**Physical and geochemical characteristics of the 2008 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 2008. 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 2008/2009 field season have six major objectives. These objectives were described as tasks in a gravel evaluation proposal submitted to the U.S. Bureau of Reclamation, Sacramento Office on June 18, 2008 and 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
- Conduct tracer rock studies in the gravel addition
- Conduct salt water tracer tests to measure spawning gravel permeability
- Create GIS maps of the study area with site and sample locations
- Compile a written report for the 2008/2009 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.

## 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 20 pebble counts downstream of 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 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 2008 (before gravel addition) and January 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.

### 3.21 Hach Chemistry

Samples collected from each mini piezometer and two random river locations (identified as surface samples) were analyzed for nitrate, nitrite, ammonia, and phosphate concentrations using a Hach DR/2010 Spectrophotometer. Pre-programmed powder packet methods specific for the Hach DR/2010 instrument were used for each constituent. Sample blanks were analyzed according to method instructions at the beginning of analysis and periodically through the analysis. A summary of these methods follows:

**Nitrate, Middle Range** (0-4.5 mg/L $NO_3^-N$)

A 25ml thick-walled glass sample cell was filled with sample and one NitraVer 5 Nitrate Reagent Powder Pellet, and allowed to react for six minutes before analysis at 400 nm.

**Nitrate, Low Range** (0-0.300 mg/L $NO_2^-N$)

A 10ml thick-walled glass sample cell was filled with sample and one NitriVer3 Nitrite Reagent Powder Pillow, and allowed to react for 20 minutes before analysis at 507 nm.

**Ammonia**, (0-2.50 mg/L $NH_3^-N$)

A 25ml aliquot of sample is measured into a 25 ml mixing graduated cylinder, and treated with mineral stabilizer and polyvinyl alcohol dispersing agent. Nessler reagent was added and allowed to react for one minute before analysis at 380 nm.

**Phosphorous, Reactive** (0-2.50 mg/L $PO_4^{3-}$)

Method 8048 – PhosVer3 (Ascorbic Acid) Method

A 10ml thick-walled sample cell was filled with sample and one PhosVer3 Phosphate Powder Pillow, and allowed to react after mixing for two minutes before analysis at 890 nm.

### 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.

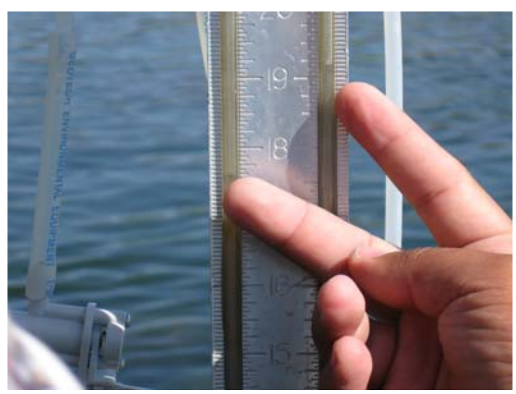

Figure 5: Picture of the manometer used for measuring the upwelling or downwelling for each mini piezometer. The photo to the right shows a close-up view of the different pressure heads from a measurement.

### 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.

**4.0 Results; Before Gravel Addition Grain Analysis**

20 Pebble counts were conducted at the restoration site and up to 3 miles downstream from the restoration site before the 2008 restoration project started. The pre-restoration downstream pebble counts showed a range in grain sizes from fine-grained sand to10 inch diameter boulders. Figure 8 shows the location of the downstream pebble counts. Figure 9 shows the cumulative frequency graph for the 20 pebble counts conducted from the western tip of Sailor Bar downstream to the Sunrise bridge. There was no trend or pattern to the grain size distribution from the upper portion of the study area (Sailor Bar) to the downstream portion of the study area (Sunrise). Median grain size diameters ( $d_{50}$ ) ranged from 7/16 inch to 1 ¼ inch.

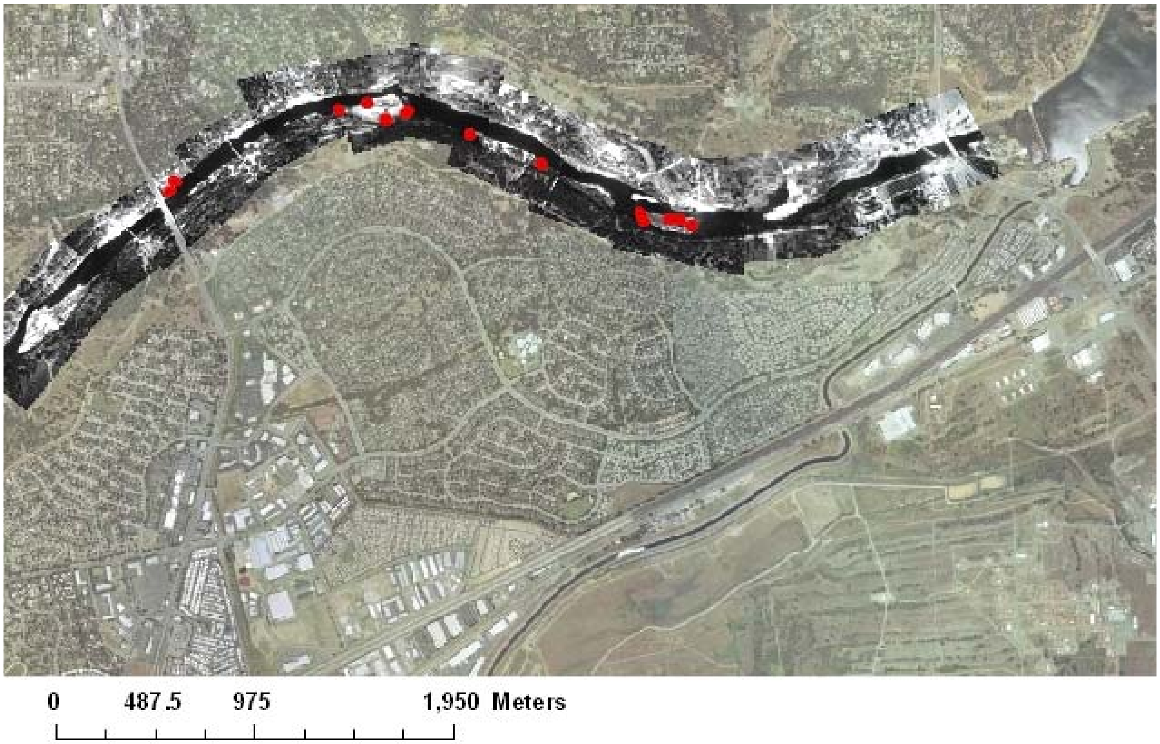


Figure 8: Map showing the downstream pebble count locations with red triangles. Pebble counts were conducted from the 2008 gravel addition downstream to the Sunrise bridge.

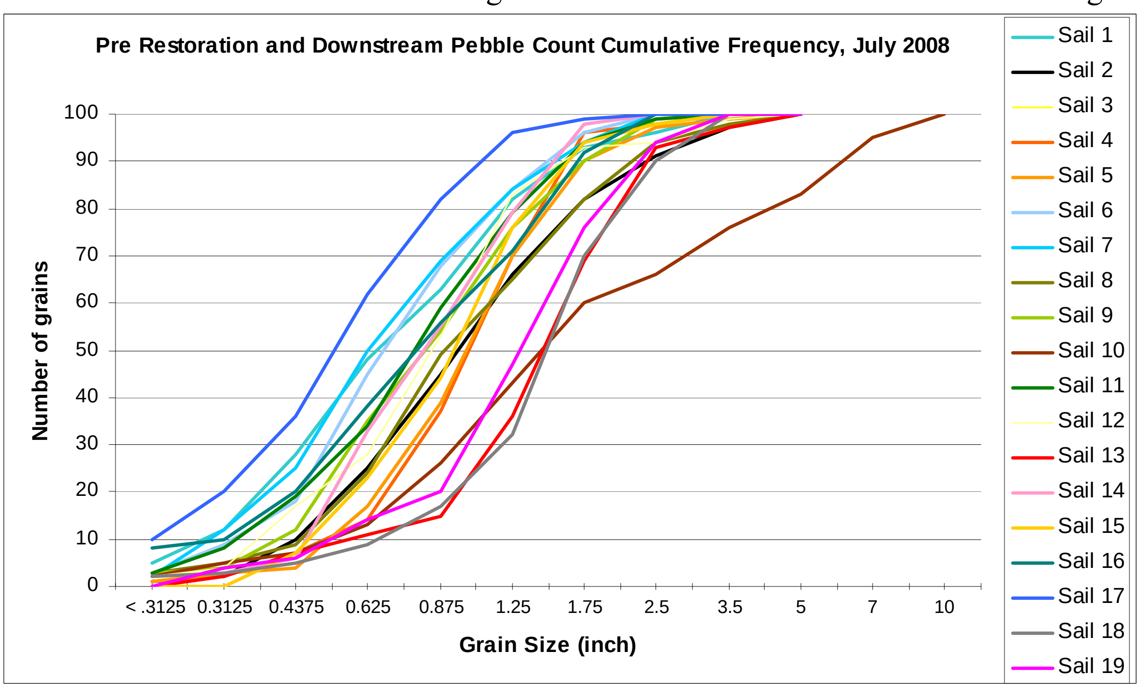


Figure 9: Graph showing the cumulative frequency of each pebble count of the downstream pebble counts. Pebble counts were conducted in the summer of 2008 prior to restoration work. Transects are listed upstream to downstream.

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### 4.1 Before Gravel Addition Water Quality

A total of 8 mini piezometers were installed before the gravel addition. Figure 10 shows the location of the mini piezometers before gravel addition. The before restoration water quality data is shown in table 1. Mean dissolved oxygen measurements before the gravel addition (Figure 11) were 4.5 mg/L with a range from 1.1 mg/L to 7.65 mg/L. The mean electrical conductivity for the gravel before restoration was 51.3 micro Siemens with a range from 37.2 micro Siemens to 69.4 micro Siemens. Mean pH for the gravel before restoration was 6.8 with a range from 6.6 to 7.2. Mean temperature at a depth of 30 cm in the gravel (before restoration) was 22.0 degrees Celsius. Gravel temperature measurements ranged from 21.6 degrees Celsius to 22.0 degrees Celsius.

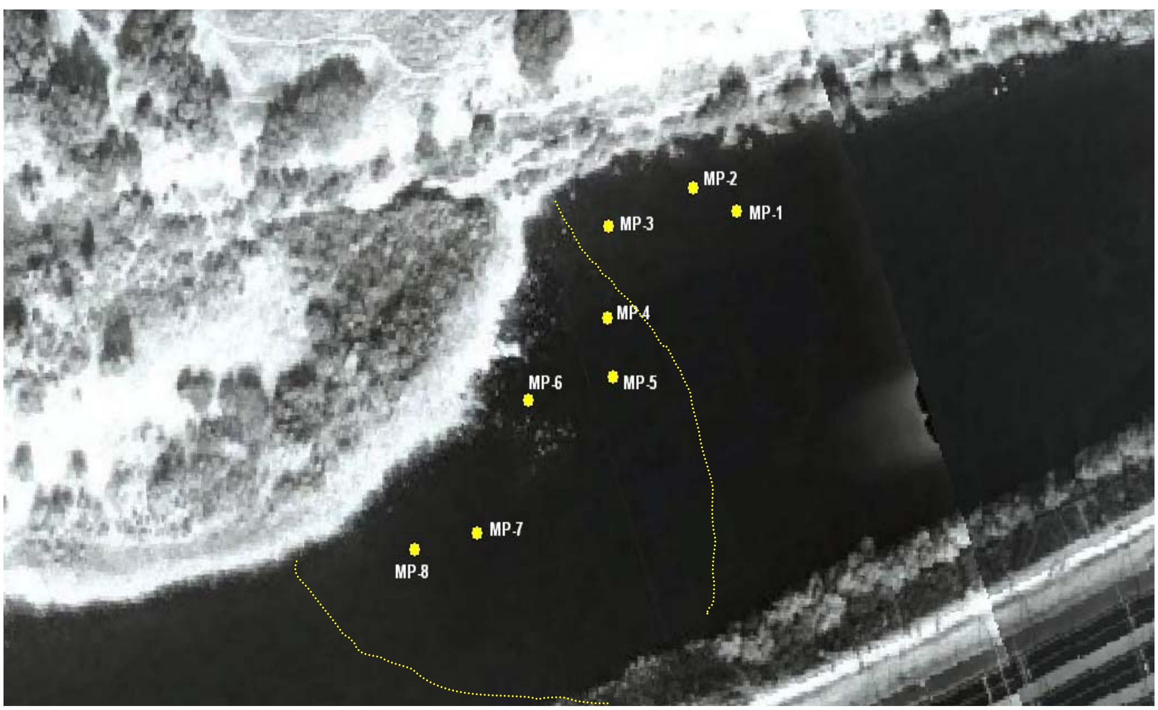



Figure 10: Before gravel addition map showing the gravel addition area outlined in yellow. Points are mini piezometer locations used to sample pre restoration and control hyporheic water quality.

| Piezometer ID | D.O. (mg/L) | pH | E.C. (µs) | Temp (C°) |
|---|---|---|---|---|
| MP-1 | 1.1 | 6.1 | 51.8 | 22.2 |
| MP-2 | 7.45 | 6.6 | 37.2 | 21.8 |
| MP-3 | 6.28 | 6.9 | 37.2 | 21.7 |
| MP-4 | 7.62 | 7.3 | 52 | 21.6 |
| MP-5 | 1.02 | 6.8 | 69.4 | 21.8 |
| MP-7 | 5.38 | 6.9 | 54.6 | 22.6 |
| MP-8 | 2.8 | 6.9 | 57.2 | 22.6 |
| **Mean** | **4.5** | **6.8** | **51.3** | **22** |
| **Surface** | **9.74** | **7.0** | **54.1** | **21.9** |

Table 1: Before gravel addition mini piezometer data September 2008.

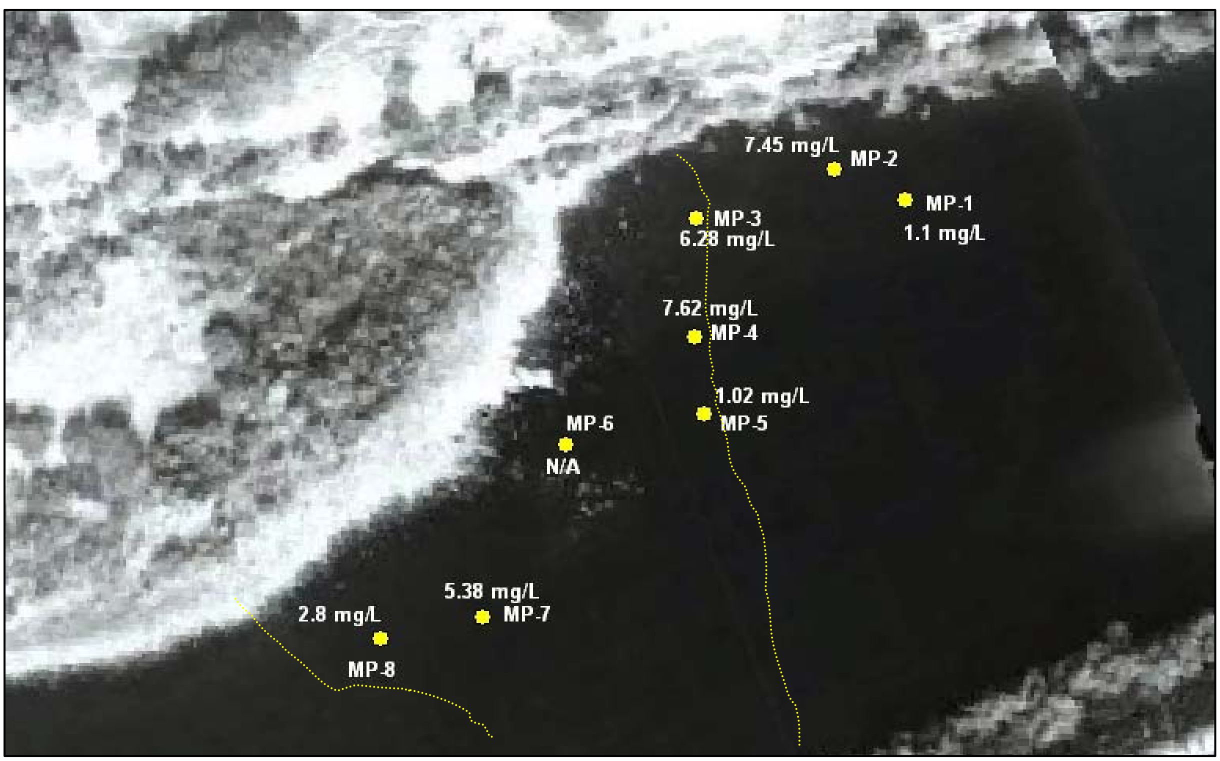



Figure 11: Before gravel addition map of the study area showing dissolved oxygen readings, September 2008.

### 4.2 Before Gravel Addition Hyporheic Pressure Head Measurements

Upwelling and downwelling measurements made before the gravel addition all showed downwelling conditions. Figure 12 shows the upwelling/downwelling map for the pre gravel addition area.

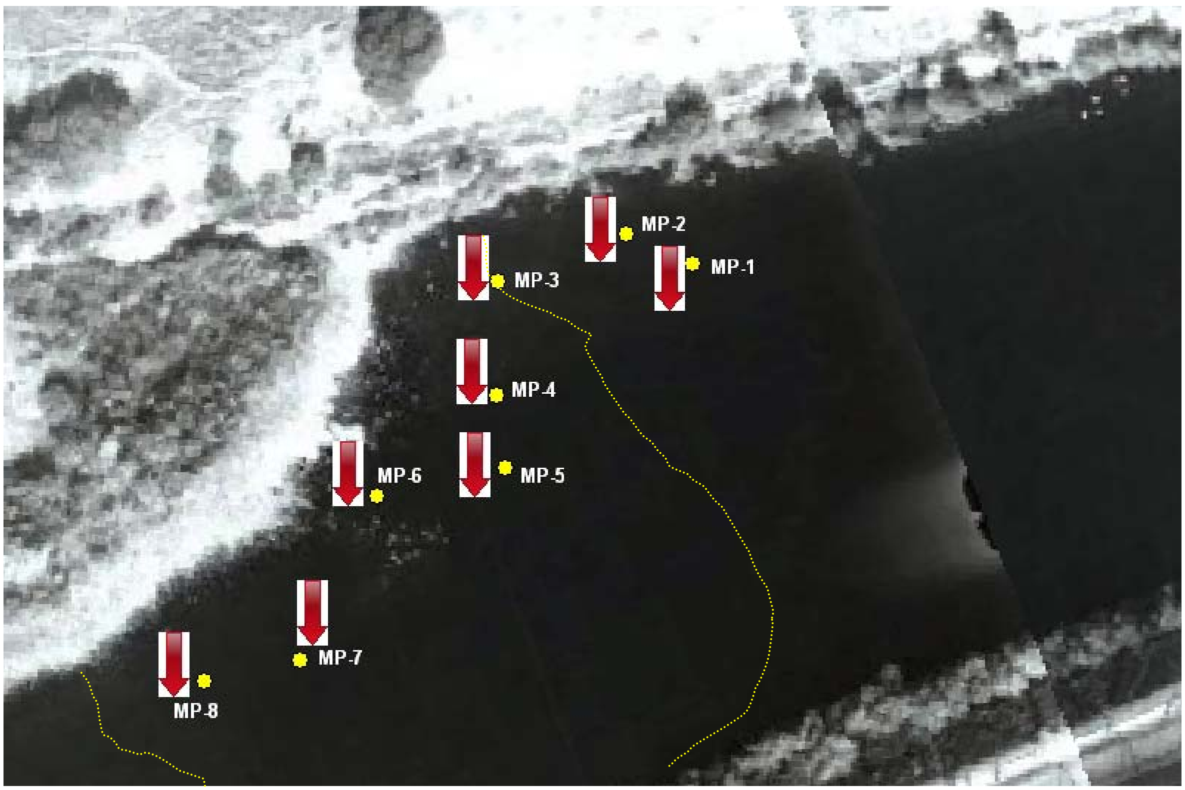



Figure 12: Before gravel addition upwelling/downwelling measurements. The red arrows pointing downward indicate downwelling.

### 4.3 Before Gravel Addition Depth/Velocity Measurements

Table 2 shows the water depth and velocity measurements before gravel was added. The flow for the September 5, 2008 sampling event was 1300 cfs. Mean velocity for surface water before restoration was 1.25 feet per second with a mean depth of 2.9 feet.

| Location | Depth (ft) | Velocity (feet/second) |
|---|---|---|
| MP-1 | 2.3 | 1.05 |
| MP-2 | 2.6 | 1.08 |
| MP-3 | 2.8 | 0.9 |
| MP-4 | 2.9 | 0.79 |
| MP-5 | 3.1 | 1.34 |
| MP-6 | 1.9 | 0.68 |
| MP-7 | 2.8 | 1.45 |
| MP-8 | 2.5 | 1.49 |
| **Mean** | **2.9** | **1.25** |

Table 2: Before gravel addition depth and velocity data for the mini piezometers September 2008.

## 4.01 Results; After Gravel Addition Grain Analysis

9 Pebble counts were conducted in June 2009 after the gravel addition was completed. Figure 13 shows a map of pebble count locations. Figure 14 shows the cumulative frequency graph for the pebble counts conducted after restoration. Median grain size diameters ($d_{50}$) ranged from 5/8 inch to 7/8 inch. Appendix B shows the data from the pebble counts.

Figure 13: After gravel addition map of the pebble counts conducted in June 2009

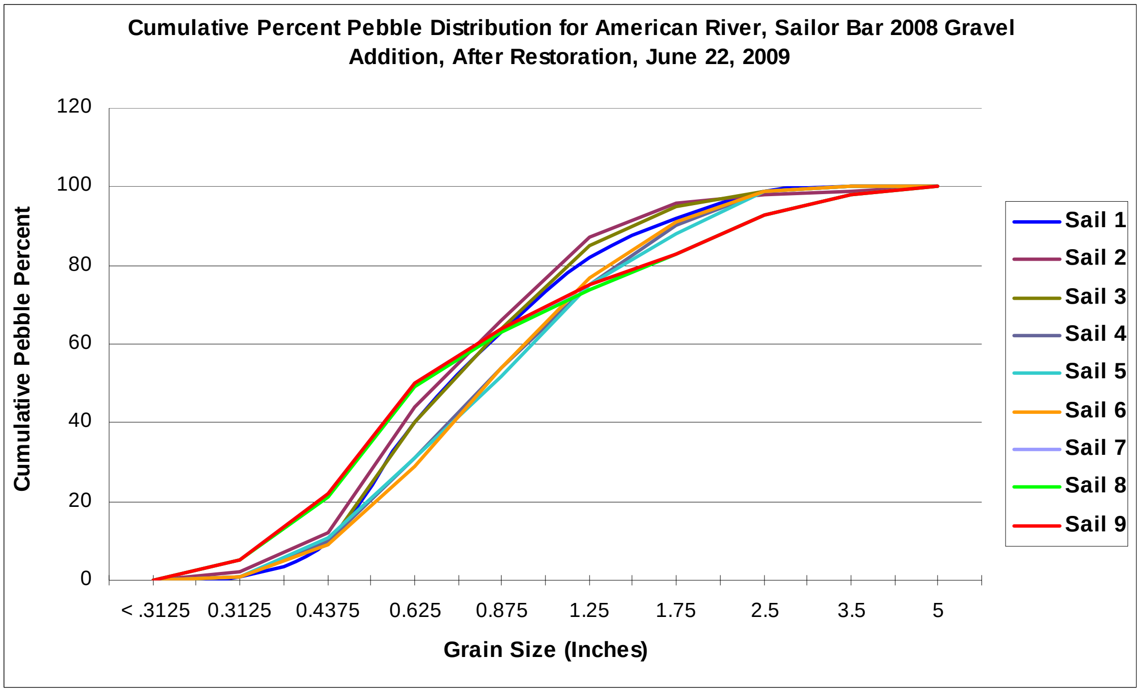



Figure 14: Graph showing the cumulative frequency of each pebble count after gravel addition, June 2009.

### 4.11 After Gravel Addition Water Quality

15 mini piezometers were installed in December 2008 after the gravel addition. Figure 15 shows the location of the mini piezometers after the gravel was added. Table 3 shows the water quality data for the post gravel addition area sampled in February and June, 2009. Water samples were collected before and after gravel addition measuring for Nitrate, Nitrite, Phosphate, and Ammonia. None of the samples showed values higher than the lowest detectable limits for any of the water samples. Appendix C shows the HACH chemistry data for the before and after gravel addition water chemistry analysis. Most of the water samples measured barely showed the lowest detectable limits for the given test; none of the samples contained even moderate concentrations of anything measured.

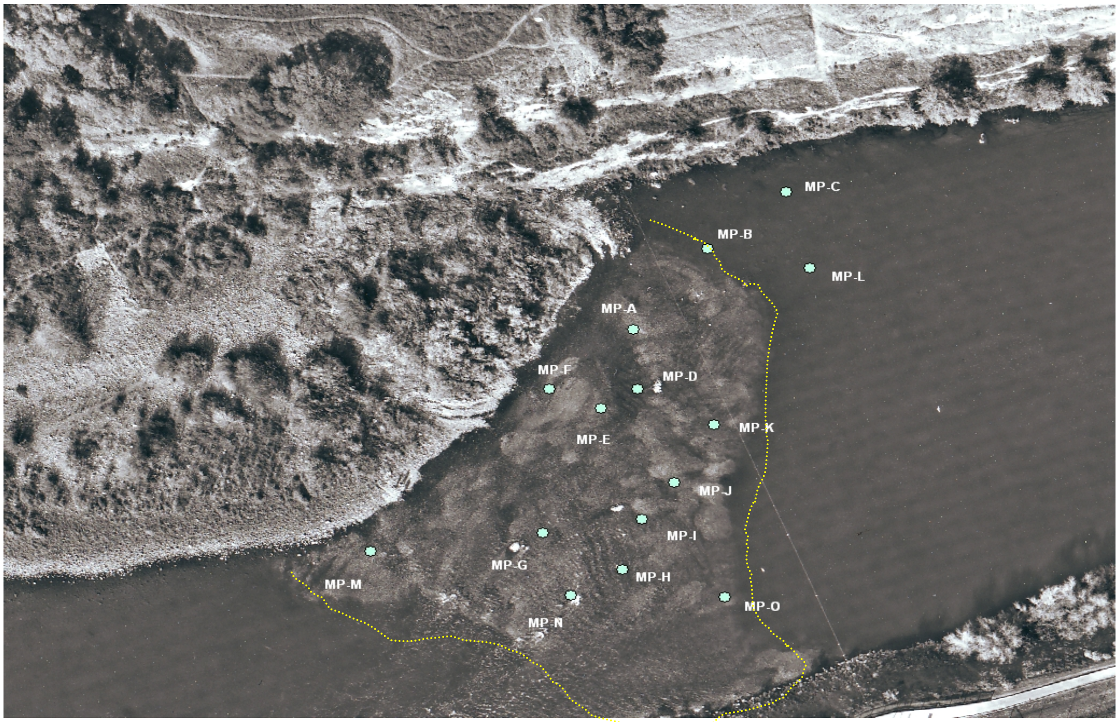


Figure 15: After gravel addition map showing the gravel addition area. Points indicate mini piezometer locations. MP C and MP L are upstream of the gravel to provide control measurements.

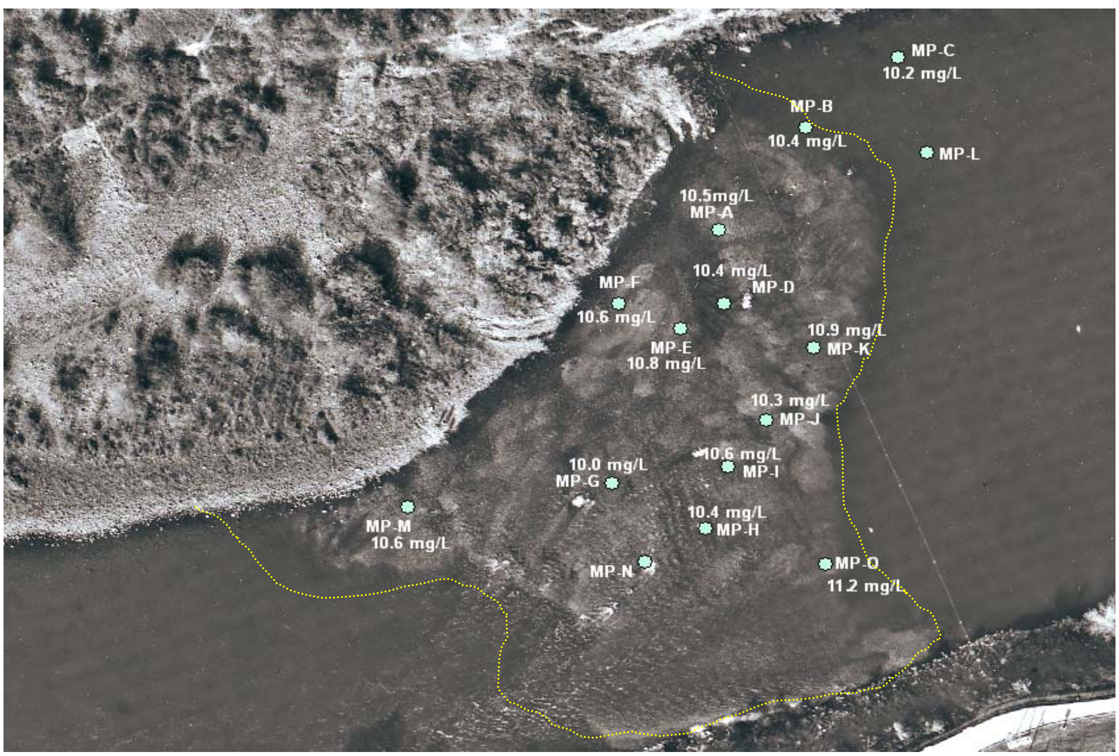


Figure 16: After gravel addition map of the study area dissolved oxygen readings February 2009.

| Piezometer ID | D.O. (mg/L) | pH | E.C. (µs) | Temp (C°) |
|---|---|---|---|---|
| MP-A | 10.5 | 7.06 | 80.7 | 9.4 |
| MP-B | 10.4 | 7.26 | 80.5 | 9.2 |
| MP-C | 10.2 | 7.55 | 82.0 | 9.6 |
| MP-D | 10.4 | 7.14 | 80.5 | 9.4 |
| MP-E | 10.8 | 7.48 | 79.1 | 10.2 |
| MP-F | 10.2 | 7.19 | 78.3 | 9.6 |
| MP-G | 10.0 | 7.46 | 78.4 | 9.5 |
| MP-H | 10.4 | 7.56 | 77.9 | 9.8 |
| MP-I | 10.6 | 7.54 | 78.5 | 9.4 |
| MP-J | 10.3 | 7.28 | 78.6 | 9.4 |
| MP-K | 10.9 | 7.51 | 79.1 | 9.4 |
| MP-M | 10.6 | 7.1 | 81.8 | 9.9 |
| MP-O | 11.0 | 7.49 | 78.8 | 9.5 |
| Surface | 11.2 | 7.52 | 80.2 | 9.6 |
| **Mean** | **10.5** | **7.4** | **79.6** | **9.6** |

Table 3: After gravel addition mini piezometer water quality data from Sailor Bar February 2009.

