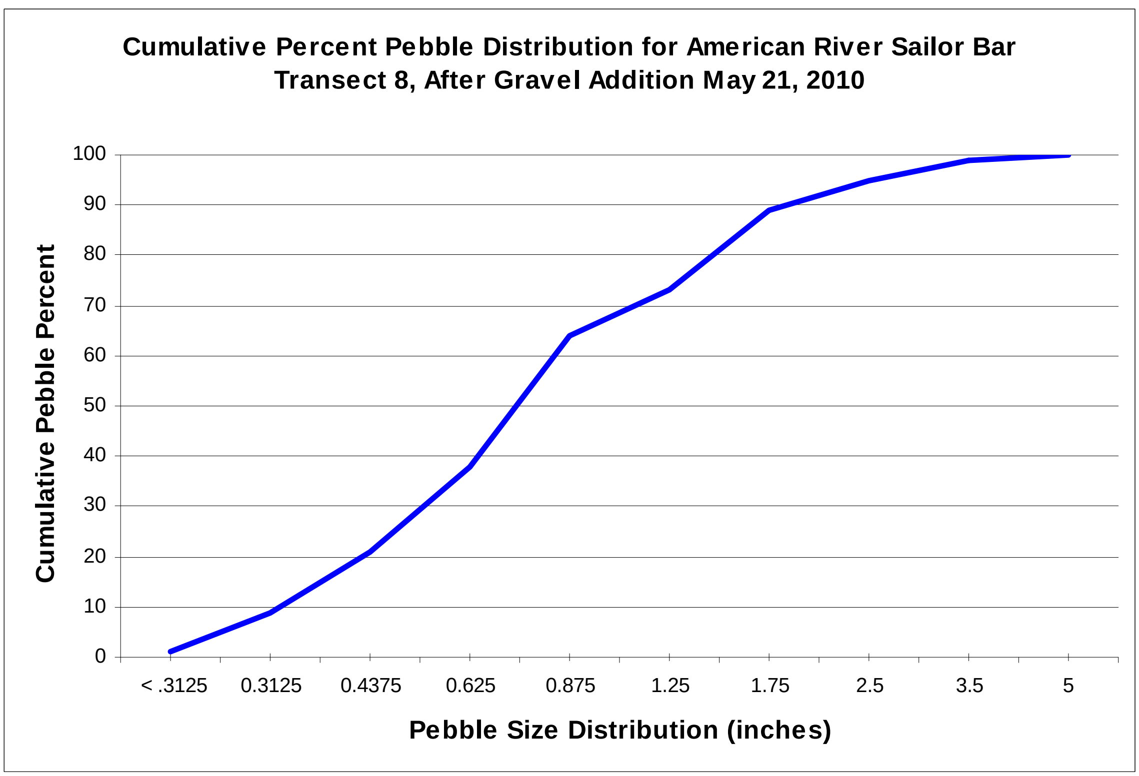

Pebble Size Distribution for American River Sailor Bar, Transect 6,
After Gravel Addition, May 21 , 2010
Number of Pebbles Counted
20
18
16
14
12
10
8
6
4
2
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)


Cumulative Percent Pebble Distribution for American River Sailor Bar
Transect 6, After Gravel Addition May 21, 2010
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)


Pebble Size Distribution for American River Sailor Bar, Transect 7, After Gravel Addition, May 21 , 2010
Number of Pebbles Counted
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)


Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 7, After Gravel Addition May 21, 2010
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)


Pebble Size Distribution for American River Sailor Bar, Transect 8, After Gravel Addition, May 21 , 2010
Number of Pebbles Counted
0
5
10
15
20
25
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
Pebble Size Distribution (inches)


Cumulative Percent Pebble Distribution for American River Sailor Bar Transect 8, After Gravel Addition May 21, 2010
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

