AN ANALYSIS OF RESTORATION WORK ON THE LOWER AMERICAN RIVER, SACRAMENTO CA, TO ENHANCE SALMONID SPAWNING HABITAT, 2008-2010

Richard Redd
B.S., Metropolitan State College, Denver, 2001

THESIS

Submitted in partial satisfaction of
the requirements for the degree of

MASTER OF SCIENCE

in

GEOLOGY

at

CALIFORNIA STATE UNIVERSITY, SACRAMENTO

SPRING
2010

AN ANALYSIS OF RESTORATION WORK ON THE LOWER AMERICAN RIVER, SACRAMENTO CA, TO ENHANCE SALMONID SPAWNING HABITAT, 2008-2010

A Thesis

by

Richard Michael Redd

Approved by:

__________________________, Committee Chair
Timothy C. Horner, Ph.D

__________________________, Second Reader
Dave Evans, Ph.D

__________________________, Third Reader
Kevin Cornwell, Ph.D

____
Date

Student: <u>Richard Michael Redd</u>

I certify that this student has met the requirements for format contained in the University format manual, and that this thesis is suitable for shelving in the Library and credit is to be awarded for the thesis.

______________________, Graduate Coordinator _______________

Tim Horner, Ph.D Date

Department of Geology

DEDICATION

This thesis is dedicated to my wife Christa, the only person who believes in me more than my mom. This thesis is also dedicated to my mother and father who can now stop asking me when I will finish my thesis.

ACKNOWLEDGEMENTS

This research was funded by the Bureau of Reclamation, The Sacramento Water Forum, and the Central Valley Improvement Act (CVPIA).

Special thanks to Tim Horner for being my advisor, my fishing buddy, and most importantly, my friend.

- Dave Evans, CSUS
- Kevin Cornwell, CSUS
- Miguel Moreno, CSUS
- Mike D’Anna, CSUS
- Jay Heffernan, CSUS
- Scott Paulinski, CSUS
- Rhianna Eads, CSUS
- Matt Power, CSUS
- Erik Hanson, CSUS
- John Hannon, Bureau of Reclamation
- Rod Hall, Water Forum
- Joe Merz and Cramer Fish Sciences field crews
- Dan Cox, US Fish and Wildlife Service

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 American River

The Lower American River is 23 miles of unobstructed channel that lies below Nimbus Dam and Folsom Lake. The river flows west/southwest from Nimbus dam in the town of Folsom towards downtown Sacramento where it joins the Sacramento River. The upper four miles of the river from Sailor Bar to Lower Sunrise produces approximately one third of the salmon in Northern California, and significant counts of steelhead trout (IEP, 2008). Anthropogenic forces such as dams, artificial levees, and channel modification have altered the natural equilibrium of the river creating habitat that is no longer suitable for salmonid spawning.

Previous work (Castleberry et al. 1993; Horner, 2005; Morita, 2005) has shown these anthropogenic changes to be probable causes in the reduction of salmon and steelhead trout that have returned to the river historically. The Lower Sunrise side channel has been shown to be a location of steelhead redds dewatering and subsequent loss of steelhead egg development for a fish that is a federally listed species. Sailor bar is located just below Nimbus dam, where the majority of the salmon spawning in the Lower American river occurs. This thesis examines three restoration projects at Sailor bar and Lower Sunrise side channel prior to, and after restoration work occurred.

1.2 Geologic and Hydrologic Settings

The American River watershed is 4,890 square kilometers in area and is bounded to the West by its confluence with the Sacramento River and extends eastward to the crest of the Sierra Nevada Mountains.

Maximum elevations for the drainage basin approach 3000 meters at the crest of the Sierra and minimum elevations close to sea level occur at the terminus of the river in Sacramento. The area is dominated by a Mediterranean climate with warm, dry summers, and cool, wet winters. Precipitation ranges greatly spatially and temporally from minimum averages of 47 cm/year in Sacramento to almost 200 cm/year at the maximum elevations.

The American river watershed can be divided into two distinct parts (Upper and Lower) divided by Folsom and Natomas Lakes. The upper part of the watershed above the lakes consists of three main forks of the American river (North, Middle, and South) flowing through steep walled bedrock canyons. Below Folsom and Natomas lakes, the watershed becomes mostly flat as the river flows across an alluvial plain. Prior to the construction of Folsom and Nimbus dams, the yearly peak flows on the American river ranged from almost 10,000 cfs to 180,000 cfs. After dam construction, yearly peak flows lowered from just less than 2,000 cfs to 135,000 cfs (USGS, 2009).

The Geology of the North side of the American river below Nimbus dam is described as Miocene to Pliocene sandstone and siltstone (Schlemon, 1967). The south side of the river is made of gently terraced Pleistocene alluvium.

The riverbed consists of coarse-grained gravel that becomes progressively smaller to sand and silt size material as the river approaches the confluence with the Sacramento River (Vyverberg et al. 1997).

1.3 Purpose

The purpose of this thesis is to collect and analyze data at the Sailor Bar and Lower Sunrise locations of the American River from the spring of 2008 through the spring of 2010 to better understand the hydrologic and geomorphic changes that occurred as a result of the restoration work. Restoration work occurred in August 2008 for the Sailor Bar location, and again in September 2009. The Lower Sunrise side channel was created in October 2008. The hydrologic and geomorphic changes will be measured by the following methods:

- Grain Size Analysis
- Hyporheic Measurements
- Water depth and Velocity Measurements
- Gravel Mobility
- Water Chemistry Measurements
- Inter Gravel Velocity
- Temperature

The compilation of this data will provide a summary of the spawning conditions (hyporheic environment and effect of gravel addition, or side channel construction) before and after restoration work. This information will allow policy makers to make more informed decisions that will lead to improved salmon and steelhead spawning habitat in the river.

1.4 Previous Work; Salmonid Spawning

Powers (1964) studied why salmon returned to the same spawning location year after year. This is one of the first published studies that look at how salmonids reproduce in streams. Briggs (1953) published a study on salmonids in a small coastal stream for the department of fish and game. Chambers et al. (1954) published a report for the Army Corps of Engineers relating the study of salmon to spawning grounds. Pollard (1955) looked at the oxygen supply to salmon eggs in spawning beds.

The 1960s generated a few more publications than the 1950s, and the studies begin to become more focused in terms of scope of investigation with the McNeil and Anhell (1964) paper that analyzed pink salmon spawning success with bed materials, Cooper (1965) showed the effects of mobile stream sediments on pink and sockeye salmon. The end of the 1960s increased the trend of more focused research with 3 papers that relate salmon egg incubation to gravel size and streamflow (Bams, 1969); (Phillips and Koski, 1969); (Horton and Rodgers, 1969).

The 1970s saw an expansion of studies that examined river and gravel conditions, and included several species (Elliot, 1975) of trout.

Cederholm and Salo (1979) were some of the first researchers to look at anthropogenic changes and fish reproduction with a study of the effects of a logging road landslide on salmon and trout spawning. Resier and Bjornn (1979) examined habitat requirements for salmonids in the Pacific Northwest.

The 1980s saw the most dramatic increase in publications to date, including the first paper to look at salmon spawning in the Upper Sacramento River (Parfitt and Buer, 1980) along with a more comprehensive study of California rivers in general (Buer et al., 1981). The discussions expanded to include more in depth looks at stream beds and how stream bed parameters are measured (Church et al., 1987; Everest et al., 1987; Buer et al.1982; Adams and Beschta 1980). The first paper looking at low flow river effects on spawning gravel was published by Carling and McMahon (1987).

Many studies from the 1990s related salmonid spawning success to various river and stream conditions (Lisle and Eads, 1991; Libelo and Bacintyre, 1994), including several studies from England (Crisp, 1993), and (Theurer et al. 1998). The 1990s also brought more studies that focused on rivers with an existing management approach (Meehan, 1991; Osenberg et al., 1994). Regulated rivers began to be considered in the 1990s, with two papers by Sear (1993, 1995). Castleberry et al. (1993) published the first study about juvenile salmon in the American river. More papers were also published examining the effects of fine-grained sediment on salmon redds (Young et al., 1990; Crisp, 1993). Flosi et al. (1998) published the first California salmonid restoration manual.

Most recently, salmonid researchers have focused on using new technology to study the physical parameters of rivers and provide a better understanding of the hyporheic zone (Malcom et al. 2003; Malcom et al. 2006). Von Schalburg et al. (2005) used gene technology to examine genes in maturing rainbow trout. Several papers were published with regional implications to the American River. MacFarlane et al. (2002) studied the ecology of the San Francisco estuary and its associated effects on salmon. Merz et al. (2004) published a paper that predicted benefits of spawning-habitat restoration for salmon.

1.5 Previous Work; Field Methods

The methods used to better understand the physical and hydrologic characteristics that affect salmonid spawning in rivers have been well documented. Many studies from the previous section are based upon data collected using the methodologies developed by the following authors. Some of the first work done to describe these field parameters was conducted by Inman (1952) when he described measures for the size distribution of sediments. Wolman (1954) described a method for sampling coarse river bed material. Terhune (1958) devised a technique for measuring the movement of water through gravel in rivers. Chow (1959) published open channel hydraulics.

The first paper examining the measured dissolved oxygen requirements for steelhead trout and salmon in different water depths was published by Silver et al. (1963) Several papers published in the 1970s have become seminal over time (Bouwer and Rice, 1978; Lee and Cherry, 1978).

Freeze and Cherry (1979) published Groundwater, a book that would be used for decades in class rooms to derive the governing equations for hydrogeology . These publications build the foundation for the science that is used to measure the parameters relevant to salmon spawning. These methods were refined and inspired the development of newer techniques using more sophisticated sampling technology. Bovee (1982) was the first to combine these widely used methods and constrain them to salmonid spawning. Several papers were written in the late 1980s that discuss convective transport of bottom sediment in rivers (Church et al. 1987), (Savant et al. 1987), (Thibodeaux and Boyle, 1987).

A common focus of publications relating to field measurements in the 1990s was on the methods used to sample gravel (Kondolf et al. 1993), (Kondolf et al. 1993), (Rice, 1995), (Rice and Church, 1996) and bottom sediment in rivers. The influence of surface water on sampling techniques in rivers was also well described (Fripp and Diplas, 1993), (Libelo and MacIntyre, 1994). Pebble count technique refinements were published during this time (Kondolf and Li, 1992), and (Kondolf, 1997). Springer et al. (1999) examined spatial variability of hydraulic conductivity in the Colorado River.

Since 2000, the focus of field methods used to investigate rivers changed to include temperature (Constanz et al. 2002), (Stonestrom and Constanz, 2003), (Nicola and Almodovar, 2004). Particle size studies and gravel studies were conducted with refined techniques (Lane, 2001), (Kondolf et al. 2003), (Horner et al. 2004), (Bunte and Abt, 2001), (Carbonneau et al. 2005), and (Malcom et al. 2003).

The hyporheic zone was also studied with better understanding and methods (Harvey et al. 2000), (Zamora, 2006), (Bush, 2006), (Malcom et al. 2003), and (Malcom et al. 2006). Flow velocity is also being studied for impacts with salmonids (Greig et al. 2005), (Zimmerman and Lapointe, 2006), and (Milan et al. 2001).

Studies will continue with increased effort and urgency as salmonids continue to struggle to survive in urban rivers. Theses studies will not only contribute to a better understanding of sustainable fish populations, but will also increase our knowledge of river processes like hyporheic characterization and temperature distributions in rivers.

1.6 Restoration Project 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 additions in September 2008 and September 2009, 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. Figure 1.1 shows the location of the two gravel additions.

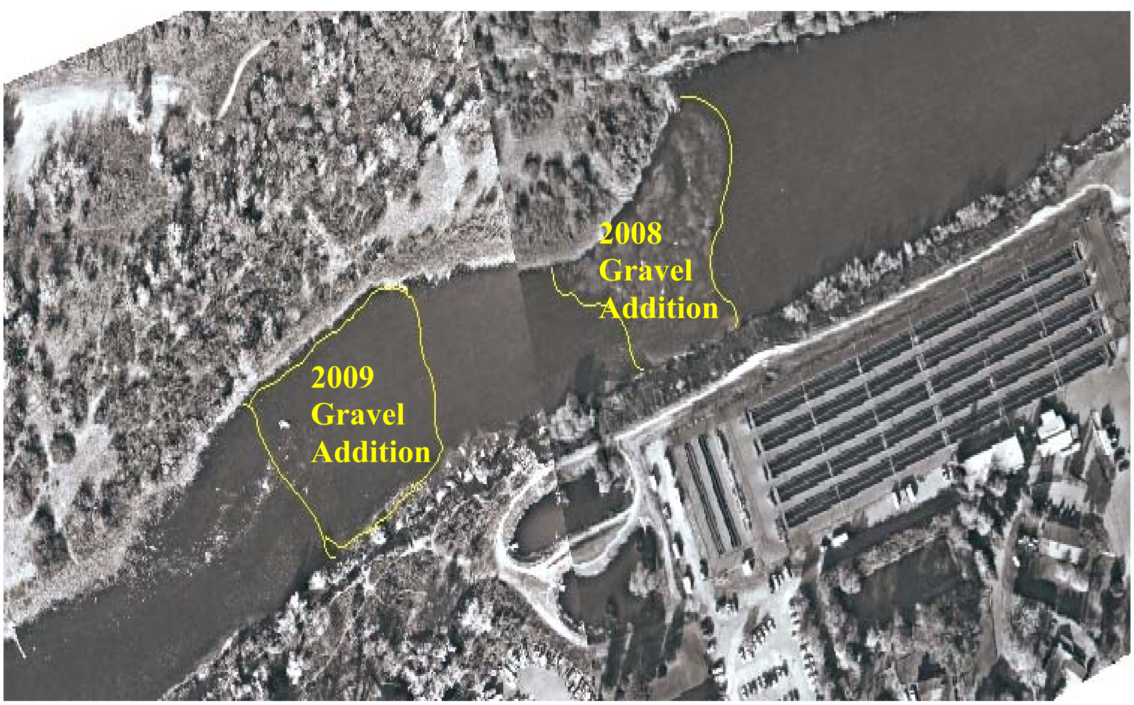


Figure 1.1: Map showing the outline in yellow of the gravel additions from 2008 and 2009. The Nimbus fish hatchery is in the lower right corner.

The Lower Sunrise site is a known location of steelhead trout and Chinook salmon spawning. These fish carve out horseshoe shaped depressions in the riverbed to create their spawning locations known as redds. Peak steelhead spawning is usually in February, when flows are high. This allows steelhead to spawn high on the banks and newly submerged areas. In some years, flows have been managed to enhance habitat or prevent dewatering of redds. Stranding may also be problematic when steelhead trout emerge into pools of water that are no longer connected to the river. These pools quickly become too hot or create easy predation by birds. Steelhead trout are a listed species under the Endangered Species Act, which compels the appropriate federal and state authorities to mitigate circumstances that create negative impacts on fish population levels. The goals of the side channel project were to minimize dewatering of steelhead redds, and maintain flow in the side channel area to a depth greater then 1 foot with a flow of 1000cfs. To accomplish this, the channel bottom was lowered and neighboring banks were sculpted to discourage redd building on topographic highs where dewatering could occur.

A preliminary site assessment was conducted by Tim Horner in 2005 with similar objectives to the post restoration study. Table 1.1 shows a summary of significant findings from the study.

Monitoring Point	**D.O. (ppm)**	**E.C. (µS)**	**Temperature C°**
SC00	6.3	49	17.2
SC01	6.7	52	18.2
SC03	7.9	54	17.6
SC04	2.7	60	23.2
SC05	4.0	53	16
SC06	3.9	55	17.2
SC07	3.2	54	18.9
SC08	6.6	51	18.1
SC09	0.5	54	28.3
Mean	**4.6**	**54**	**19.4**

Table 1.1: Summary of 2005 data collected by Tim Horner and CSUS for preliminary assessment of the side channel. Several high temperatures are the result of the sample location being very shallow or dry at the surface. Dissolved Oxygen values are consistently lower prior to restoration.

Stream velocity, hyporheic pressure measurements, and grain size analysis were also conducted prior to restoration. All of the tasks conducted in the 2005 assessment were replicated in the 2008-2010 assessments with the exception of temperature analysis. Side channel construction occurred during the last three weeks of October 2008.

Chapter 2

METHODS

2. Methods

Several methods were used to analyze spawning conditions at the restoration sites. These included grain size and gravel mobility, physical and chemical conditions in the hyporheic zone, streamflow, and temperature.

2.1 Grain Size

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 30 pebble counts at Sunrise Side Channel and 30 at the 2008 Sailor Bar gravel addition. An additional 18 pebble counts were collected at the 2009 Sailor Bar gravel addition. Bulk samples and weighted pebble counts were also used to better characterize the pre-restoration grain sizes in the Sunrise side channel.

Bulk samples were collected by digging holes to a depth of three times the diameter of the largest grain size in a randomly selected 1 meter circle.

Sample mass was at least 100 times the weight of the largest grain. The material collected was sieved into grain sizes and weighed in the field using large rocker sieves. The weight of each grain size was compared with the total weight of the sample to determine the percent weight distribution. Samples were collected from the surface (river bottom) and a depth of 30 cm considered the subsurface in this study. Five weighted pebble counts were conducted before side channel creation to compare grain size and weight. Each of the grain sizes used in the pebble count was weighed to determine the percent weight distribution from pebble counts.

2.2 Gravel Mobility

Tracer rocks were deployed at the 2008 gravel addition and the Sunrise side channel in transects across the restoration area (after gravel addition and side channel creation) 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 and side channel at upstream, mid gravel addition/side channel, 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 50 cm horizontal error. Figures 2.1 and 2.2 show pictures of a grouping of the two largest grain sizes used in the tracer rock study.

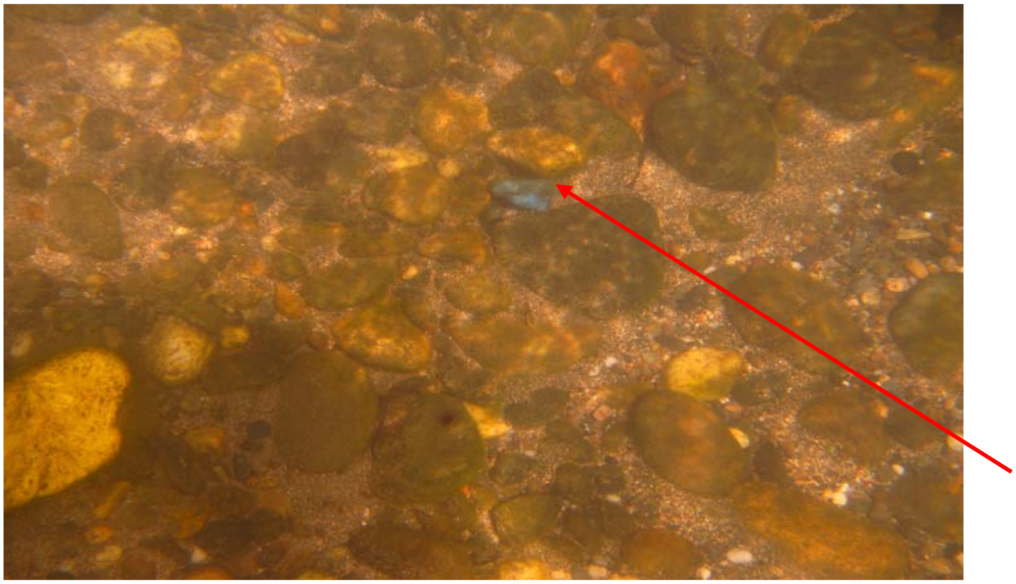


Figure 2.1: Picture showing the two largest grain sizes used in the tracer rock study.

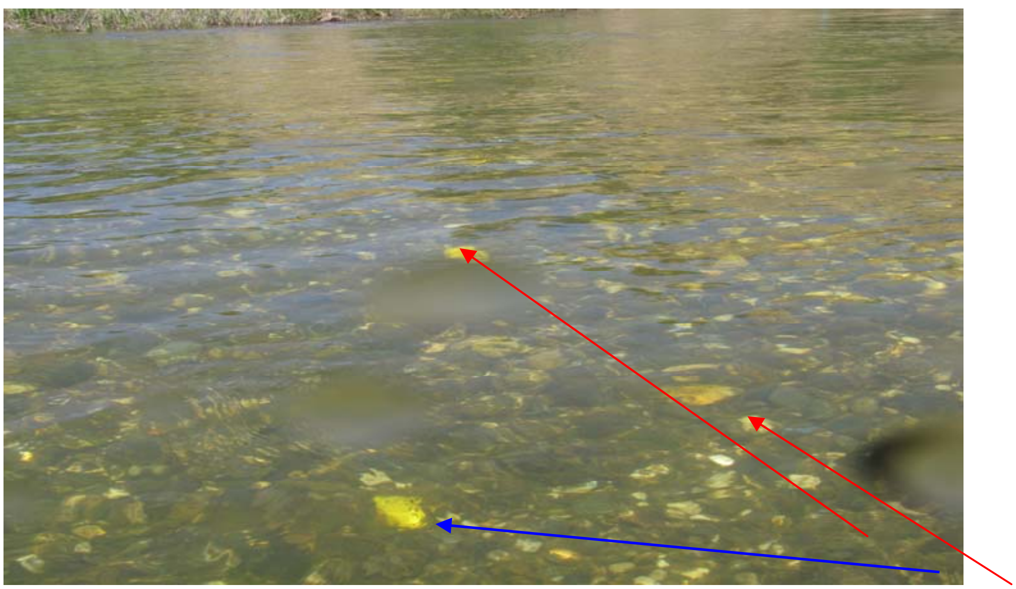


Figure 2.2: Picture showing yellow tracer rocks in a tracer rock (red arrows) transect. The blue arrow is pointing to a rock that has moved relative to tracer rock transect.

2.3 Water Quality

Mini piezometers were installed throughout the restoration sites before and after the restoration work was completed to measure changes in water chemistry, temperature, and vertical pressure gradient.

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 sites at upstream, mid gravel/side channel, and downstream locations. Several mini piezometers were installed outside of the restoration areas at upstream locations to show natural river conditions and provide controls 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 2.3 shows the piezometer tip with polyethylene tubing.

Figure 2.3: 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 2.4 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.

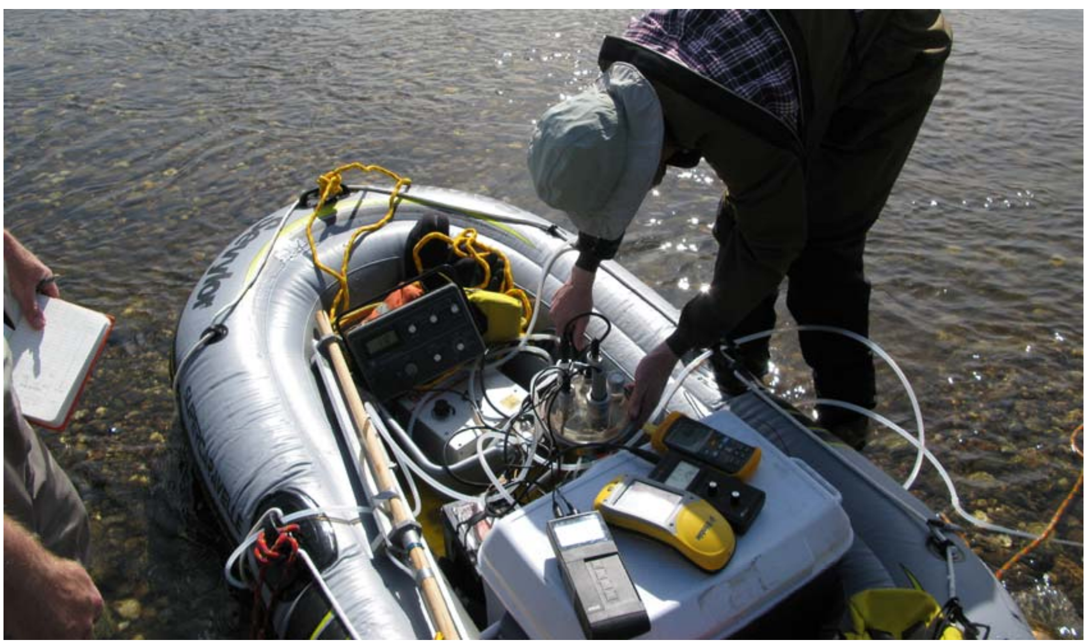


Figure 2.4: Picture of the field setup for the flow-through cell and water quality equipment.

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.

2.4 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. The tubing from the manometer board was then connected to the baffle bubble. Figures 2.5 and 2.6 show the manometer used for measurements and the difference in pressure from a measurement.

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.