Mean E.C. measured after the gravel addition was 79.6 µs with measurements ranging from 78µs -82µs. The mean D.O. recorded (Figure 16) was 10.5 mg/L with a measurement range of 10.0 mg/L to 11.2 mg/L. The mean pH was 7.4 with a range from 7.1 to 7.5. The mean temperature recorded was 9.6 degrees Celsius with a range from 9.2 to 10.2 degrees Celsius.

### 4.21 After Gravel Addition Hyporheic Pressure Head Measurements

Figure 17 shows the upwelling/downwelling map for the post gravel restoration area. Measurements were made in February 2009 with a river flow approximately 750 cfs. Table 4 shows the vertical gradient for each mini piezometer. Gradient was calculated by taking the measurement from the monometer board (difference in hydraulic head dh) and dividing it by the 30 cm length of the piezometer (dl).

| Piezometer ID | Gradient |
|---|---|
| MP-A | 0.02 |
| MP-B | 0.01 |
| MP-C | Even |
| MP-D | -0.06 |
| MP-E | 0.03 |
| MP-F | -0.06 |
| MP-G | 0.02 |
| MP-H | 0.02 |
| MP-I | 0.05 |
| MP-J | 0.03 |
| MP-K | 0.05 |
| MP-M | 0.02 |

Table 4: After gravel addition vertical gradient data from February 2009. Negative values indicate upwelling, positive values indicate downwelling.

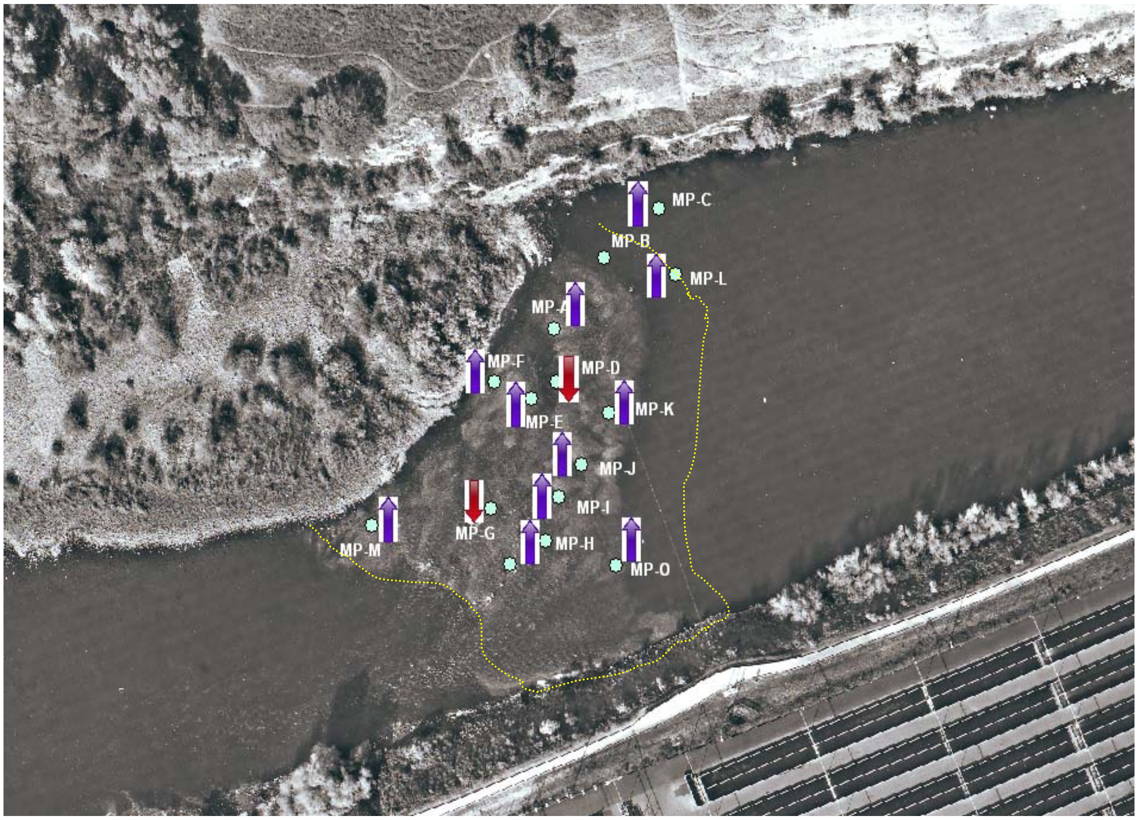


Figure 17: After gravel addition map showing upwelling/downwelling measurements. The red arrows pointing downward indicate downwelling, the purple arrow pointing upward indicate upwelling conditions February 2009.

### 4.31 After Gravel Addition Depth/Velocity Measurements

Velocity and depth were measured in February 2009, after the gravel was added. Table 5 shows the depth and velocity measurements. The flow for the February 21, 2009 sampling event was 780 cfs. The low flow caused many locations to be too shallow to measure the stream velocity for the post gravel addition data. The mean velocity for the restoration area was 2.55 feet per second. The mean depth was 0.9 feet. Figure 18 shows the locations of the velocity measurements.

| Location | Depth (ft) | Velocity (feet/second) |
|---|---|---|
| MP-A | 0.8 | 2.81 |
| MP-E | 1.0 | 1.97 |
| MP-G | 0.5 | 1.86 |
| MP-H | 1.0 | 4.35 |
| MP-I | 1.4 | 3.21 |
| MP-J | 0.9 | 2.4 |
| MP-K | 0.5 | 1.45 |
| MP-O | 1.3 | 5.01 |
| MP-B | 0.6 | 0.2 |
| **Mean** | **0.9** | **2.55** |

Table 5: After gravel addition depth and velocity data. Several piezometers were omitted due to insufficient water depth for measurement February 2009. River flow was 780cfs.

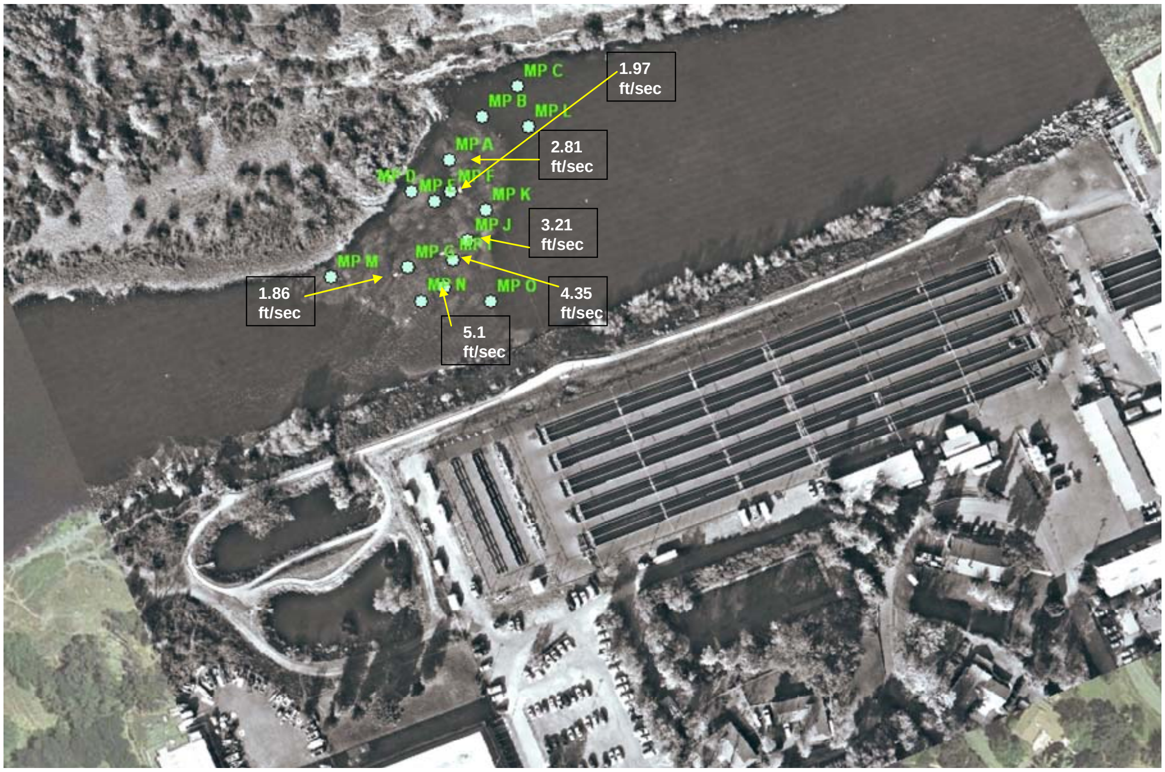


Figure 18: After gravel addition map showing average surface water velocity measurements in February 2009. Stream flow was 780 cfs. Mini piezometers without velocity values were either too shallow or less than 1 foot per second.

### 4.4 After Gravel Addition Gravel Mobility

Figure 19 shows the tracer rock transects installed after gravel addition. The gravel addition is highlighted with a (yellow) dotted line. 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. This was witnessed on multiple occasions by the field crew. Substantial numbers of yellow and blue rocks were located 8 months after the gravel addition was completed. The upper transect recovered 19 large (yellow, 2 ½ -3 inch) rocks, 12 intermediate-sized (blue, 1 ¼ - 1 ¾ inch) and 6 small-sized (red, 5/8 – 7/8 inch) rocks. The middle transect recovered 17 large rocks, 9 blue rocks and 7 red rocks. Only 5 rocks from the lower transect were located.

After 8 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.

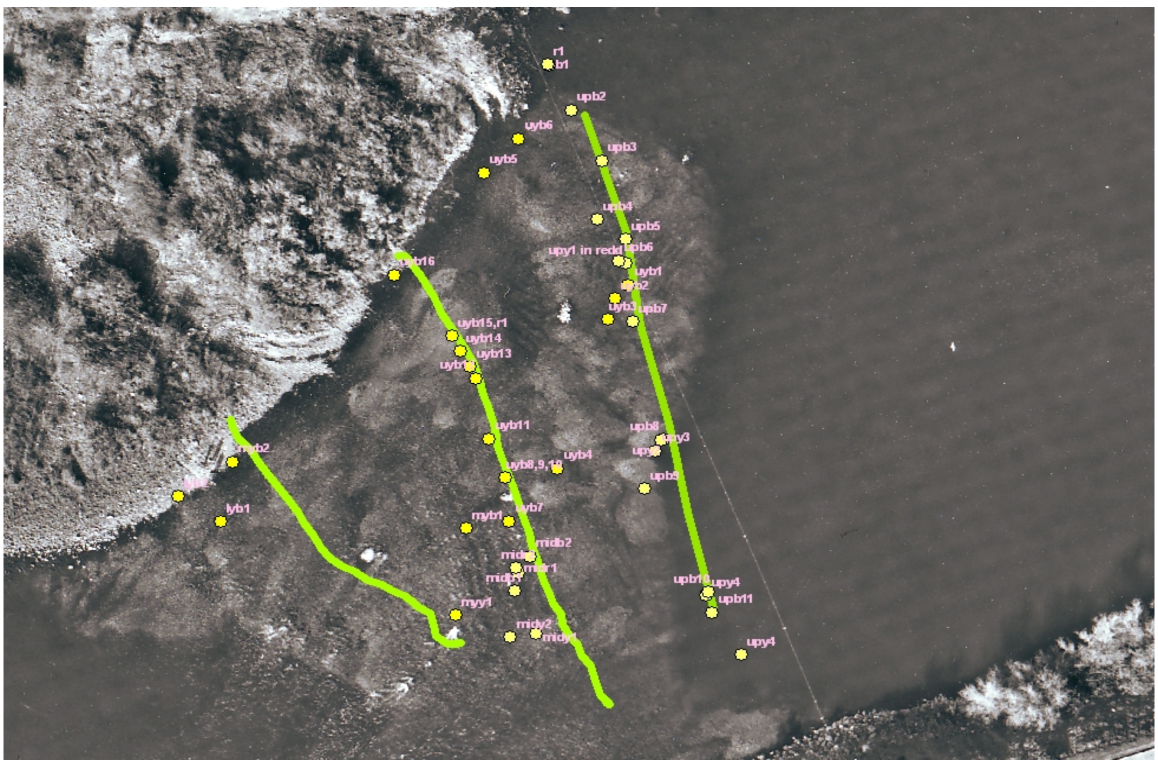



Figure 19: After gravel addition map showing the tracer rock transects from June 2009. Yellow points indicate rocks located.

### 4.5 After Gravel Addition Inter Gravel Velocity Measurements

Four salt water tracer tests were conducted at Sailor Bar in March 2010.The location of these tracer tests is shown on Figure 20. Figures 21-24 show graphs of electrical conductivity versus time for the 4 tests. The tracer tests yielded inter gravel velocities of 10 cm/min to 50cm/min, at a depth of 30 cm and 18 months after restoration work. A monitoring well, spaced 10 cm from the injection well showed elevated electrical conductivity values immediately after sodium chloride injection for every test. Inter gravel velocities for the 10 cm and 20 cm monitoring wells were between 20 cm/min and 50 cm/min. The velocities recorded at the 30 cm and 40 cm distances were between 10 cm/min and 12 cm/min. Distances greater than 50cm from the injection often missed the tracer plume except for test 2, where the monitoring well 47 cm from the injection well showed a velocity of 24 cm/min. The tracer test was added at time= 0; and the arrival time is taken as the midpoint of the E.C. curve for each monitoring well.

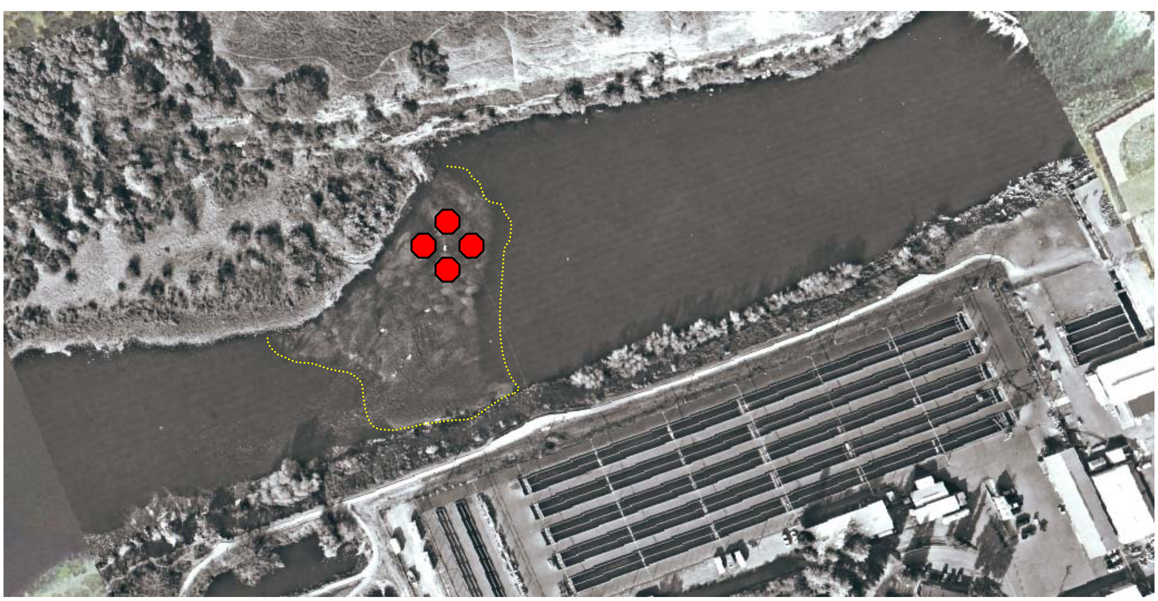


Figure 20: After gravel addition map of the salt water tracer tests. Tracer tests were conducted in March 2010.

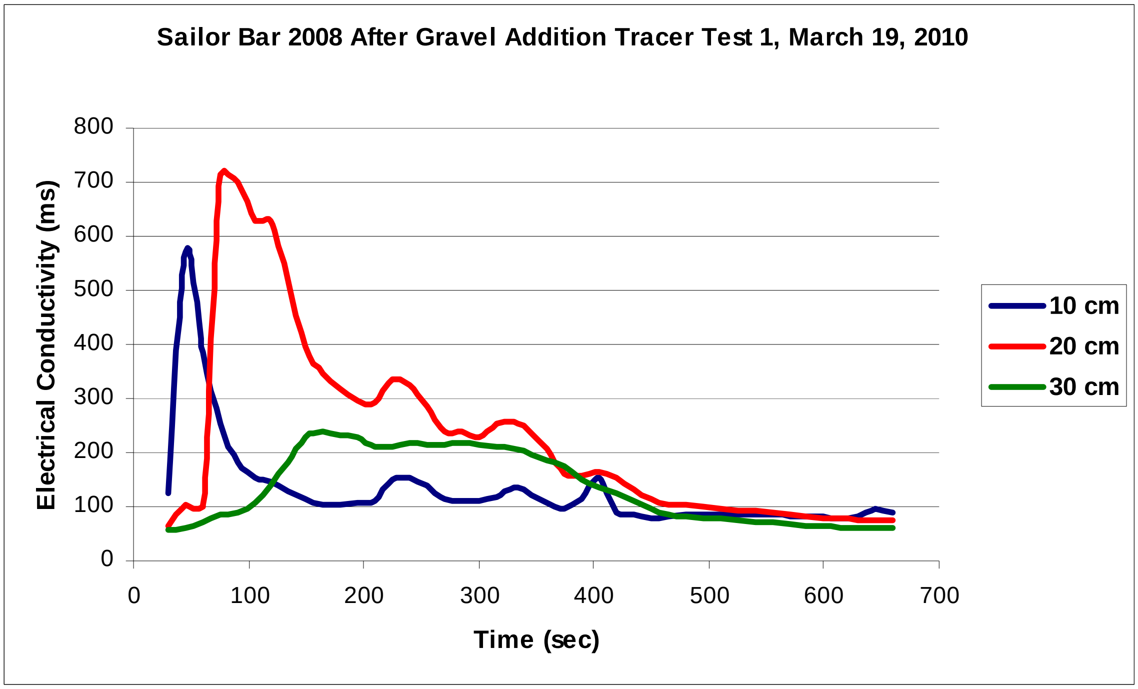



Figure 21: Electrical conductivity versus time graph of a salt water tracer test 1 from Sailor Bar, March 2010.

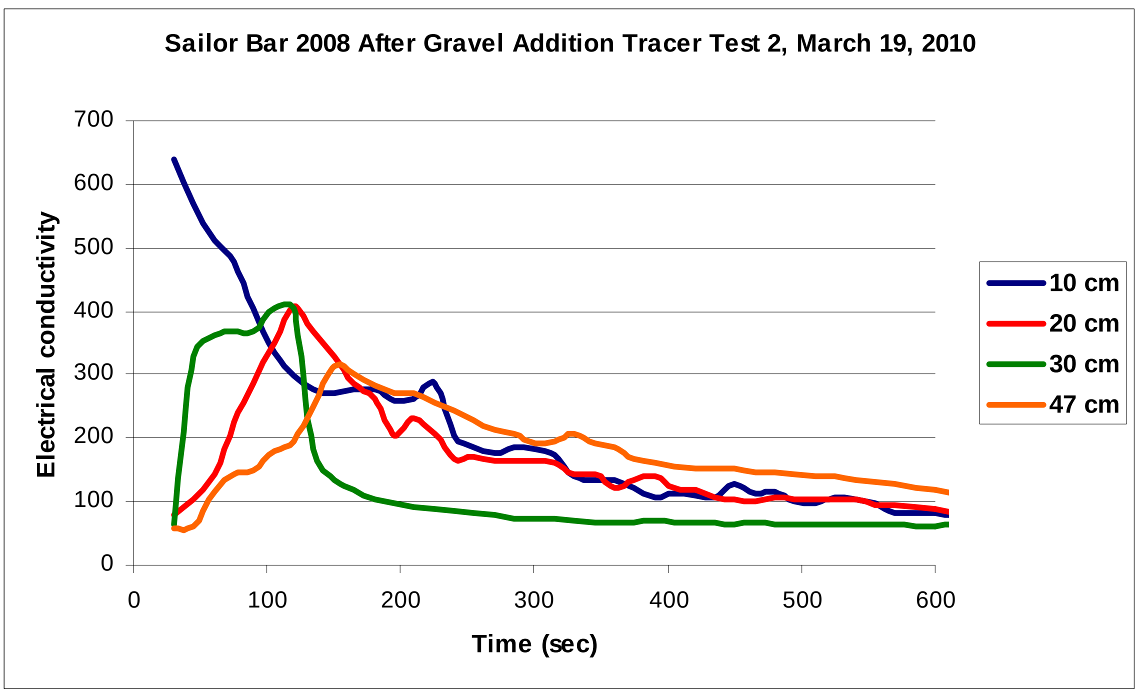



Figure 22: Electrical conductivity versus time graph of salt water tracer test 2 from Sailor Bar, March 2010.

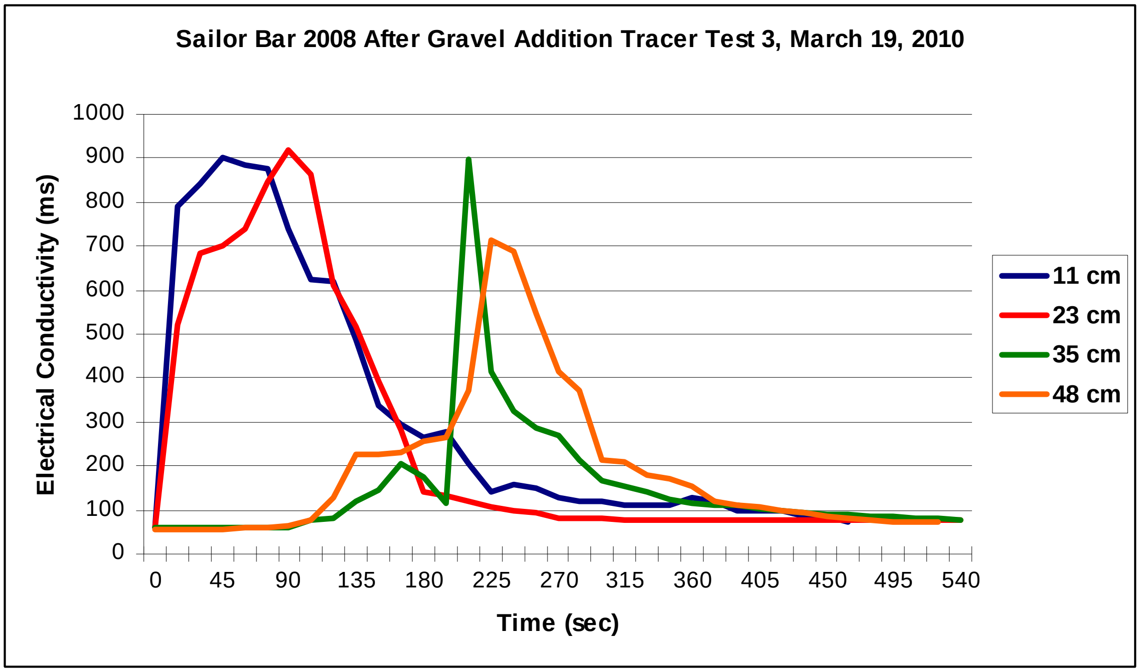



Figure 23: Electrical conductivity versus time graph of salt water tracer test 3 from Sailor Bar, March 2010.

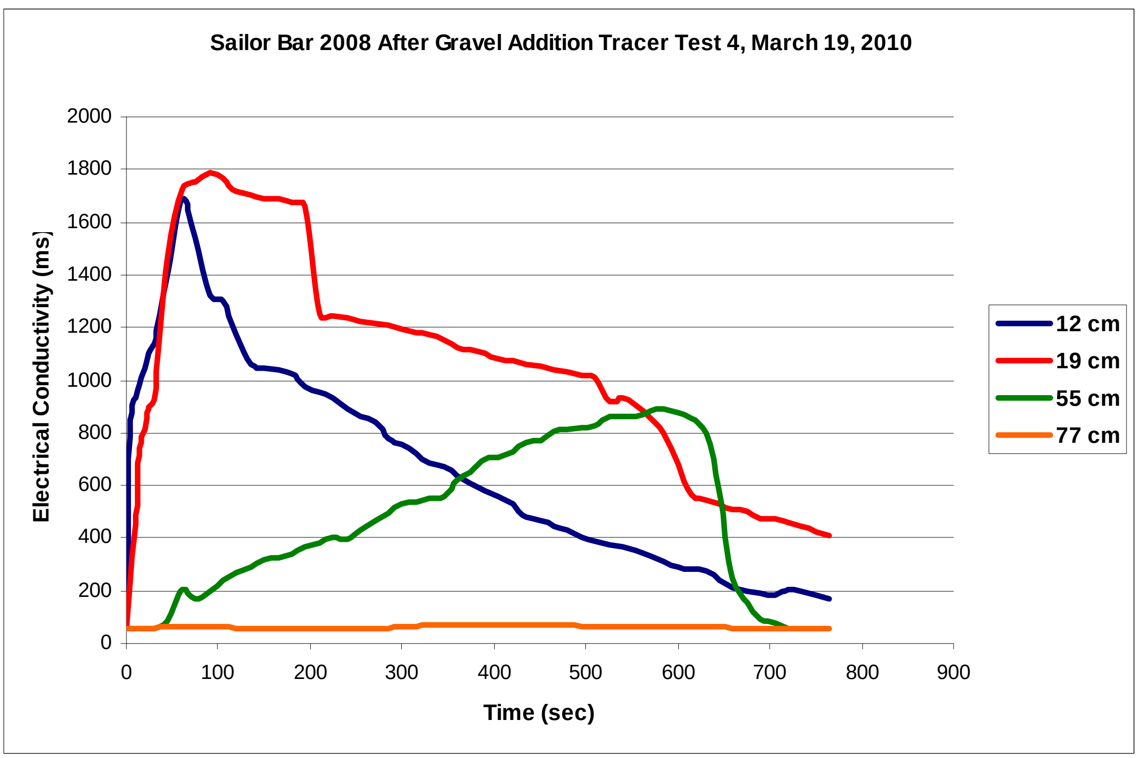



Figure 24: Electrical conductivity versus time graph of salt water tracer test 4 from Sailor Bar, March 2010.

## 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 smaller and more uniform gravel size with 80% of the new gravel less than 1.25 inch diameter with a mean of 0.875 inches. This changed from the previous grains sizes that ranged from .325 inches to over 12 inches intermediate diameter with a mean diameter of 3 inches. Dissolved oxygen measurements were significantly higher in the new gravel area. Mean D.O. before gravel was added was 4.5 mg/L. The mean D.O. measured after the gravel was added was 10.5 mg/L. Some of this difference is attributed to water temperature differences from summer and winter. pH and electrical conductivity were more uniform in the new gravel, with less than 1% deviation in the measurements for E.C. and 15% deviation for the pH.

Tracer rocks studies showed that the smallest tracer rocks (5/8” to ¾’ were mobilized and washed downstream from the study area by this year’s maximum flow of 5000 cfs. Many of the intermediate and largest tracer rocks were still present in the new gravel area 8 months after the rocks were inserted, moving up to 20 meters in some cases.

Salt water tracer tests has showed the gravel addition to be highly permeable with seepage values of 20 cm/min to 50 cm/min within 20 cm of the injection well, with the 10 cm monitoring well having an immediate reaction to the sodium chloride at all tests. Velocities decreased to 10 cm/min and 14 cm/min at distances of 30 cm to 40 cm away from the injection well. Only one monitoring well observed changes more than 50 cm away from the injection well during testing, having a velocity of 14 cm/min. These times indicate rapid movement of water between the pore spaces in the tested locations.

Physical and hydrologic measurements conducted at the Sailor Bar gravel addition site indicate a positive effect in terms of improving spawning habitat. Inter gravel velocities and dissolved oxygen measurements are both elevated in the new gravel. The gravel addition has also had a stabilizing affect on the pH, electrical conductivity, and temperature. Hyporheic pressure changed from complete downwelling prior to restoration to almost complete upwelling after the gravel was added.