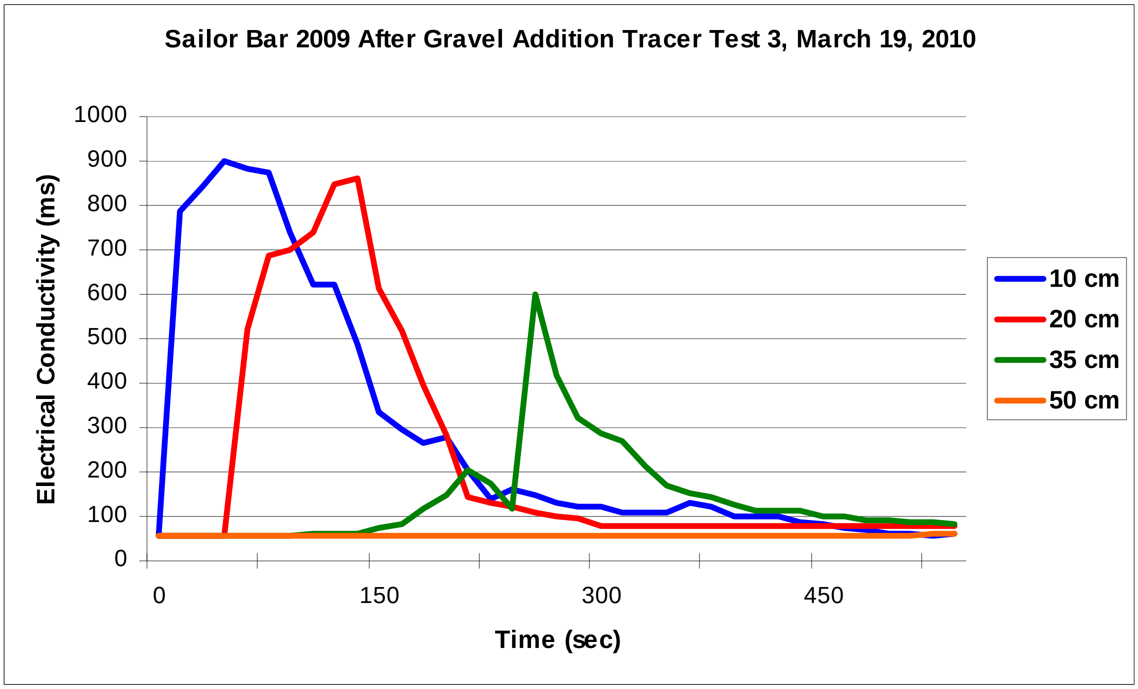
Appendix C: After gravel addition inter gravel velocity, March and April 2010

	10 cm	20cm	30cm
Time (sec)	**EC 1**	**EC 2**	**EC 3**
0	54.2	54.4	54.2
5	54.2	54.4	54.2
10	54.2	54.4	54.2
15	66	54.4	54.2
20	279	54.4	54.2
25	342	54.4	54.2
30	372	54.4	54.2
45	800	54.4	62.3
60	823	102.7	70
75	857	714	85
90	423	700	91
105	412	630	106
120	378	630	140
135	354	518	183
150	218	395	230
165	104	348	239
180	102	318	233
195	107	298	227
210	110	293	212
225	150	334	210
240	155	324	218
255	141	284	215
270	115	241	214
285	111	238	217
300	111	229	215
315	118	254	211
330	135	257	207
345	122	235	197
360	107	208	185
375	95	160	175
390	116	158	150
405	152	166	136
420	89	155	125
435	84	130.8	109
450	78	115.5	97
465	83	104.7	84
480	85	103.2	82
495	85	101	80
510	86	97.2	78
525	85	93	75
540	87	93	73

After gravel addition tracer test 1 data, March 2010.