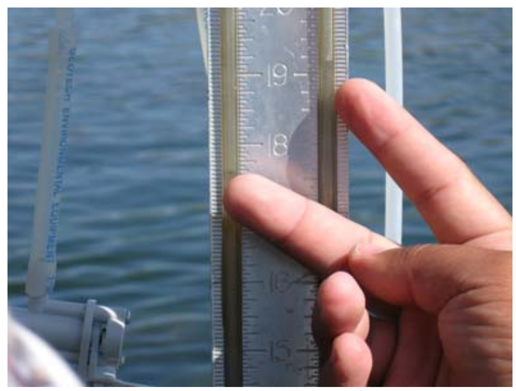


Figure 2.6: The photo to the right shows a close-up view of the different pressure heads from a measurement.

Figure 2.5: Picture of the manometer used for measuring the upwelling or downwelling for each mini piezometer.

2.5 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 velocity per minute 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 2.7 shows a picture of the equipment used to measure the velocity and depth of the study area.

Figure 2.7: Picture showing the Price AA wading rod stream velocity measuring equipment.

2.6 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. Reynolds's number calculations were used to verify the seepage velocities measured were within non turbulent flow parameters allowing equation 3 to be used. 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 2.8 shows the monitoring well configuration for salt water tracer tests with a 30cm monitoring well spacing from the injection well.

Figure 2.8: 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.

2.7 Temperature Analysis

Hobo water Temp Pro v2 data loggers were installed at thr 2009 Sailor Bar gravel addition 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 ten minutes 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. The detection limit of the temperature loggers is 0.1 degrees Celsius. Temperature changes less than 0.1 degrees Celsius can not be accurately measured with the Hobo temperature logger. Changes in temperature as small as 0.1 degrees Celsius have potential impacts on salmonid spawning success.

Chapter 3

LOWER SUNRISE SIDE CHANNEL RESTORATION PROJECT RESULTS

3.1 Pre Restoration Grain Analysis

Figure 3.1 shows a GIS map of the side channel with the pebble count transects used in this study prior to side channel creation. Figure 3.2 shows a grain size distribution graph for one of the furthest upstream locations, Figure 3.3 shows the grain distribution for one of the furthest downstream locations. The majority of the grains counted in the downstream transect are less than 1 inch in diameter. The majority of the grains counted at the upstream location where larger than 1 inch in diameter. The downstream portion also has more grains counted in the smallest diameter sizes of the classification scale used, while the upstream location had larger observed amounts of grain sizes in the largest grain size classifications. Figure 3.4 shows a map created on March 29, 2009 of areas that contained more than 80% sand by area. The deposition of fine (sand) grains was documented after the creation of the side channel by observing tracer rocks which became buried by fine grained material.

Large areas covered entirely by fine grain materials or sandy river bottom formed at the downstream end of the side channel. Figure 3.7 shows a comparison between the grain size distributions of an up stream transect versus a down stream transect before side channel creation. Grain size decreased from the upstream to the downstream end of the channel. Appendix A shows the bulk sample data collected before restoration. Appendix B shows pebble count data before side channel creation.

Appendix C shows the weighted pebble counts conducted before restoration.

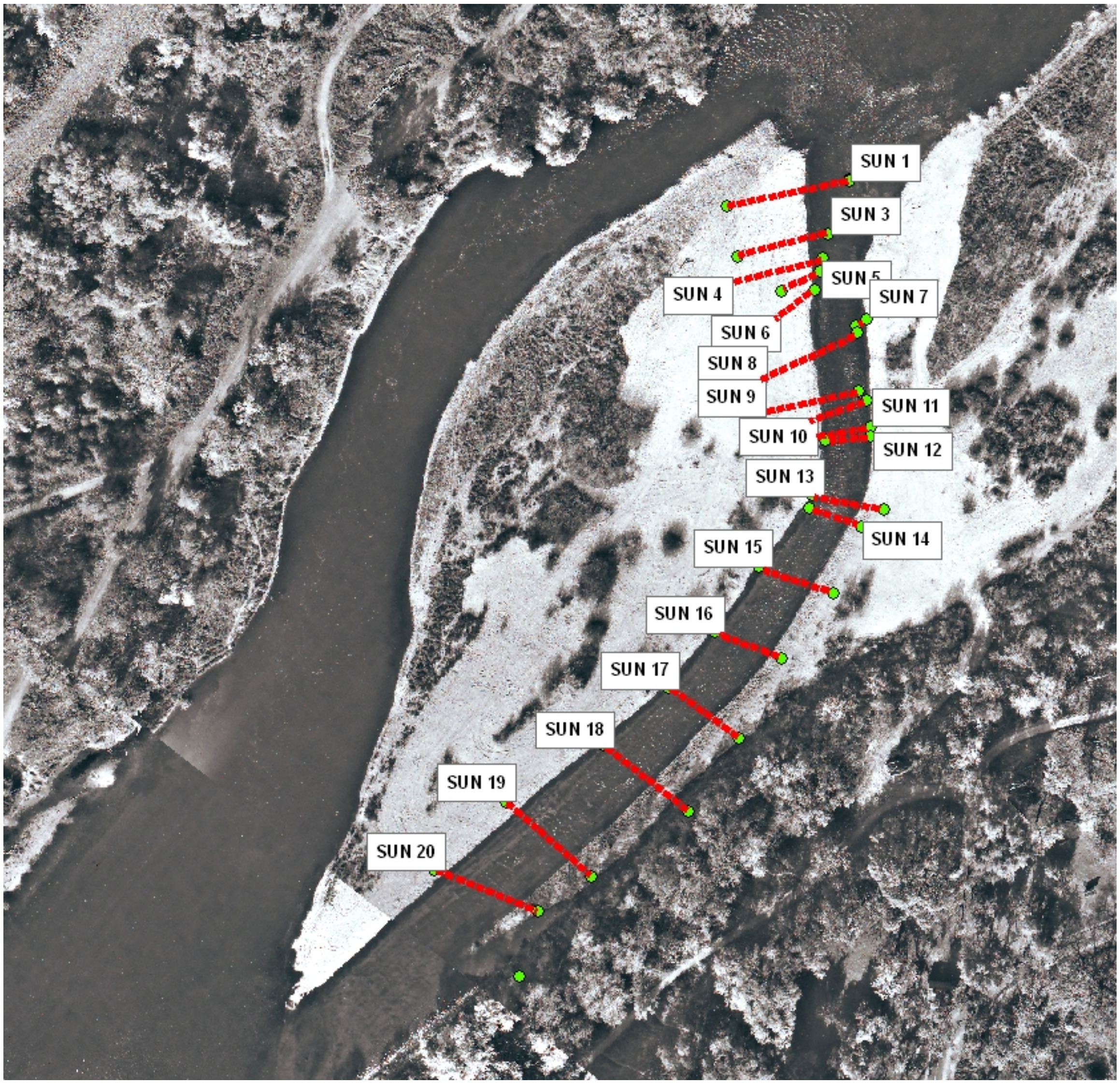


Figure 3.1: GIS map of the pebble count transect locations conducted before side channel creation.

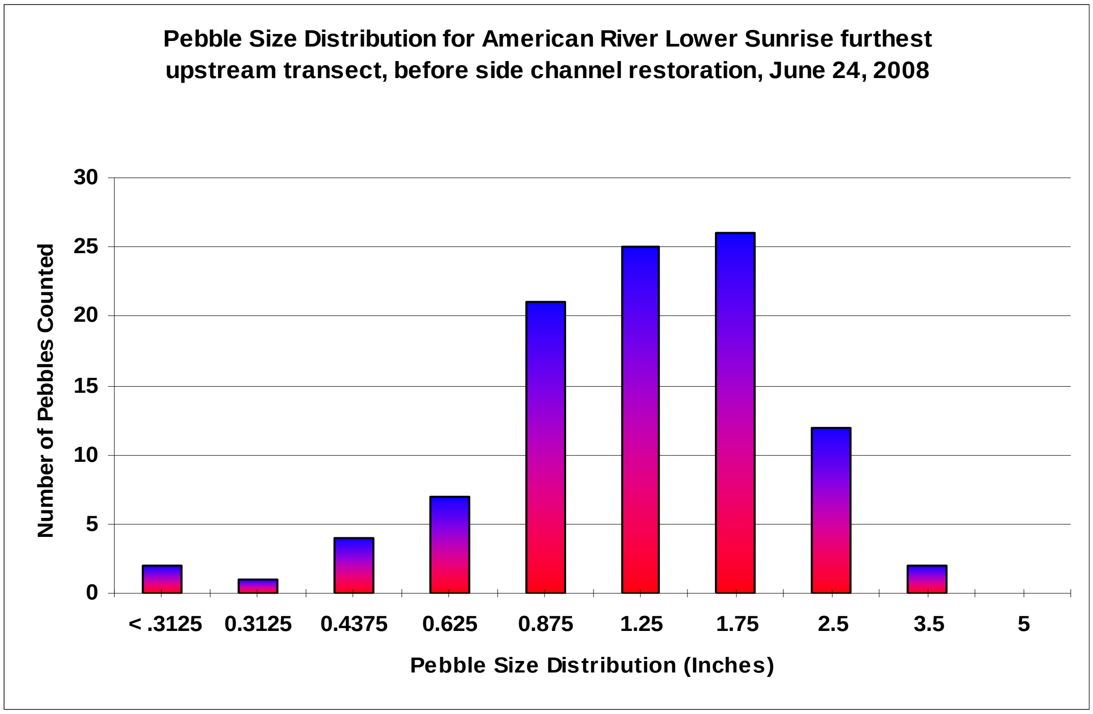


Figure 3.2: Graph showing the grain size distribution for the furthest upstream transect before side channel creation.

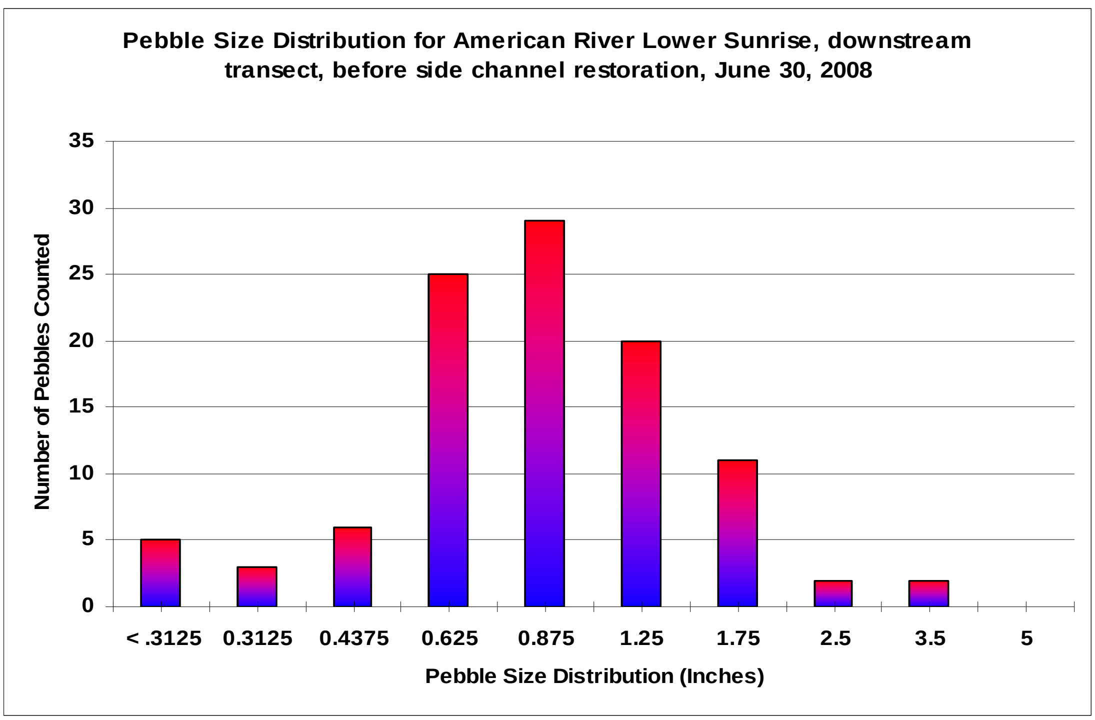


Figure 3.3: Graph showing the grain size distribution for a downstream transect before side channel creation.

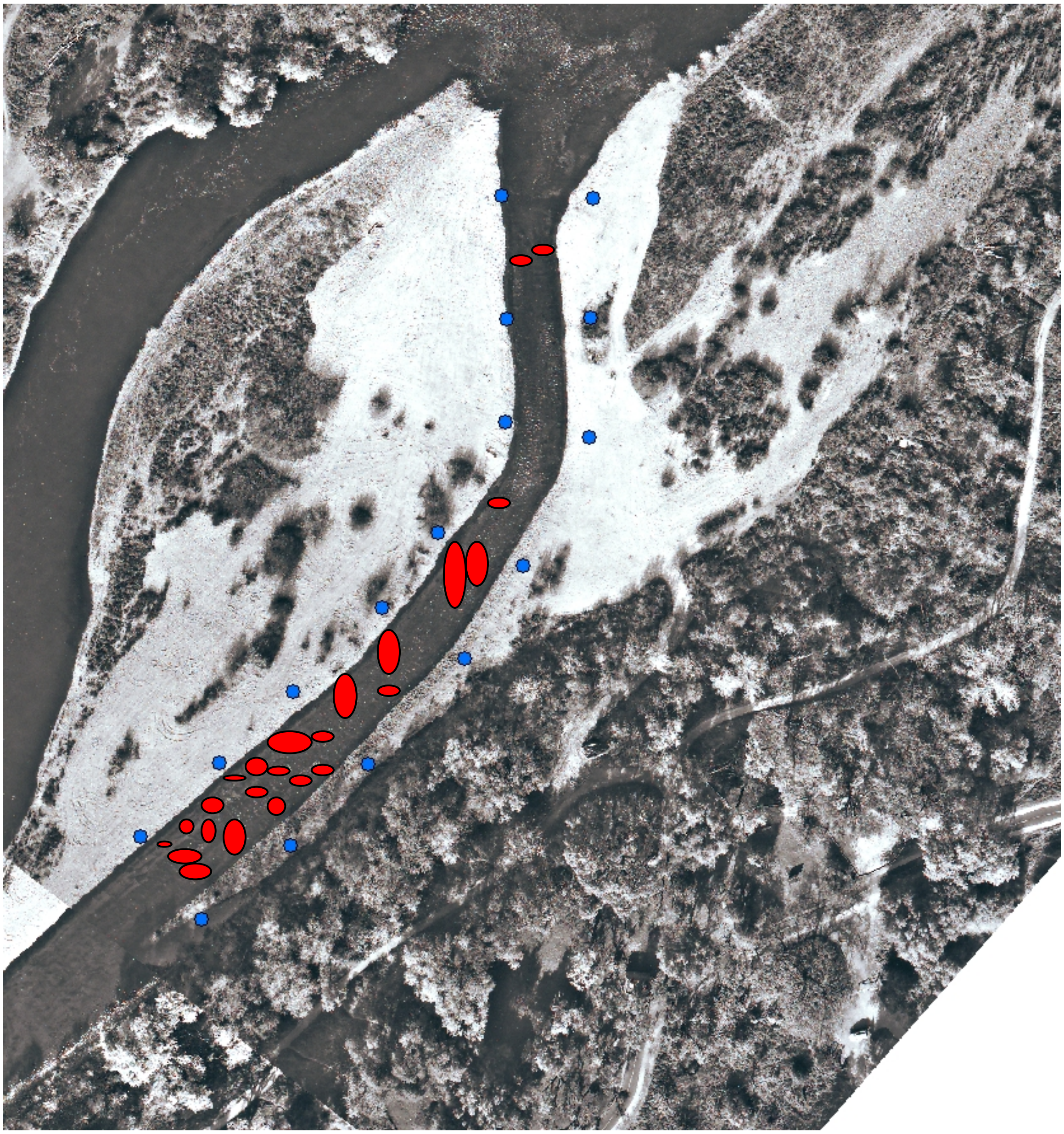


Figure 3.4: Map showing the locations where the side channel bottom was more than 80% sand by area.

Figure 3.5 shows a map of the locations for the bulk samples collected before side channel creation. The results for the bulk samples are shown in appendix 3-A. The bulk samples showed larger amounts of 8 mm (fine) grain sizes in the subsurface samples, and small increases in fine grain material compared to the surface samples. All four of the bulk sample locations contained gravel that conforms to the established limits for steelhead spawning. Figure 3.6 shows a grain size distribution generated from a bulk sample. The dashed black lines are experimentally derived suitable habitat range in terms of minimum and maximum preferred grain sizes.

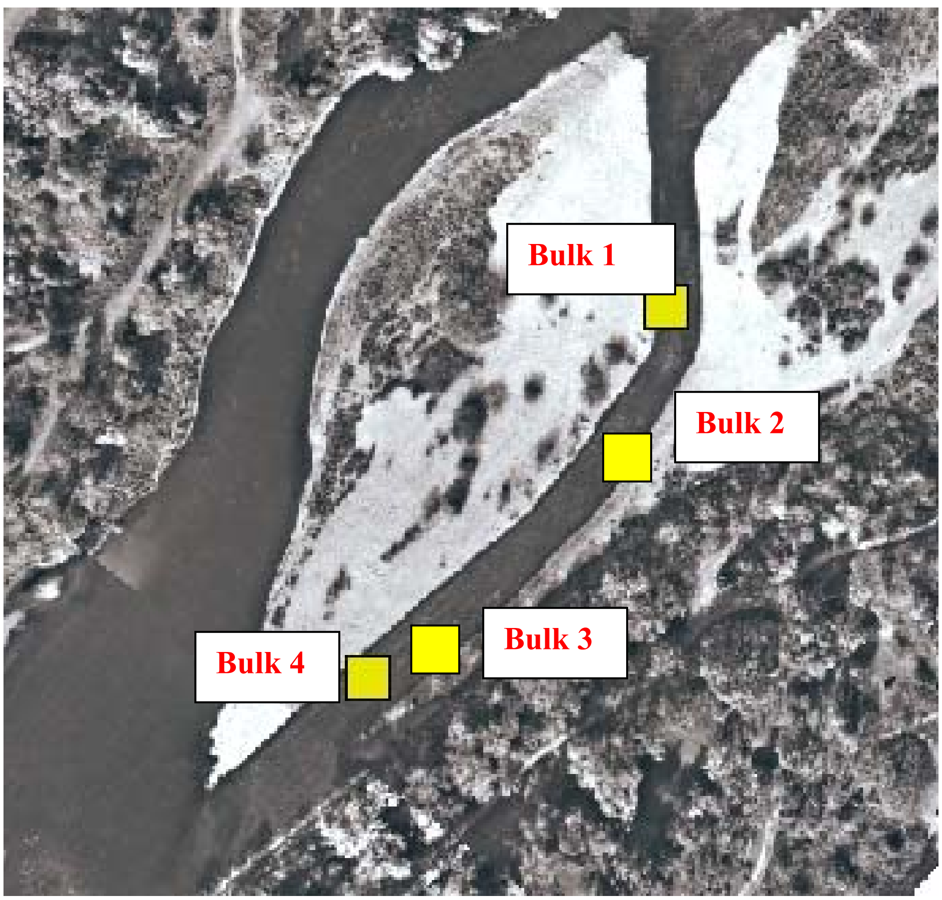


Figure 3.5: GIS map showing the bulk sample locations before side channel creation.

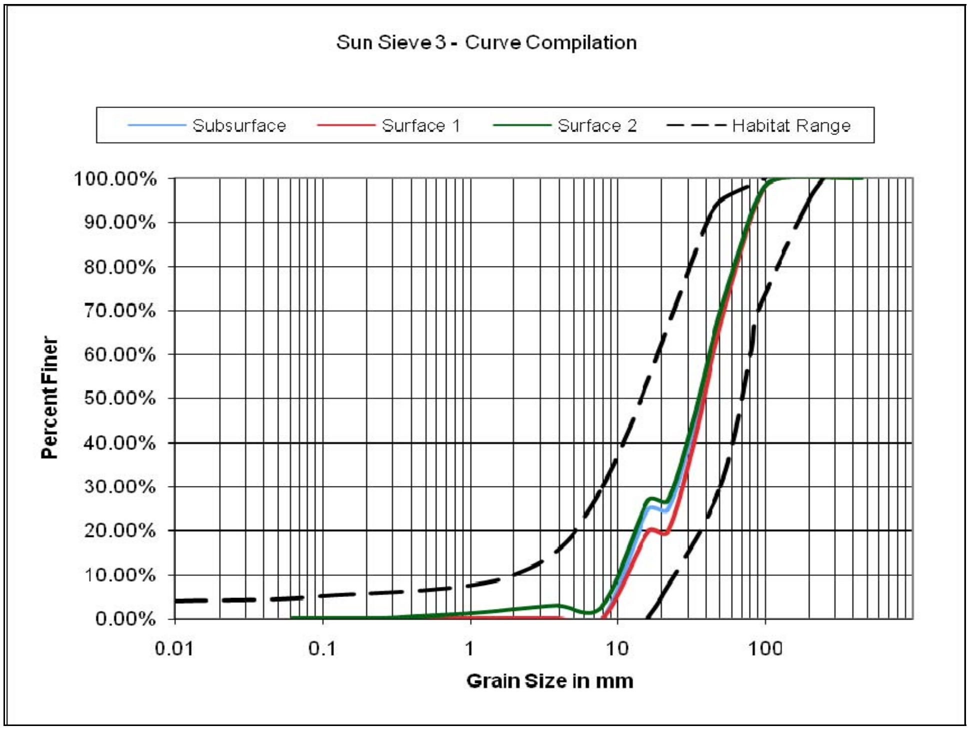


Figure 3.6: Graph showing the cumulative percent grain size for bulk sample 3, a downstream location before side channel creation.

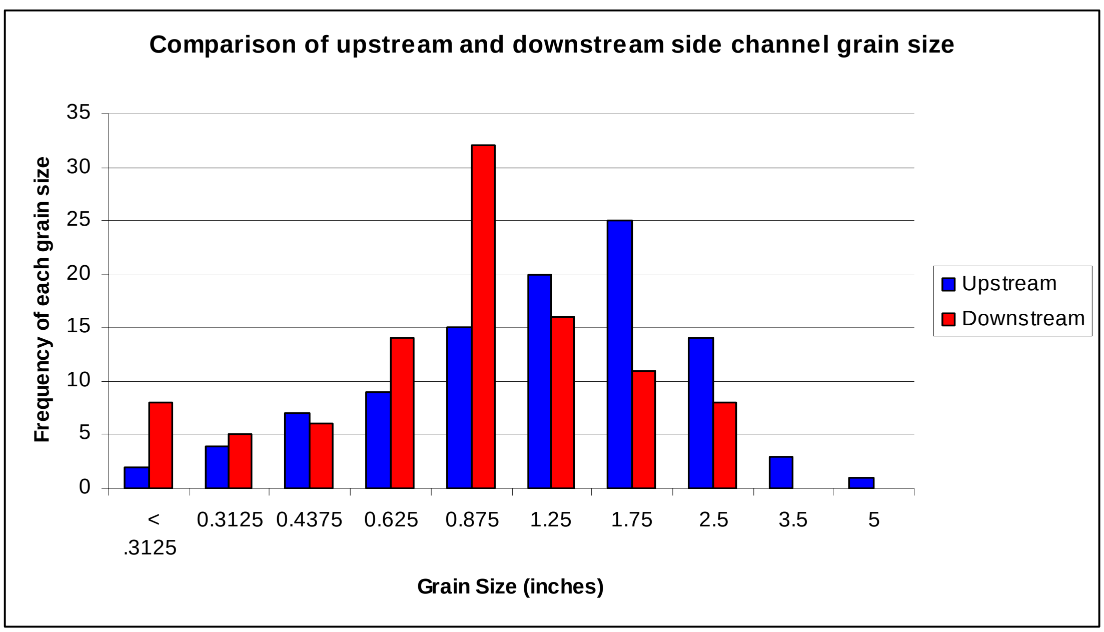


Figure 3.7: Comparison of the grain size from the upper section of the side channel and the downstream section of the side channel before creation. The red bars (downstream section) show more fine grains. The blue bars (upstream section) show more coarse grains.

3.2 Water Quality

Twelve mini piezometers were installed at the side channel location after side channel construction to measure geochemical parameters related to fish spawning in the channel. Figure 3.8 shows the location of the mini piezometers in the side channel. Ten mini piezometers were sampled on February 21, 2009 to measure dissolved oxygen (D.O.), pH, Electrical Conductivity (E.C.), temperature, and also collect water samples. The results from the D.O. measurements (Table 3.1) show a high degree of variability with values ranging from 2 mg/L to over 10 mg/L. The results from water samples analyzed using the Hach Spectrophotometer showed values approaching the smallest detectable limits for Nitrate, Nitrite, Phosphate, and Ammonia. Appendix D shows the data.

Figure 3.8: GIS Map showing the side channel mini piezometer locations.