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 during the fall Chinook salmon run. The salmon were able to move the gravel to build redds with relative ease compared to previous years, when embedded rocks inhibited spawning. Improved hyporheic 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.

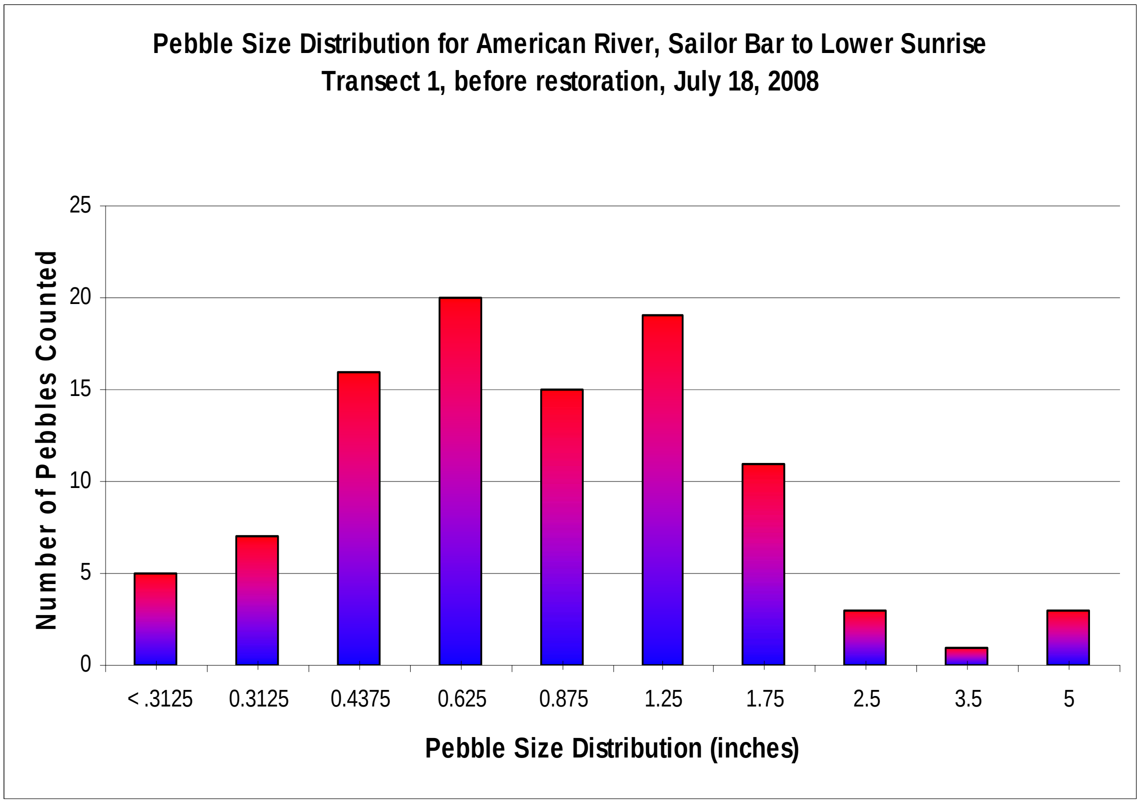
Snider, B., Christophel, D.B., Jackson, B.L., and Bratovitch, P.M., 1992, Habitat characterization of the Lower American River, California Department of Fish and Game, Environmental Services Division in cooperation with Beak Consultants and the county of Sacramento, California, Unpublished report, 20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

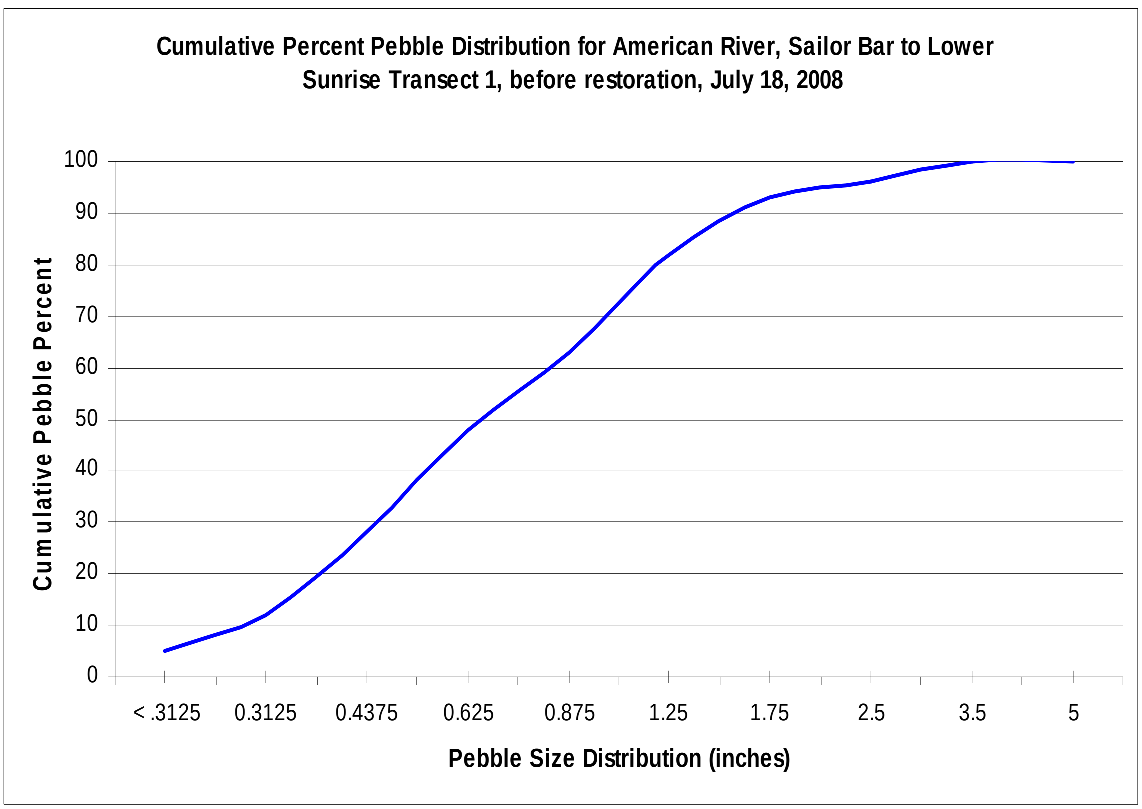
Wolman, M. G. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union 35:951-956.

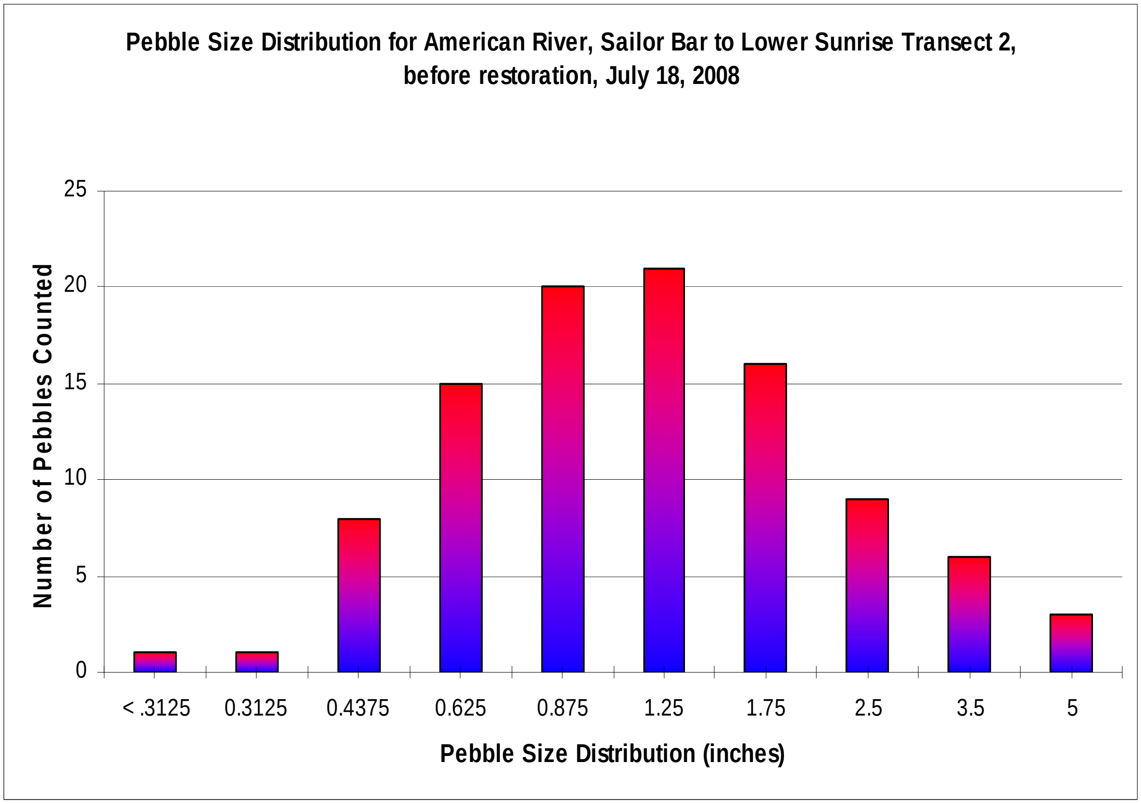
Vyverberg, K., Snider, B., and Titus, R.G., 1997, Lower American River Chinook Salmon spawning habitat evaluation October 1994: California Department of Fish and Game Environmental Services Division Technical Report Number 97-2, 112 p.

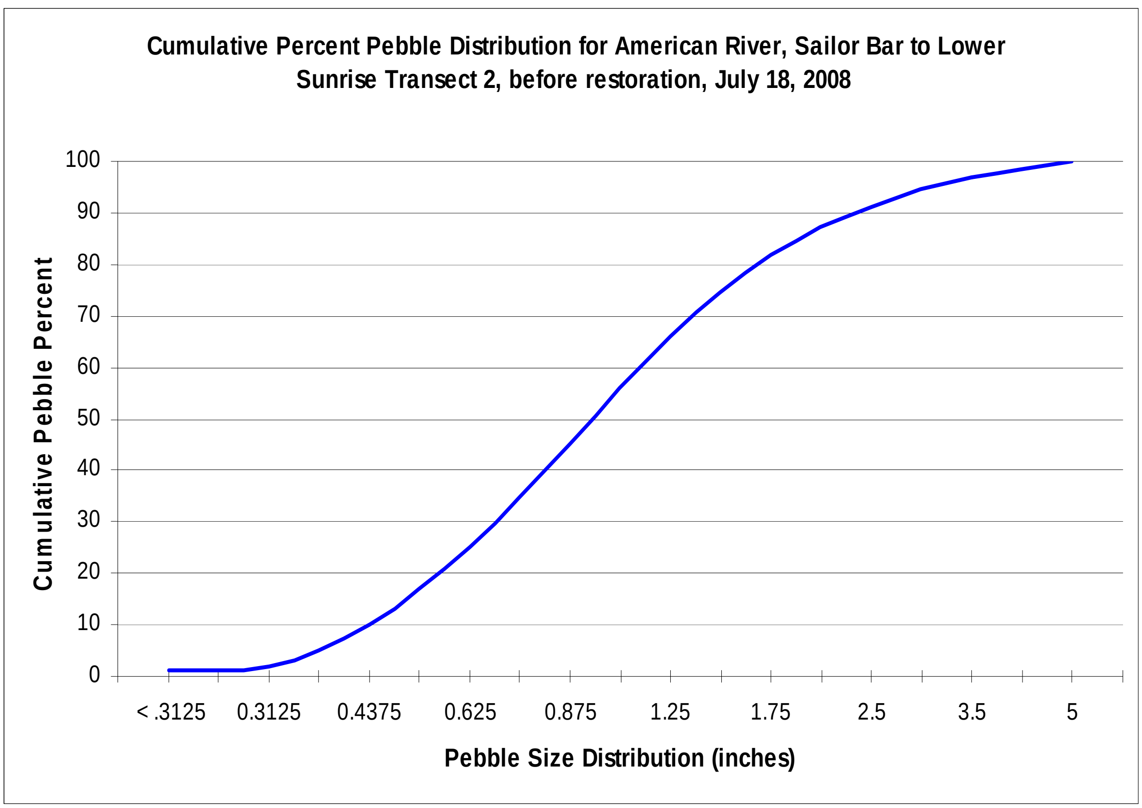
Zamora, C. 2006. Estimating rates of exchange across the sediment/water interface in the lower Merced River, CA. M.S. thesis. CSUS.

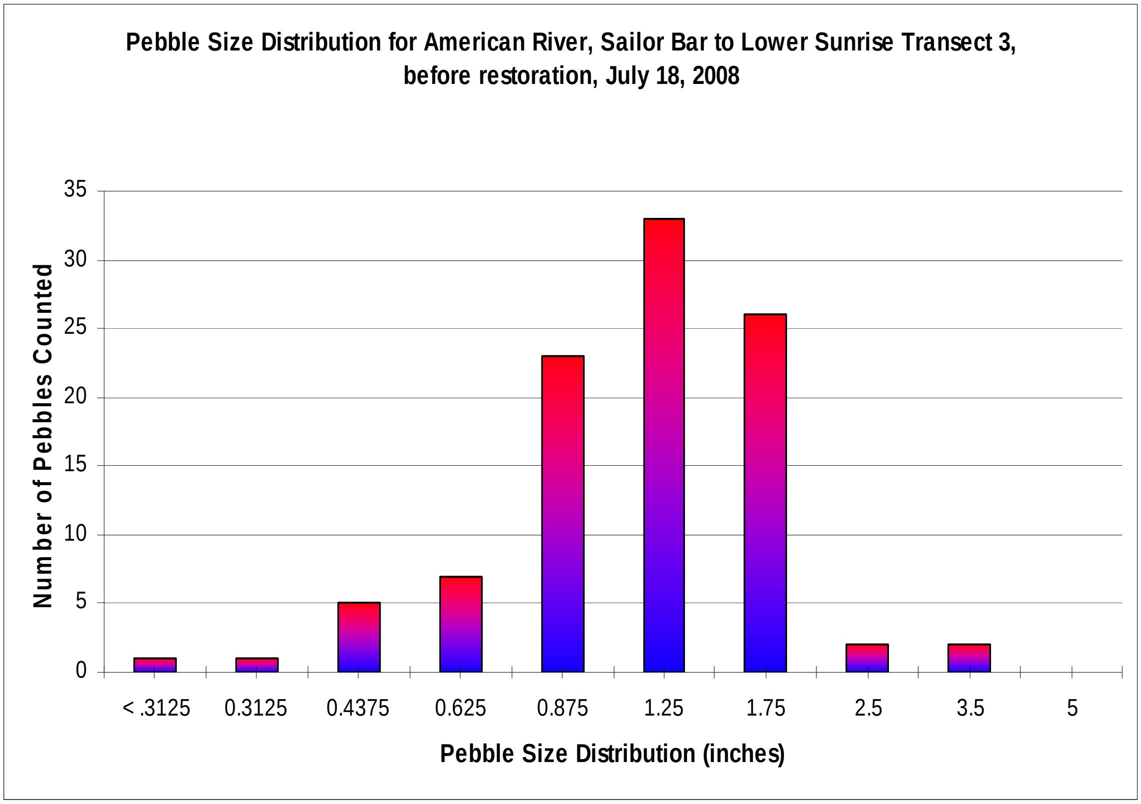
Appendix A: Downstream Pebble Counts from Sailor Bar to Sunrise Ave., before gravel addition

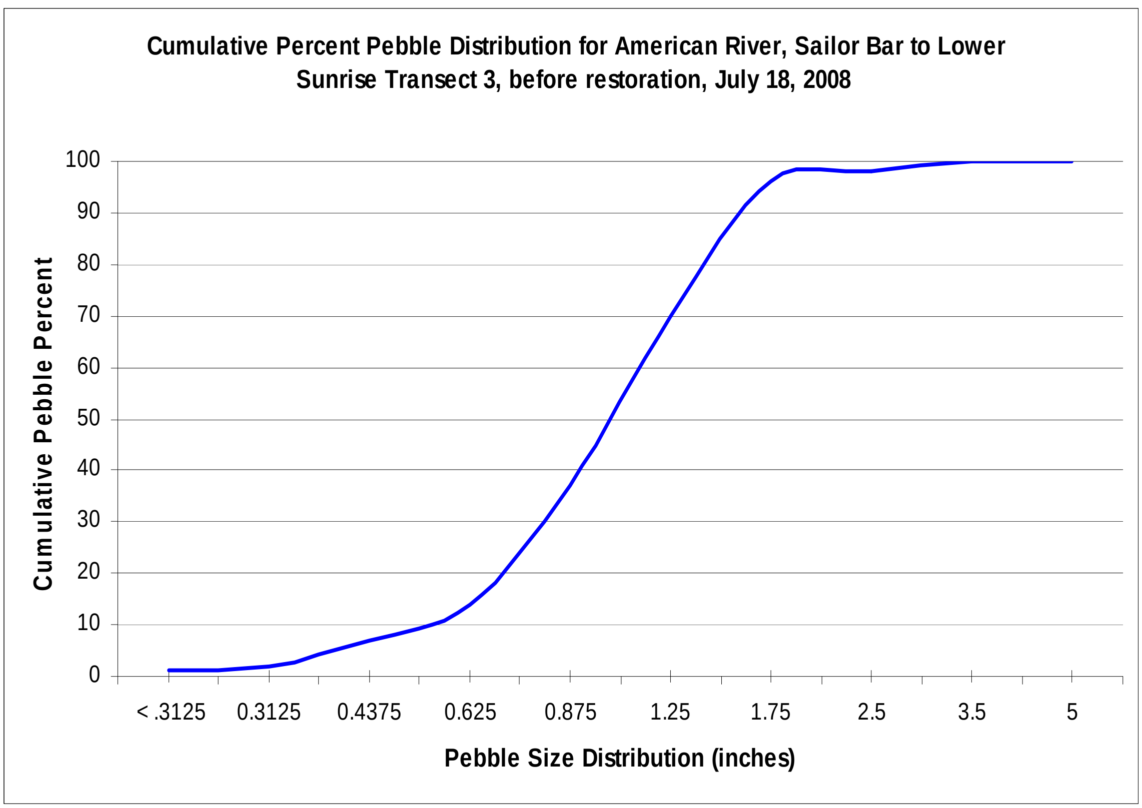

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise
Transect 1, before restoration, July 18, 2008
Number of Pebbles Counted
0
5
10
15
20
25
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

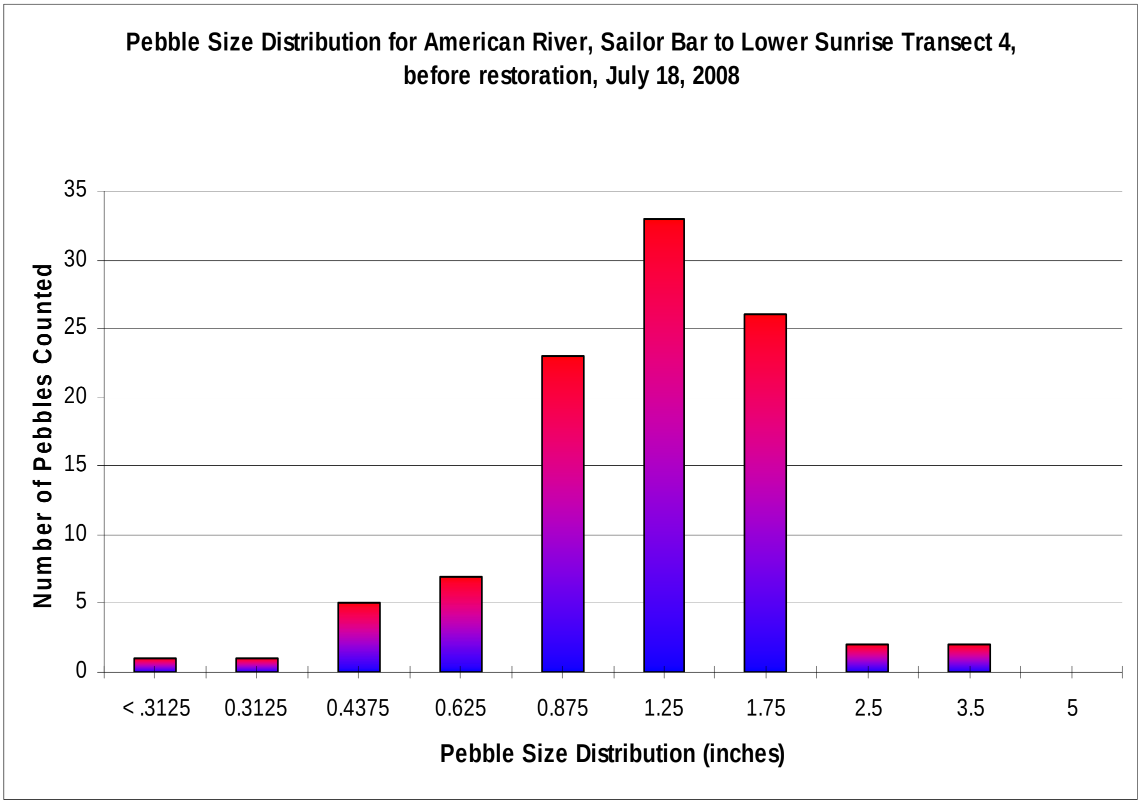

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower
Sunrise Transect 1, before restoration, July 18, 2008
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

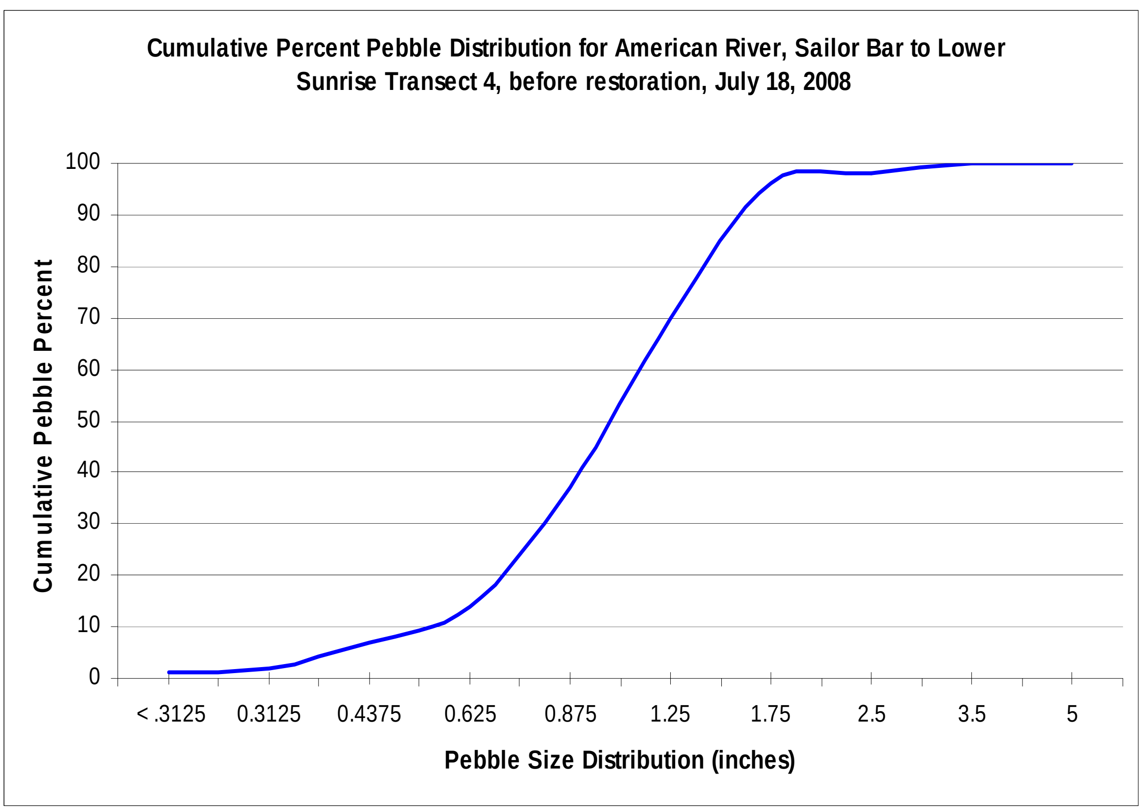

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 2, before restoration, July 18, 2008
Number of Pebbles Counted
0
5
10
15
20
25
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

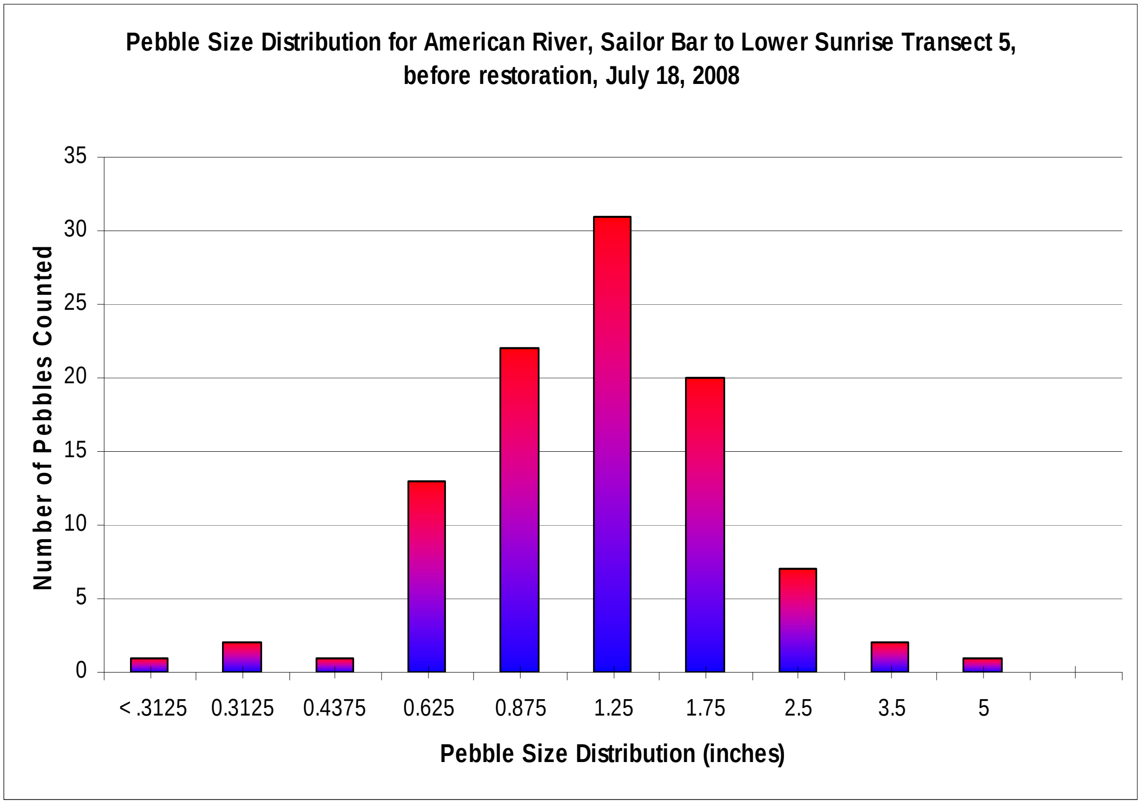

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 2, before restoration, July 18, 2008
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

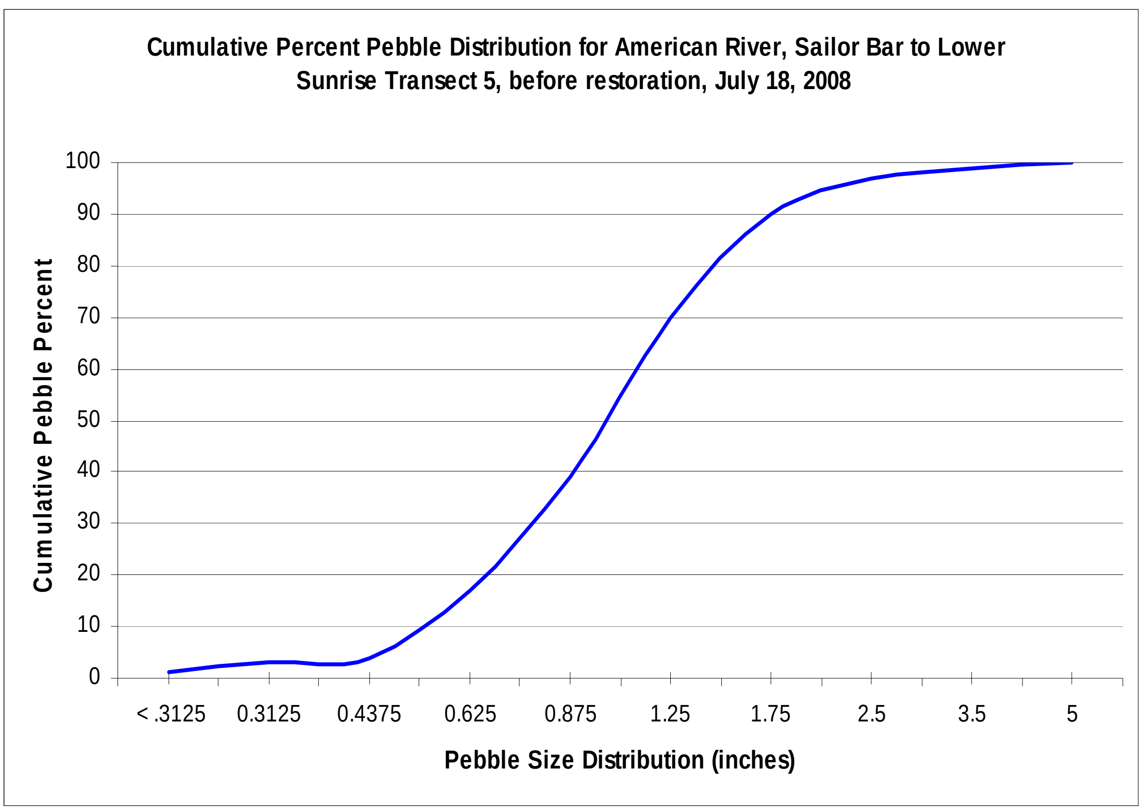

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 3, before restoration, July 18, 2008
Number of Pebbles Counted
35
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