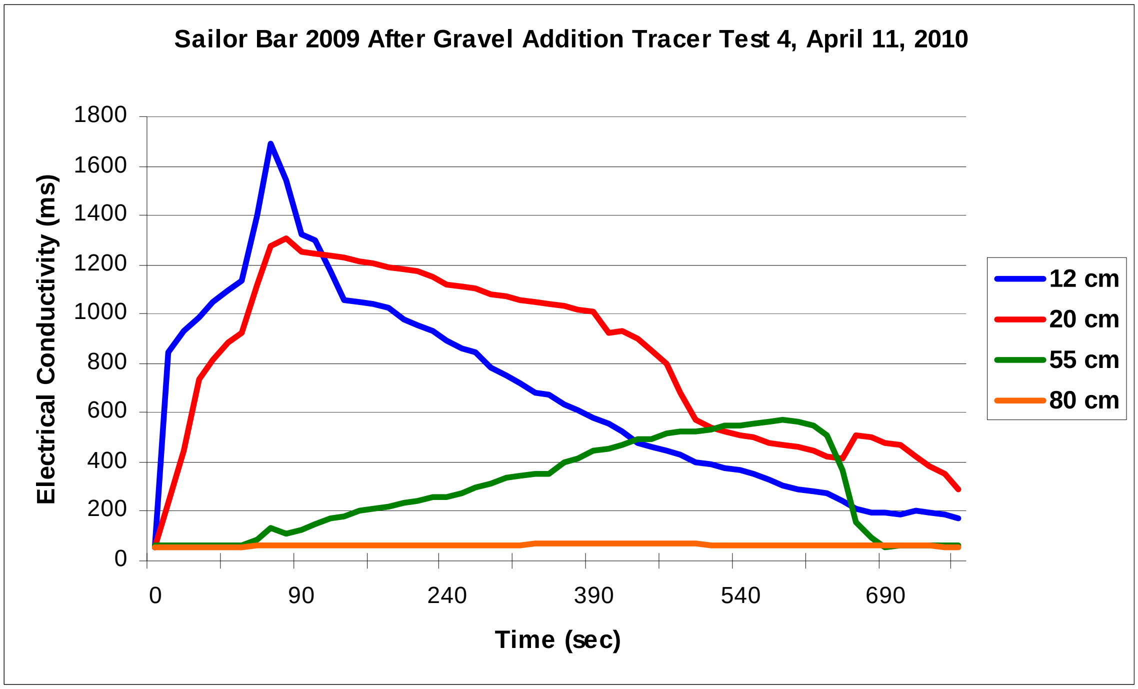
10 cm	20 cm	30cm	50cm
163	59	59	59
316	59	59	59
748	59	59	59
1153	174	59	59
1681	189	59	59
1786	201	67	59
1906	222	79	59
1696	294	88	59
1522	414	123	59
1420	666	143	59
1204	849	166	142
988	1035	197	148
877	1215	378	179
814	1092	537	195
796	975	390	250.3
817	846	351	315
814	771	306	301
766	603	282	282
772	681	261	271
841	612	252	270
595	486	243	257
547	498	234	243
520	483	231	229
547	480	213	213
538	480	210	207
502	474	213	191
406	414	201	196
388	420	192	207
385	354	195	193
355	387	192	185
307	411	198	167
328	354	195	162
313	345	80	155
307	312	74	152
370	200	73	153
322	185	74	152
334	209	70	146
286	203	67	147
280	194	68	142
307	203	67	140
292	203	69	140
280	167	68	135
232	173	67	131

After gravel addition tracer test 2data, March 2010



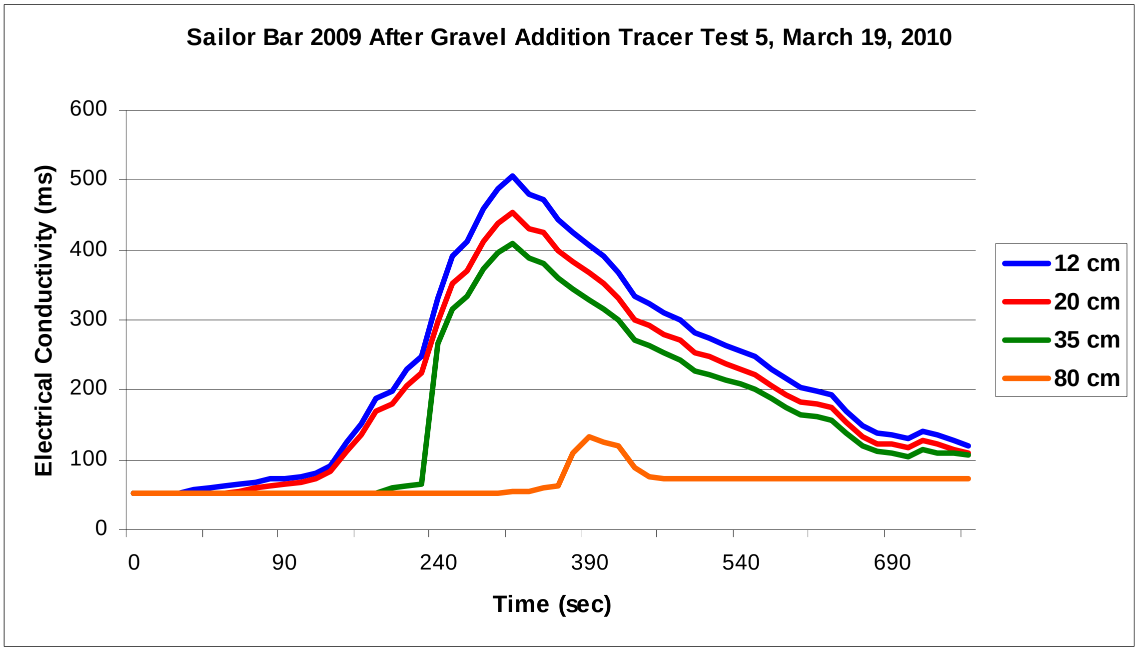
10 cm	20 cm	35 cm	50 cm
58	58	58	57
789	58	58	57
842	58	58	57
902	58	58	57
883	522	58	57
874	685	58	57
741	699	58	57
623	741	60	57
620	846	60	57
487	863	61	57
336	611	75	57
294	518	81	57
265	395	119	57
277	281	146	57
203	143	204	57
140	132	175	57
160	121	116	57
150	108	599	57
130	98	416	57
120	94	323	57
120	80	285	57
110	80	269	57
110	80	212	57