Location	Temp (C deg)	DO (mg/L)	EC (ms)	pH
MP-1	10	10.1	52.4	7.4
MP-2	10	10.2	55.1	7.39
MP-4	9.8	9.6	50.9	7.23
MP-5	10.1	10.1	55.4	7.33
MP-6	9.9	10.5	51.3	7.4
MP-7	10.4	9.7	42.4	7.04
MP-8	10.5	3.5	40.8	7.13
MP-9	10.3	8.8	44.4	7.1
MP-10	10.8	2.1	56.1	6.8
MP-12	10.4	9.1	56.5	7.02
Mean	**10.2**	**8.4**	**50.5**	**7.2**
Surface 1	11.8	11.8	54.7	7.72
Surface 2	12.2	12.2	53.7	8.14

Table 3.1: Summary of data collected from installed mini piezometers, Feb 21, 2009.

Table 3.1 and Figure 3.9 show D.O. values higher than 8.0mg/L for eight of the mini piezometers sampled. Two mini piezometer locations showed very low D.O. values of 3.5 ppm and 2.1 ppm. The map showing the locations of sand in the side channel (Figure 3.4) shows the mini piezometer locations with the low D.O. are in areas that are predominantly sand or fine-grained.

The increase in fine grain material is inferred to be creating the low D.O. amounts and limiting the oxygen and pore water from moving through the pore spaces of the substrate. Mini Piezometers MP-3 and MP-11 were lost or removed from the river prior to data collection. pH values ranged from 7.04 to 7.4 within a temperature range of 9.8-10.8 degrees Celsius. The Electrical conductivity values range from 80.8 to 95.4 micro Siemens/cm.

Figure 3.9: GIS map showing the D.O. values measured.

The lowest pH, E.C. and D.O. readings are all present at the two locations where fine-grained material has overtaken the mini piezometer locations. Surface samples were taken twice during the sampling event to compare river water to subsurface conditions.

The surface samples showed expectedly higher levels of D.O. due to atmospheric mixing. Temperature was also higher by more than 1 degree Celsius in surface water. The gravel formed by the side channel provides a measurably cooler environment at 30 cm depth.

3.3 Hyporheic Pressure Head Measurements

Figure 3.10: GIS map showing the bubble monometer measurements for the side channel from February 2009.

The manometer measurements (Figure 3.10) from February 2009 showed less than ½ inch pressure changes, indicating upwelling conditions at the majority of the locations. Several mini piezometers showed “even” pressure readings, with no significant pressure difference between the surface and subsurface. An additional 75 measurements were made in February 2010 using a well spike to create temporary wells to a depth of 30 cm. Figure 3.11 shows a map of the locations sampled in February 2010 with up or down arrows indicating direction of the vertical pressure gradient. Figures 3.11 and 3.12 show areas where downwelling or upwelling occurred.

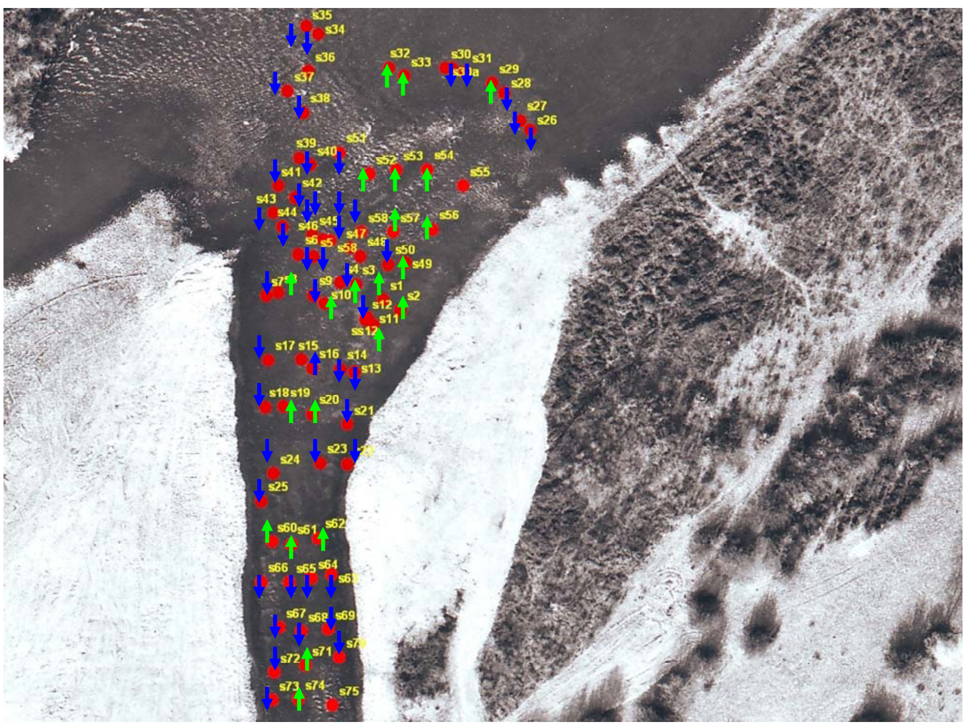


Figure 3.11: Map showing vertical pressure gradient measurements from February 2010. Blue arrows indicate downwelling and green arrows indicate upwelling.

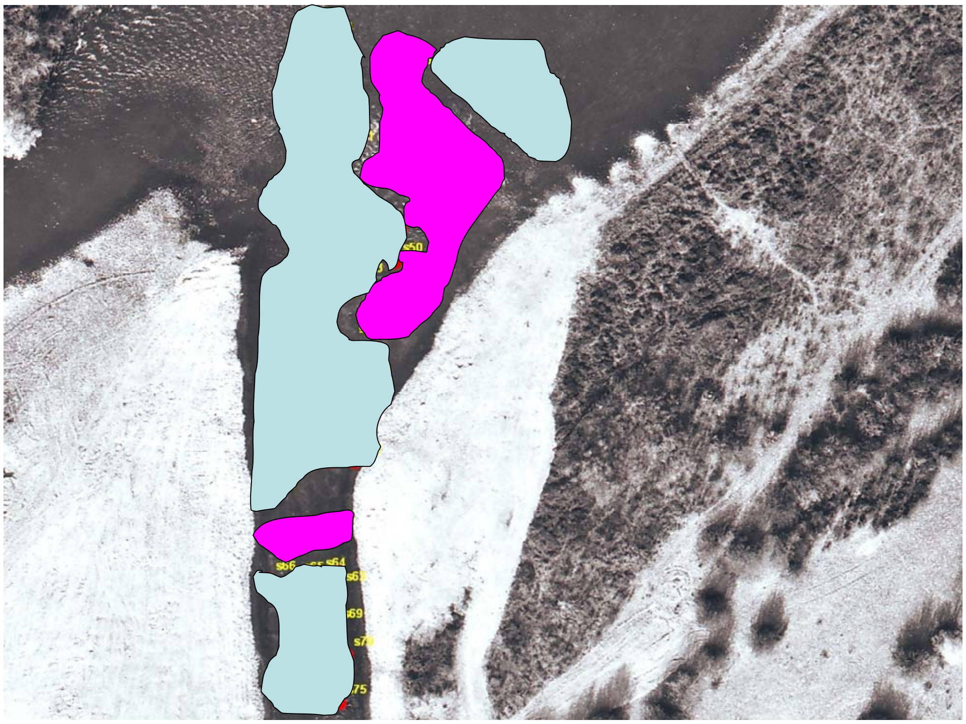


Figure 3.12: Map showing the areas of upwelling in pink and downwelling in light blue. Measurements were made February 2010.

3.4 Water Depth and Velocity

After side channel creation, water depth and velocity were measured at 8 transects across the side channel. Figure 3.13 shows the location of the transects used to create the streamflow data. Figure 3.14 shows the velocities measured in feet per second for the 2008 transects. These values ranged from 0.5 feet per second to almost 4 feet per second in the upstream portions of the side channel. Figures 3.15 and 3.16 show the depth at each segment of the cross section. Measurements were made for the two sampling events in November 2008 and in June 2009 to show changes in the side channel over time. Stream flow for the 2008 measurements (from the USGS Fair Oaks gage) was 1165 cfs, and 2000 cfs for the 2009 sampling event.

The changes in depth shown in Figures 3.15 and 3.16 show a general pattern of down cutting and erosion for the upstream portion of the channel and sand deposition for the downstream portion of the channel. This depth difference also shows that the side channel has incised more than 1 foot in some upper portions. The uppermost transect was not measured because several of the measuring points in the transect were too deep (greater than 4.5 feet) for the wading rod. Appendix D shows the data for the flow velocity calculations.

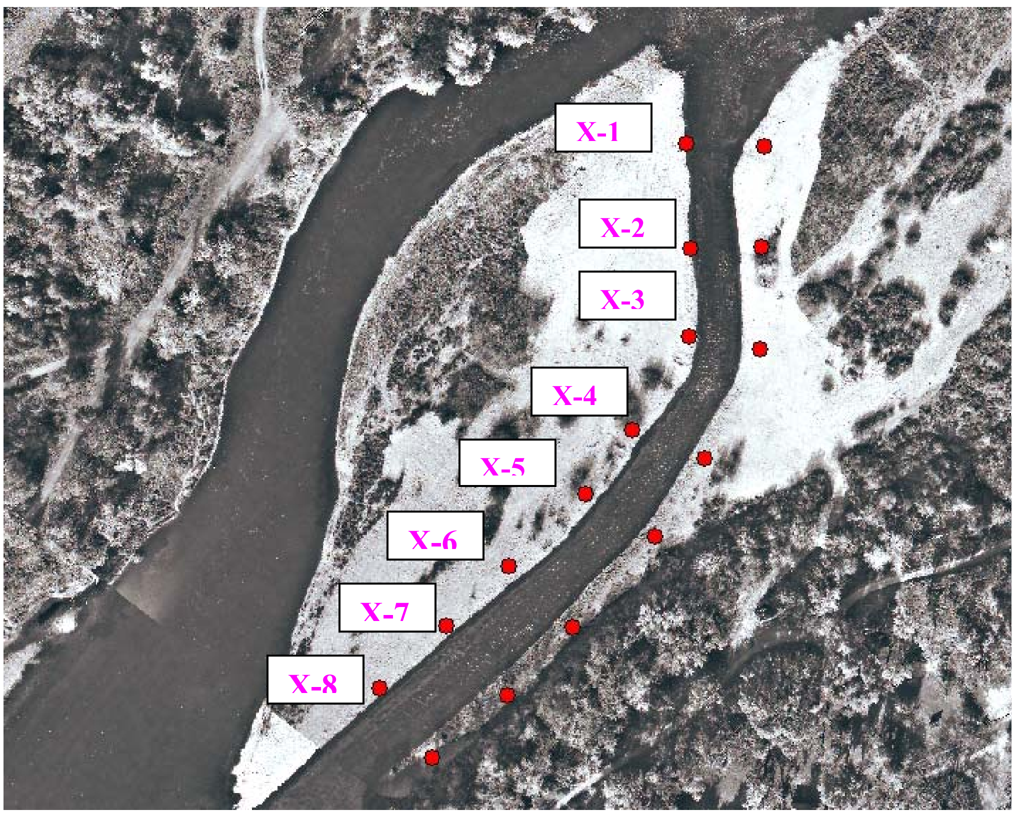


Figure 3.13: GIS map showing the velocity transects used to determine streamflow in the river.

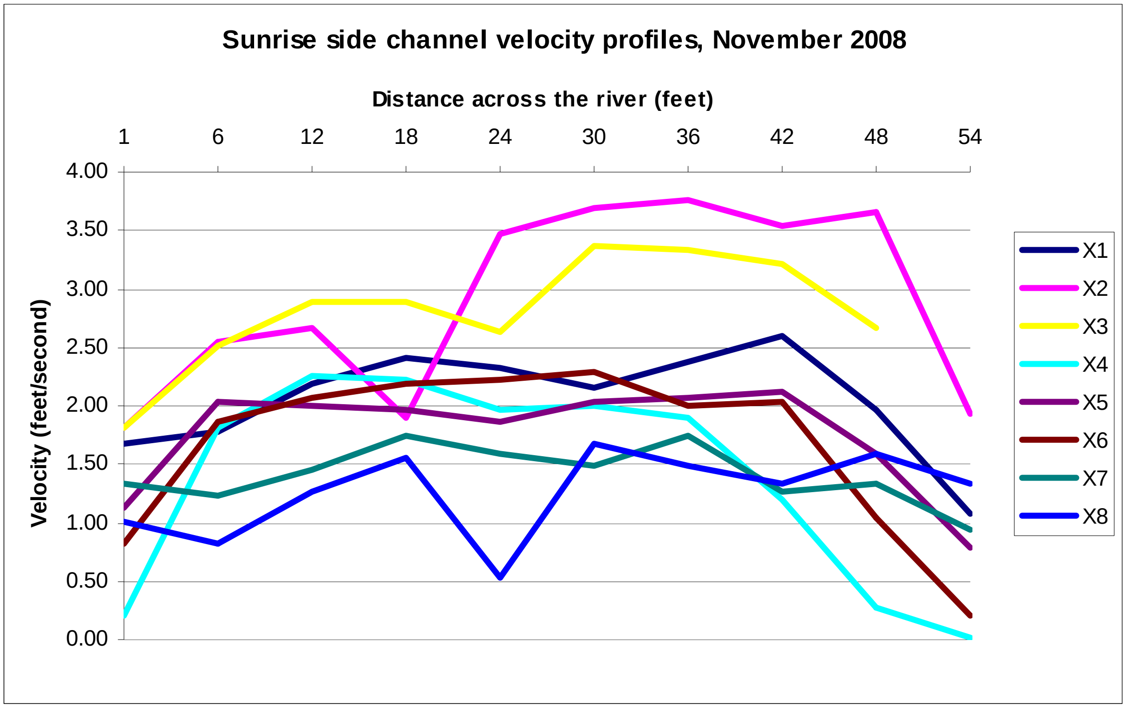


Figure 3.14: Graph showing the measured stream velocity in feet per second at each transect from November 2008. Flow was 1165cfs.

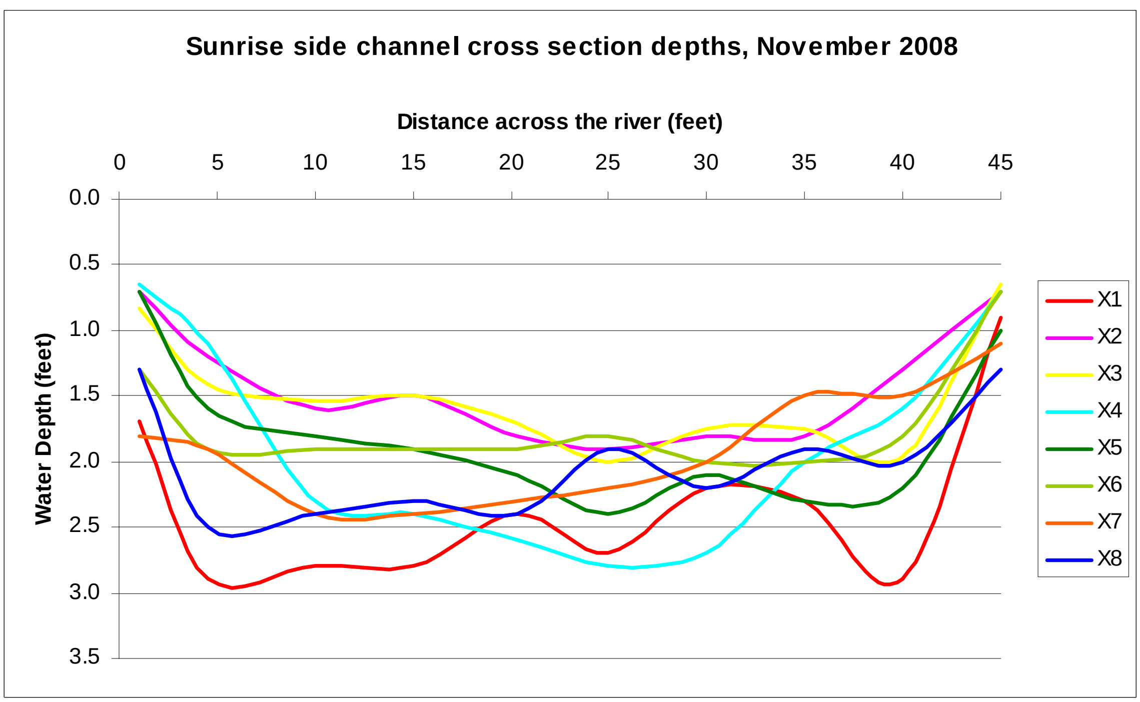


Figure 3.15: Graph showing the depths of each cross section. X1 is the upper most portion of the side channel and X8 is the furthest downstream transect. Flow was 1165cfs.

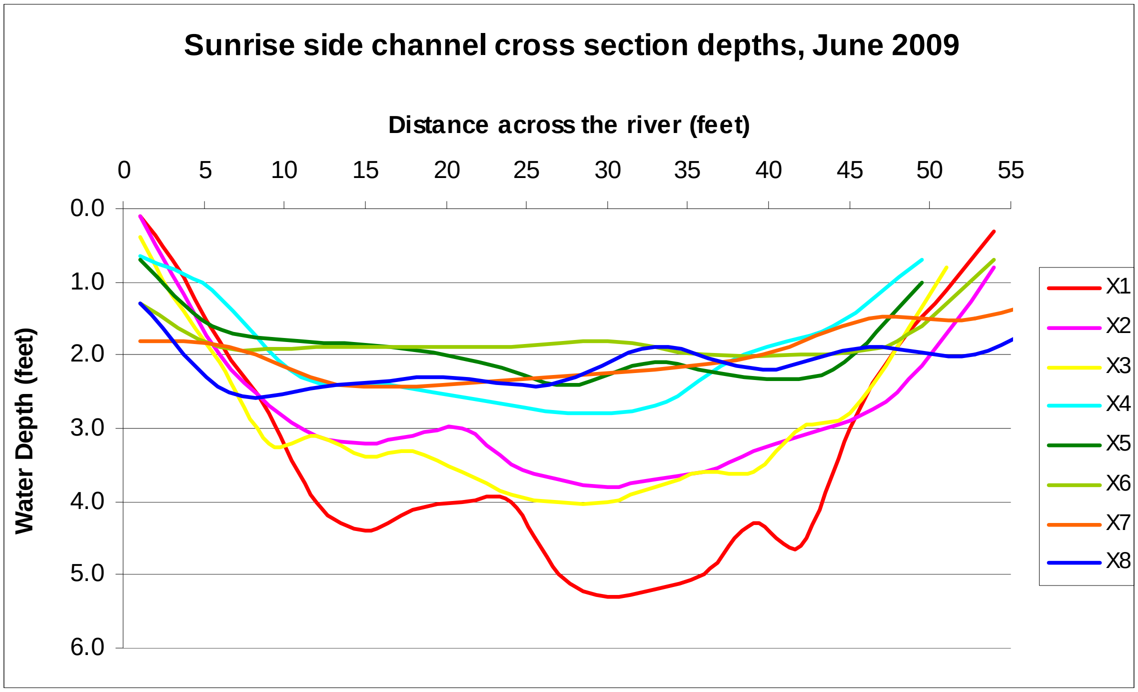


Figure 3.16: Graph showing the depths of each cross section and significant down cutting 8 months later. X1 is the upper most portion of the side channel and X8 is the furthest downstream transect. Stream flow was 2000 cfs.

3.5 Gravel Mobility

Tracer rocks were initially deployed in transects crossing the side channel in December 2008, at upstream, midstream, and downstream locations. The rocks were located on March 29, 2009 when the flow recorded at the USGS Fair Oaks river gage was 1750 cfs and again on April 29, 2009 when the flow was 3000 cfs. The March sampling event showed more movement of larger rocks at the upstream transect (Figure 3.18). Sixteen out of thirty of the largest size tracer rocks were mapped with an average downstream movement of 3.7 feet.

Eight of the intermediate size (blue rocks) and 3 of the smallest size (red rocks) were located with average downstream movements of 8.9 feet and 14.3 feet respectively.

A single small sized (red tracer rock) migrated to within 3 feet of the middle transect line. This red rock is probably from the upstream transect showing a downstream movement of 100 feet.

During the March and April sampling events, 18 large (yellow) size rocks were located and mapped along with 7 intermediate (blue) and 6 small (red) rocks at the up stream transect. The tracer rocks on the northern portion of the middle transect were partially or completely covered in fine grained sand and silt (Figure 3.17).

Figure 3.17: Picture from the lower transect on March 29, 2009 showing the burial of a yellow rock in fine grained material.

The rocks located at the middle transect did not move further than a few feet from the original transect location. The furthest downstream transect of tracer rocks yielded the smallest return of rocks due to burial from fine grained material. Almost half of the transect's width was consumed by sand and silt along the downstream transect. Figure 3.18 shows a GIS map of the lower Sunrise study area.

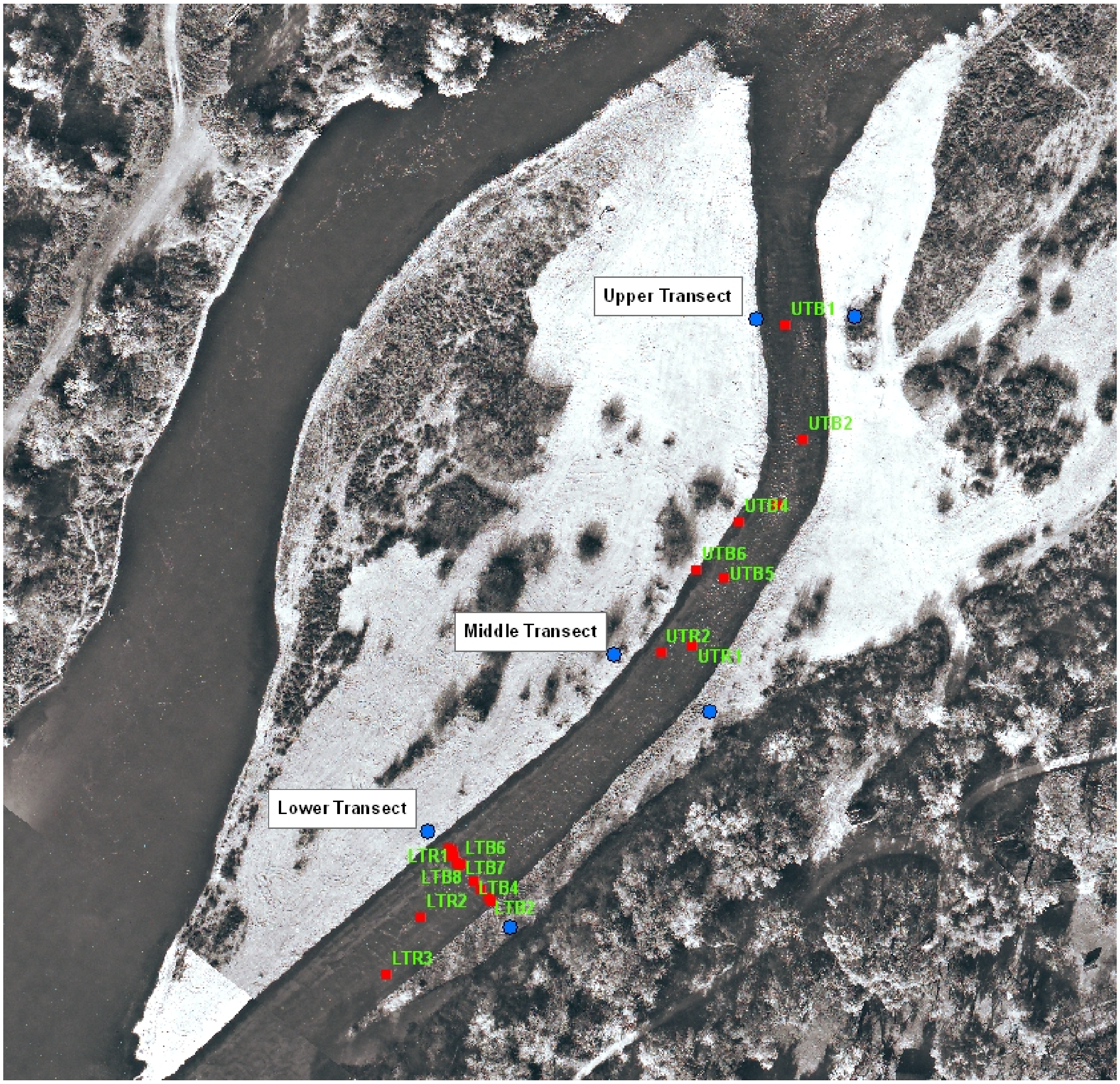


Figure 3.18: GIS map showing the results from the tracer rock test. Labels show the new position of Upper Transect (UT) rocks and Lower Transect rocks (LT). R is the red colored (smallest size), B represents the Blue (intermediate) rocks, and Y represents the Yellow (largest) rocks. Middle transect rocks did not move a significant distance from origin.