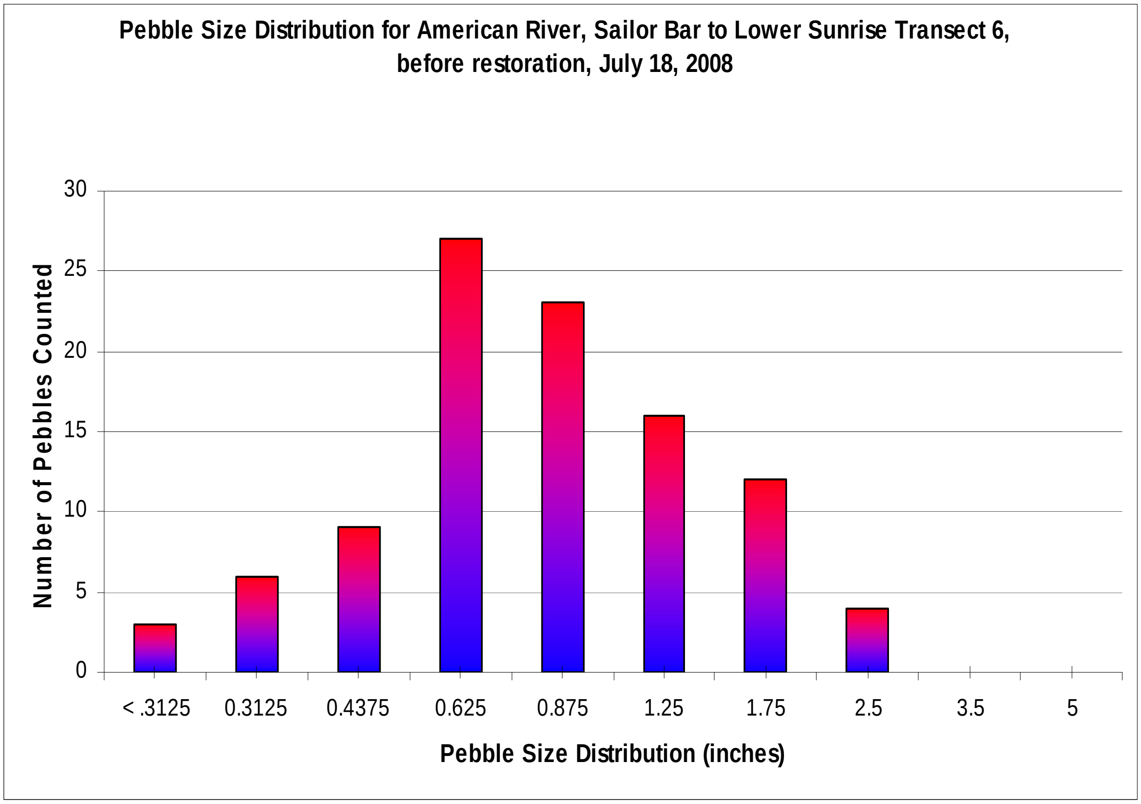

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 3, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

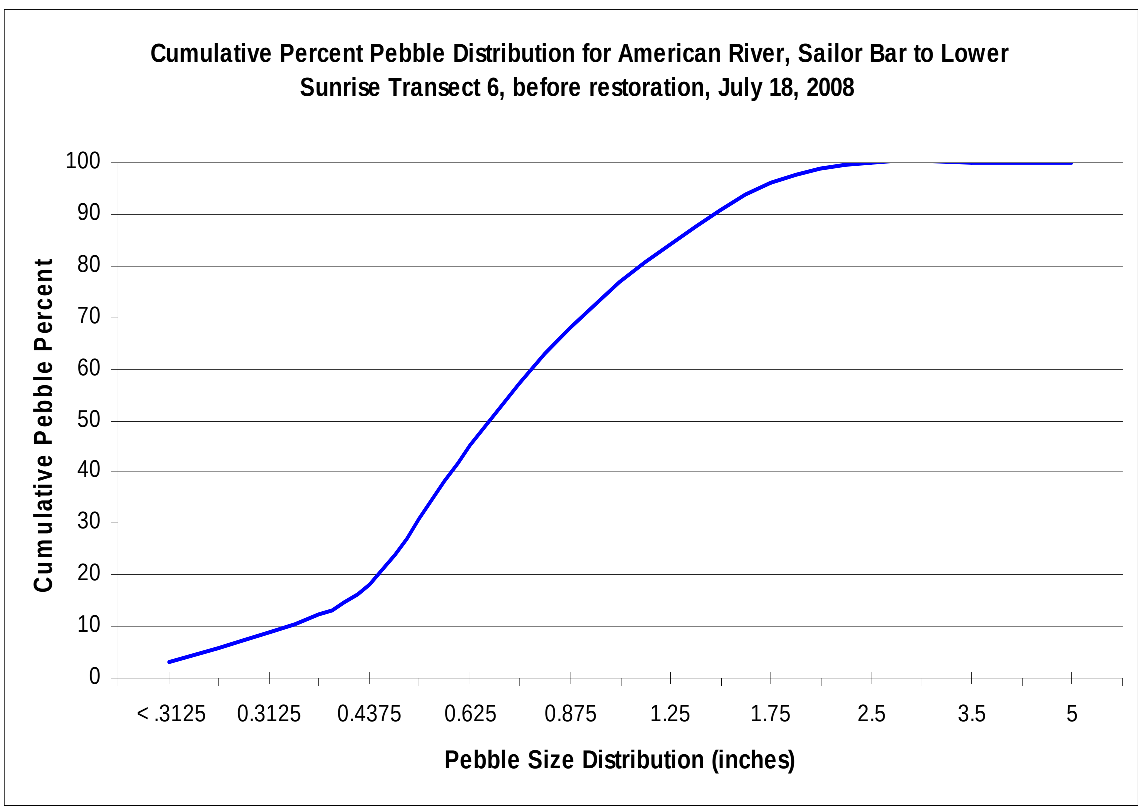

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 4, before restoration, July 18, 2008
Number of Pebbles Counted
35
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

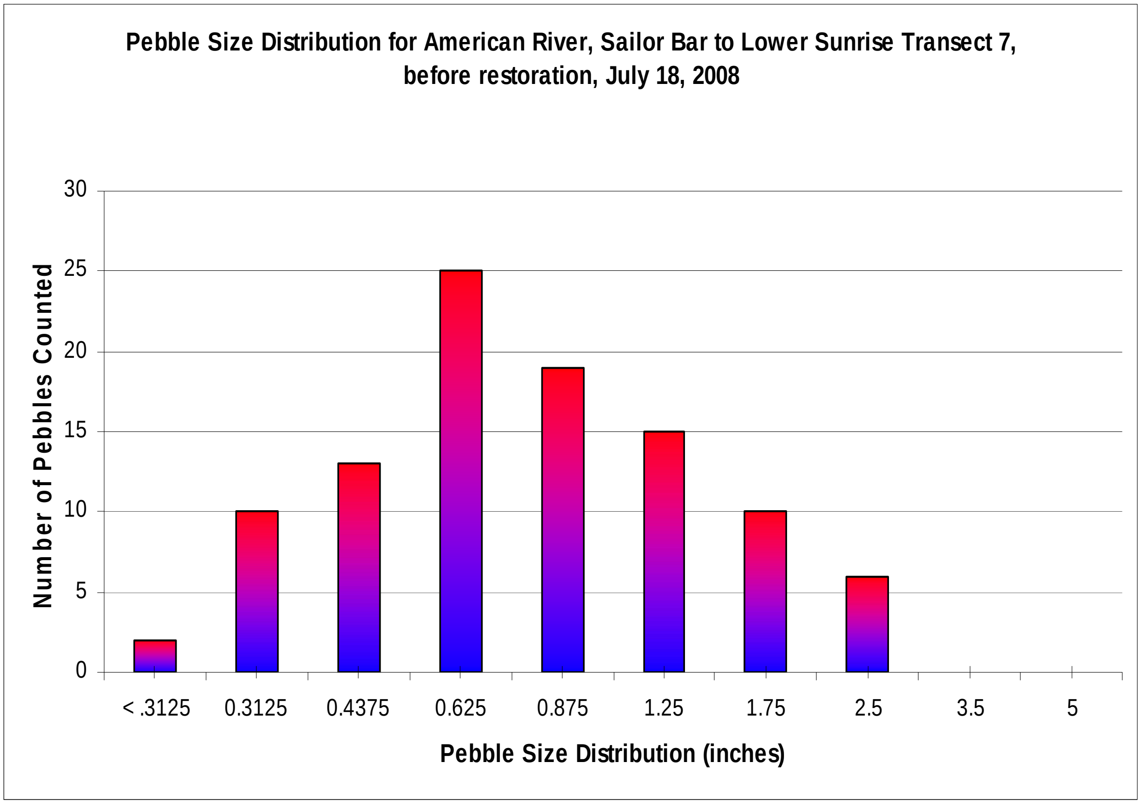

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 4, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)


Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 5, before restoration, July 18, 2008
Number of Pebbles Counted
35
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

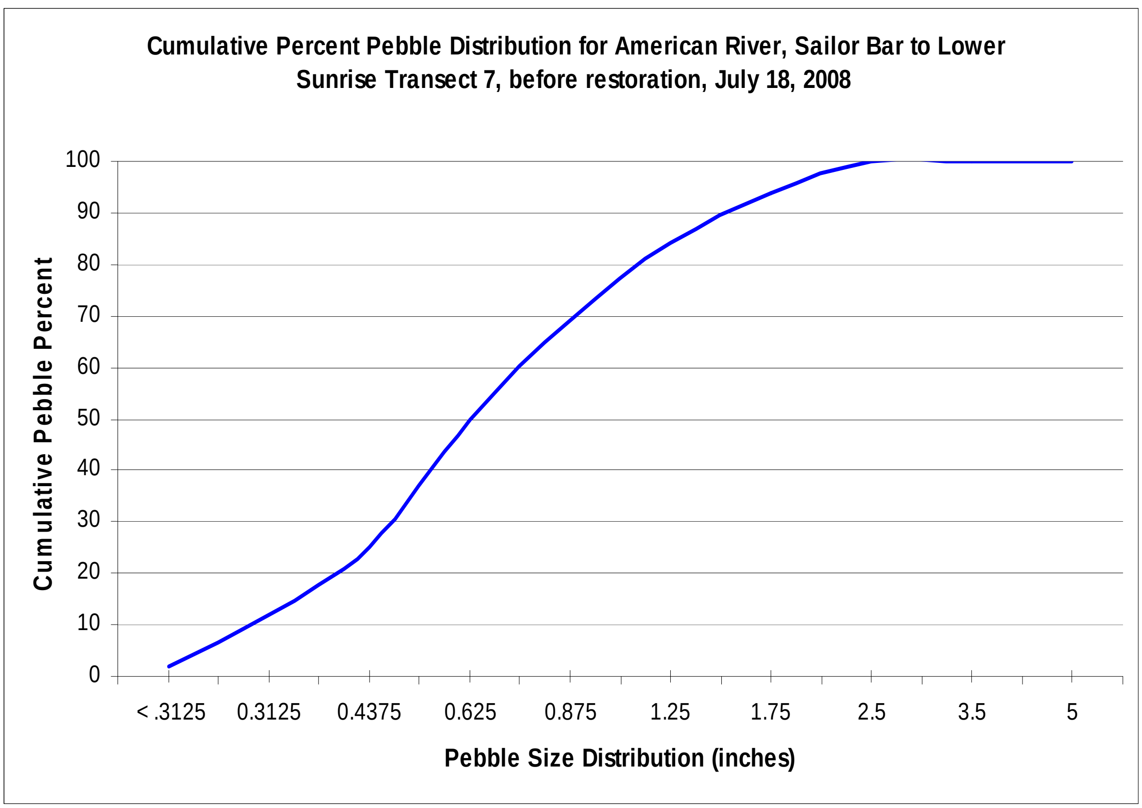

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 5, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)


Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 6, before restoration, July 18, 2008
Number of Pebbles Counted
0
5
10
15
20
25
30
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

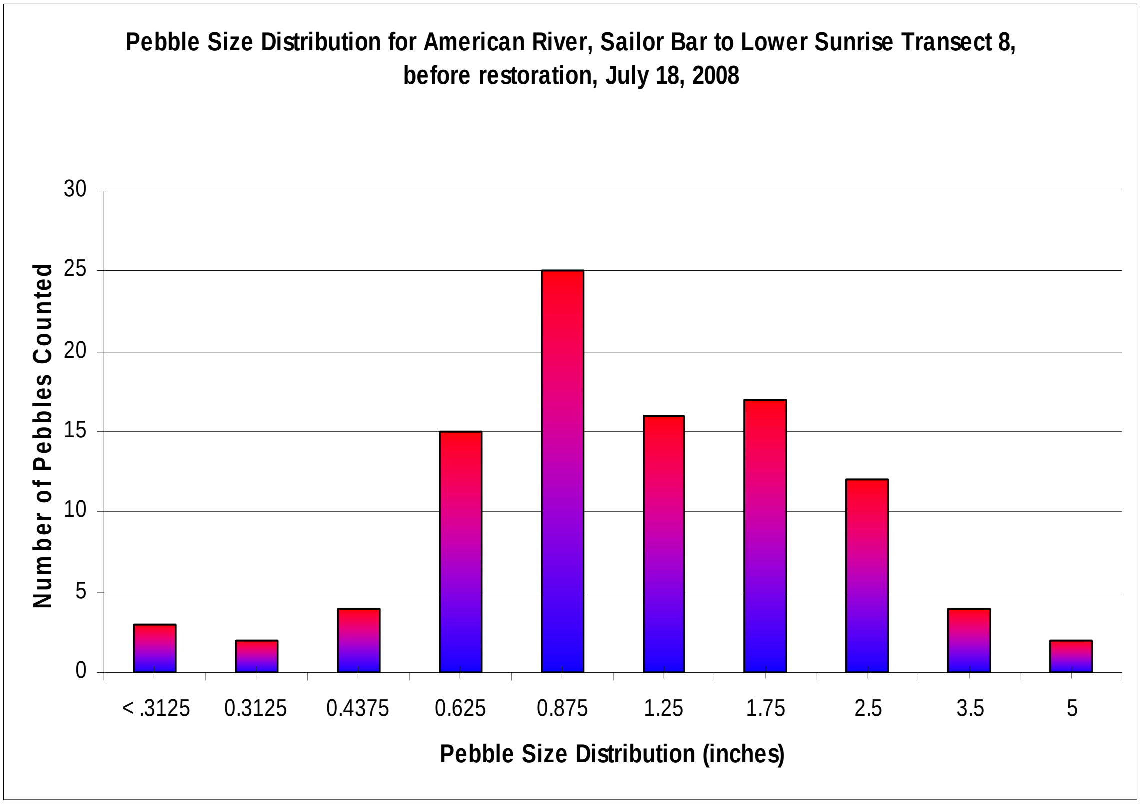

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 6, before restoration, July 18, 2008
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

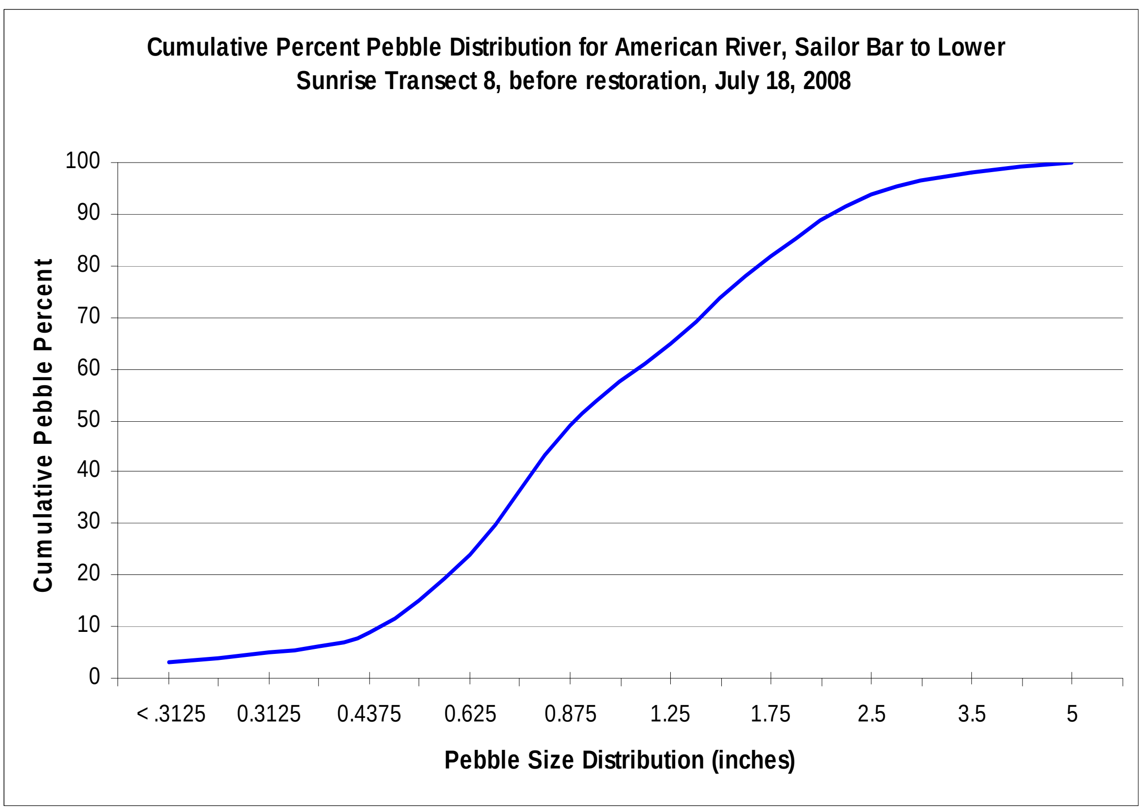


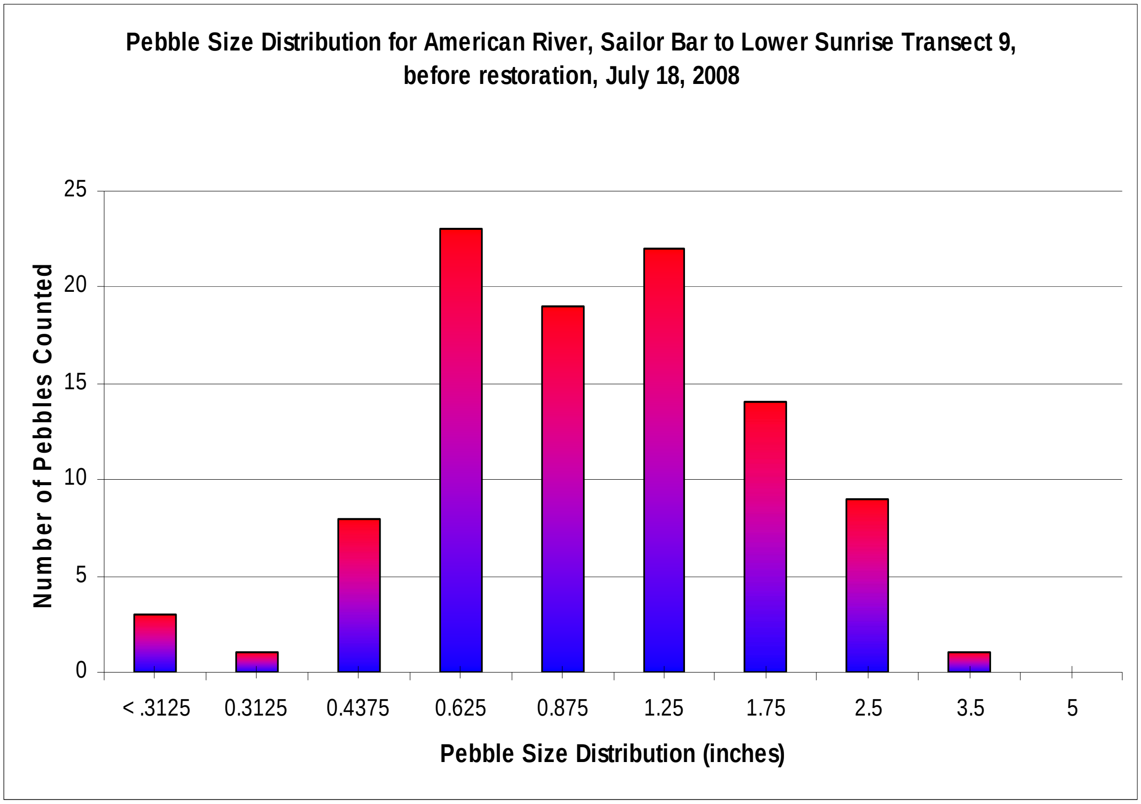
Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 7, before restoration, July 18, 2008
Number of Pebbles Counted
0
5
10
15
20
25
30
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

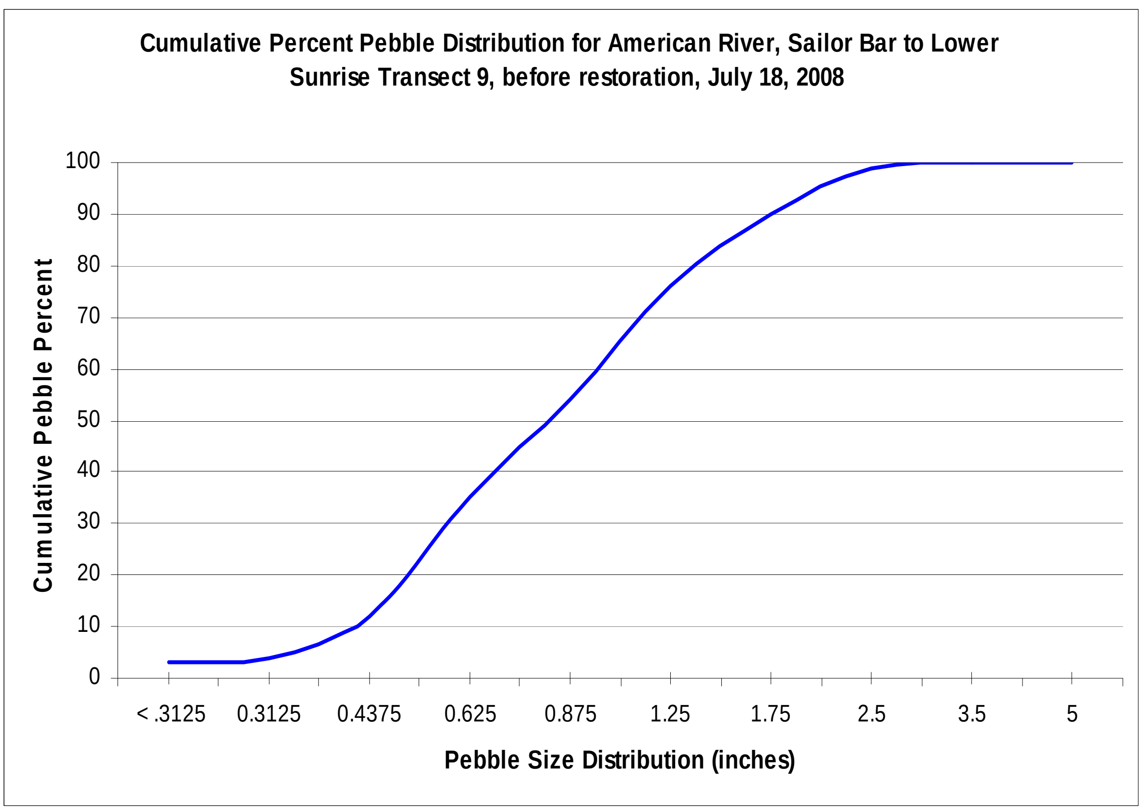



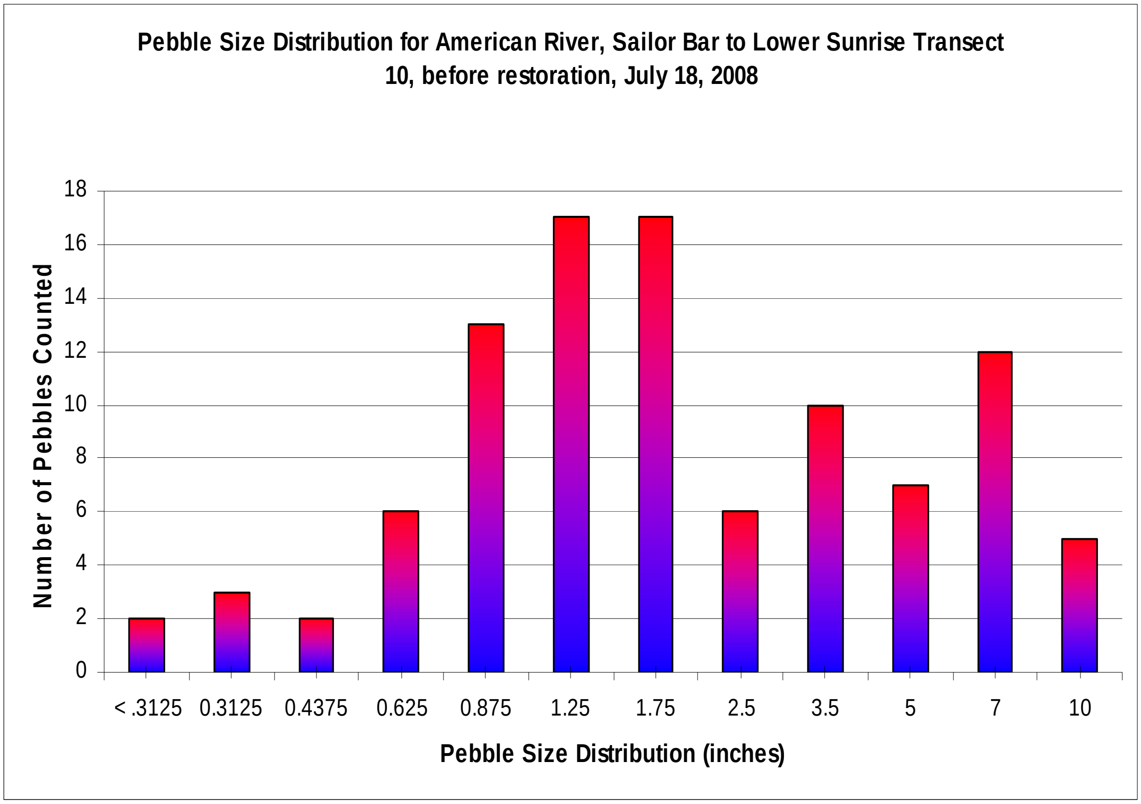
Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 7, before restoration, July 18, 2008
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

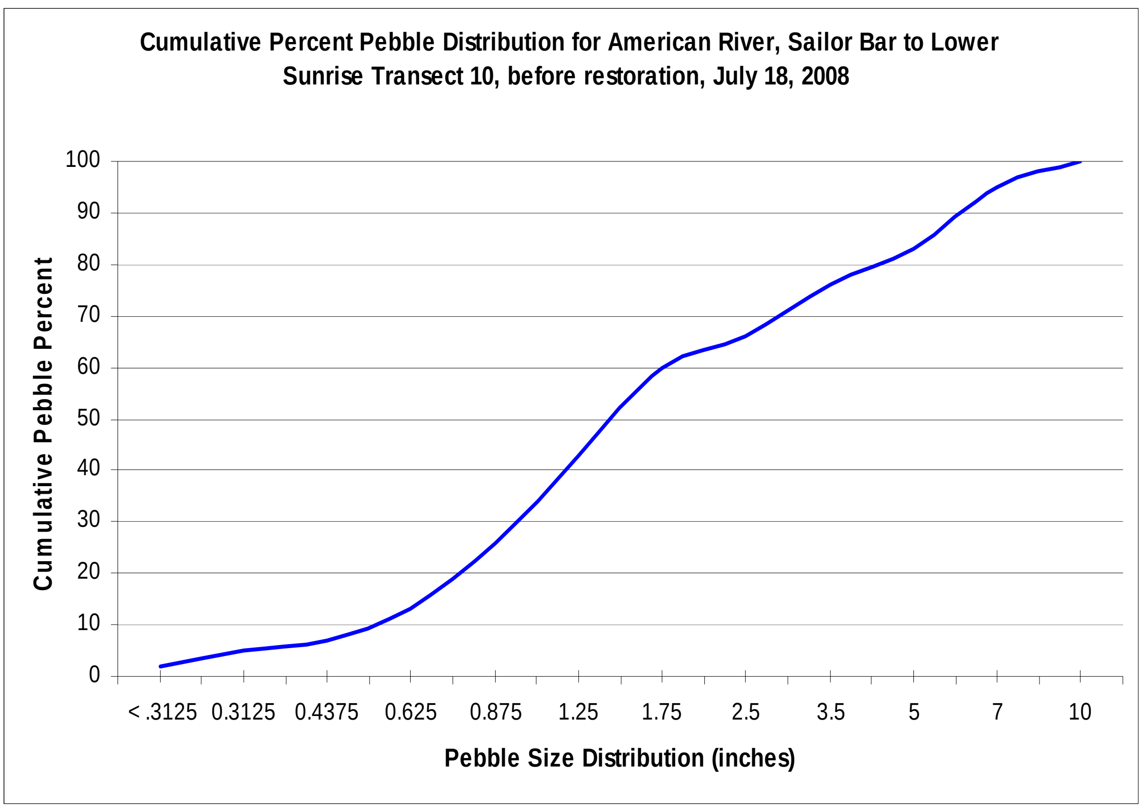

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 8, before restoration, July 18, 2008
Number of Pebbles Counted
0
5
10
15
20
25
30
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