After gravel addition tracer test 3data, March 2010



	12 cm	20 cm	55 cm	80 cm
Time (sec)	EC 1	EC 2	EC 3	EC 4
0	58	58	59	58
5	845	231	59	58
10	932	449	59	58
15	985	739	59	58
20	1048	813	59	58
25	1099	887	59	58
30	1136	924	59	58
45	1400	1123	86	62
60	1689	1278	129.92	62
75	1544	1309	108.16	61
90	1325	1254	124.8	61
105	1301	1247	151.68	61
120	1174	1236	172.8	60
135	1058	1225	183.68	60
150	1046	1213	203.52	60
165	1037	1205	209.92	59
180	1022	1192	218.24	59
195	975	1181	234.88	59
210	951	1171	243.84	59
225	933	1154	256	60
240	889	1121	255.36	60
255	861	1114	273.92	60
270	844	1100	297.6	60

After gravel addition tracer test 4 data, April 2010



	12 cm	20 cm	40 cm	70 cm
Time (sec)	EC 1	EC 2	EC 3	EC 4
	52	53	53	53
	52	53	53	53
	53	53	53	53
	53	53	53	53
	57	53	53	53
	59	53	53	53
	62	53	53	53
	65	56	53	53
	69	60	53	53
	72	63	53	53
	73	65	53	53
	76	68	53	53
	80	72	53	53
	92	83	53	53
	124	112	53	53
	150	135	53	53
	189	170	53	53
	199	179	60	53
	230	207	63	53
	248	223	65	53
	330	297	267	53
	391	352	317	53
	411	370	333	53
	459	413	372	53

After gravel addition tracer test 5 data, April 2010

Appendix D: 2008 Gravel Addition Tracer Test Data

	11 cm	20 cm	30 cm	50cm
Time (sec)	EC 1	EC 2	EC 3	EC 4
0	671	161	59	58
5	740	314	59	58
10	782	517	59	58
15	832	568	59	58
20	873	620	59	58
25	902	646	59	58
30	1112	1025	59	58
45	1341	1204	59	58
60	1226	1227	59	58
75	1052	1251	59	58
90	1033	1235	59	60
105	932	1198	59	60
120	840	1132	59	60
135	831	1045	59	60
150	823	1000	59	60
165	811	923	59	60
180	774	921	59	60
195	755	877	73	60
210	741	872	114	60
225	706	864	168	60
240	684	856	192	60
255	670	848	204	60
270	619	842	226	60
285	599	833	233	60
300	573	826	242	60
315	543	819	261	60
330	535	807	271	73
345	503	784	284	73
360	484	779	283	73
375	462	769	304	73
390	444	757	330	73
405	418	751	351	68
420	380	741	377	68
435	368	735	381	68
450	353	728	390	68
465	341	720	395	68
480	318	714	441	65
495	311	706	462	65
510	298	643	495	65
525	291	651	503	65
540	281	631	518	65

2008 Gravel Addition Tracer Test Data T-1, April 2010

	11 cm	23cm	35 cm	48 cm
Time (sec)	EC 1	EC 2	EC 3	EC 4
0	58	58	58	57
15	710	58	58	57
30	758	58	58	57
45	812	58	58	57
60	795	470	60	61
75	787	617	60	61
90	667	629	61	66
105	561	667	75	75
120	558	700	81	130
135	438	715	119	226
150	302	623	146	226
165	265	550	204	231
180	239	466	175	257
195	249	356	116	263
210	183	253	554	373
225	126	129	416	401
240	144	119	323	414
255	135	109	285	454
270	117	97	269	414
285	108	88	212	373
300	108	85	168	212
315	99	72	153	209
330	99	72	143	181
345	99	72	126	172
360	117	71	115	152
375	108	71	111	119
390	90	71	113	110
405	90	71	101	105
420	90	70	99	99
435	77	69	93	94
450	76	69	91	85
465	67	69	89	81
480	65	69	87	78
495	62	66	84	74
510	63	66	80	74
525	61	65	82	73
540	62	61	79	72

2008 Gravel Addition Tracer Test Data T-2, April 2010