Chapter 4

2008 SAILOR BAR GRAVEL ADDITION RESULTS

4.1 Before Gravel Addition Grain Size

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 4.1 shows the location of the downstream pebble counts. Figure 4.2 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. Appendix F shows pebble count data.

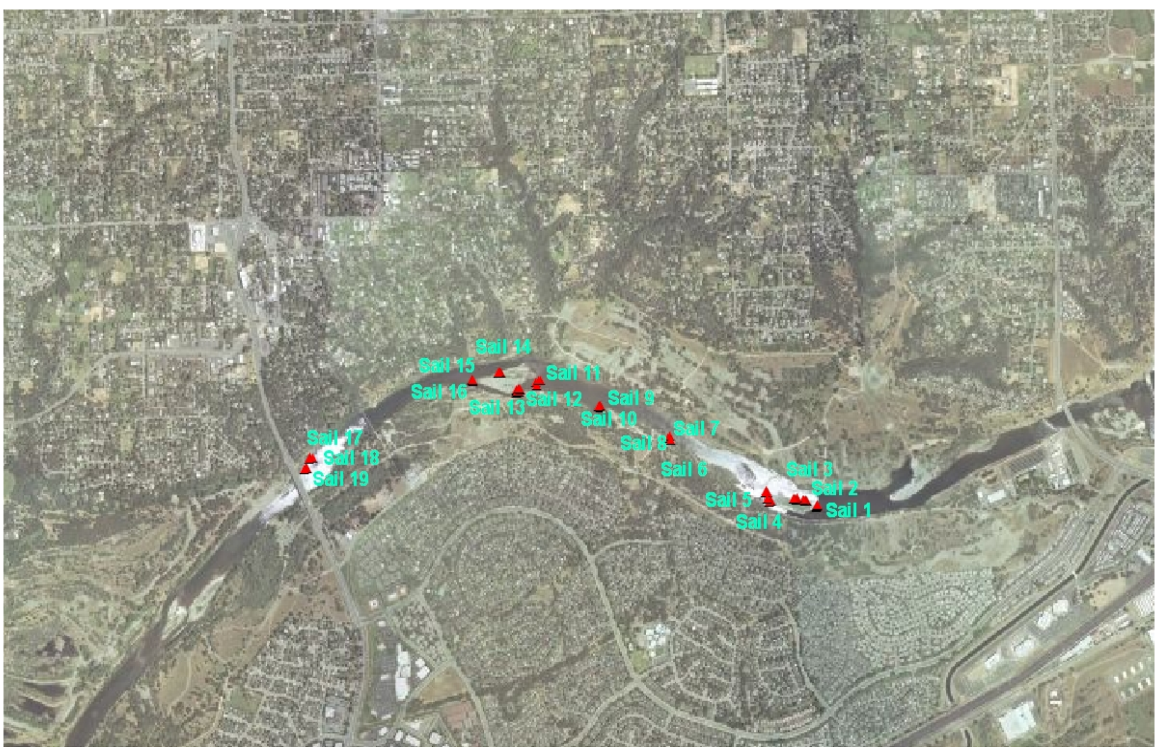


Figure 4.1: Map showing the downstream pebble count locations with red triangles. Pebble counts were conducted from the 2008 gravel addition downstream to the Sunrise bridge.

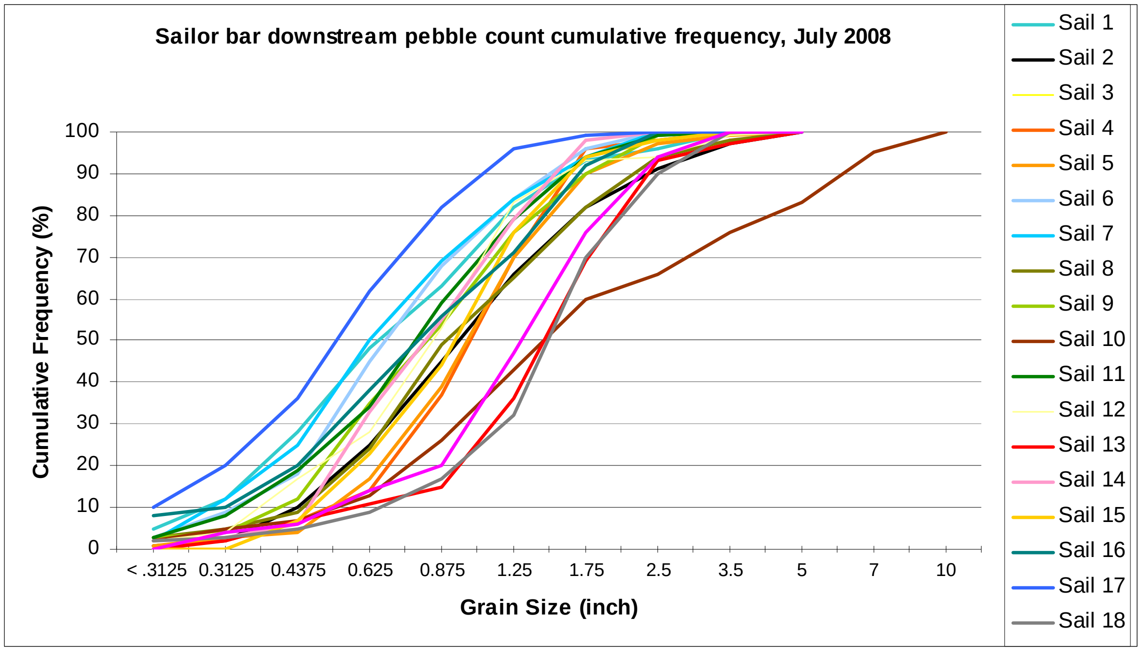


Figure 4.2: Graph showing the cumulative frequency of each pebble count from the downstream pebble counts. Pebble counts were conducted in the summer of 2008 prior to restoration work. Transects are listed upstream to downstream.

.

4.2 Before Gravel Addition Water Quality

A total of 8 mini piezometers were installed before the gravel addition. Figure 4.3 shows the location of the mini piezometers before gravel addition. The before restoration water quality data is shown in Table 4.1. Mean dissolved oxygen measurements before the gravel addition (Figure 4.4) 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.

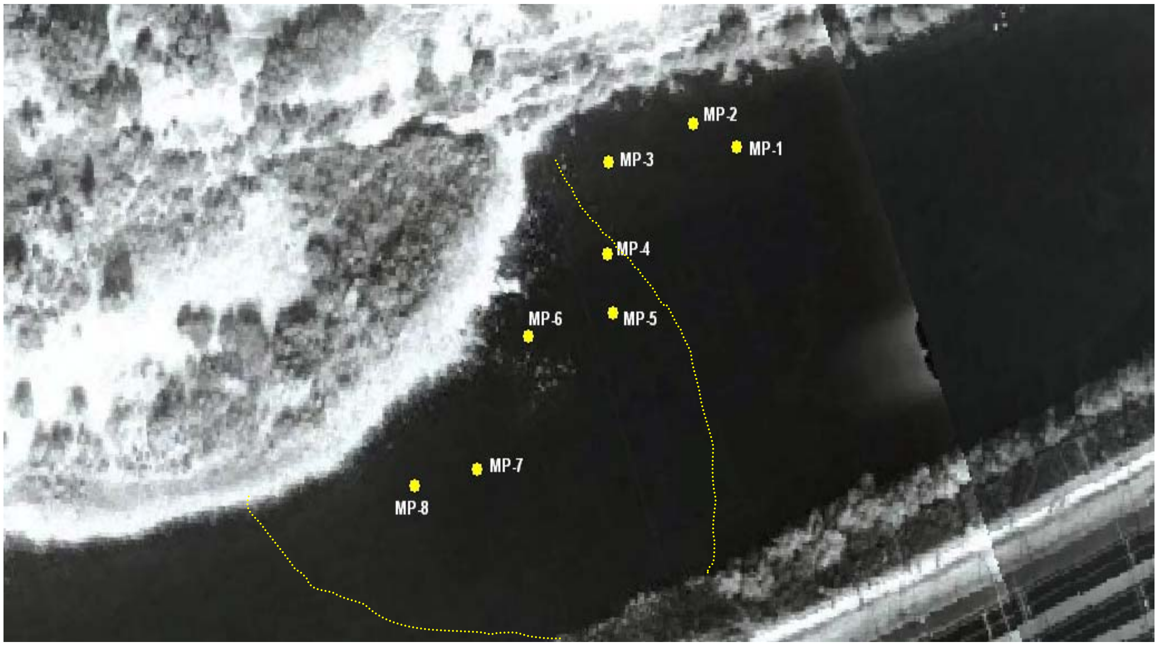


Figure 4.3: Before gravel addition map showing the gravel addition area outlined in yellow. Points are mini piezometer locations used to sample pre restoration and control hyporheic water quality.

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 4.1: Before gravel addition mini piezometer data September 2008.

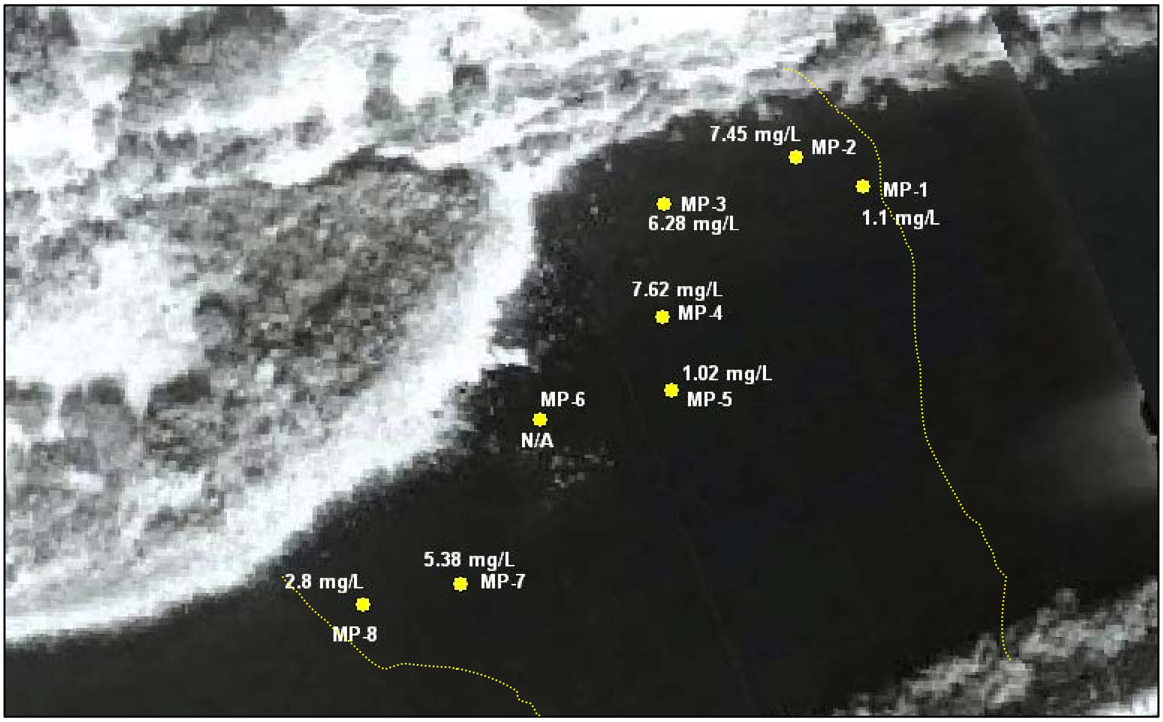


Figure 4.4: Before gravel addition map of the study area showing dissolved oxygen readings, September 2008.

4.3 Before Gravel Addition Hyporheic Pressure Head

Upwelling and downwelling measurements made before the gravel addition all showed downwelling conditions. Figure 4.5 shows the upwelling/downwelling map for the pre gravel addition area.

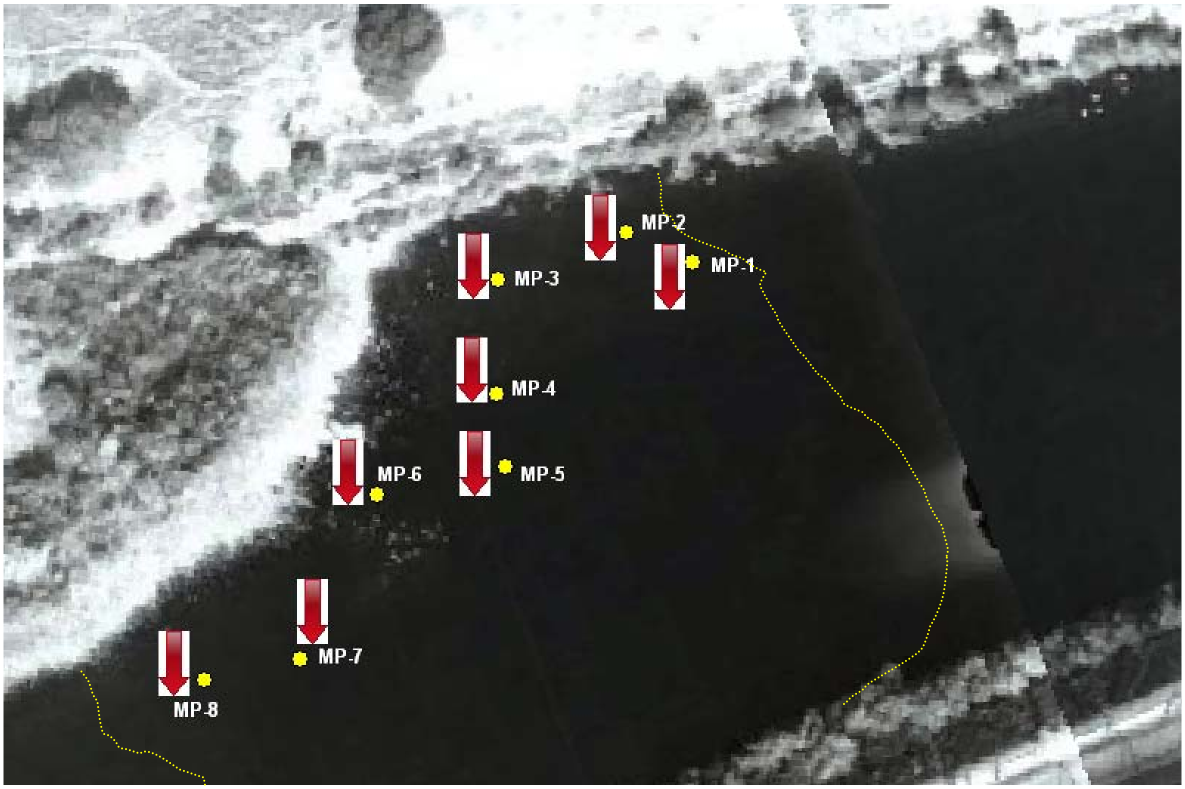


Figure 4.5: Before gravel addition upwelling/downwelling measurements. The red arrows pointing downward indicate downwelling.

4.4 Before Gravel Addition Water Depth/Velocity

Table 4.2 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 4.2: Before gravel addition depth and velocity data for the mini piezometers September 2008.

4.5 After Gravel Addition Grain Size

9 Pebble counts were conducted in June 2009 after the gravel addition was completed. Figure 4.6 shows a map of pebble count locations. Figure 4.7 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 G shows the data from the pebble counts.

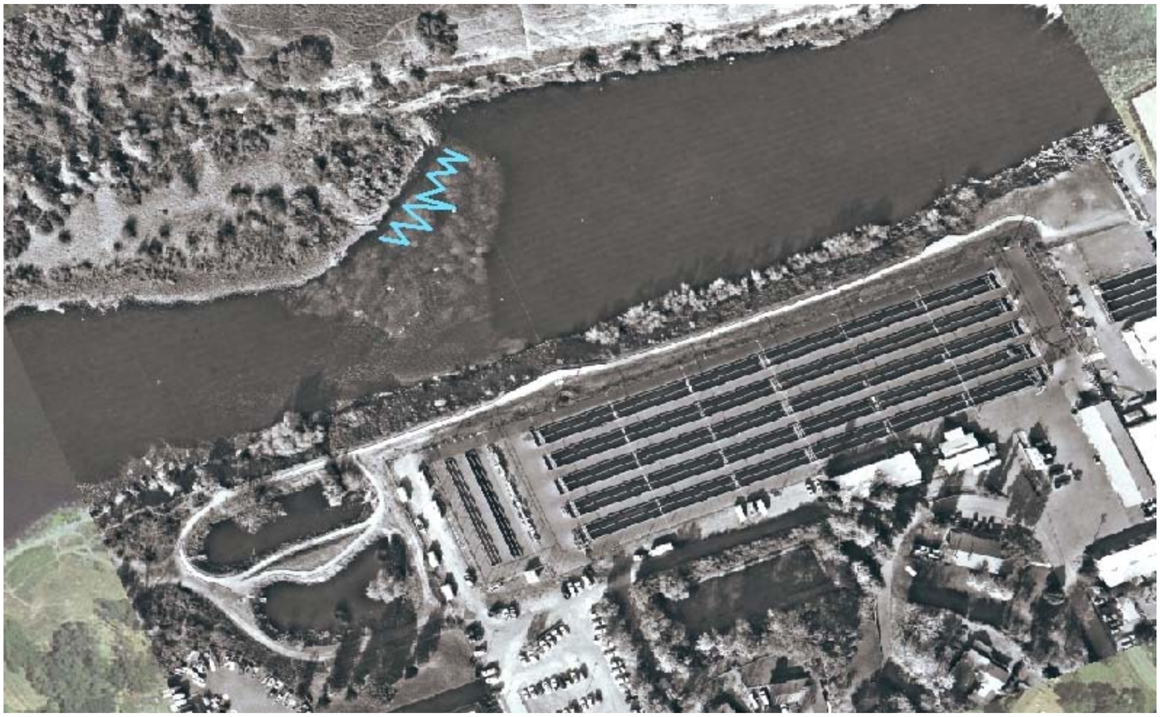


Figure 4.6: After gravel addition map of the pebble counts conducted in June 2009

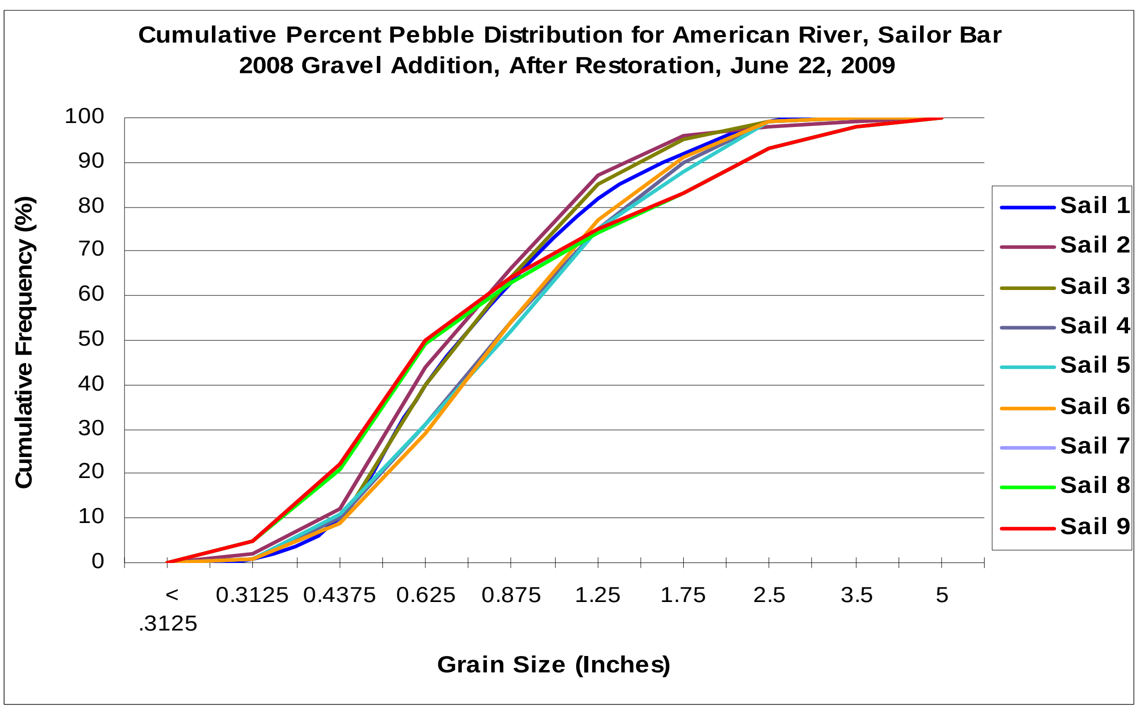


Figure 4.7: Graph showing the cumulative frequency of each pebble count after gravel addition, June 2009.

4.6 After Gravel Addition Water Quality

15 mini piezometers were installed in December 2008 after the gravel addition. Figure 4.8 shows the location of the mini piezometers after the gravel was added**.** Table 4.3 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 H 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.

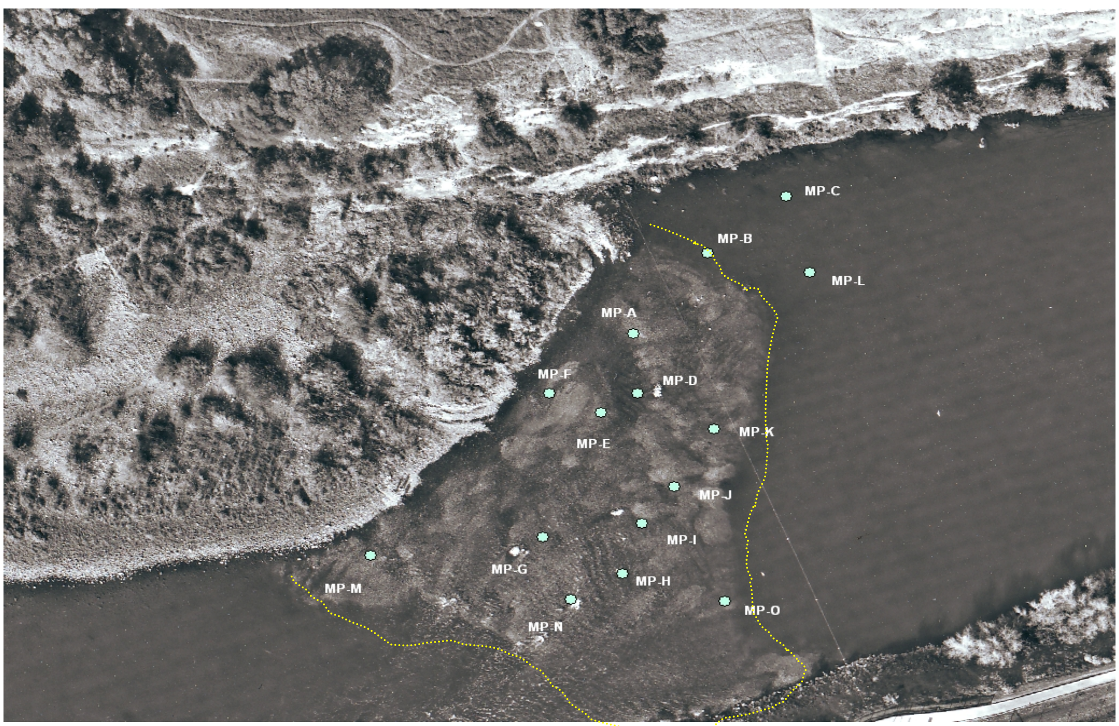


Figure 4.8: After gravel addition map showing the gravel addition area. Points indicate mini piezometer locations. MP C and MP L are upstream of the gravel to provide control measurements.