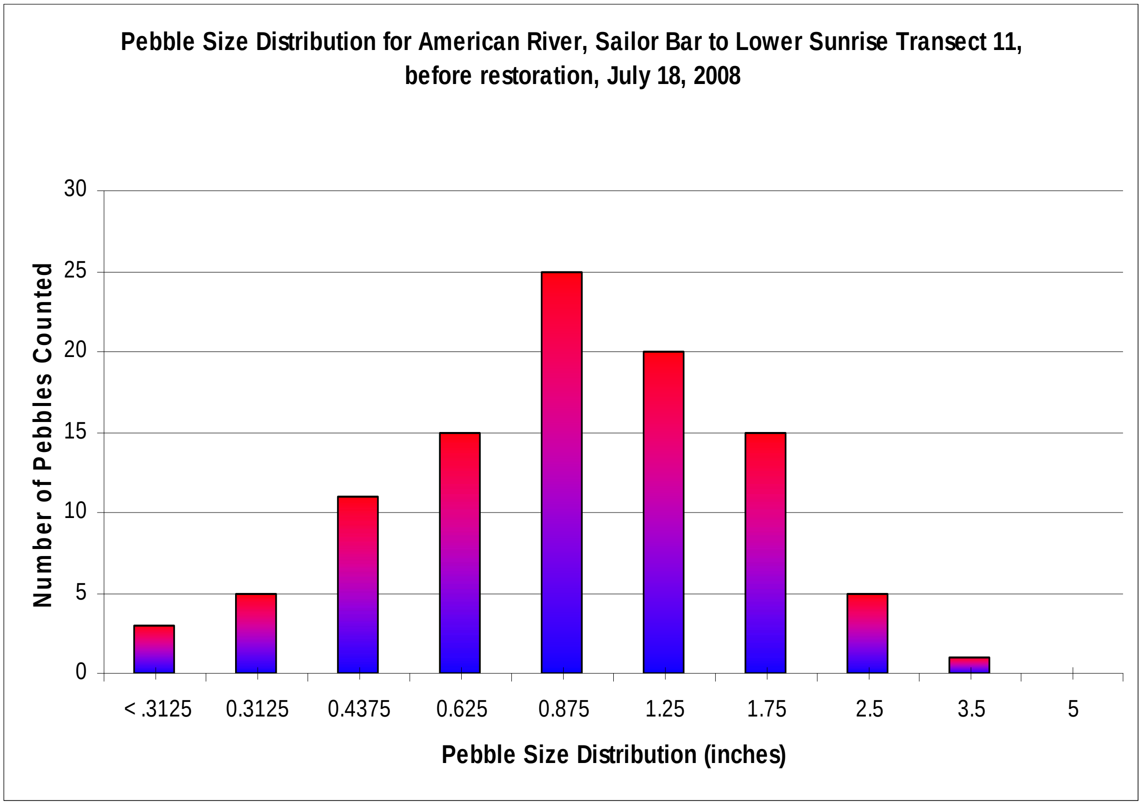

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 8, before restoration, July 18, 2008
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

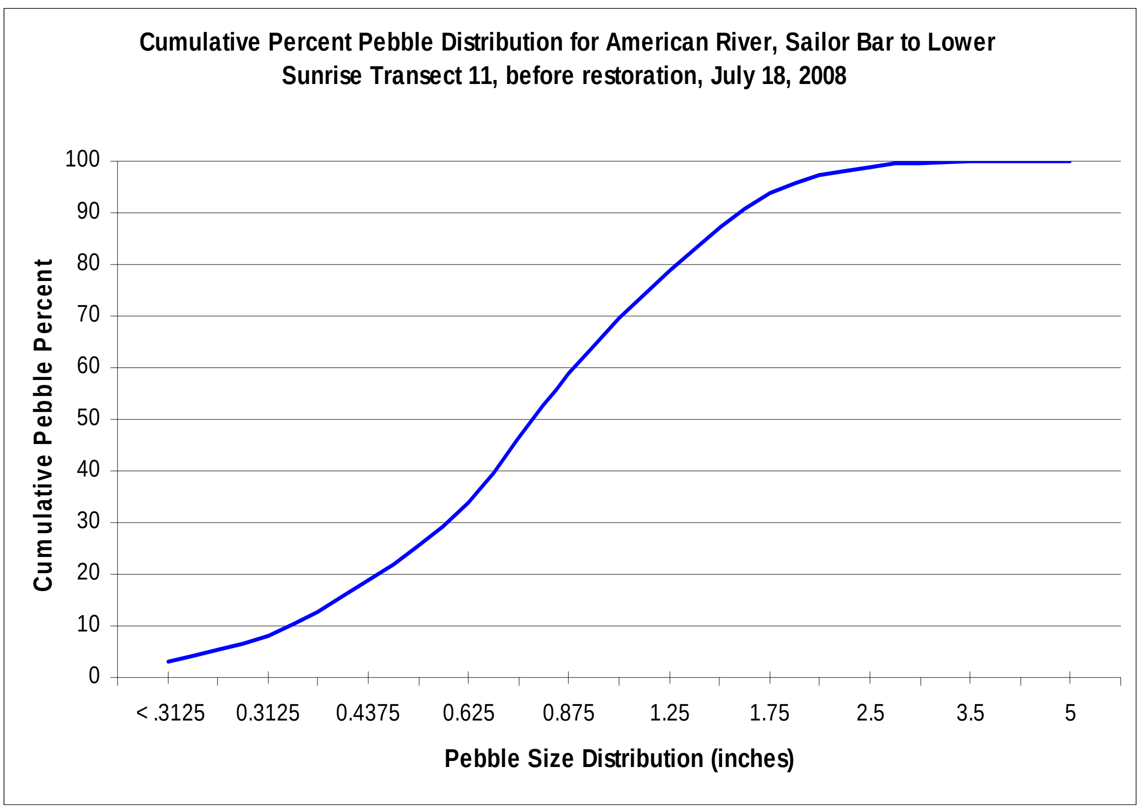

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 9, before restoration, July 18, 2008
Number of Pebbles Counted
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

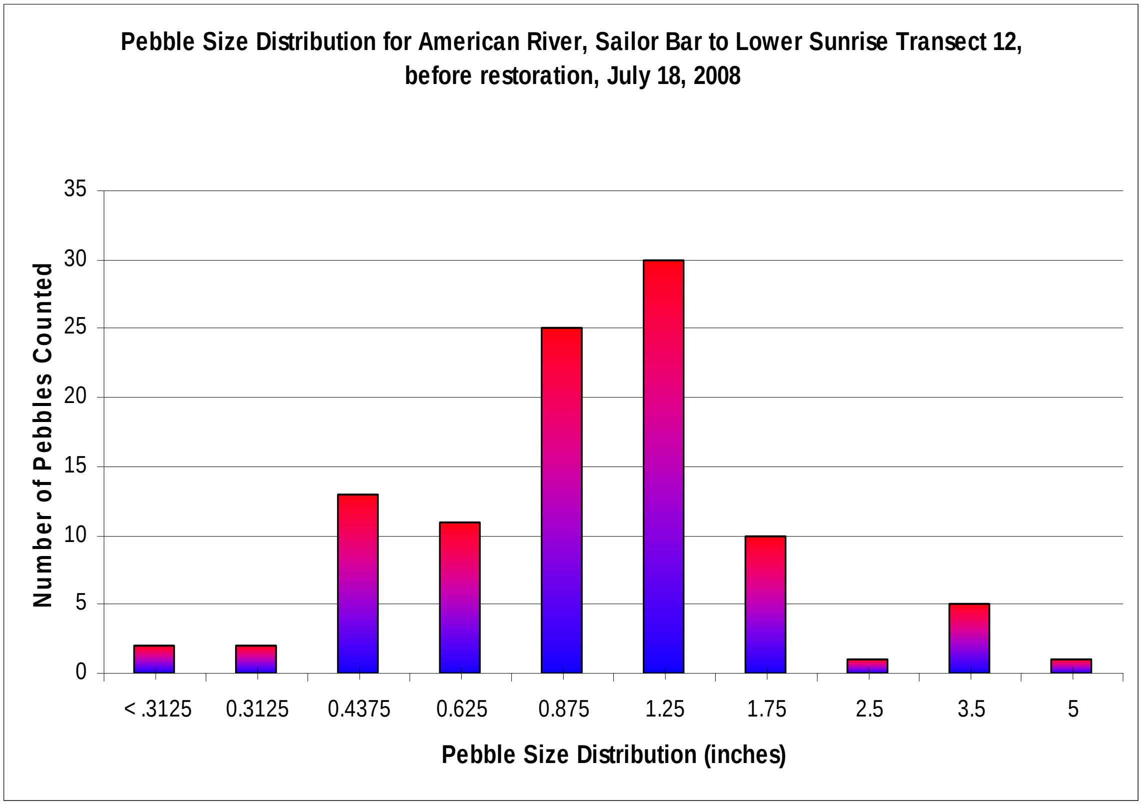

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 9, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

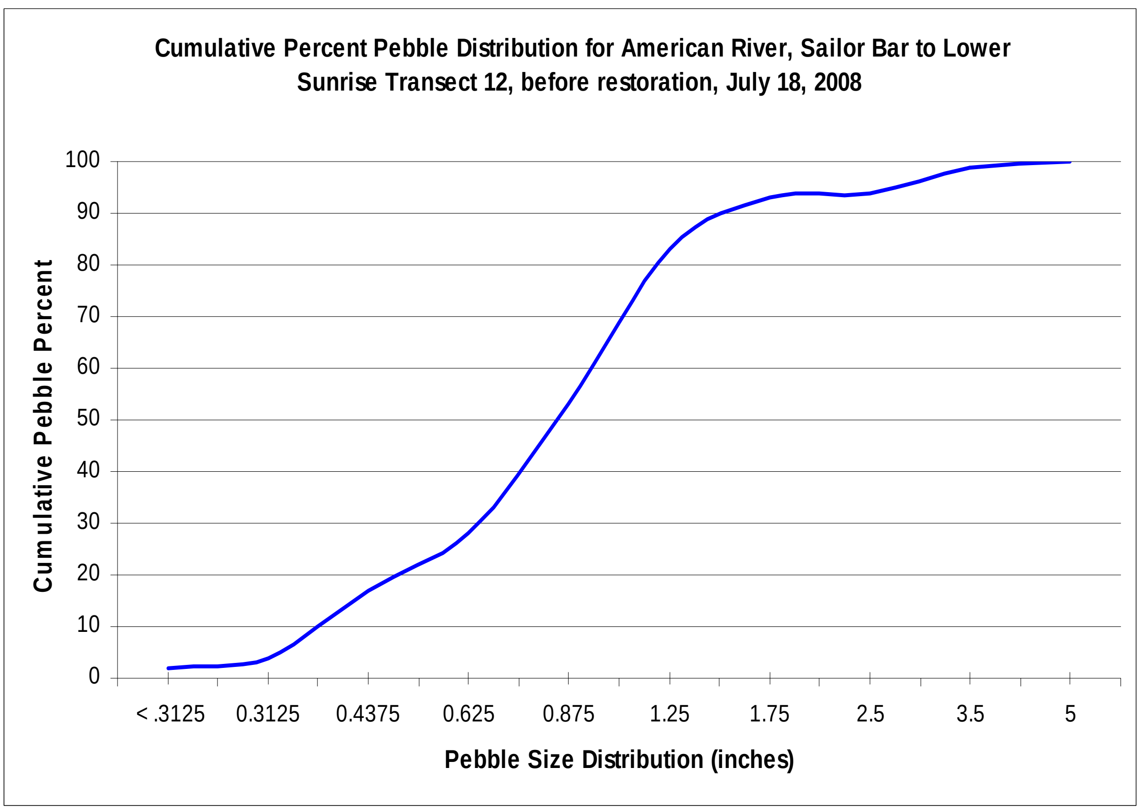

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 10, before restoration, July 18, 2008
Number of Pebbles Counted
0
2
4
6
8
10
12
14
16
18
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

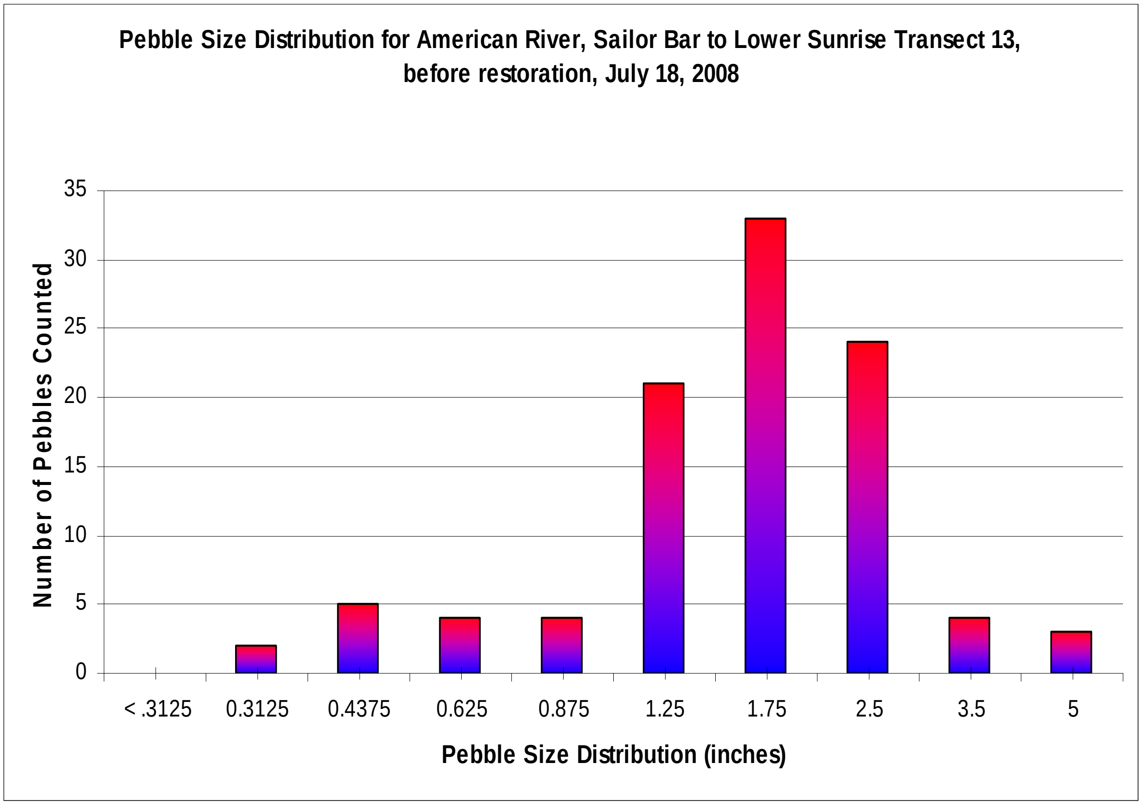

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 10, before restoration, July 18, 2008
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
7
10
Pebble Size Distribution (inches)

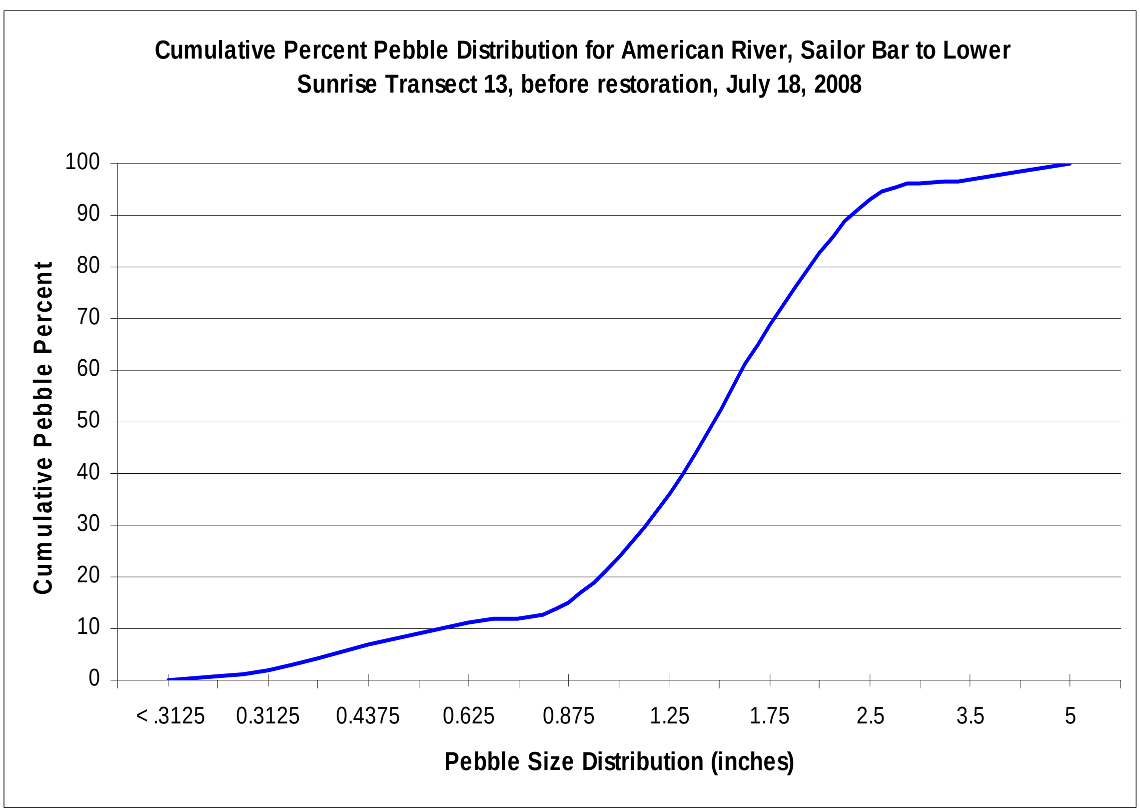

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 11, before restoration, July 18, 2008
Number of Pebbles Counted
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

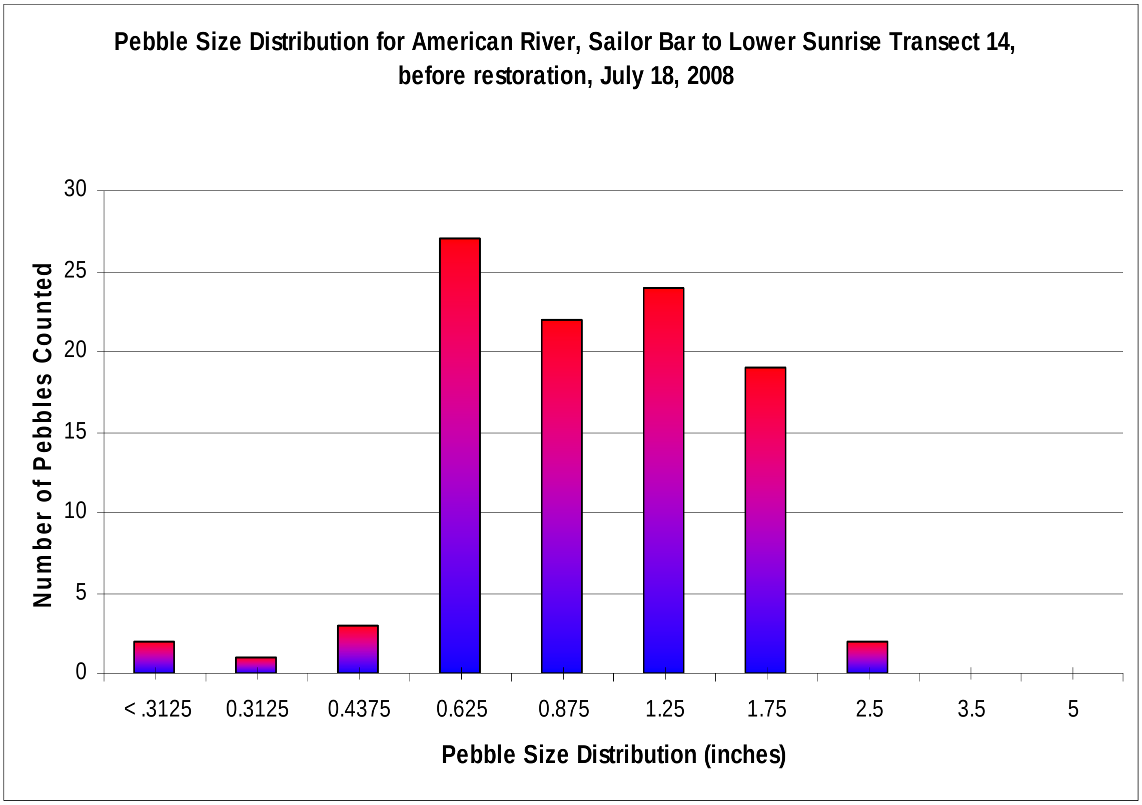

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 11, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

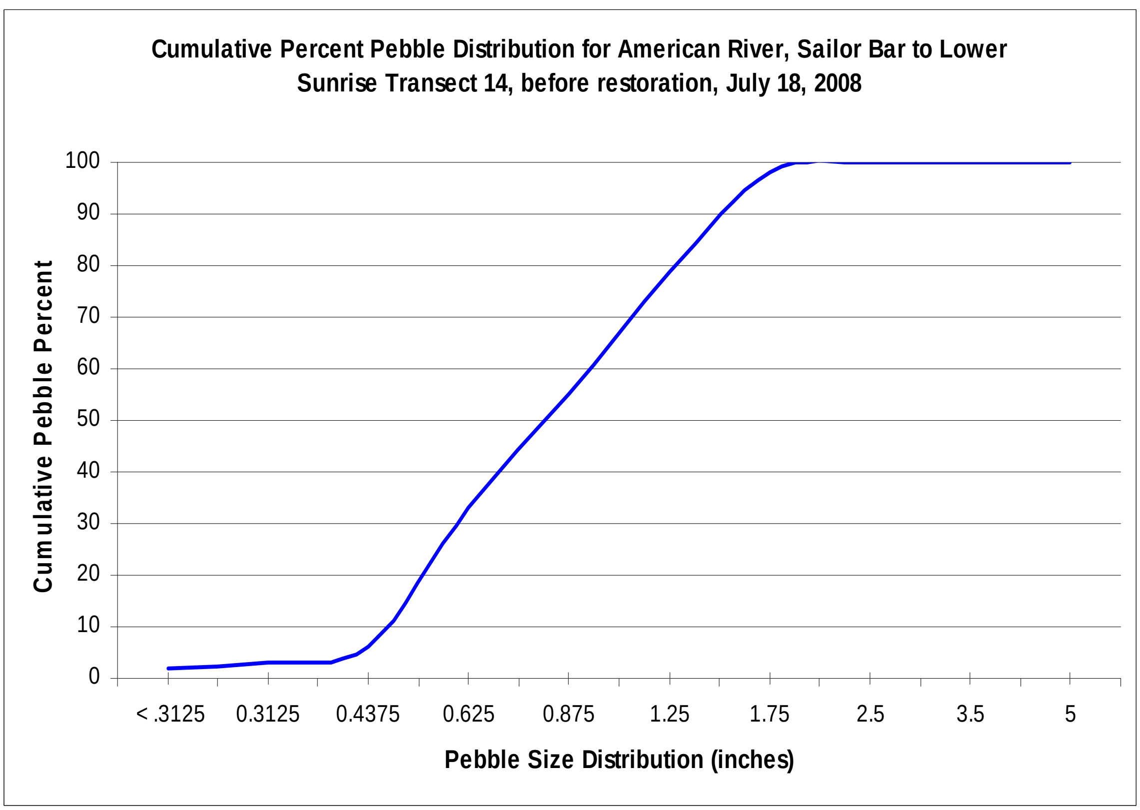

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 12, before restoration, July 18, 2008
Number of Pebbles Counted
35
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

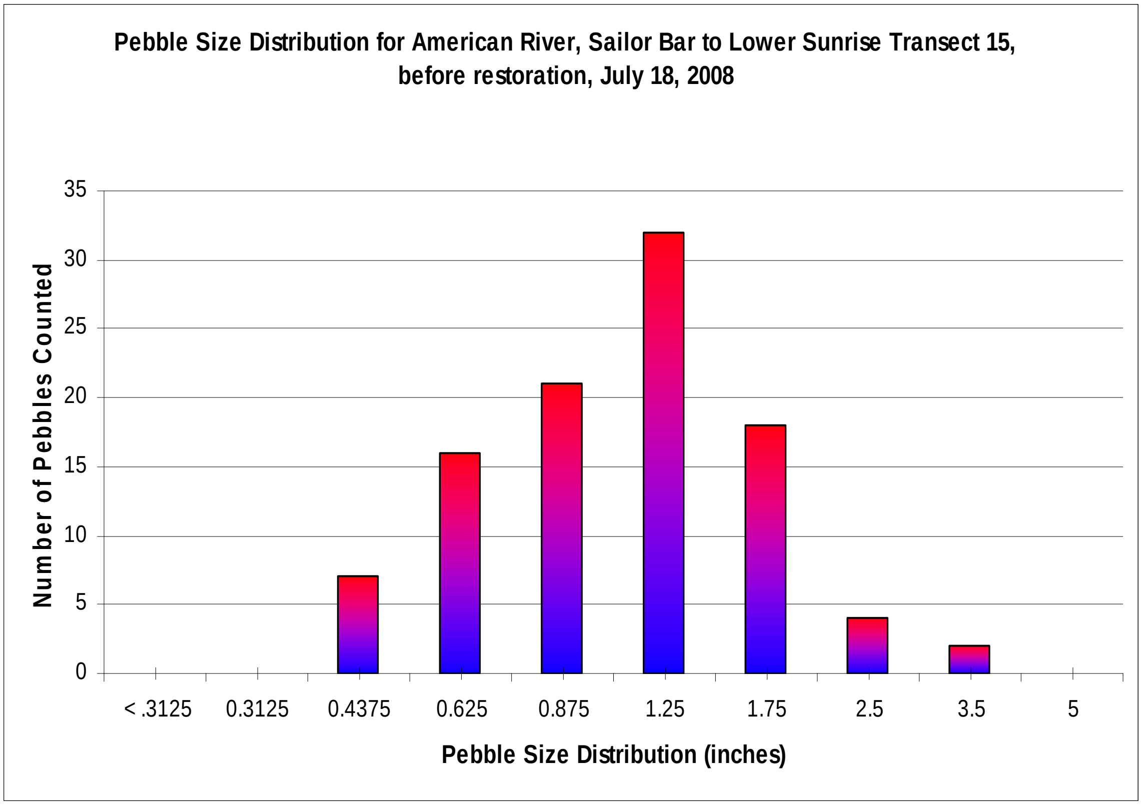

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 12, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

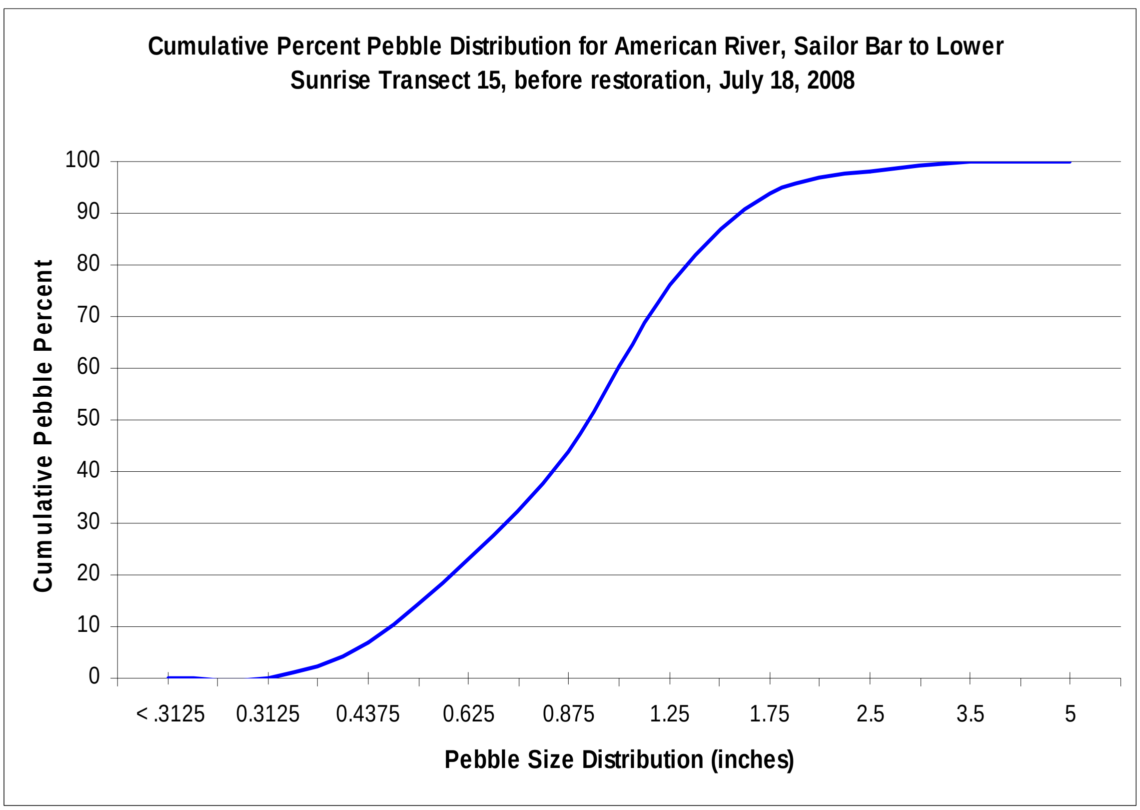

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 13,
before restoration, July 18, 2008
Number of Pebbles Counted
35
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