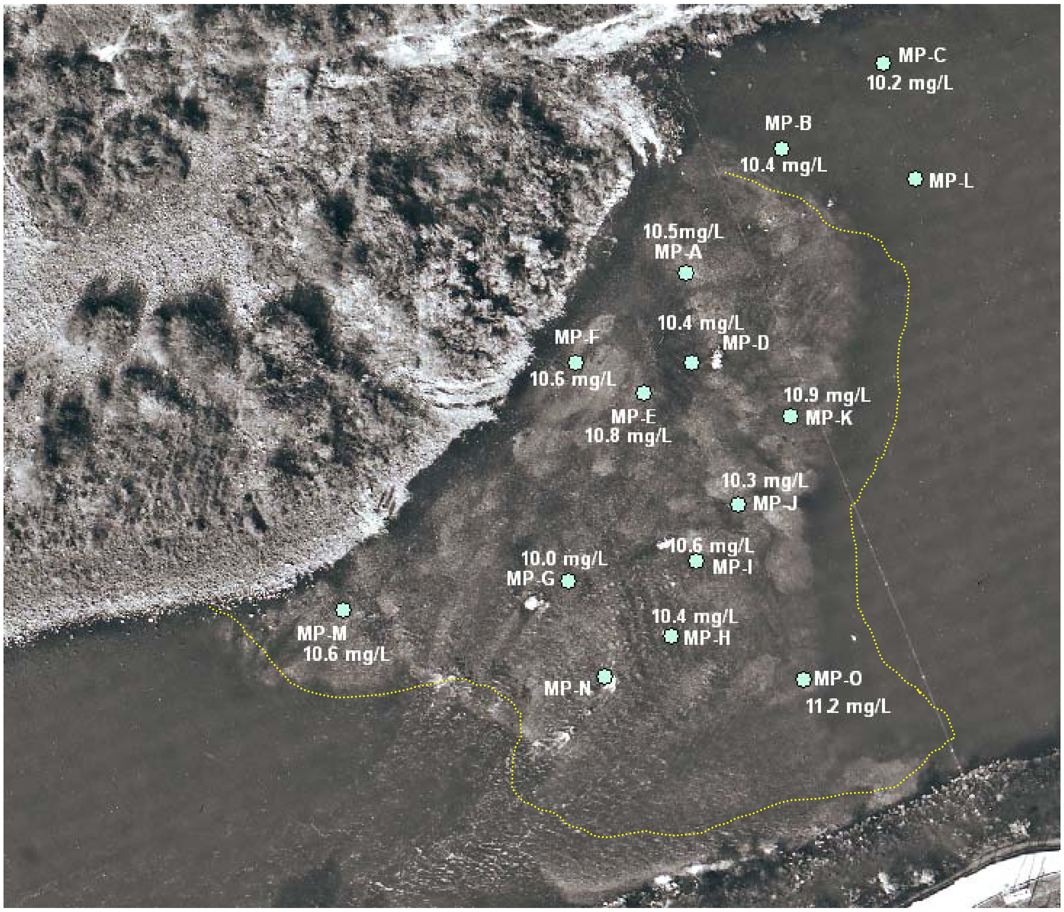


Figure 4.9: After gravel addition map of the study area dissolved oxygen readings February 2009.

Piezometer ID	**D.O. (mg/L)**	**pH**	**E.C. (µS/cm)**	**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 4.3: 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 4.9) 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.

4.7 After Gravel Addition Hyporheic Pressure Head

Figure 4.10 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 4.4 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 4.4: After gravel addition vertical gradient data from February 2009. Negative values indicate upwelling, positive values indicate downwelling.

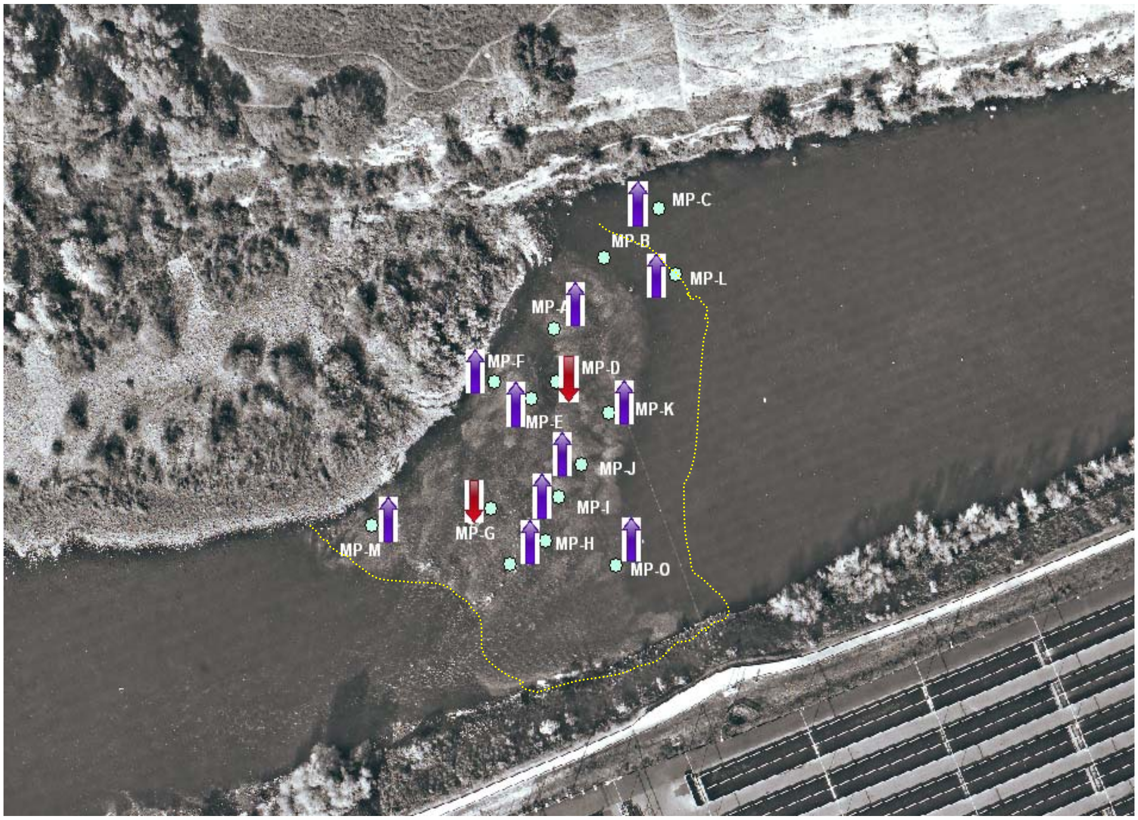


Figure 4.10: After gravel addition map showing upwelling/downwelling measurements. The red arrows pointing downward indicate downwelling, the purple arrow pointing upward indicate upwelling conditions February 2009.

4.8 After Gravel Addition Water Depth/Velocity

Velocity and depth were measured in February 2009, after the gravel was added. Table 4.5 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 4.11 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 4.5: After gravel addition depth and velocity data. Several piezometers were omitted due to insufficient water depth for measurement February 2009. River flow was 780cfs.

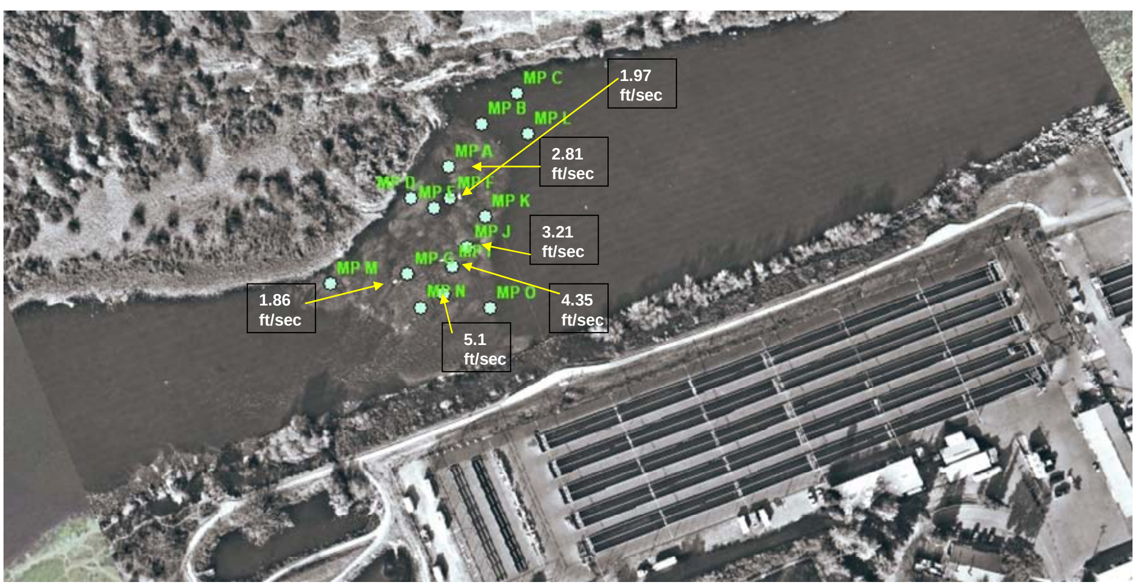


Figure 4.11: After gravel addition map showing average surface water velocity measurements in February 2009. Stream flow was 780 cfs. Mini piezometers without velocity values were either too shallow or less than 1 foot per second.

4.9 After Gravel Addition Gravel Mobility

Figure 4.12 shows the tracer rock transects (Figure 4.12 green lines) 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.

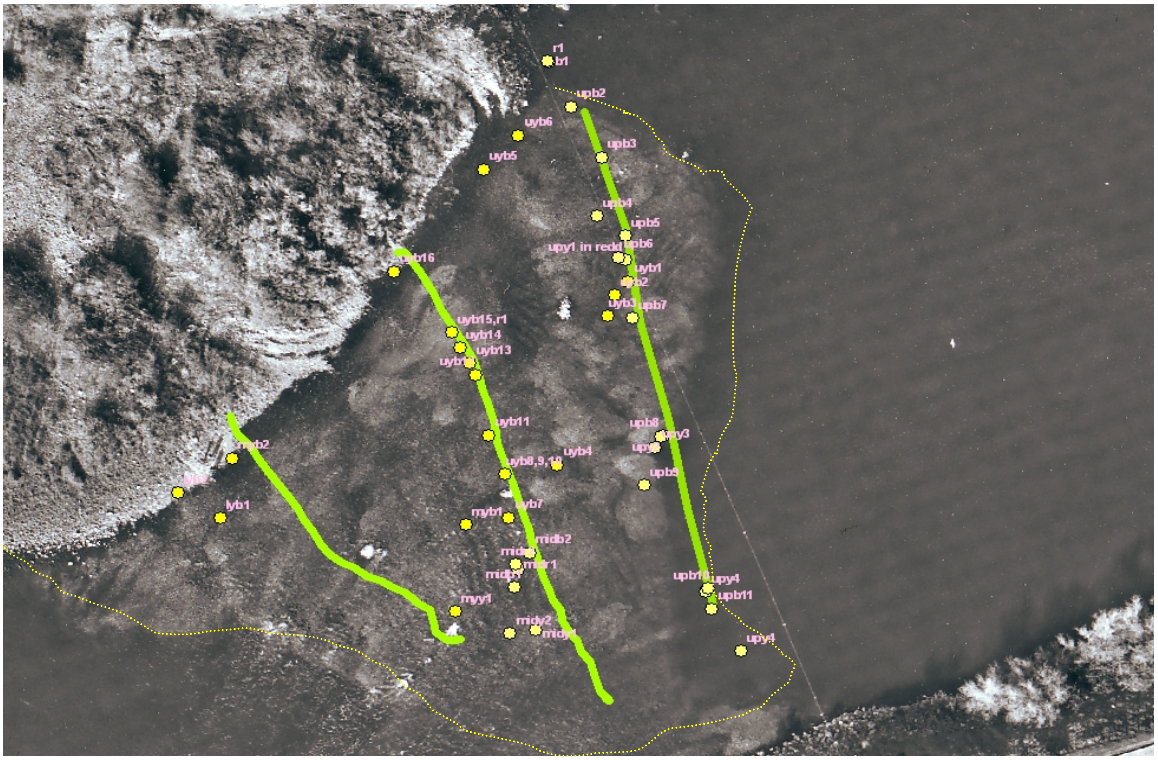


Figure 4.12: After gravel addition map showing the tracer rock transects from June 2009. Yellow points indicate rocks located.

4.10 After Gravel Addition Inter Gravel Velocity

Four salt water tracer tests were conducted at Sailor Bar in March 2010.The location of these tracer tests is shown on Figure 4.13. Figures 4.14-4.17 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. Appendix I shows the data from the tracer tests.

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.

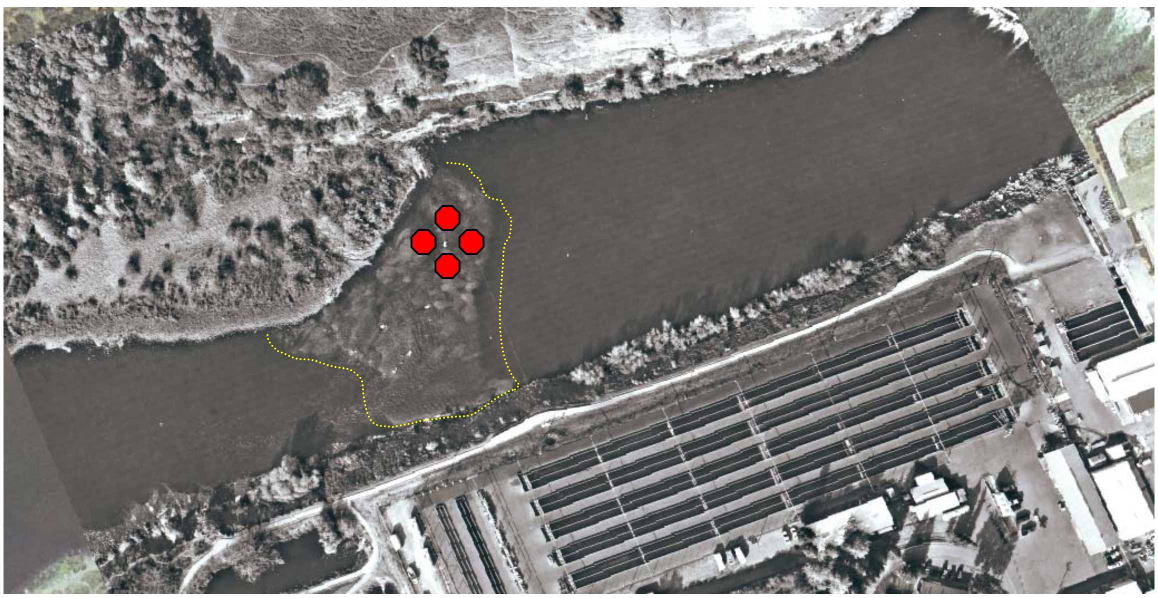


Figure 4.13: After gravel addition map of the salt water tracer tests. Tracer tests were conducted in March 2010.

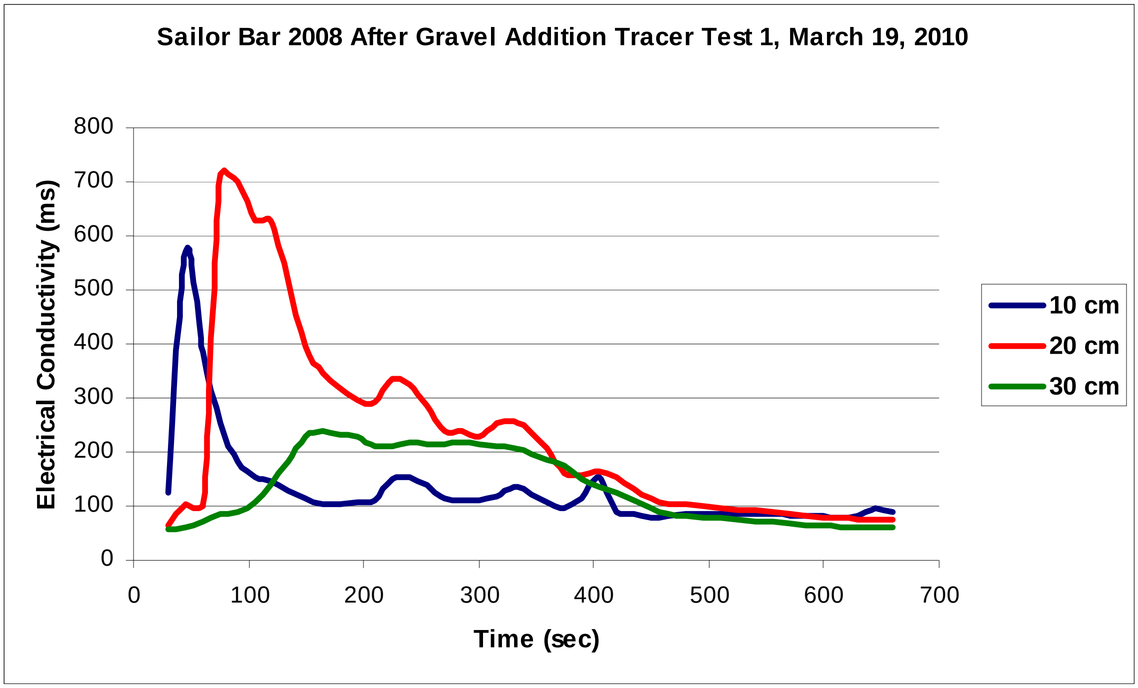


Figure 4.14: Electrical conductivity versus time graph of a salt water tracer test 1 from Sailor Bar, March 2010.

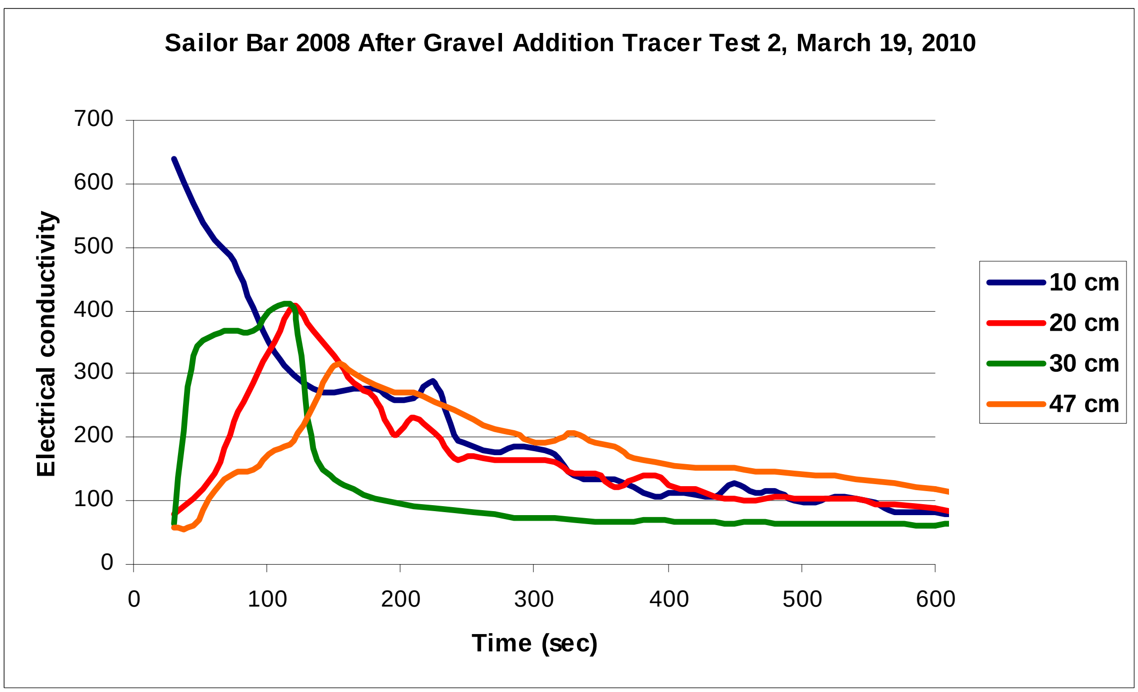


Figure 4.15: Electrical conductivity versus time graph of salt water tracer test 2 from Sailor Bar, March 2010.

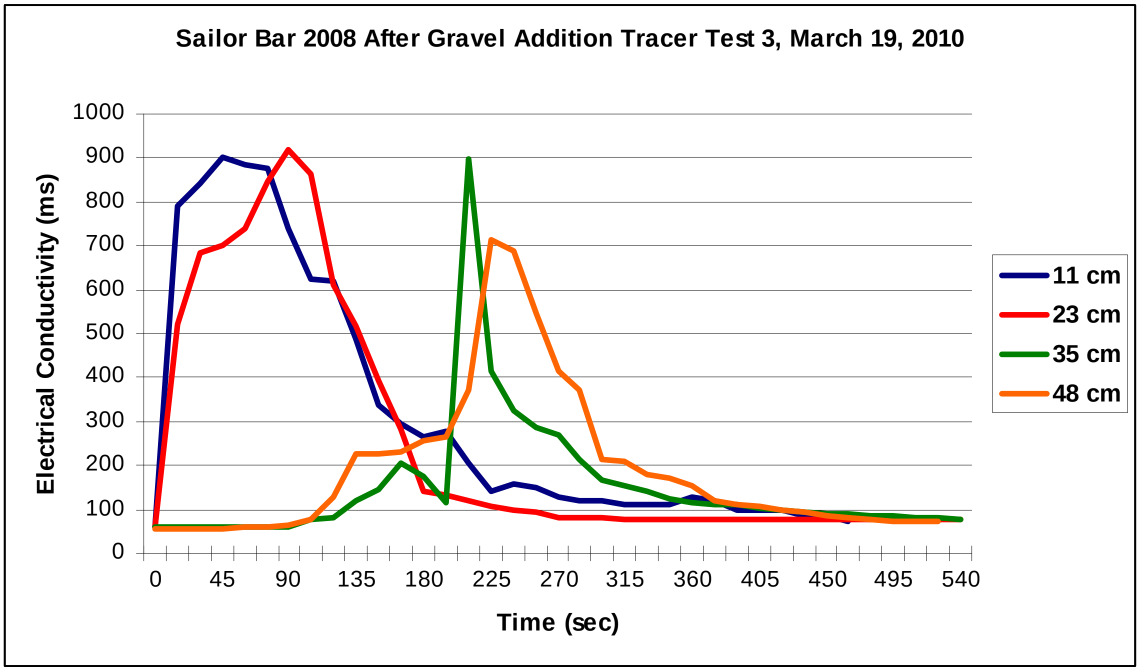


Figure 4.16: Electrical conductivity versus time graph of salt water tracer test 3 from Sailor Bar, March 2010.

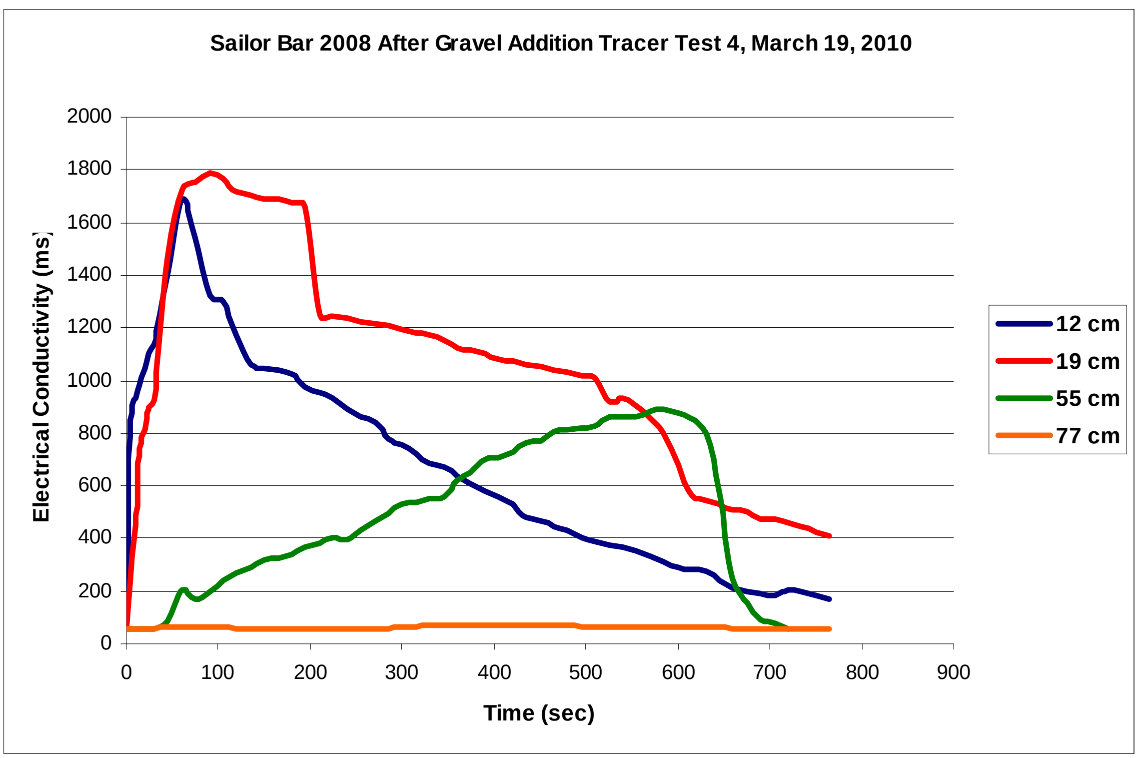


Figure 4.17: Electrical conductivity versus time graph of salt water tracer test 4 from Sailor Bar, March 2010.

Chapter 5

2009 SAILOR BAR GRAVEL ADDITION RESULTS, WITH ADDITIONAL 2008 SAILOR BAR RESULTS

5.1 Before Gravel Addition Grain Size

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 5.1 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 5.2 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.

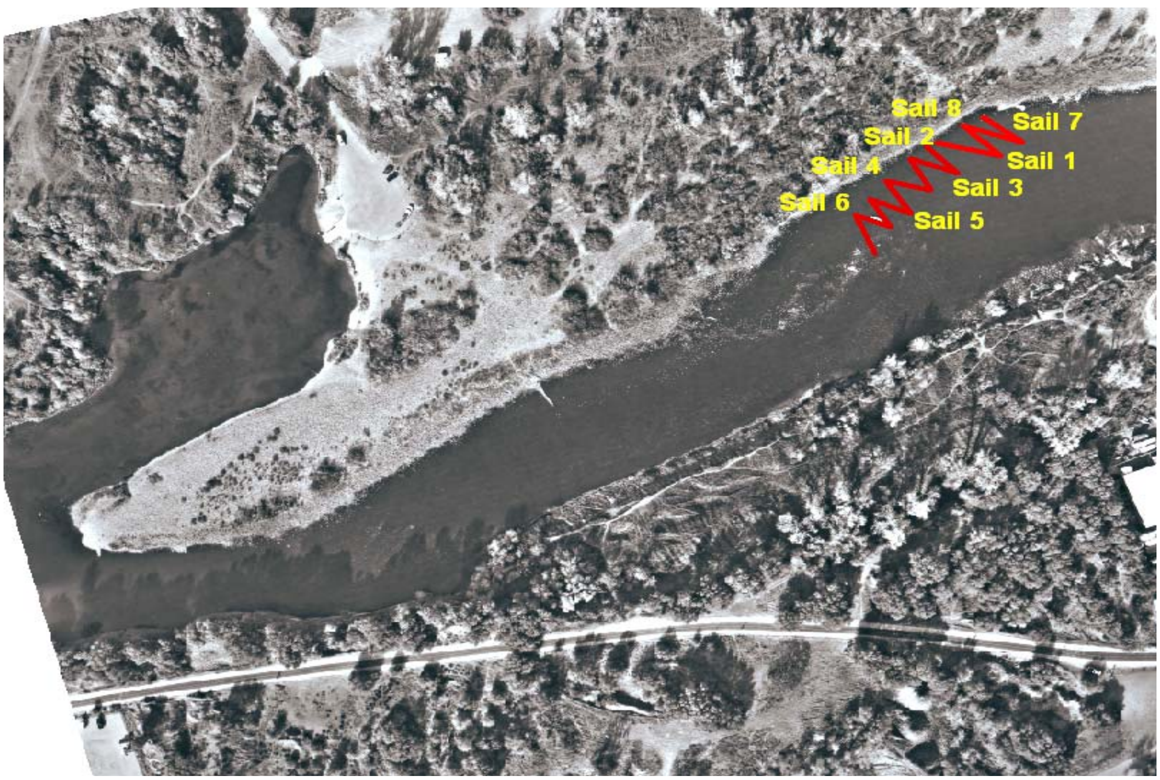


Figure 5.1: Map showing before gravel addition pebble count locations, August 2009.

Figure 5.3 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 5.2 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. Appendix J shows the before gravel addition pebble count data.

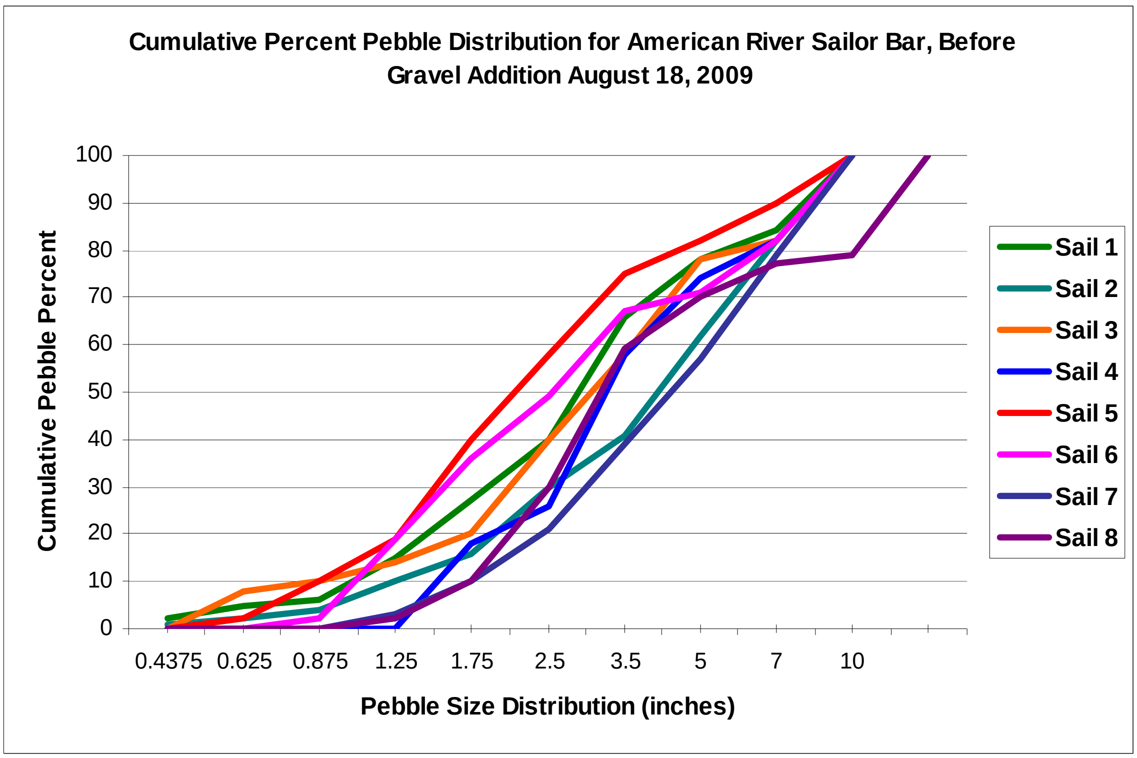


Figure 5.2: Graph showing the cumulative frequency of each pebble count, before gravel was added, August 2009.

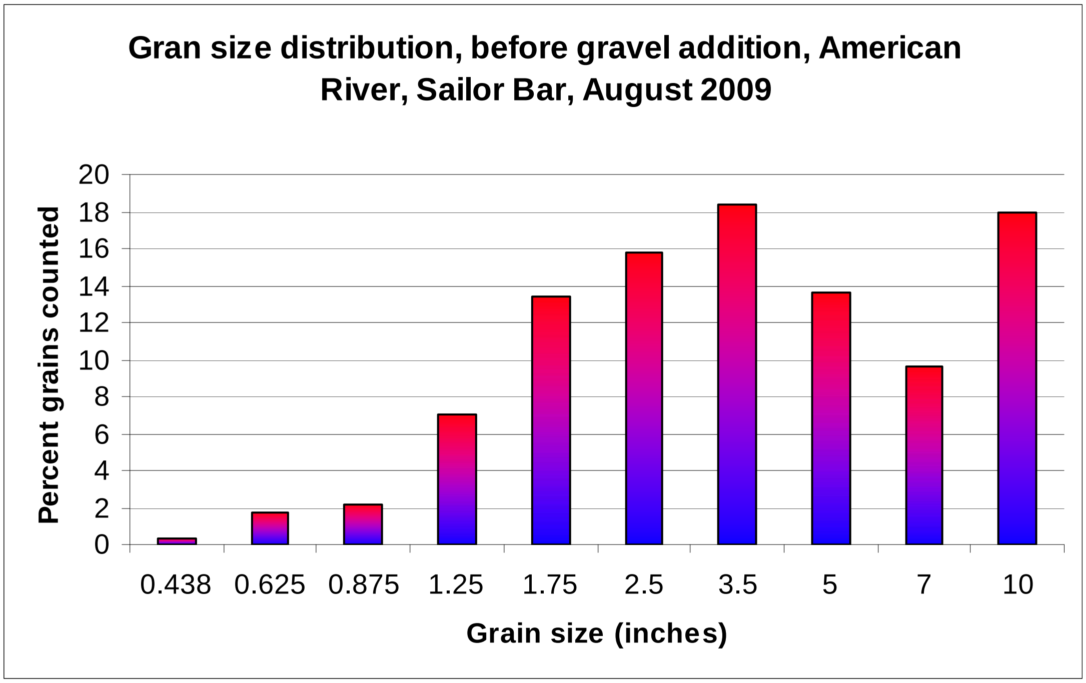


Figure 5.3: Graph showing the percent of the total grains counted from all pebble counts before gravel addition, August 2009.

5.2 Before Gravel Addition Water Quality

A total of 12 mini piezometers were installed before the gravel addition in August 2009. Figure 5.4 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 5.1 shows the before gravel addition water quality data.

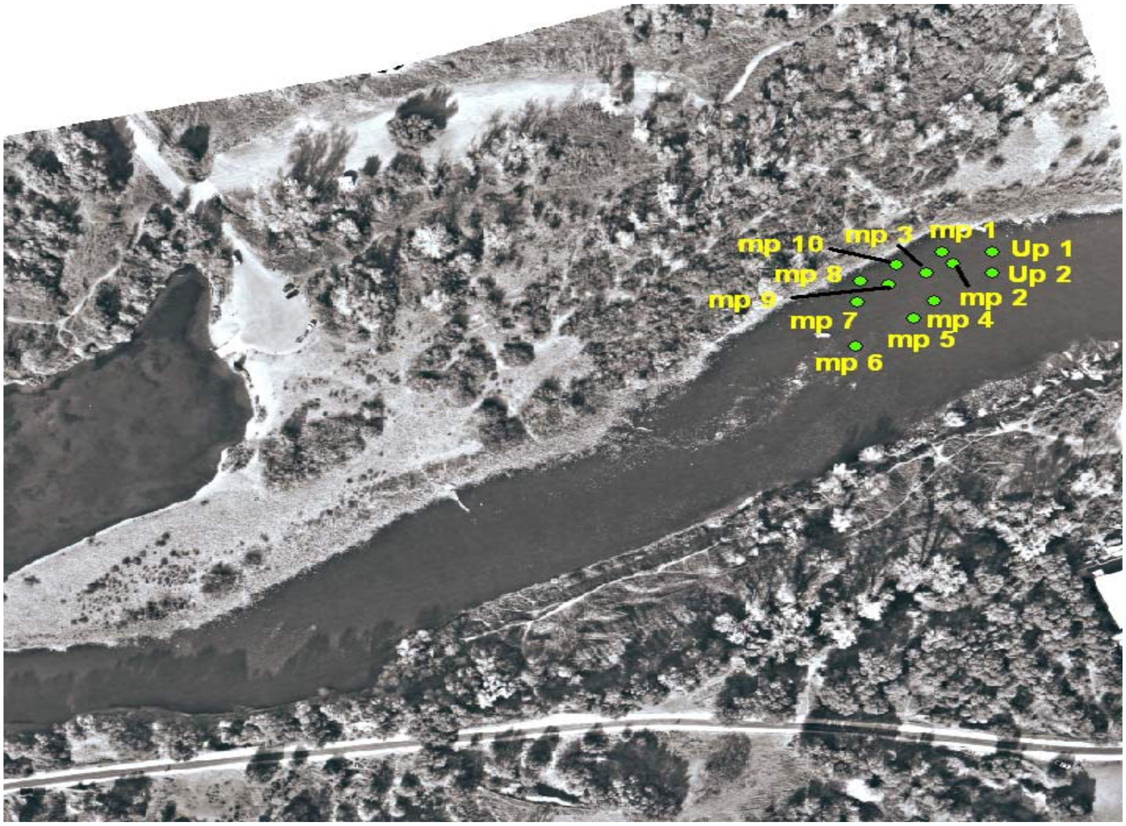


Figure 5.4: Map of the mini piezometer locations before gravel addition, September 2009.

D.O. values from Table 5.1 shows a mean D.O. of 3.5 mg/L for the study area. The control D.O. mean was 3.8 mg/L and the mean D.O. of the surface water samples was 7.7 mg/L. Figure 5.5 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 C°)	Temp (well C°)	EC (ms/cm)	pH	D.O. (mg/L)	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 5.1: Before gravel addition water quality data, September 2009.

The data from Table 5.1 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 5.6 shows a map with D.O. readings.

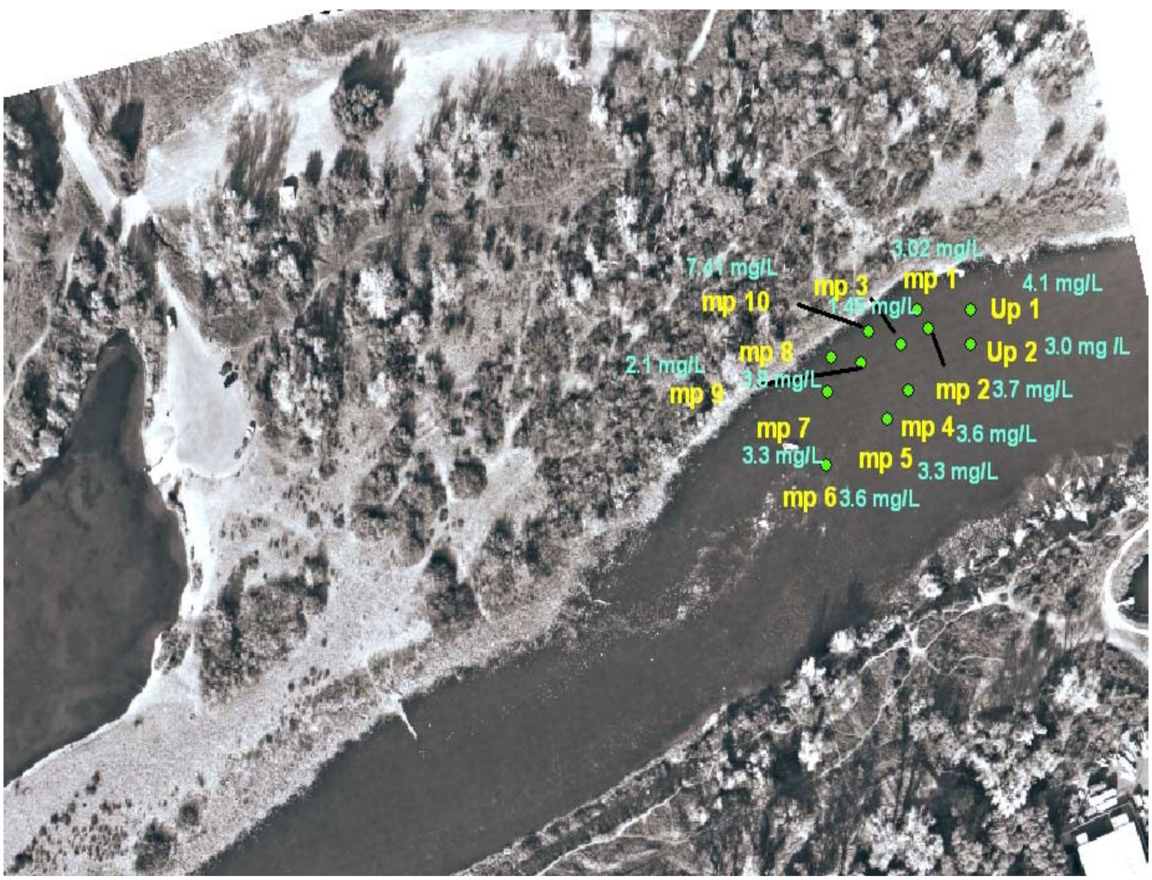


Figure 5.5: Map showing the distribution of the D.O. measurements before gravel addition, September 2009.

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 degree Celsius temperature increase from the river water temperature.

5.3 Before Gravel Addition Hyporheic Pressure Head

The pre gravel addition upwelling and downwelling measurements all showed downwelling conditions. Figure 5.6 shows a map of the before gravel addition upwelling and downwelling measurements.

Figure 5.6: Before gravel addition map showing the downwelling measurements, September 2009.

5.4 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 5.7 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 5.8 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.

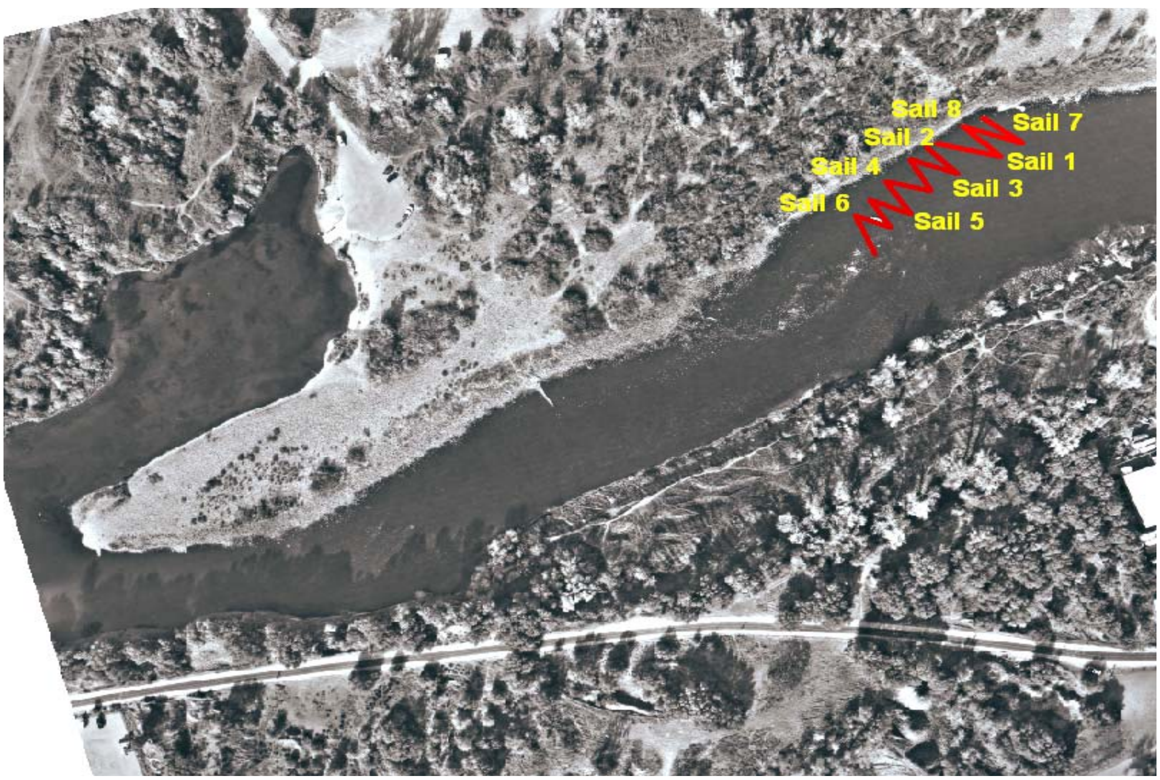


Figure 5.7: Map showing before gravel addition pebble count locations, August 2009.

Figure 5.9 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 5.9 shows that 10% of the grains counted after gravel addition were greater than 2 1/2 inches in diameter. Appendix K shows the after gravel addition pebble count data.

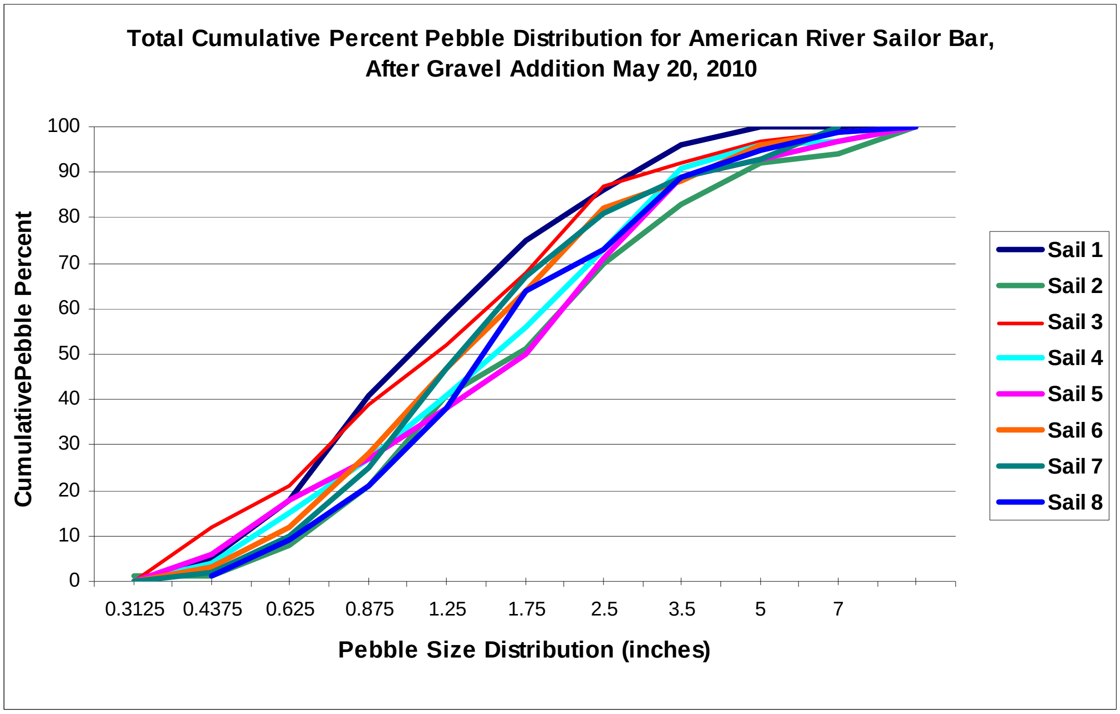


Figure 5.8: Graph showing the cumulative frequency of each pebble count, after gravel was added, May 2010.

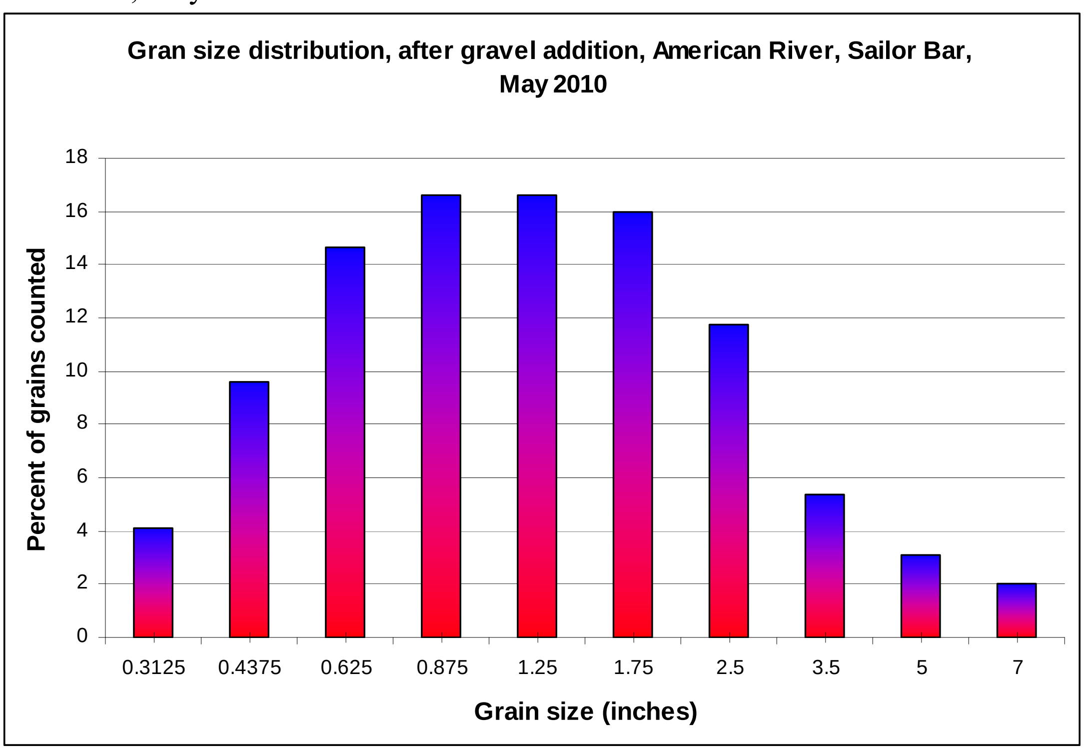


Figure 5.9: Graph showing the percent of the total grains counted from all pebble counts after gravel addition, May 2010.

5.5 After Gravel Addition Water Quality

Figure 5.10 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 5.2 shows the water quality data from November 2009. Table 5.3 shows the water quality data from January 2010.