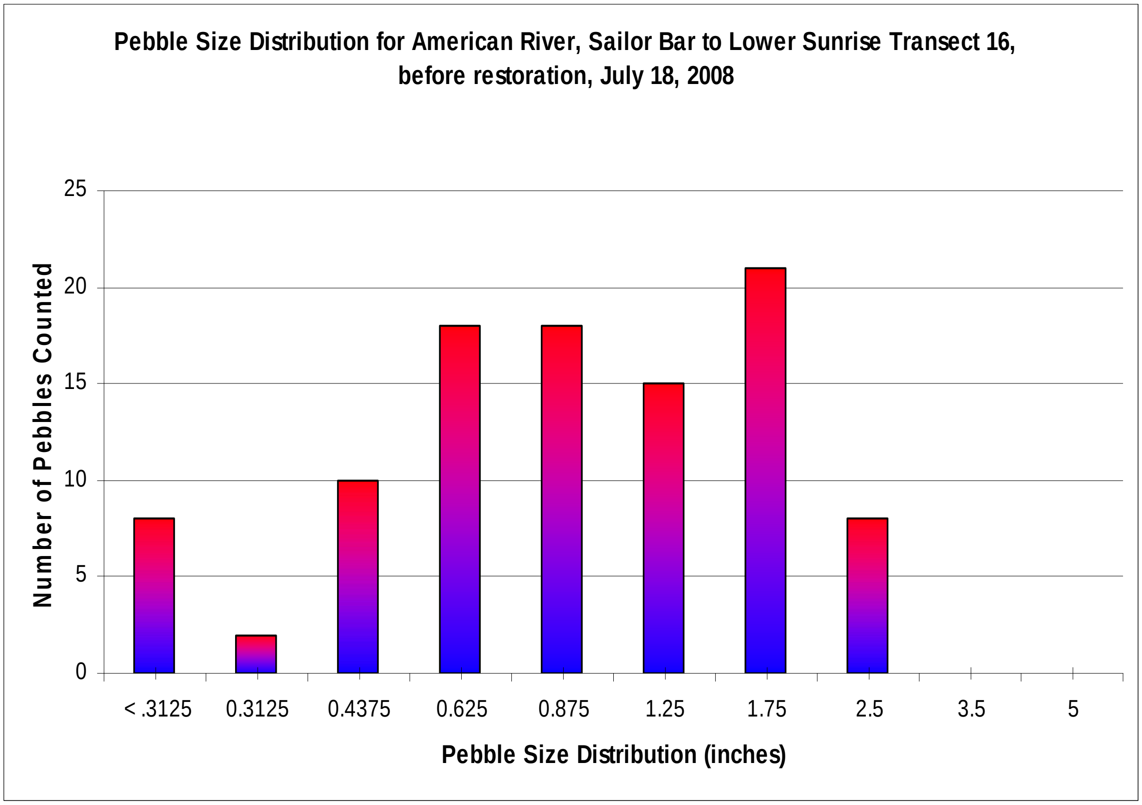

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower
Sunrise Transect 13, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

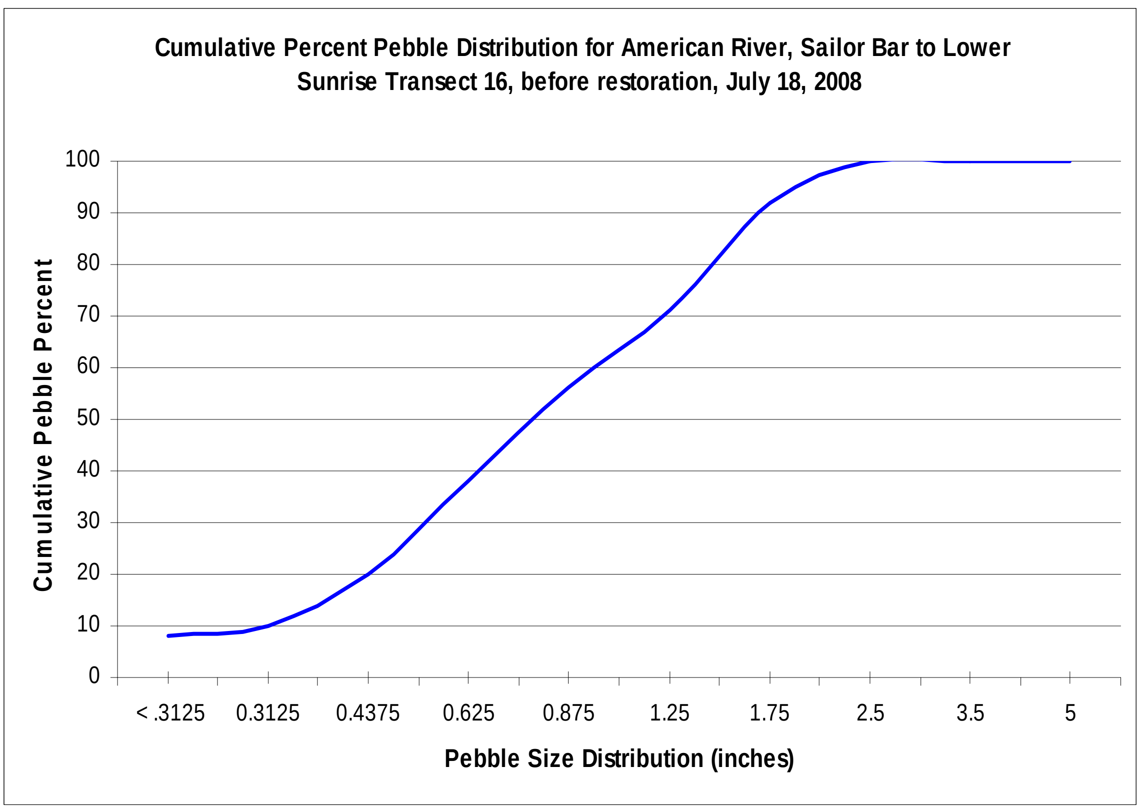

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 14, before restoration, July 18, 2008
Number of Pebbles Counted
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

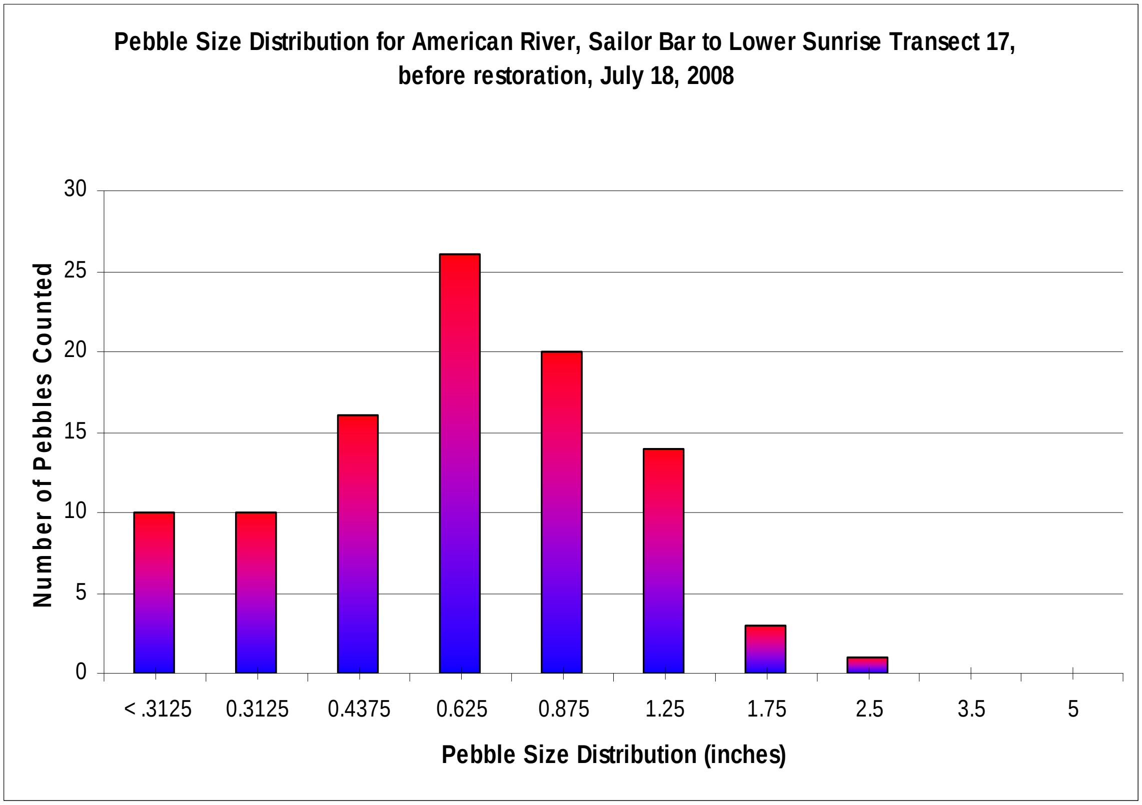

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 14, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

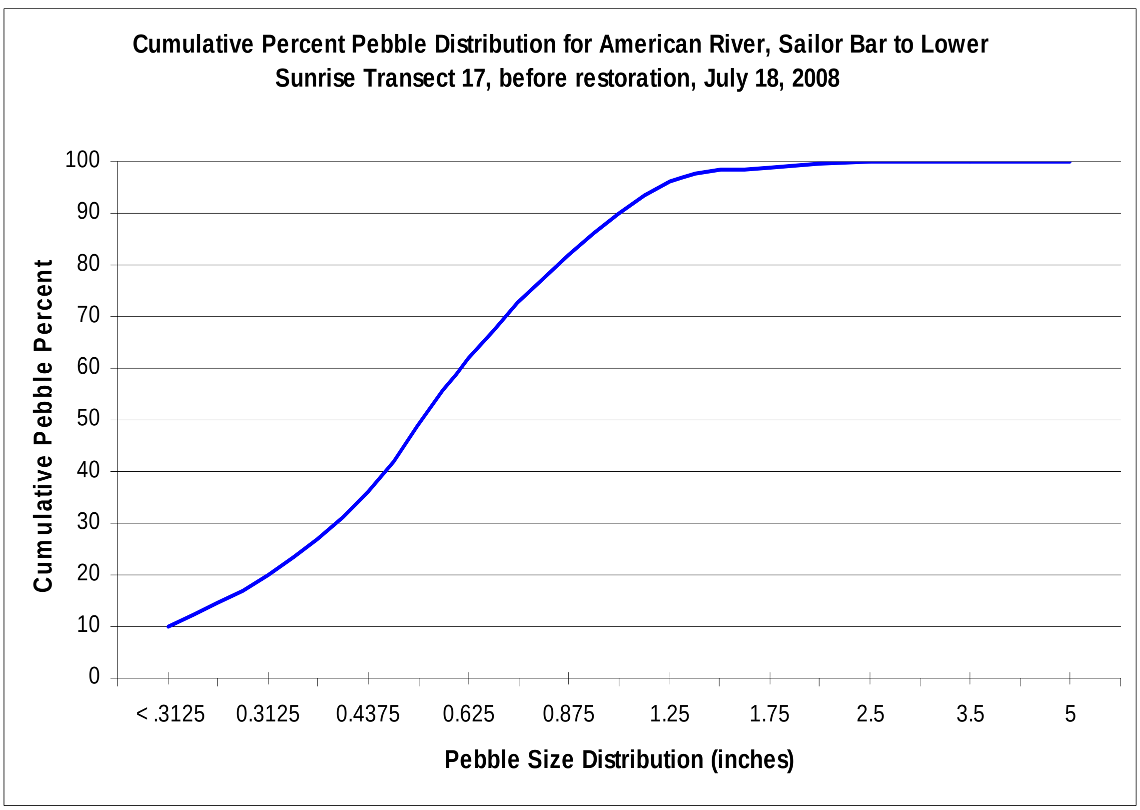

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 15, before restoration, July 18, 2008
Number of Pebbles Counted
35
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

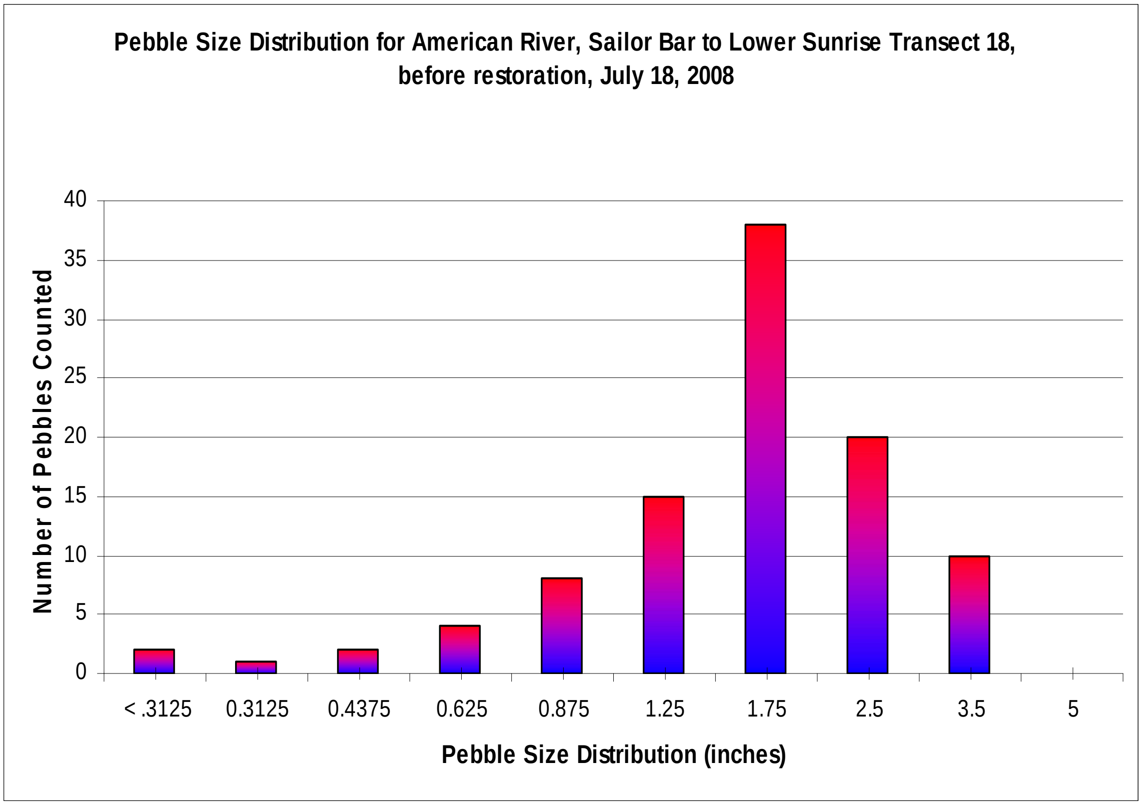

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 15, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

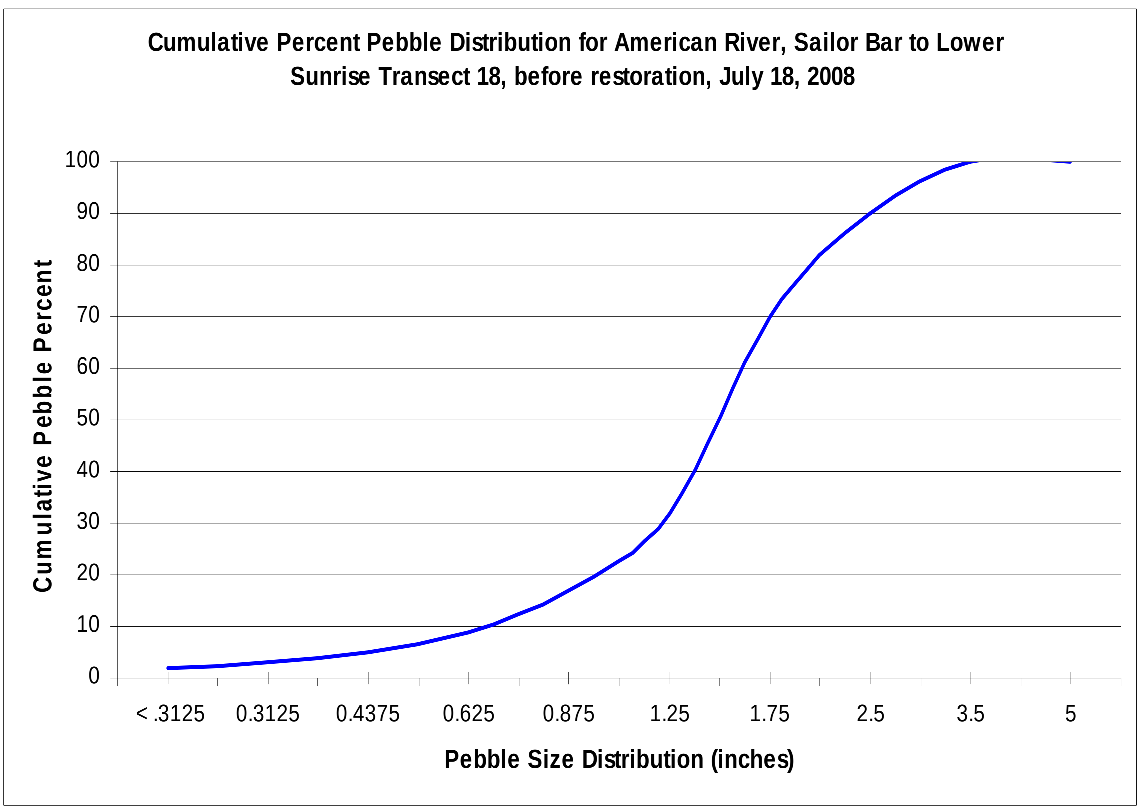

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 16, before restoration, July 18, 2008
Number of Pebbles Counted
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

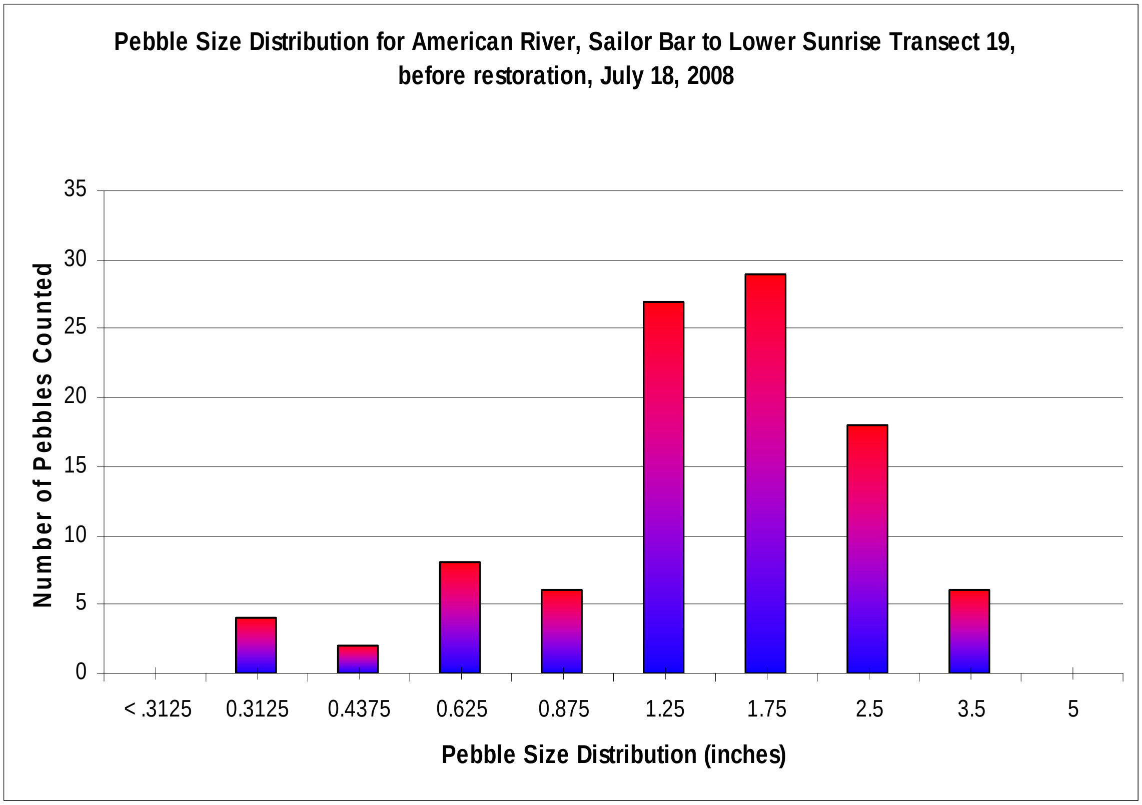

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 16, before restoration, July 18, 2008
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

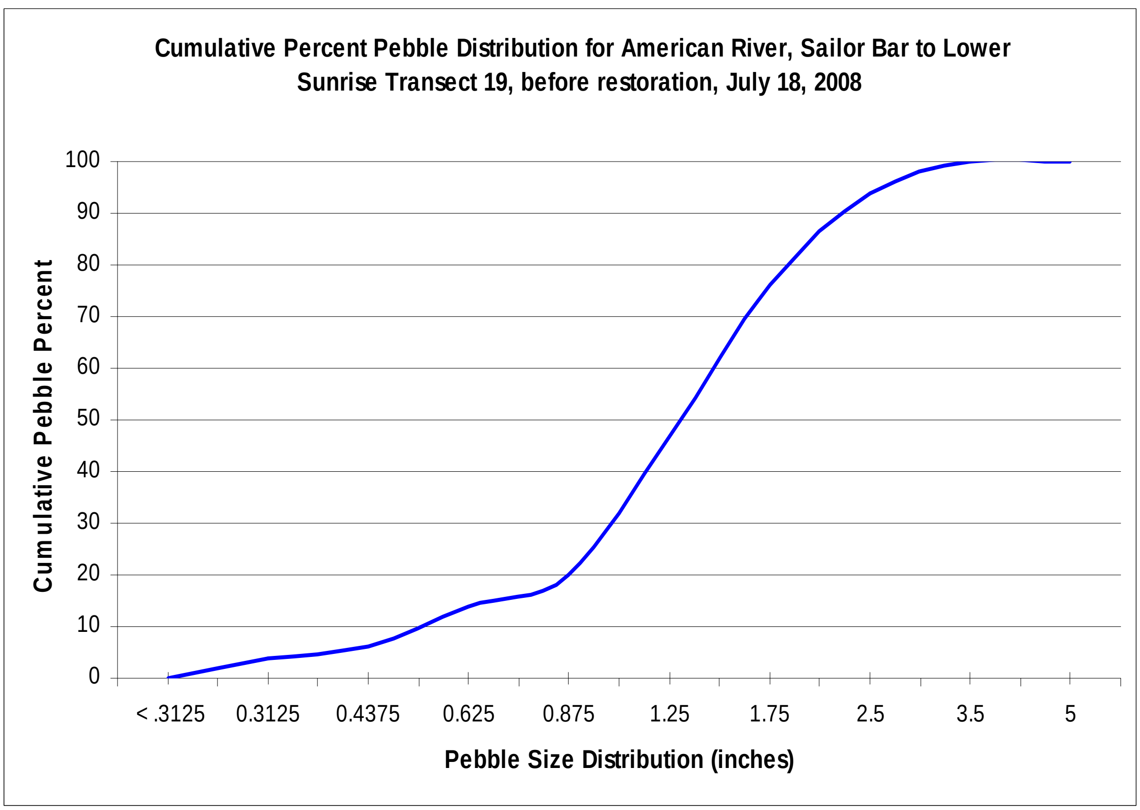

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 17, before restoration, July 18, 2008
Number of Pebbles Counted
0
5
10
15
20
25
30
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)


Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 17, before restoration, July 18, 2008
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)

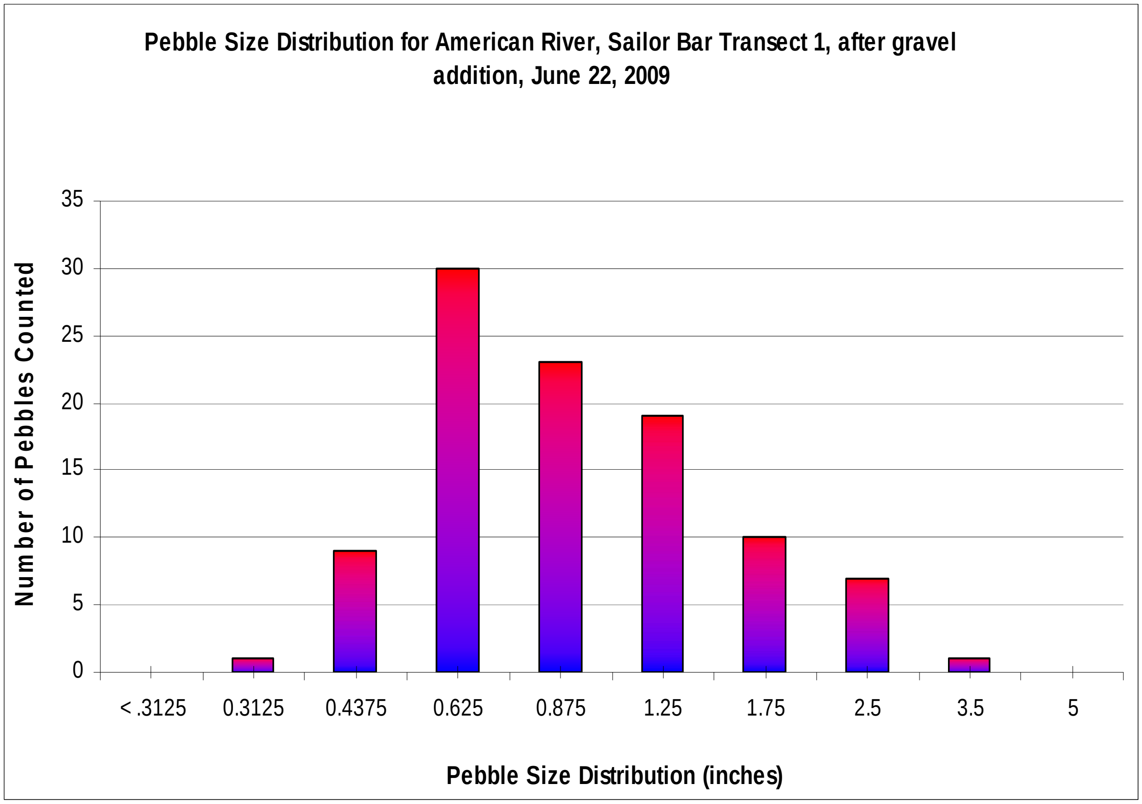

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 18, before restoration, July 18, 2008
Number of Pebbles Counted
0
5
10
15
20
25
30
35
40
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

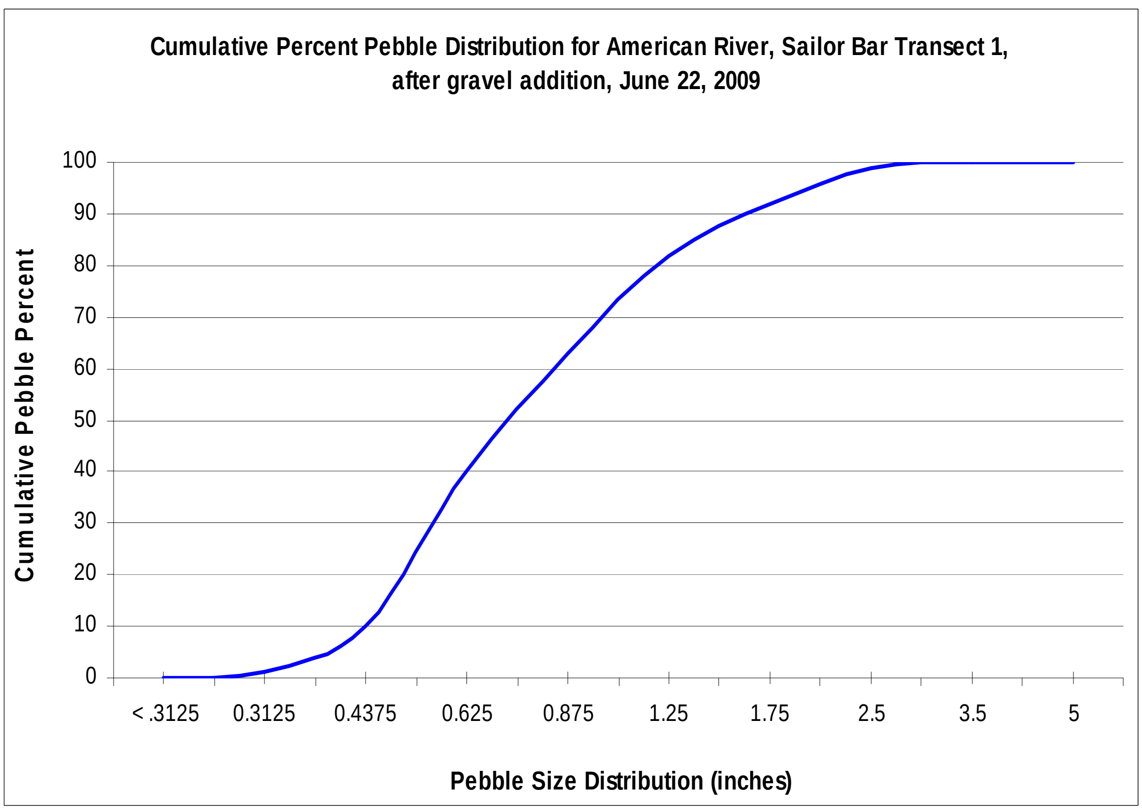

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 18, before restoration, July 18, 2008
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

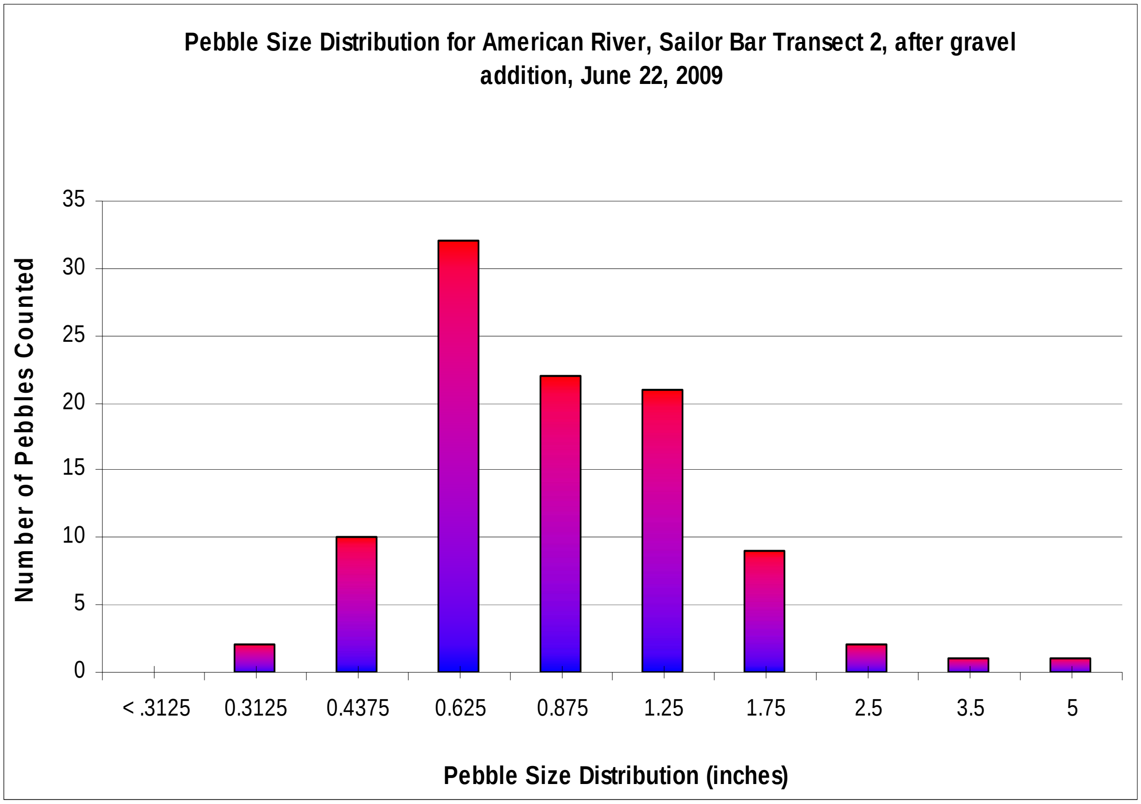

Pebble Size Distribution for American River, Sailor Bar to Lower Sunrise Transect 19, before restoration, July 18, 2008
Number of Pebbles Counted
0
5
10
15
20
25
30
35
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

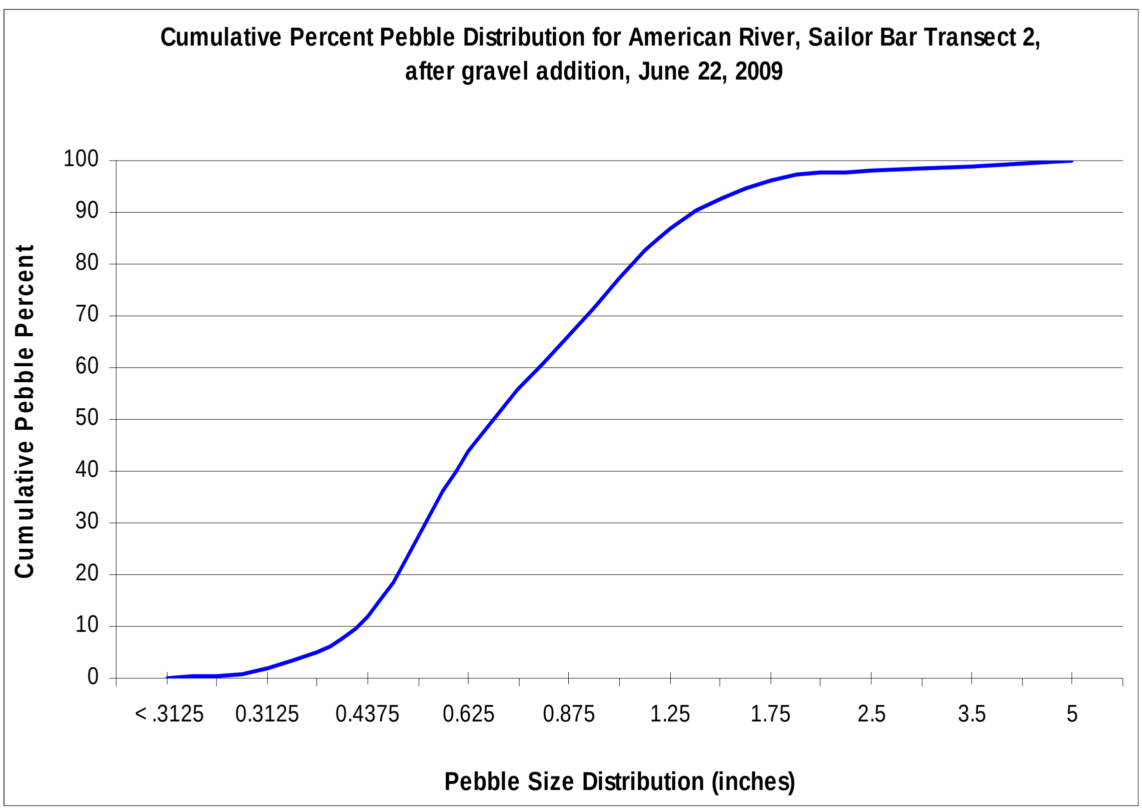

Cumulative Percent Pebble Distribution for American River, Sailor Bar to Lower Sunrise Transect 19, before restoration, July 18, 2008
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

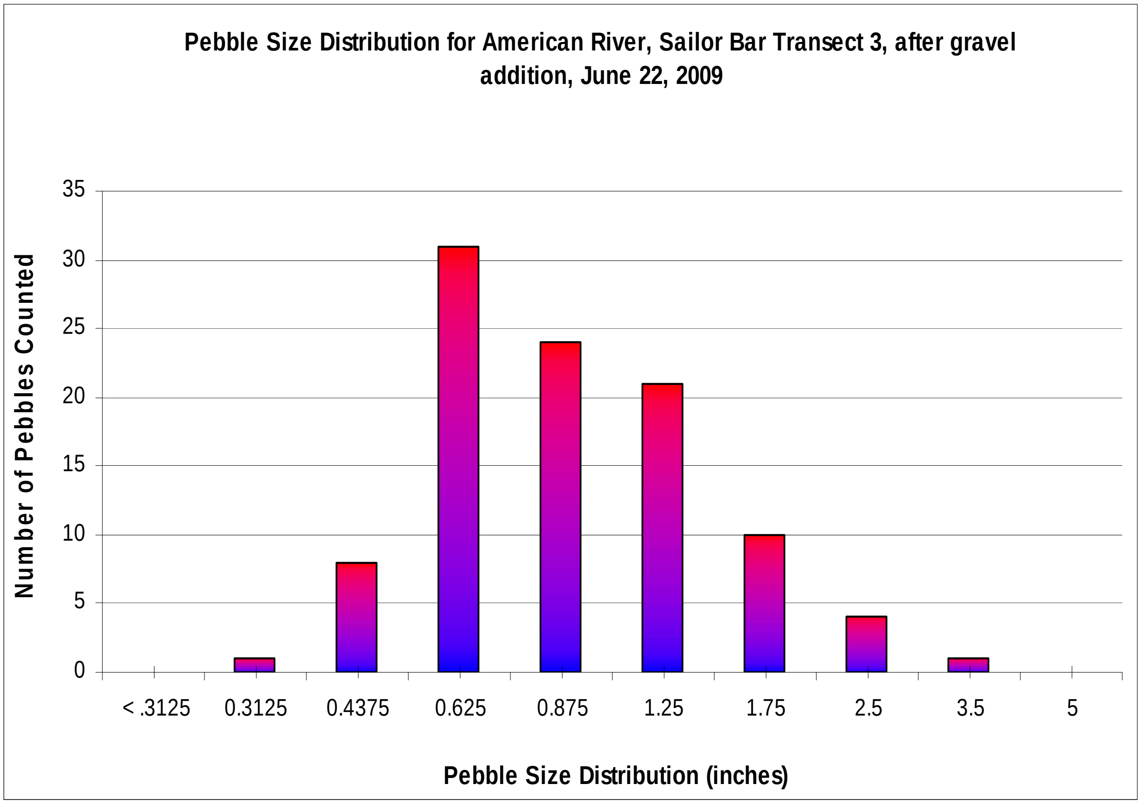
Appendix B: After gravel addition pebble count analysis


Pebble Size Distribution for American River, Sailor Bar Transect 1, after gravel addition, June 22, 2009
Number of Pebbles Counted
35
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

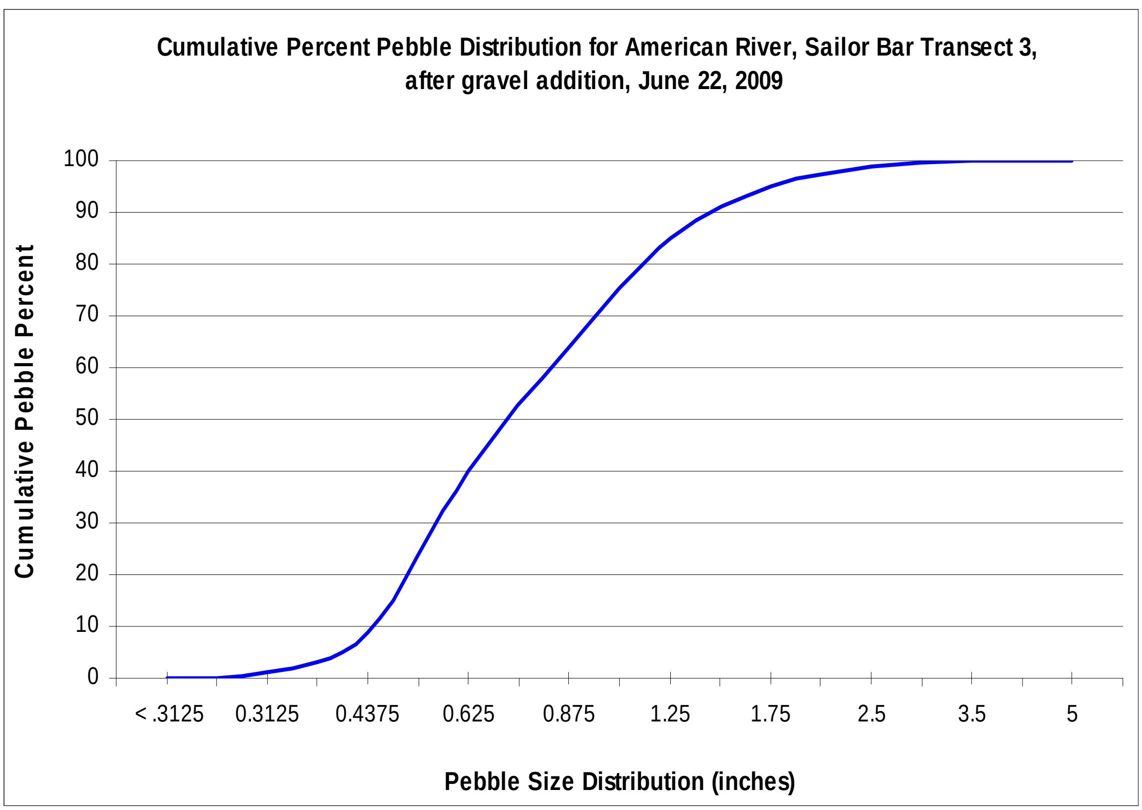

Cumulative Percent Pebble Distribution for American River, Sailor Bar Transect 1, after gravel addition, June 22, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)


Pebble Size Distribution for American River, Sailor Bar Transect 2, after gravel addition, June 22, 2009
Number of Pebbles Counted
0
5
10
15
20
25
30
35
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

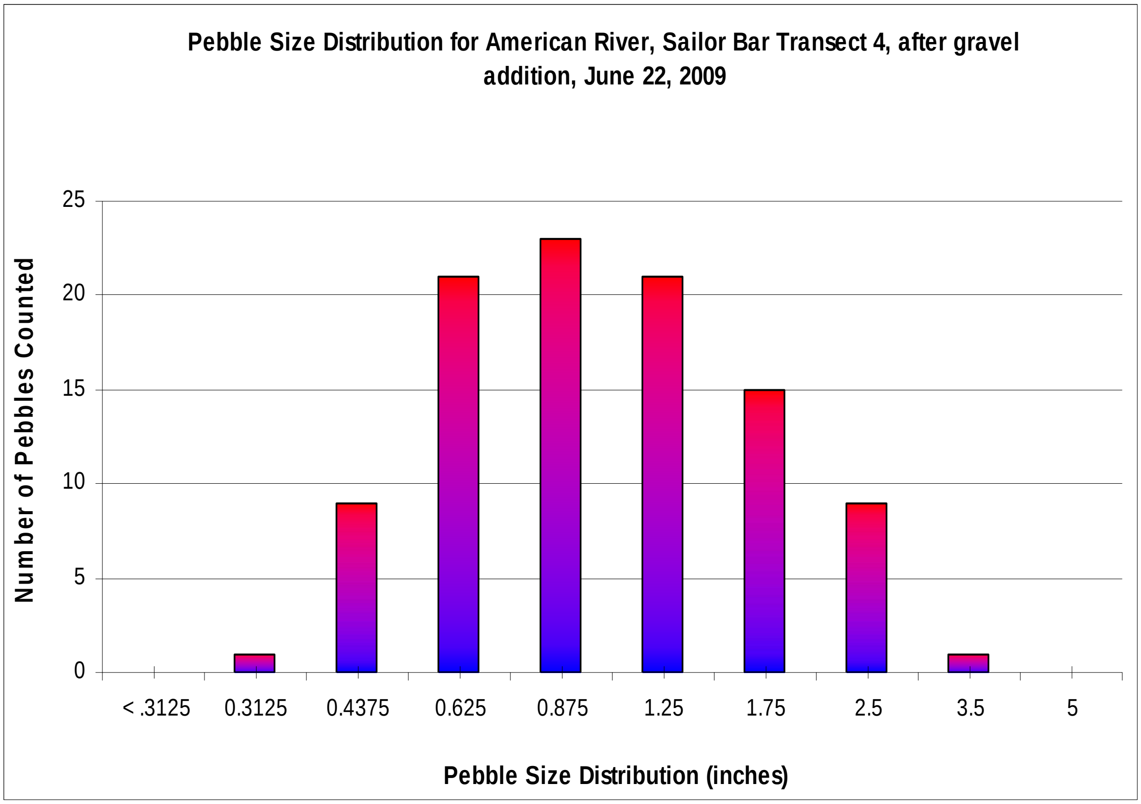

Cumulative Percent Pebble Distribution for American River, Sailor Bar Transect 2, after gravel addition, June 22, 2009
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

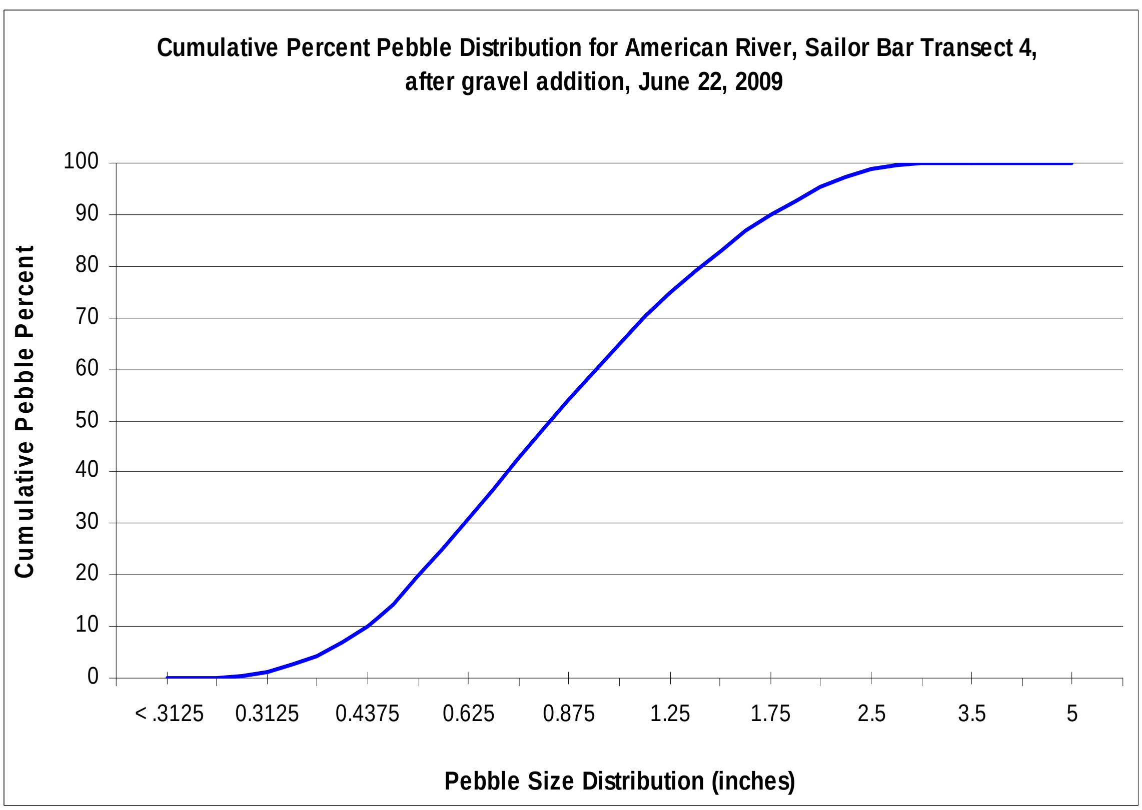


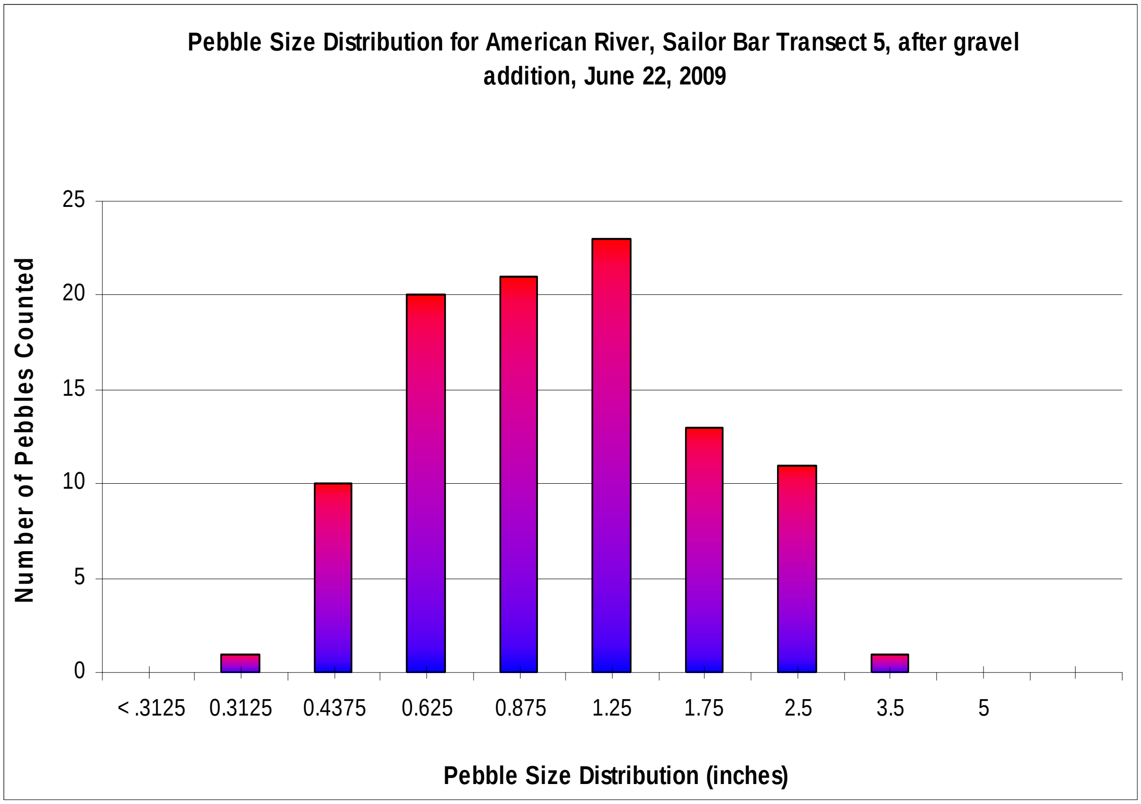
Pebble Size Distribution for American River, Sailor Bar Transect 3, after gravel addition, June 22, 2009
Number of Pebbles Counted
35
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

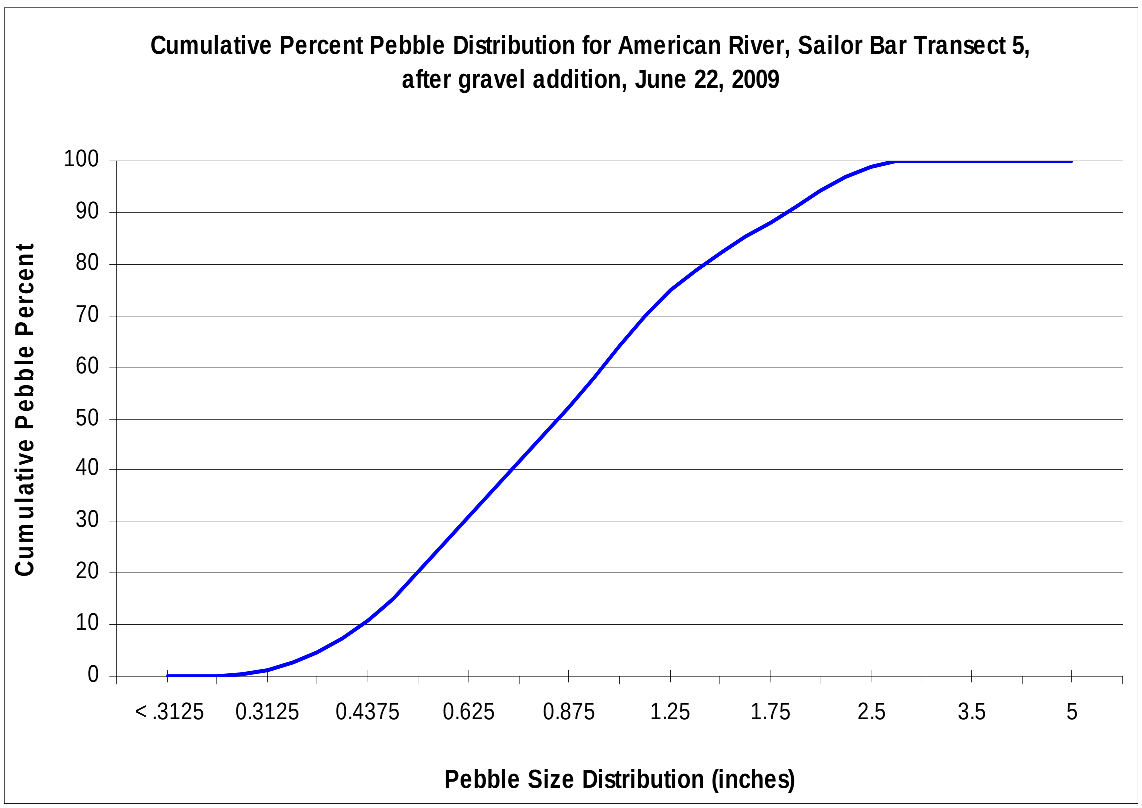



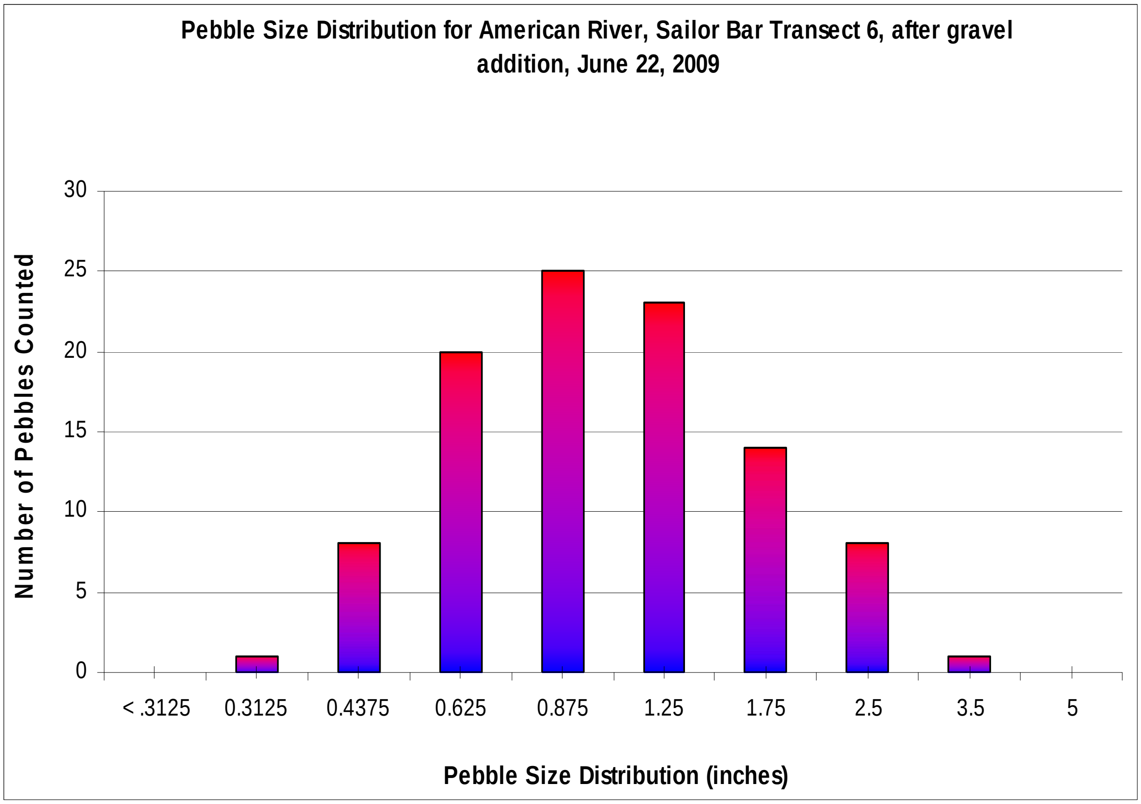
Cumulative Percent Pebble Distribution for American River, Sailor Bar Transect 3, after gravel addition, June 22, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)


Pebble Size Distribution for American River, Sailor Bar Transect 4, after gravel addition, June 22, 2009
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
Pebble Size Distribution (inches)

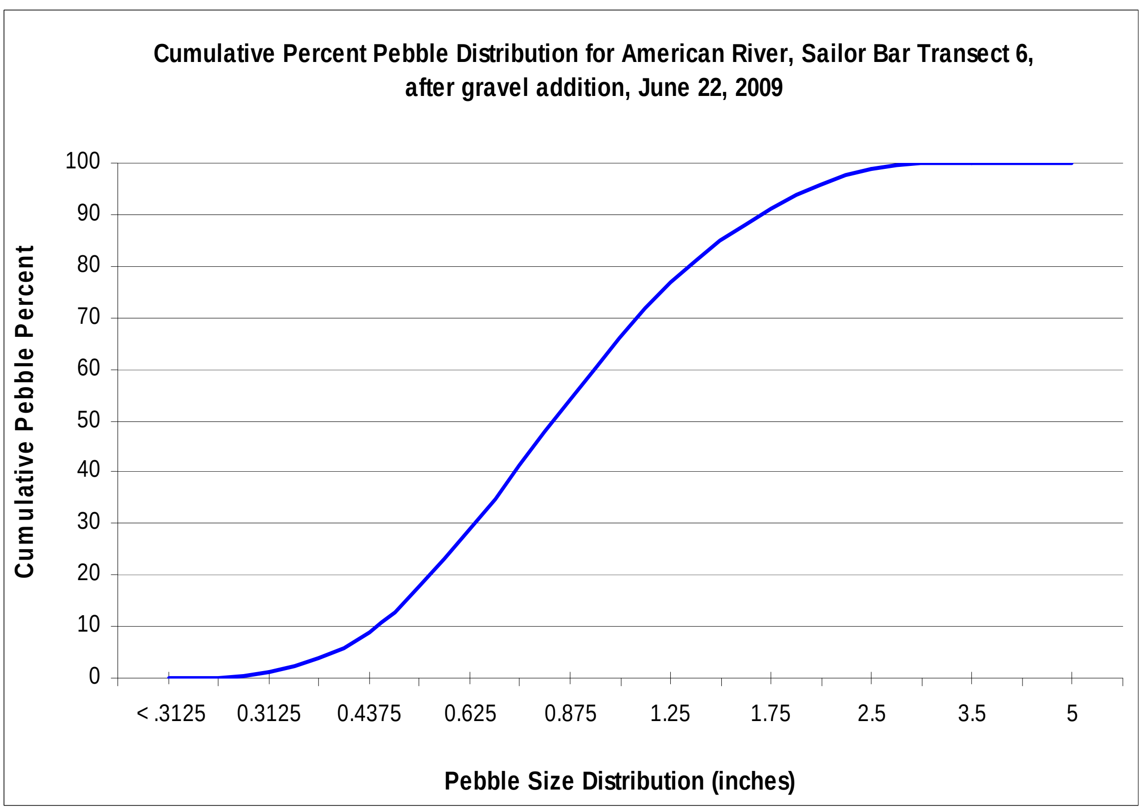

Cumulative Percent Pebble Distribution for American River, Sailor Bar Transect 4, after gravel addition, June 22, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)