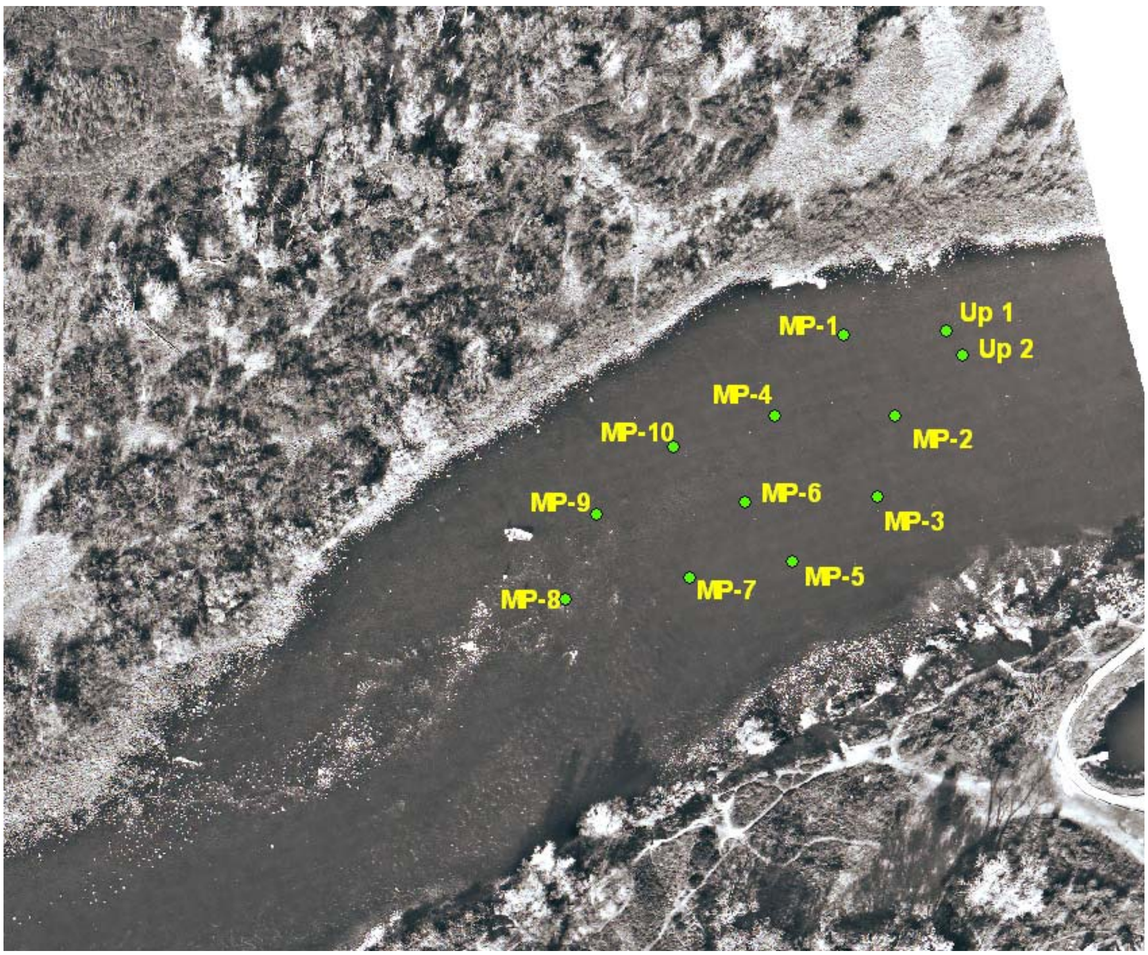


Figure 5.10: Map of the after gravel addition mini piezometer locations, installed September 2009.

Location	Temp (River C°)	Temp (well C°)	EC (ms/cm)	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 5.2: 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 C°)	Temp (well C°)	EC (ms/cm)	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 5.3: Water quality data for the 2009 gravel addition after gravel addition. Data was collected January 2010.

Parameters measured in January (Table 5.3) 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.

5.6 After Gravel Addition Hyporheic Pressure Head

Hyporheic pressure was measured after gravel addition in November 2009 and January 2010. Figure 5.11 shows the November 2009 measurements. Figure 5.12 shows the January 2010 measurements. Figures 5.11 and 5.12 show the majority of the mini piezometers having 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 5.4 shows the hyporheic gradient data.

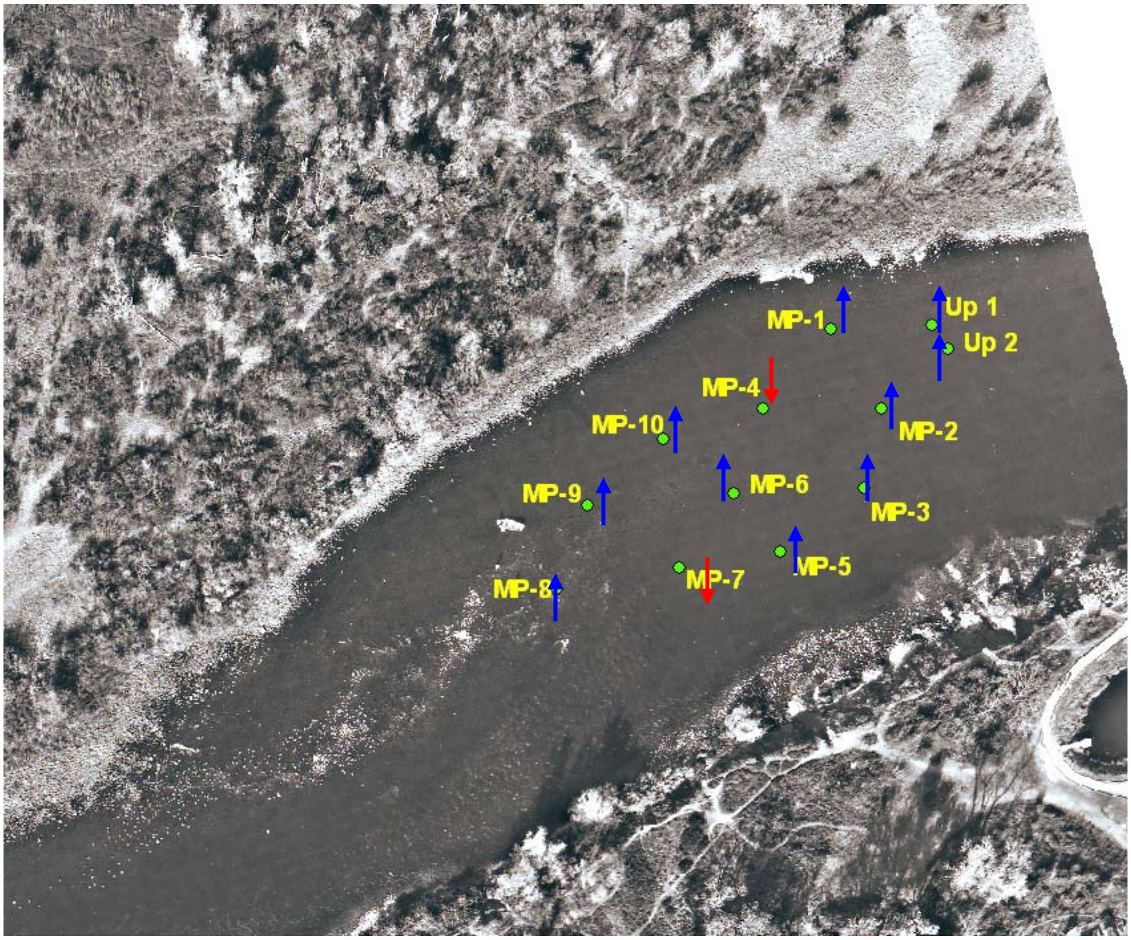


Figure 5.11: After gravel addition map showing the upwelling/downwelling conditions for the 2009 gravel addition. Data was collected November 2009.

.

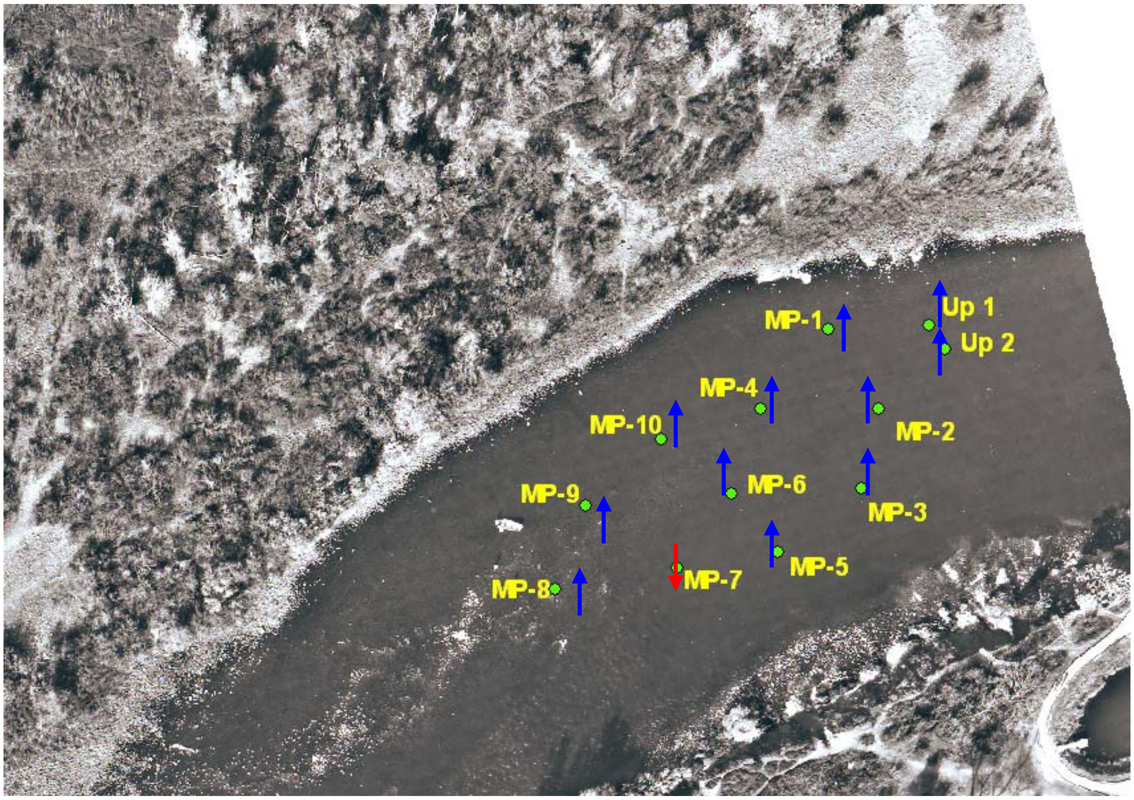


Figure 5.12: After gravel addition map showing the upwelling/downwelling conditions for the 2009 gravel addition. Data was collected January 2010.

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

5.7 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 5.5 shows the data recorded in November 2009. Table 5.6 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 5.5: 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 5.6: After gravel addition depth and velocity data. January 2010, river flow was1600cfs.

5.8 After Gravel Addition Inter Gravel Velocity

Five Salt water tracer tests were conducted in March 2010 and April 2010. Figure 5.13 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 5.14 and 5.14 show graphs of electrical conductivity versus time for Trace 1 and Trace 2 . Appendix L shows the data collected and additional E.C. versus time graphs.

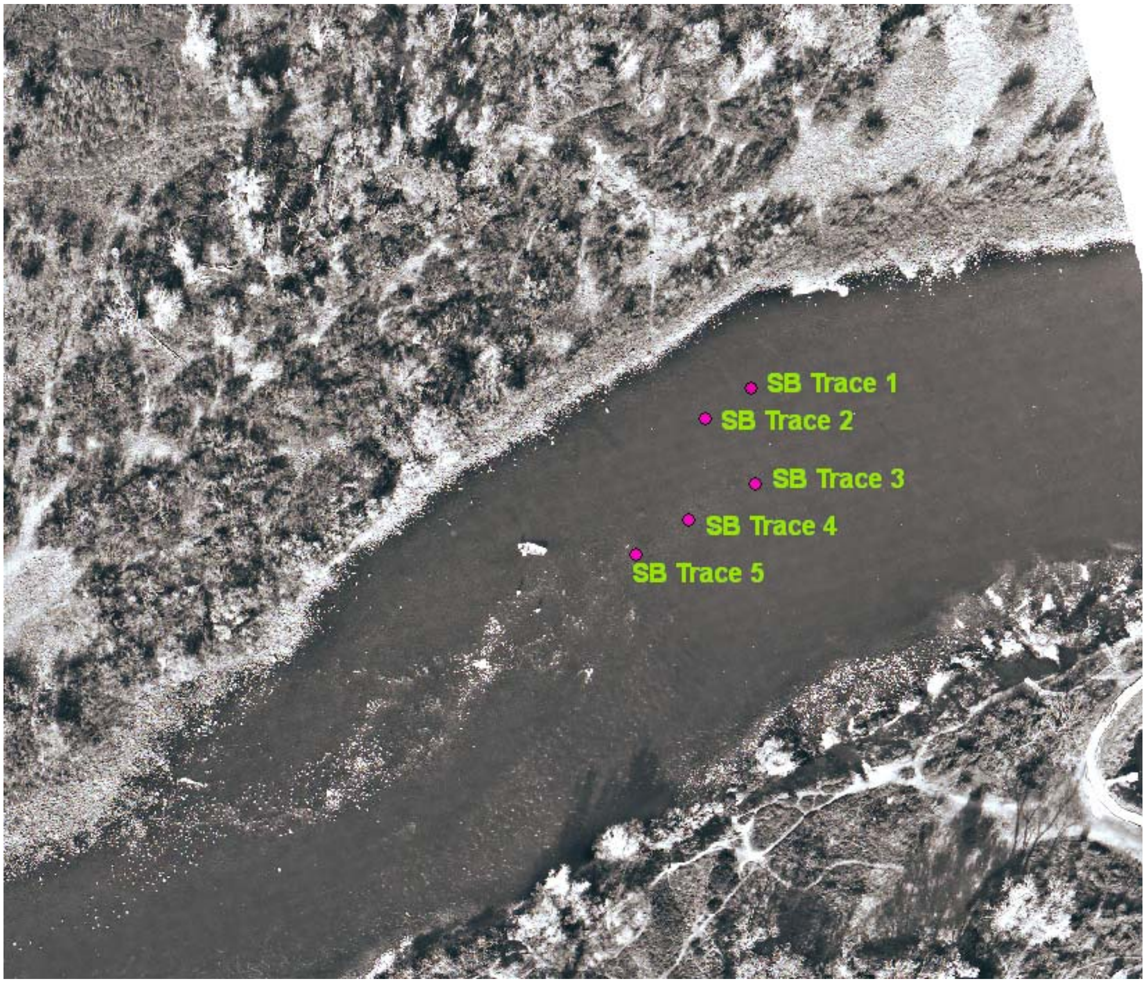


Figure 5.13: After gravel addition map of inter gravel velocity locations. SB Trace 1 and SB Trace 2 were conducted March 2010. SB Trace 3-5 were conducted April 2010.

Figures 5.14 and 5.15 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. Trace 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. Trace 5 showed a monitoring well 80 cm from the injection well with elevated electrical conductivity levels.

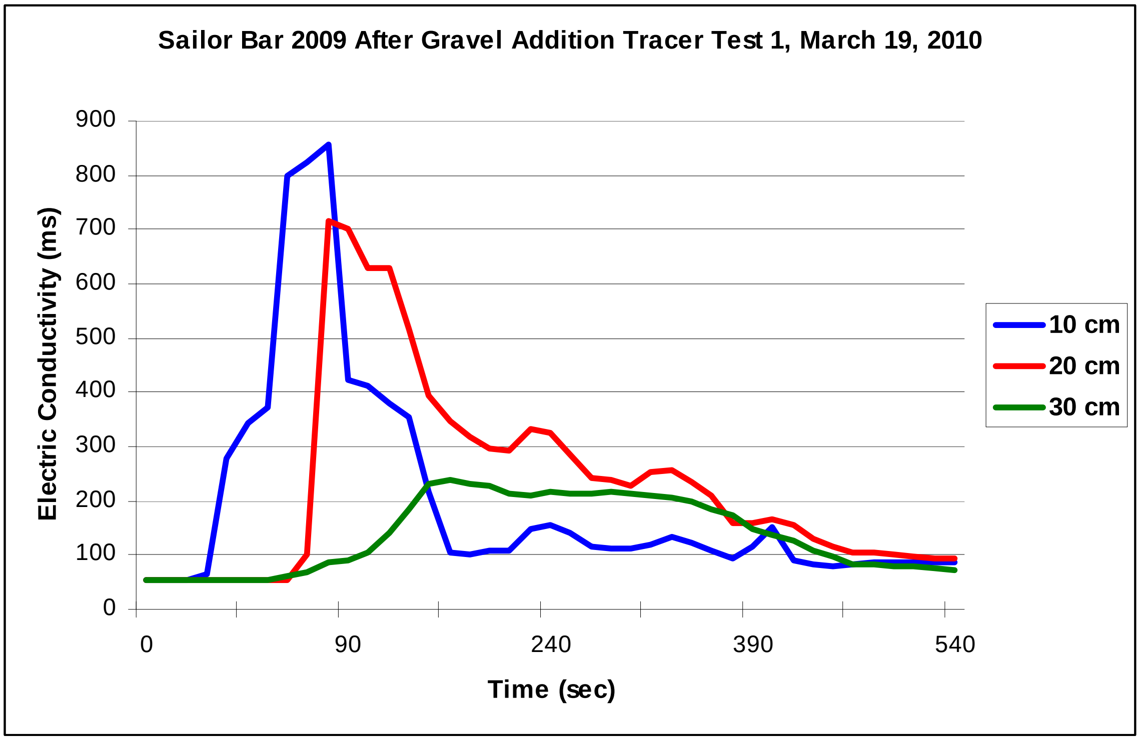


Figure 5.14: After gravel addition graph of electrical conductivity and time, March 2010.

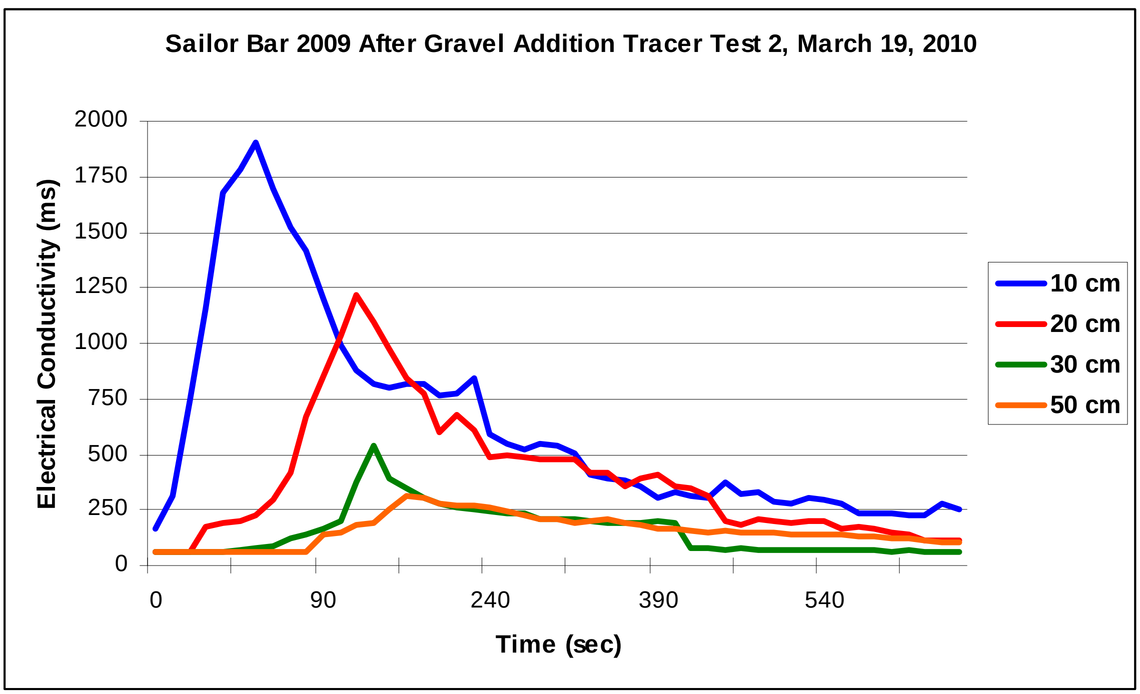


Figure 5.15: After gravel addition graph of electrical conductivity and time, March 2010.

5.9 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 10 meters upstream of the gravel addition to provide control data in October 2009. Figure 5.16 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 5.17 and 5.18 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. None of the temperature loggers showed detectable changes in temperature. Appendix N shows the temperature data uploaded in January 2010.

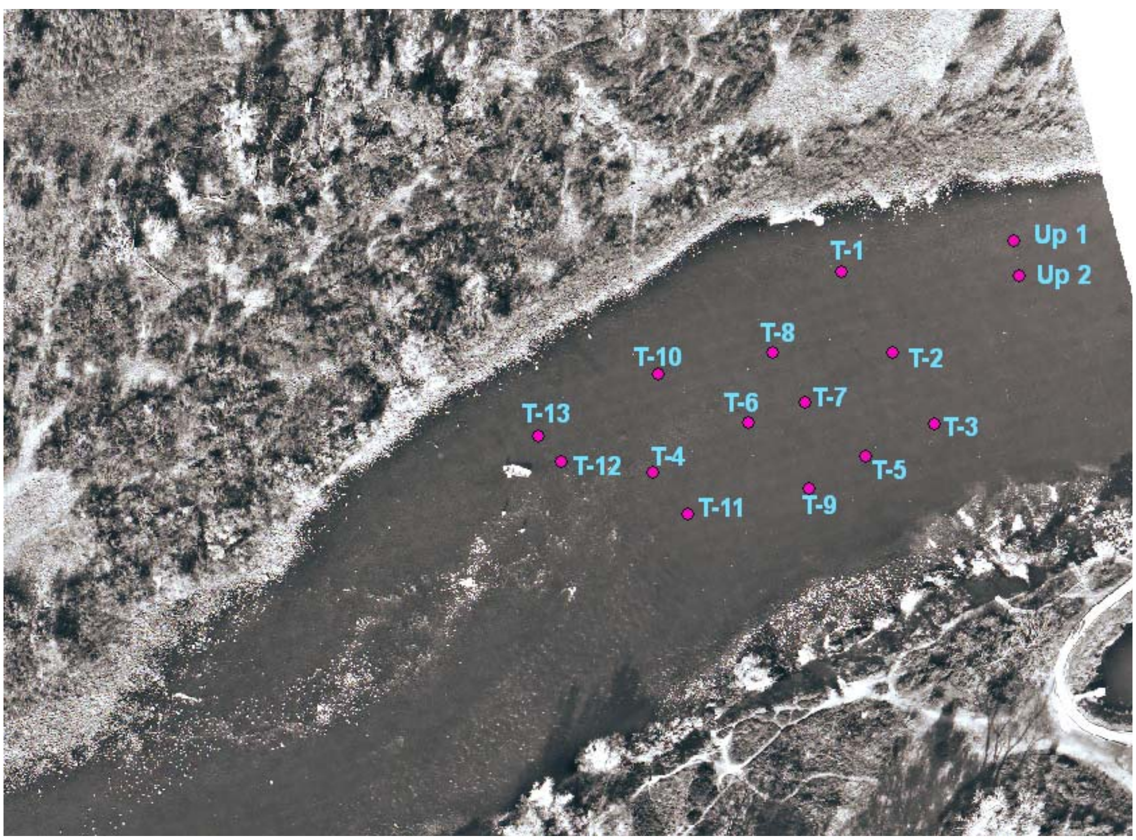


Figure 5.16: After gravel addition map of the temperature logger locations. Loggers were deployed in October 2009.

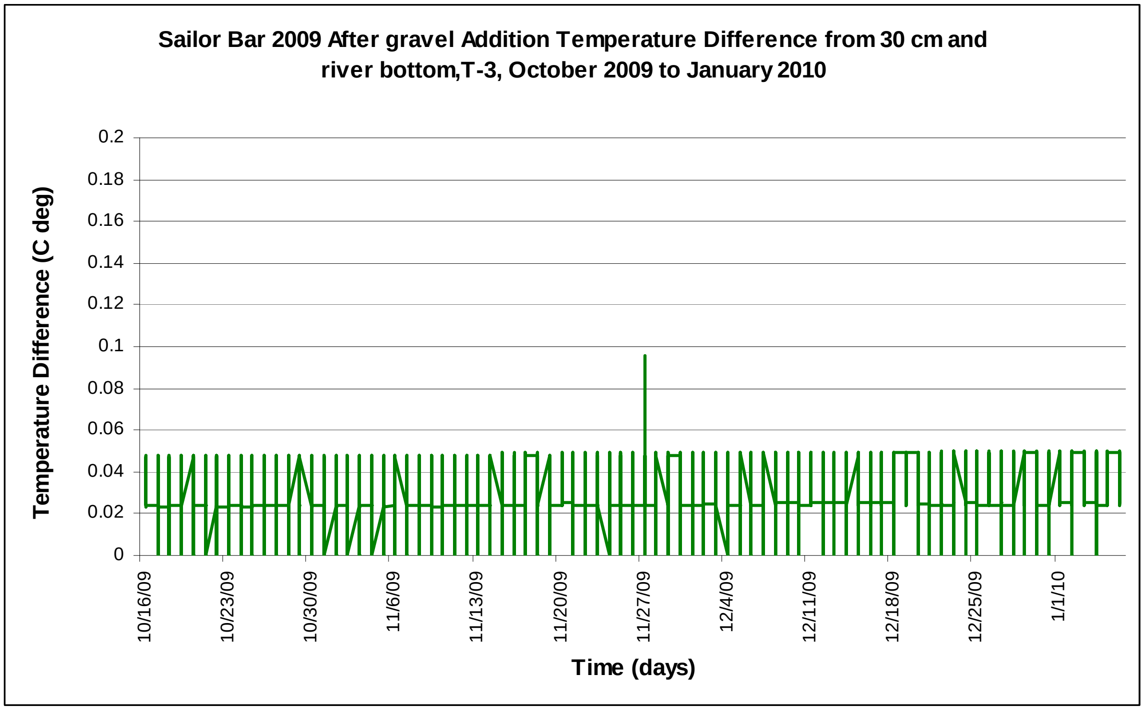


Figure 5.17: After gravel addition graph showing temperature differences between the 30 cm depth and the river bottom. Loggers were deployed in October 2009, uploaded in January 2010.