Pebble Size Distribution for American River, Sailor Bar Transect 5, after gravel addition, June 22, 2009
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
Pebble Size Distribution (inches)

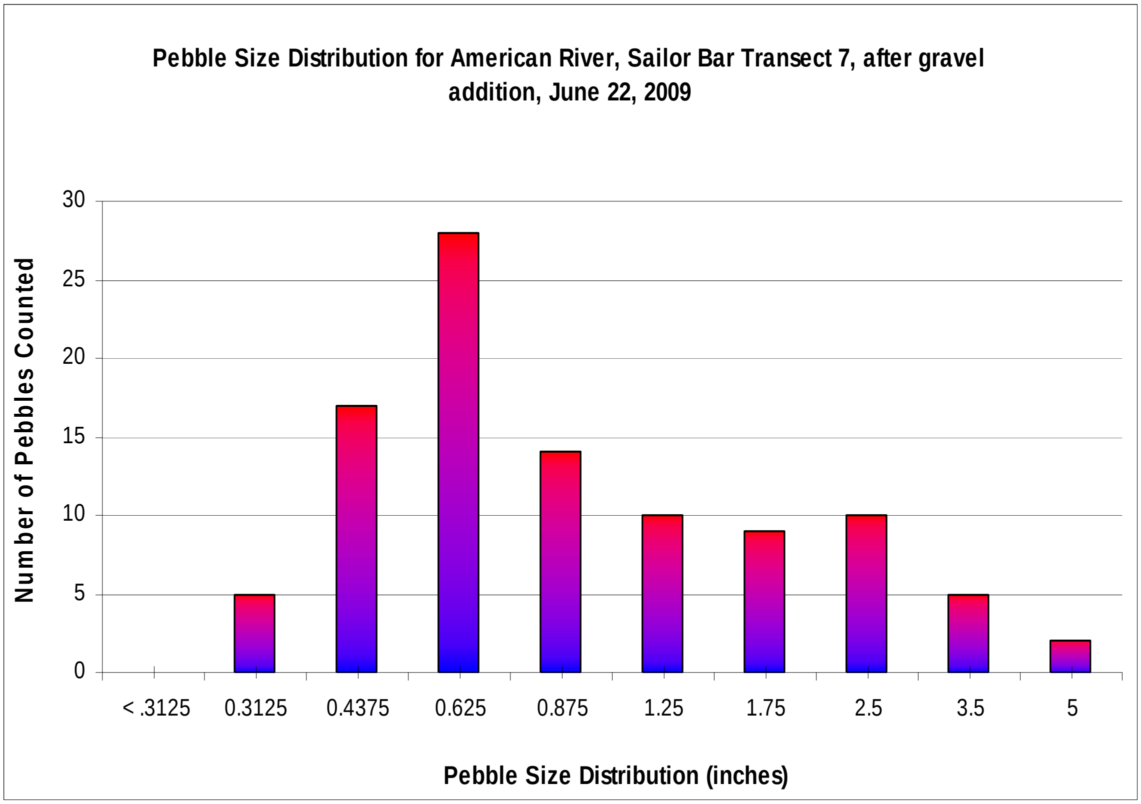

Cumulative Percent Pebble Distribution for American River, Sailor Bar Transect 5, after gravel addition, June 22, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)



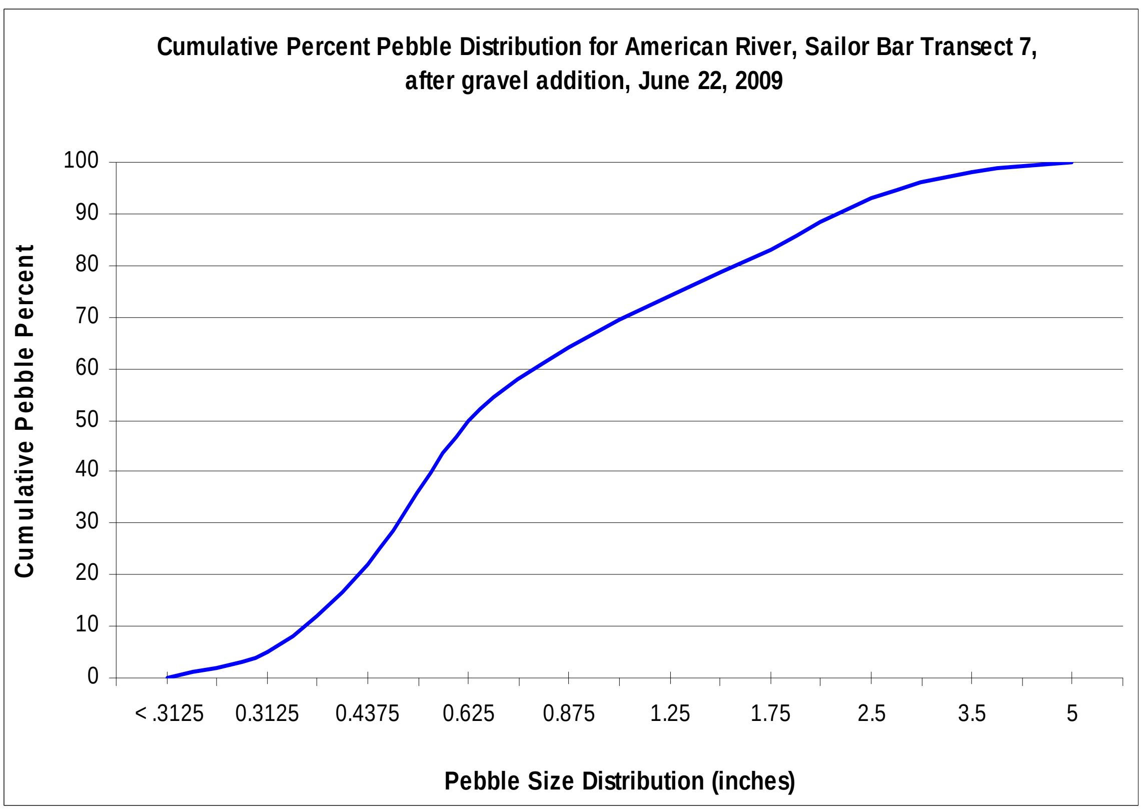
Pebble Size Distribution for American River, Sailor Bar Transect 6, after gravel addition, June 22, 2009
Number of Pebbles Counted
0
5
10
15
20
25
30
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

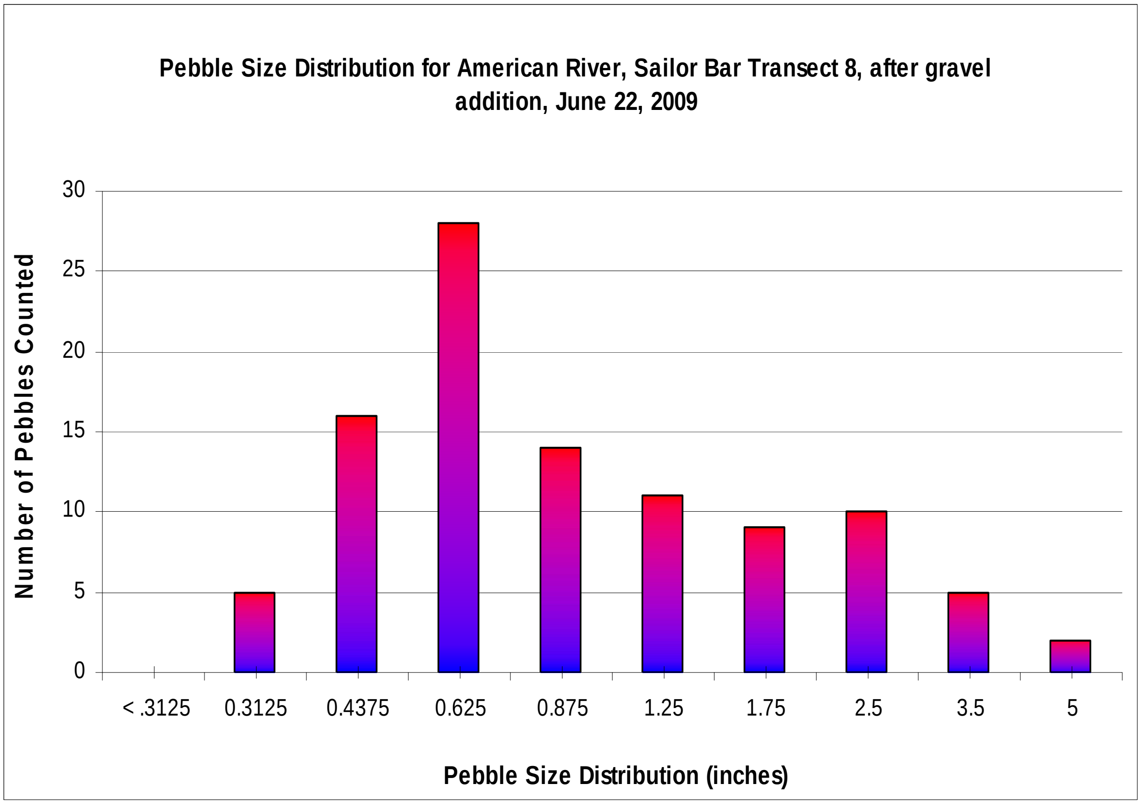
Cumulative Percent Pebble Distribution for American River, Sailor Bar Transect 6, after gravel addition, June 22, 2009
Cumulative Pebble Percent
0
10
20
30
40
50
60
70
80
90
100
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

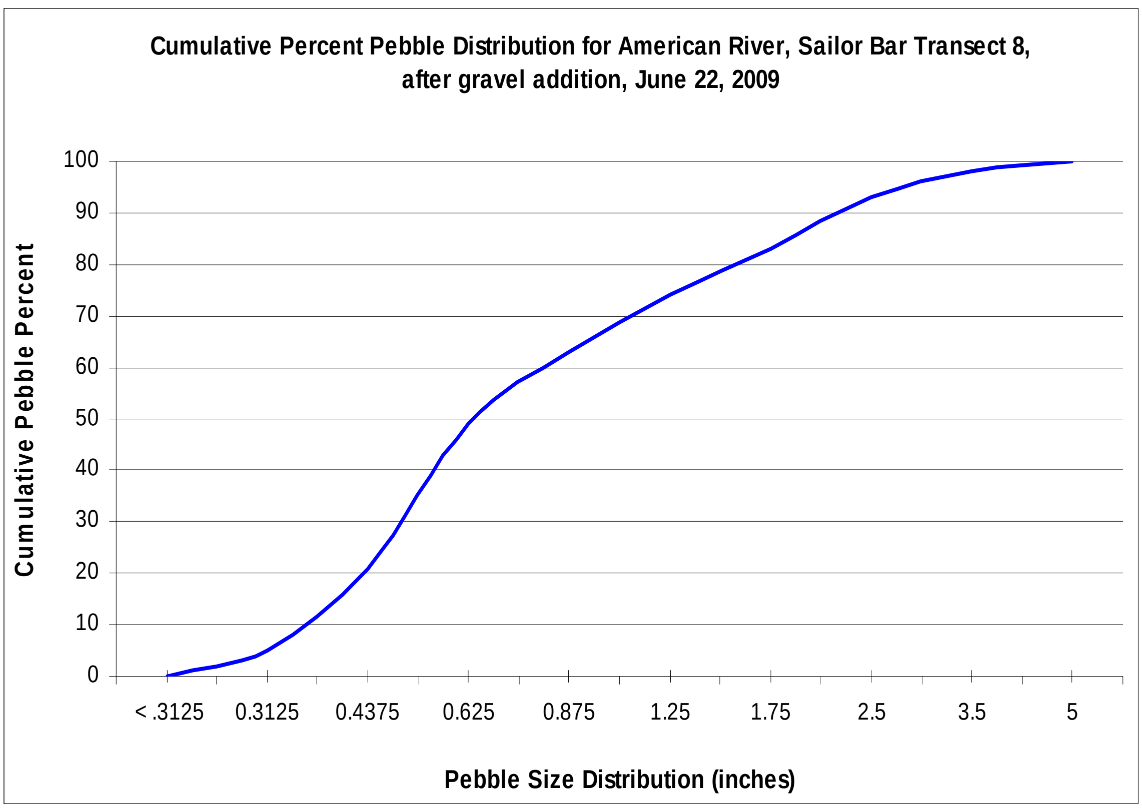


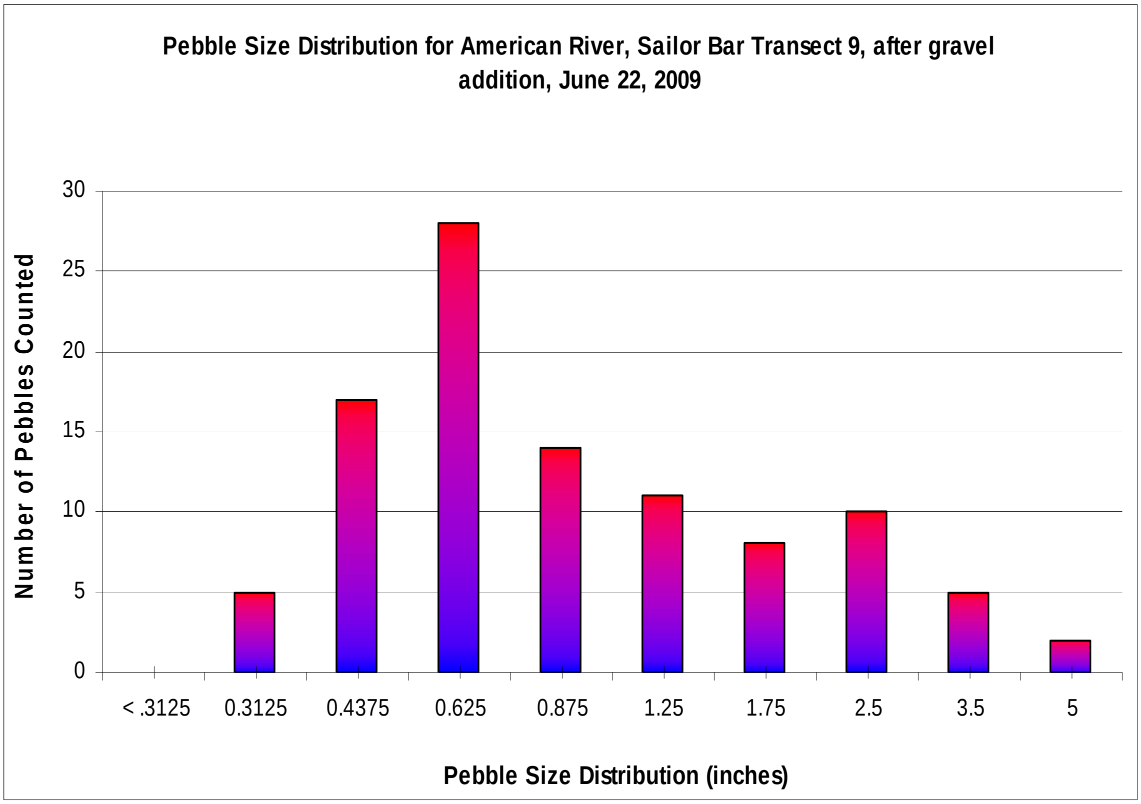
Pebble Size Distribution for American River, Sailor Bar Transect 7, after gravel addition, June 22, 2009
Number of Pebbles Counted
30
25
20
15
10
5
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)

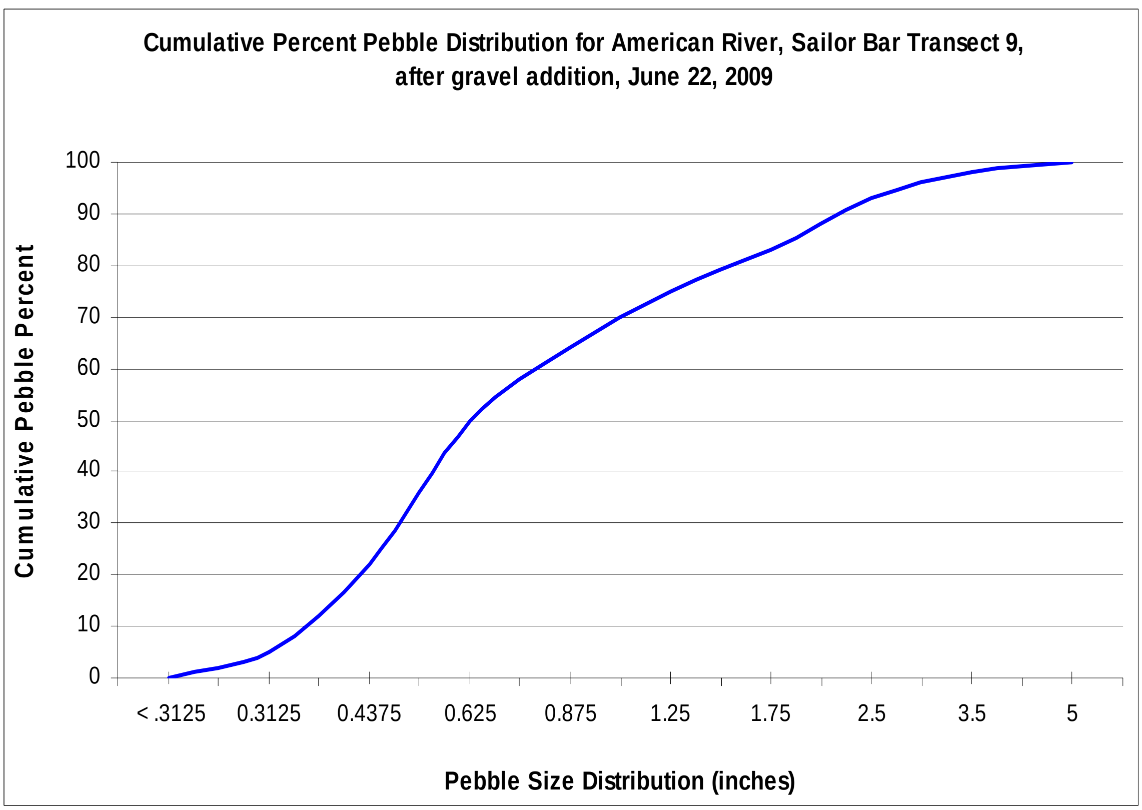



Cumulative Percent Pebble Distribution for American River, Sailor Bar Transect 7, after gravel addition, June 22, 2009
Cumulative Pebble Percent
100
90
80
70
60
50
40
30
20
10
0
< .3125
0.3125
0.4375
0.625
0.875
1.25
1.75
2.5
3.5
5
Pebble Size Distribution (inches)


Pebble Size Distribution for American River, Sailor Bar Transect 8, after gravel addition, June 22, 2009
Number of Pebbles Counted
30
25
20
15
10
5
0
< .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 8, after gravel addition, June 22, 2009
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 9, after gravel addition, June 22, 2009
Number of Pebbles Counted
0
5
10
15
20
25
30
< .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 9, after gravel addition, June 22, 2009
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: Hach Chemistry (Chemical analysis) of surface water and gravel pore water before and after gravel addition

**Chemical Analysis for Sailor Bar (Before gravel addition June, 2008)**

| Location | Date Sampled | Sample ID | Nitrate, mg/L | Nitrite, mg/L | Ammonia, mg/L | Phosphate, mg/L |
|---|---|---|---|---|---|---|
| | | Blank | 0.3 | 0.002 | 0 | - |
| Sailor, pre | 9/19/2008 | Surface Water 1 | 0.3 | 0.003 | 0 | 0.02 |
| Sailor, pre | 9/19/2008 | Surface 2 | 0.3 | 0.003 | 0.01 | 0.01 |
| Sailor, pre | 9/19/2008 | MP2-4 | 0.4 | 0.002 | 0 | 0 |
| Sailor, pre | 9/19/2008 | MP2-5 | 0.3 | 0.004 | 0.1 | 0.07 |
| Sailor, pre | 9/19/2008 | MP2-6 | 0.3 | 0.003 | 0.01 | 0.06 |
| Sailor, pre | 9/19/2008 | MP2-7 | 0.4 | 0.002 | 0 | 0.01 |
| Sailor, pre | 9/19/2008 | MP2-8 | 0.4 | - | 0 | 0.25 |
| Surface 1 (am) | 9/19/2008 | | 0.4 | 0.002 | 0 | 0.1 |
| Surface 2 (pm) | 9/19/2008 | | 0.4 | 0.003 | 0 | 0.08 |

**Chemical Analysis for Sailor Bar (After gravel addition February, 2009)**

| Location | Date Sampled | Sample ID | Nitrate, mg/L | Nitrite, mg/L | Ammonia, mg/L | Phosphate, mg/L |
|---|---|---|---|---|---|---|
| Sailor, post | 2/20/2009 | Surface | 0.4 | 0.003 | 0 | 0.17 |
| Sailor, post | 2/20/2009 | MPA | 0.5 | 0.002 | 0 | 0.02 |
| Sailor, post | 2/20/2009 | MPB | 0.5 | 0.002 | 0.06 | 0.05 |
| Sailor, post | 2/20/2009 | MPC | 0.4 | 0.003 | 0.01 | 0.06 |
| Sailor, post | 2/20/2009 | MPD | 0.6 | 0.003 | 0.02 | 0.07 |
| Sailor, post | 2/20/2009 | MPE | 0.4 | 0.002 | 0.02 | 0.16 |
| Sailor, post | 2/20/2009 | MPF | 0.4 | 0.003 | 0 | 0.13 |
| Sailor, post | 2/20/2009 | MPG | 0.6 | 0.004 | 0 | 0.24 |
| Sailor, post | 2/20/2009 | MPH | 0.5 | 0.003 | 0.07 | 0.04 |
| Sailor, post | 2/20/2009 | MPI | 0.5 | 0.003 | 0.16 | 0.14 |
| Sailor, post | 2/20/2009 | MPJ | 0.6 | 0.003 | 0.05 | 0.09 |
| Sailor, post | 2/20/2009 | MPK | 0.4 | 0.003 | 0.01 | 0.14 |
| Surface 1 (am) | 2/20/2009 | | 0.4 | 0.002 | 0 | 0.1 |
| Surface 2 (pm) | 2/20/2009 | | 0.3 | 0.003 | 0 | 0.1 |

Appendix D: Inter gravel velocity test data, after gravel addition

| | 10 cm | 20 cm | 30 cm |
|---|---|---|---|
| **Time (sec)** | **EC 1** | **EC 2** | **EC 3** |
| 0 | 57 | 57 | 57.6 |
| 5 | 57 | 57 | 57.6 |
| 10 | 57 | 57 | 57.6 |
| 15 | 70 | 57 | 57.6 |
| 20 | 93 | 58 | 57.6 |
| 25 | 114 | 62 | 57.6 |
| 30 | 124 | 64 | 57.6 |
| 45 | 570 | 102 | 62.3 |
| 60 | 386 | 102.7 | 70 |
| 75 | 252 | 714 | 85 |
| 90 | 183 | 700 | 91 |
| 105 | 152 | 630 | 106 |
| 120 | 148 | 630 | 140 |
| 135 | 130 | 518 | 183 |
| 150 | 115 | 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 |

Tracer test 1 time and electrical conductivity data, after gravel addition, March 2010.

| | 10 cm | 20cm | 30cm | 47 cm |
|---|---|---|---|---|
| Time (sec) | EC 1 | EC 2 | EC 3 | EC 4 |
| 0 | 59 | 59 | 59 | 59 |
| 5 | 110 | 59 | 59 | 59 |
| 10 | 254 | 59 | 59 | 59 |
| 15 | 389 | 62 | 59 | 59 |
| 20 | 565 | 67 | 60 | 59 |
| 25 | 600 | 71 | 61 | 59 |
| 30 | 640 | 78 | 63 | 59 |
| 45 | 570 | 102 | 330 | 60 |
| 60 | 512 | 142 | 363 | 116 |
| 75 | 478 | 226 | 367 | 142 |
| 90 | 406 | 287 | 367 | 148 |
| 105 | 334 | 349 | 404 | 179 |
| 120 | 297 | 409 | 404 | 195 |
| 135 | 276 | 368 | 182 | 250.3 |
| 150 | 270 | 329 | 133 | 315 |
| 165 | 277 | 286 | 120 | 301 |
| 180 | 276 | 261 | 105 | 282 |
| 195 | 260 | 205 | 97 | 271 |
| 210 | 262 | 231 | 90 | 270 |
| 225 | 285 | 208 | 87 | 257 |
| 240 | 203 | 166 | 84 | 243 |
| 255 | 187 | 170 | 81 | 229 |
| 270 | 178 | 165 | 80 | 213 |
| 285 | 187 | 164 | 74 | 207 |
| 300 | 184 | 164 | 73 | 191 |
| 315 | 172 | 162 | 74 | 196 |
| 330 | 140 | 142 | 70 | 207 |
| 345 | 134 | 144 | 67 | 193 |
| 360 | 133 | 122 | 68 | 185 |
| 375 | 123 | 133 | 67 | 167 |
| 390 | 107 | 141 | 69 | 162 |
| 405 | 114 | 122 | 68 | 155 |
| 420 | 109 | 119 | 67 | 152 |
| 435 | 107 | 108 | 66 | 153 |
| 450 | 128 | 104 | 65 | 152 |
| 465 | 112 | 99 | 66 | 146 |
| 480 | 116 | 107 | 64 | 147 |
| 495 | 100 | 105 | 64 | 142 |

Tracer test 2 time and electrical conductivity data, after gravel addition, March 2010.

| | 11 cm | 23cm | 35 cm | 48 cm |
|---|---|---|---|---|
| Time (sec) | EC 1 | EC 2 | EC 3 | EC 4 |
| 0 | 58 | 58 | 58 | 57 |
| 15 | 789 | 522 | 58 | 57 |
| 30 | 842 | 685 | 58.3 | 57 |
| 45 | 902 | 699 | 58 | 57 |
| 60 | 883 | 741 | 60 | 61 |
| 75 | 874 | 846 | 60 | 61 |
| 90 | 741 | 917 | 61 | 66 |
| 105 | 623 | 863 | 75 | 75 |
| 120 | 620 | 611 | 81 | 130 |
| 135 | 487 | 518 | 119 | 226 |
| 150 | 336 | 395 | 146 | 226 |
| 165 | 294 | 281 | 204 | 231 |
| 180 | 265 | 143 | 175 | 257 |
| 195 | 277 | 132 | 116 | 263 |
| 210 | 203 | 121 | 899 | 373 |
| 225 | 140 | 108 | 416 | 712 |
| 240 | 160 | 98 | 323 | 688 |
| 255 | 150 | 94 | 285 | 547 |
| 270 | 130 | 80 | 269 | 414 |
| 285 | 120 | 80 | 212 | 373 |
| 300 | 120 | 80 | 168 | 212 |
| 315 | 110 | 79 | 153 | 209 |
| 330 | 110 | 79 | 143 | 181 |
| 345 | 110 | 79 | 126 | 172 |
| 360 | 130 | 79 | 115 | 152 |
| 375 | 120 | 78 | 111 | 119 |
| 390 | 100 | 77 | 113 | 110 |
| 405 | 100 | 77 | 101 | 105 |
| 420 | 100 | 77 | 99 | 99 |
| 435 | 85 | 77 | 93 | 94 |
| 450 | 84 | 77 | 91 | 85 |
| 465 | 74 | 77 | 89 | 81 |
| 480 | 74 | 77 | 87 | 78 |
| 495 | 74 | 77 | 84 | 74 |
| 510 | 74 | 77 | 80 | 74 |
| 525 | 74 | 77 | 82 | 73 |
| 540 | 74 | 77 | 79 | 72 |

Tracer test 3 time and electrical conductivity data, after gravel addition, March 2010.

| | 12 cm | 19cm | 55 cm | 77 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 | 1466 | 86 | 62 |
| 60 | 1689 | 1722 | 203 | 62 |
| 75 | 1544 | 1756 | 169 | 61 |
| 90 | 1325 | 1789 | 195 | 61 |
| 105 | 1301 | 1767 | 237 | 61 |
| 120 | 1174 | 1714 | 270 | 60 |
| 135 | 1058 | 1703 | 287 | 60 |
| 150 | 1046 | 1692 | 318 | 60 |
| 165 | 1037 | 1690 | 328 | 59 |
| 180 | 1022 | 1675 | 341 | 59 |
| 195 | 975 | 1664 | 367 | 59 |
| 210 | 951 | 1254 | 381 | 59 |
| 225 | 933 | 1247 | 400 | 60 |
| 240 | 889 | 1236 | 399 | 60 |
| 255 | 861 | 1225 | 428 | 60 |
| 270 | 844 | 1213 | 465 | 60 |
| 285 | 779 | 1205 | 495 | 60 |
| 300 | 754 | 1192 | 531 | 61 |
| 315 | 722 | 1181 | 537 | 64 |
| 330 | 684 | 1171 | 549 | 71 |
| 345 | 674 | 1154 | 556 | 71 |
| 360 | 633 | 1121 | 621 | 71 |
| 375 | 609 | 1114 | 651 | 70 |
| 390 | 582 | 1100 | 697 | 70 |
| 405 | 559 | 1083 | 708 | 70 |
| 420 | 527 | 1074 | 730 | 69 |
| 435 | 478 | 1060 | 766 | 69 |
| 450 | 463 | 1052 | 771 | 68 |
| 465 | 445 | 1042 | 806 | 68 |
| 480 | 429 | 1030 | 815 | 68 |
| 495 | 401 | 1021 | 822 | 67 |
| 510 | 392 | 1010 | 827 | 66 |

Tracer test 4 time and electrical conductivity data, after gravel addition, March 2010.