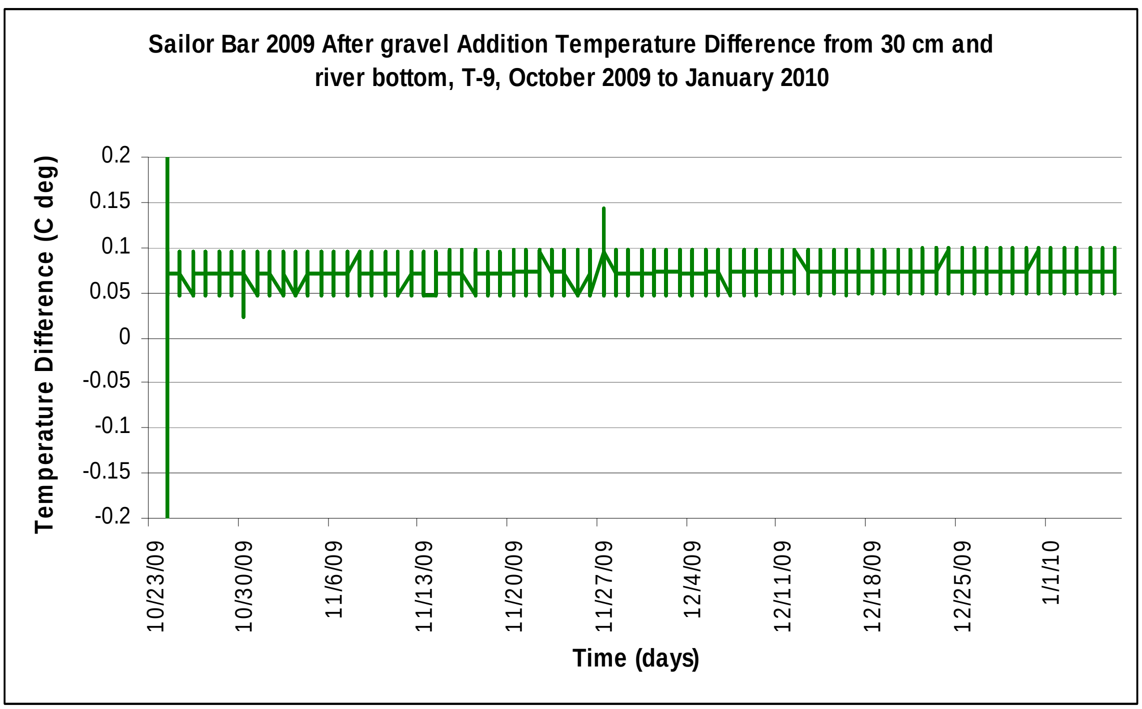


Figure 5.18: After gravel addition graph showing temperature differences between the 30 cm depth and the river bottom. Loggers were deployed in October 2009, uploaded in January 2010.

5.10 2008 Gravel Addition Gravel Mobility

Figure 5.19 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. Twenty percent of the yellow rocks did not move or were located within 5 meters of emplacement. 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 5.19 shows that only a few of the tracer rocks located in June 2010 had moved from the previous June. Latest measurements showed 26 out of 120 yellow rocks were located, 4 out of 120 blue rocks, and 2 out of 120 red rocks were located.

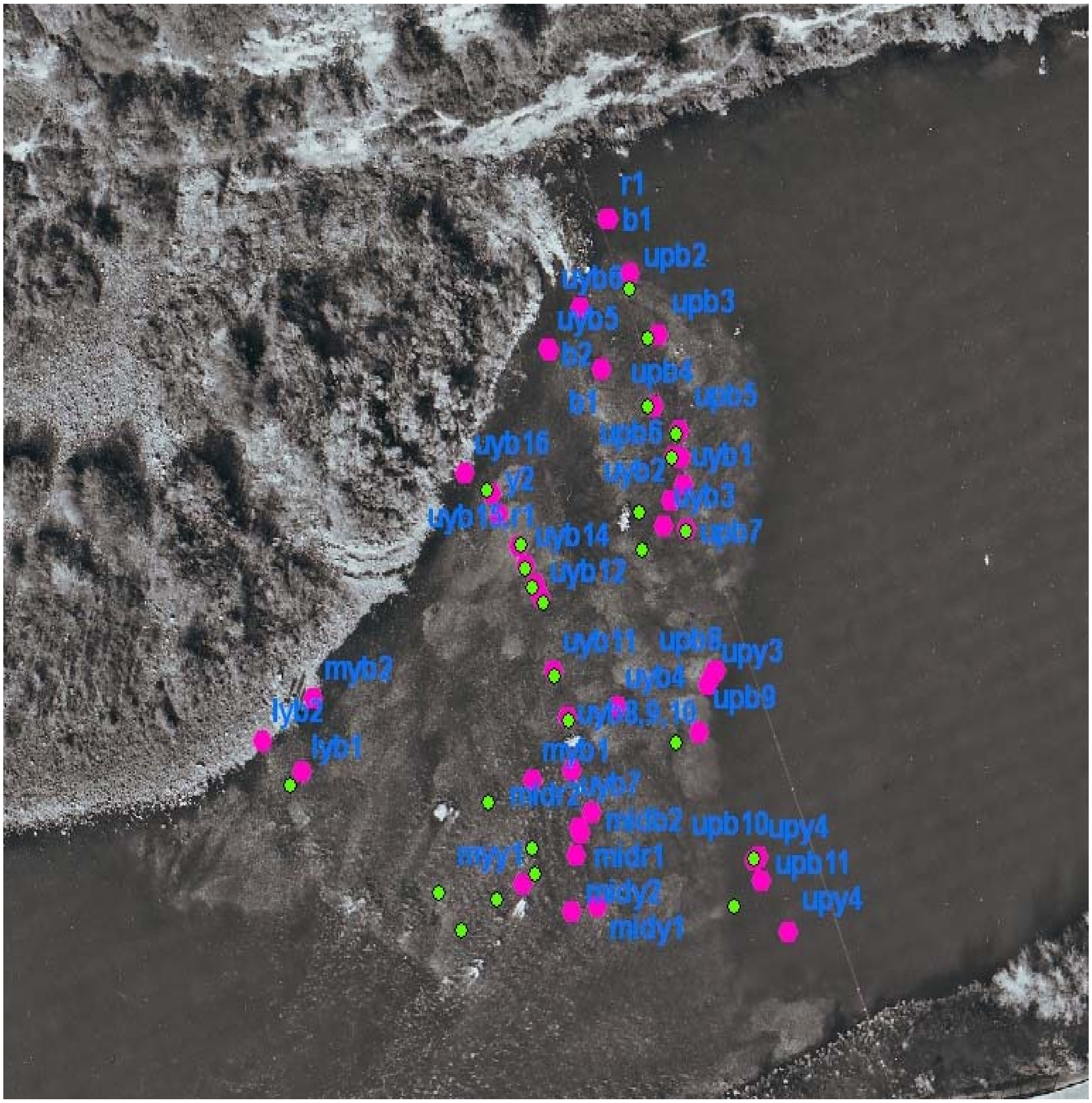


Figure 5.19: After gravel addition map showing the tracer rock transects from June 2009 in pink. Green points indicate tracer rocks identified in June 2010.

5.11 2008 Gravel Addition Water Quality

Figure 5.20 shows a map of the mini piezometer locations from the 2008 gravel addition. Mini piezometers were sampled in November 2009 and January 2010. Tables 5.7 and 5.8 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.

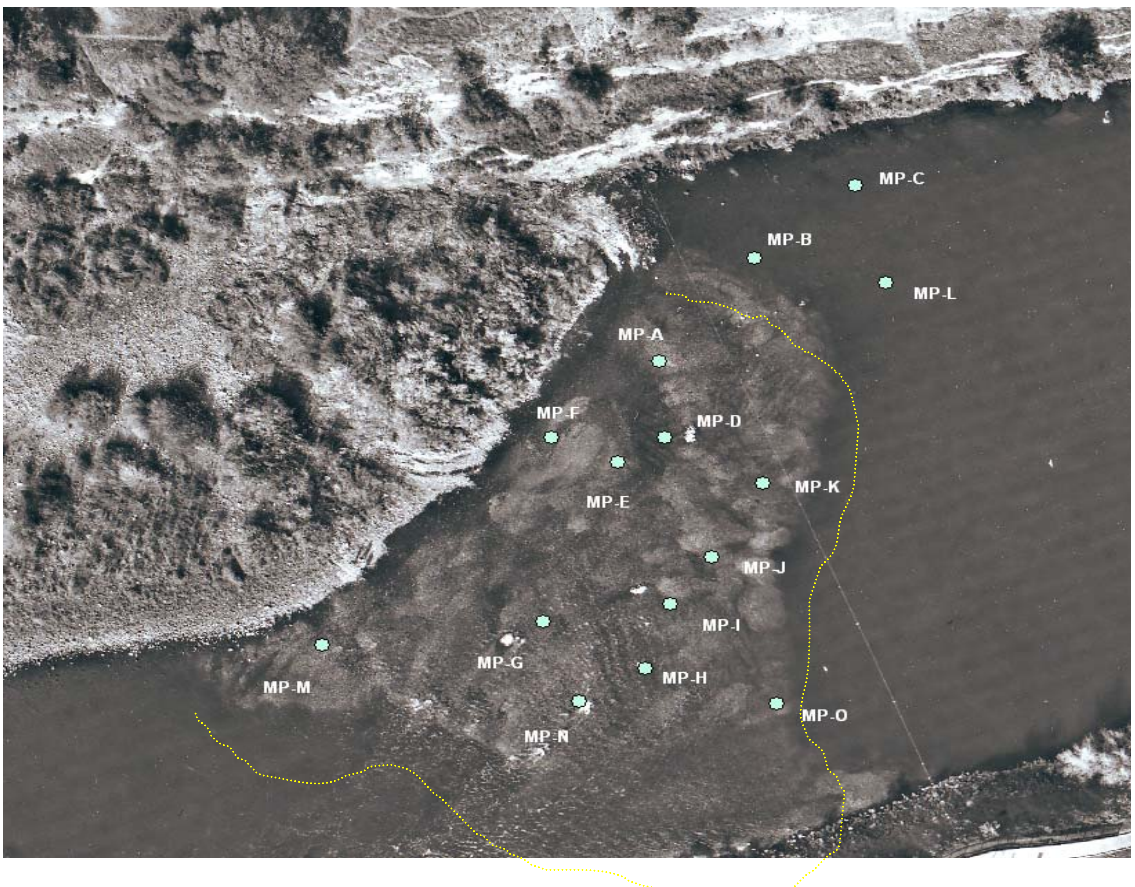


Figure 5.20: After gravel addition map showing the gravel addition area. Points indicate mini piezometer locations. MP C and MP L are upstream of the gravel to provide control measurements.

Location	Temp (River C°)	Temp (well C°)	EC (ms/cm)	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 5.7: Water quality data for the 2008 gravel addition. Data was collected November 2009.

Location	Temp (River C°)	Temp (well C°)	EC (ms/cm)	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 5.8: Water quality data for the 2008 gravel addition. Data was collected January 2010.

5.12 2008 Gravel Addition Hyporheic Pressure Head

Figure 5.21 shows a map of the upwelling and downwelling conditions measured in November 2009 and January 2010. All measurements were upwelling accept for MP-F and Control MP-L. Table 5.9 shows the gradient values measured from each location.

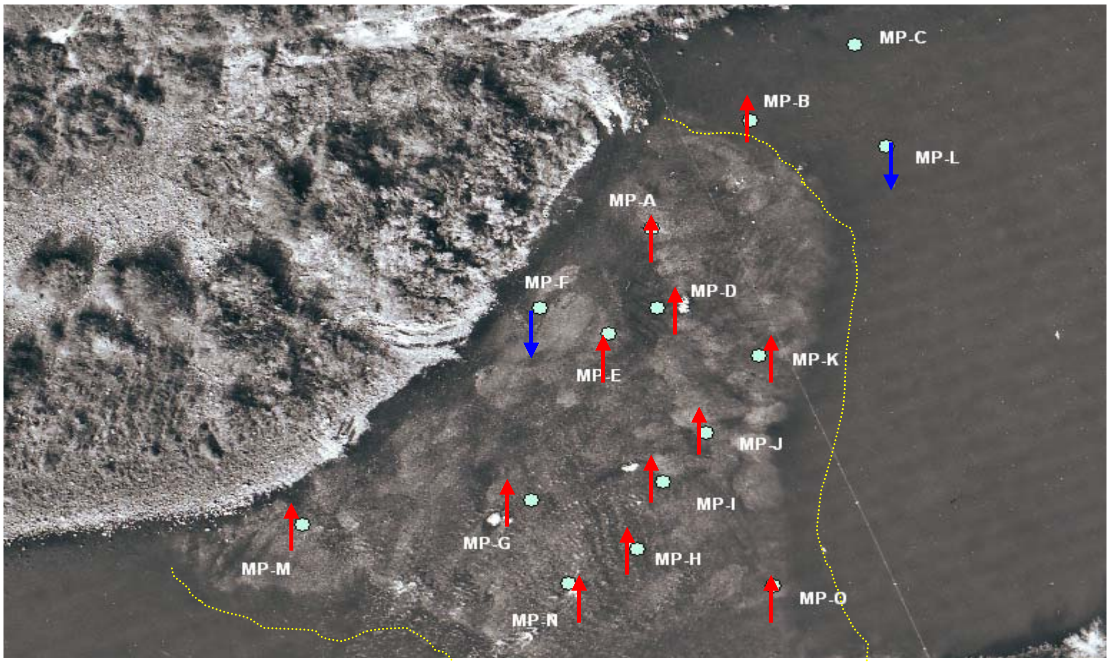


Figure 5.21: 2008 Gravel Addition map showing upwelling and downwelling measurements from November 2009 and January 2010.

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

5.13 2008 Gravel Addition Water Depth/Velocity

Table 5.10 shows the water depth and velocity measurements for the 2008 gravel addition measured in November 2009 and Table 5.11 shows measurements from January 2010. The river flow in November 2009 was 1900 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 5.10: 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 5.11: 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 5.10 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 (Table 5.11) showed a mean depth of 2.2 feet and an average velocity at the 0.6 depth of 2.0 feet per second.

5.14 2008 Gravel Addition Inter Gravel Velocity

Two salt water tracer tests were conducted in April 2010 at the 2008 gravel addition. Figure 5.22 shows the location of tracer tests conducted. Figures 5.23 and 5.24 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 for both tests showed a response to the sodium chloride immediately following injection. Appendix M shows the data collected from April 2010.

Figure 5.22: Map showing the 2008 gravel addition with April 2010 inter gravel velocity test locations.

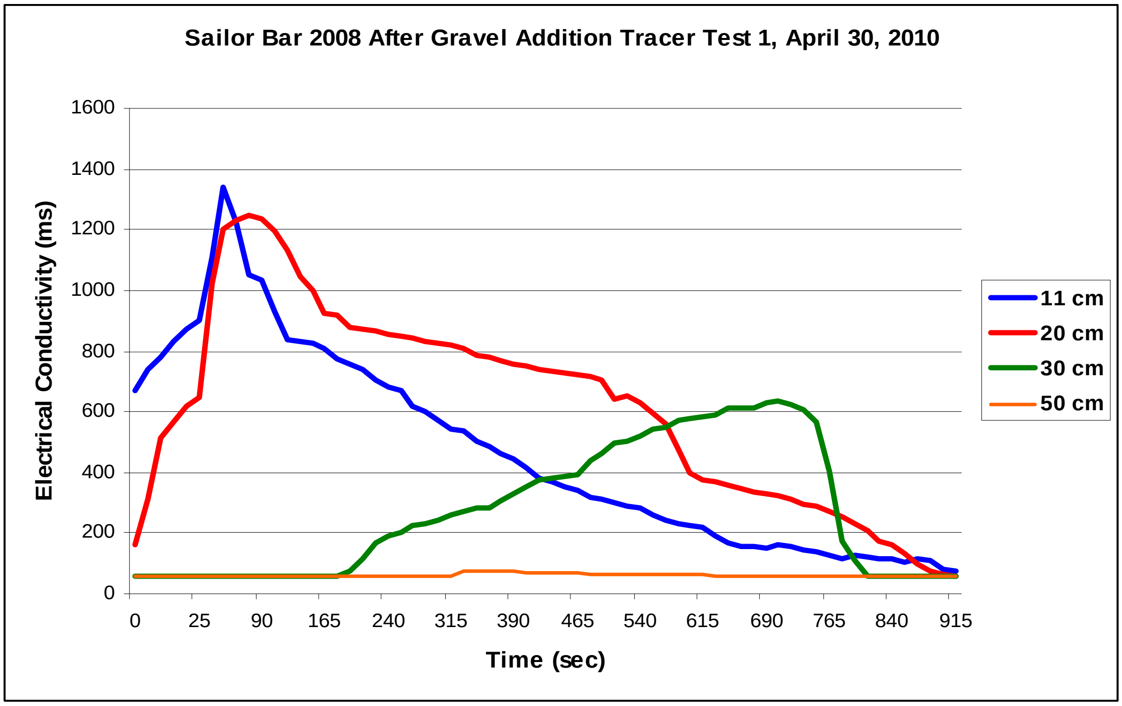


Figure 5.23: Electrical conductivity versus time graph of a salt water tracer test from Sailor Bar 2008 gravel addition, April 2010.

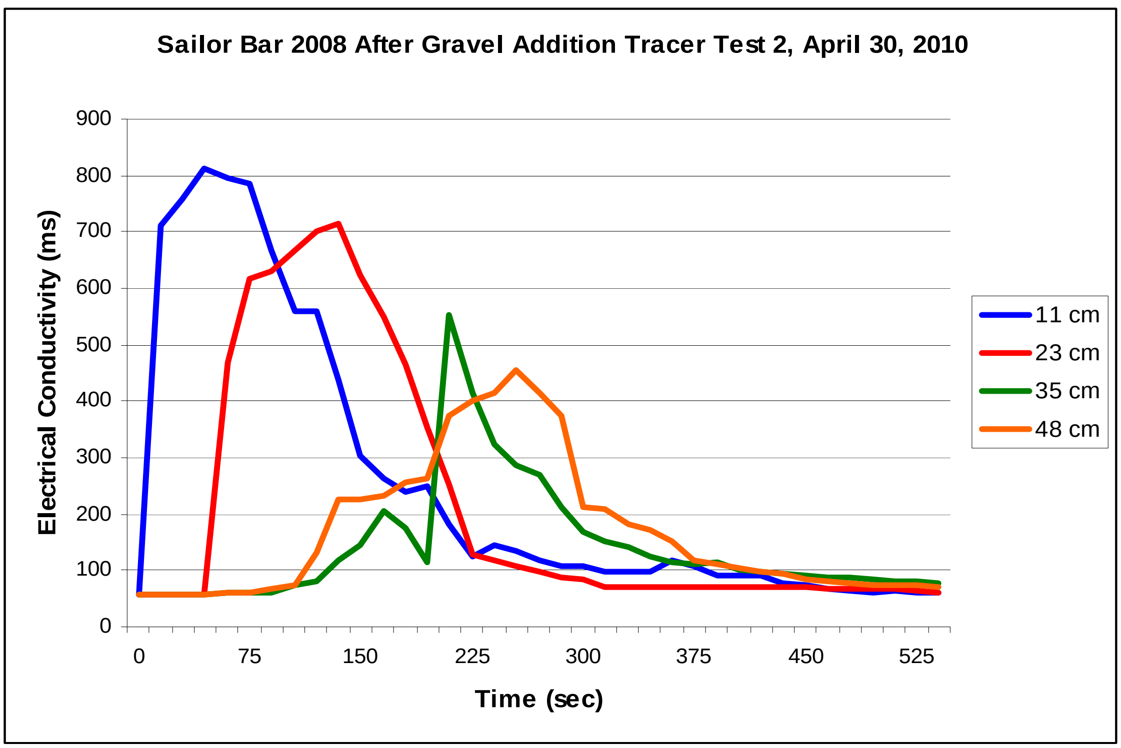


Figure 5.24: Electrical conductivity versus time graph of a salt water tracer test from Sailor Bar 2008 gravel addition, April 2010.

Chapter 6

CONCLUSION

6. Conclusions

Changes that occurred at the three restoration sites varied due to differences in river flow, sediment, and restoration treatments. Many of the changes measured at the restoration sites improved salmonid spawning conditions.

6.1 Sunrise Side Channel

The Lower Sunrise side channel restoration project allowed researchers to examine the physical and geochemical changes that affect steelhead spawning habitat before and after restoration work occurred.

Mean temperature decreased after side channel construction. The methods used in the 2005 study were applied to the side channel after completion. The post restoration monitoring contains data from the incremental increases in flow that occur annually during the spring and early summer, allowing the opportunity to monitor changes to the side channel from the lowest annual river flows to the highest annual flows during 2008/2009.

The side channel continues to change daily in terms of substrate and levee morphology and grain size distribution. The upstream portion of the side channel is eroding due to increased stream velocity (Figure 3.14) and a lack of sufficient anchoring or support mechanisms to stabilize the mostly less than 1.75 inch diameter grain sizes in the channel. Vertical pressure gradient measurements show the majority of the upstream portion of the side channel is downwelling after side channel construction.

Increased velocities promote the down cutting (erosion) in the upstream portion of the side channel shown in Figures 3.15 and 3.16.

Tracer rock movements show the largest size tracer rocks moving the furthest amounts in the upper portion of the side channel. The sediment in the side channel is mobile, and finer grained material has been mobilized and re deposited in large areas (Figure 3.4) of the downstream portion of the side channel.

There are many downstream locations that do not have any grains larger than 7/16 inch diameter. Increased fine grained deposition in the lower end of the side channel could be hindering spawning by choking potential spawning areas with excess fine-grained sediment. This leads to decreased dissolved oxygen from a lack of oxygenated surface water that can not move through the sandy material readily. Tracer rocks in the downstream end of the channel moved very little, or were buried by fine-grained sediment deposited by lower water velocities than the upstream end of the channel. Figures 3.15 and 3.16 show the depth in the downstream end to be decreasing, indicating that deposition is occurring. The lowest dissolved oxygen values from the site were recorded in the downstream end of the side channel in locations where the mini piezometer had been inundated with fine grains.

The middle portion of the channel is also showing signs of increased fine grain deposition near the bend. The left banks (southern side) of the channel is eroding where the most energy and erosive power is located. This lateral erosion is contributing to the increased fine-grained material downstream.

6.2 2008 Sailor Bar Gravel Addition

All of the parameters studied in this chapter 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.

6.3 2009 Sailor Bar Gravel Addition

All of the parameters studied in this project 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 . 80% of the new material is less than 1.25 inches in diameter, whereas gravel size in samples collected before restoration ranged from 0.325 inches to over 12 inches intermediate diameter.

Dissolved oxygen measurements in the new gravel are also significantly higher, providing another improvement to spawning habitat. After restoration, D.O. measurements increased by a factor of 10 at some locations in the study area, and the pH and electrical conductivity becoming more uniform with less than 1% deviation for E.C. and 15% for the pH. Gravel and surface water temperature was also examined. This analysis showed no significant temperature difference between the stream bottom ("surface" conditions) and measurements taken at 30 cm in the gravel. Our method of analyzing temperature uses calibrated temperature loggers that are accurate to within 0.1°C, and stable over time. This should produce accurate comparisons of surface and subsurface temperatures. Tracer rock studies showed that the smallest tracer rocks were mobile with this year's maximum flow of 5000 cfs, and many of these smaller particles were probably flushed downstream and off of the project site. Many of the middle-sized and larger size rocks (up to 3 1/2 inch diameter) were still near the site of emplacement 8 months after the rocks were inserted into the gravel.

Preliminary work with salt water tracer tests has shown the upstream portion of the gravel addition to be highly permeable, with values ranging from 12 cm/min to 32 cm/min. These times indicate rapid movement of water between the pore spaces in the tested locations.

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

APPENDIX A

Sunrise Bulk Sample Analysis: Conducted Before Side Channel Creation

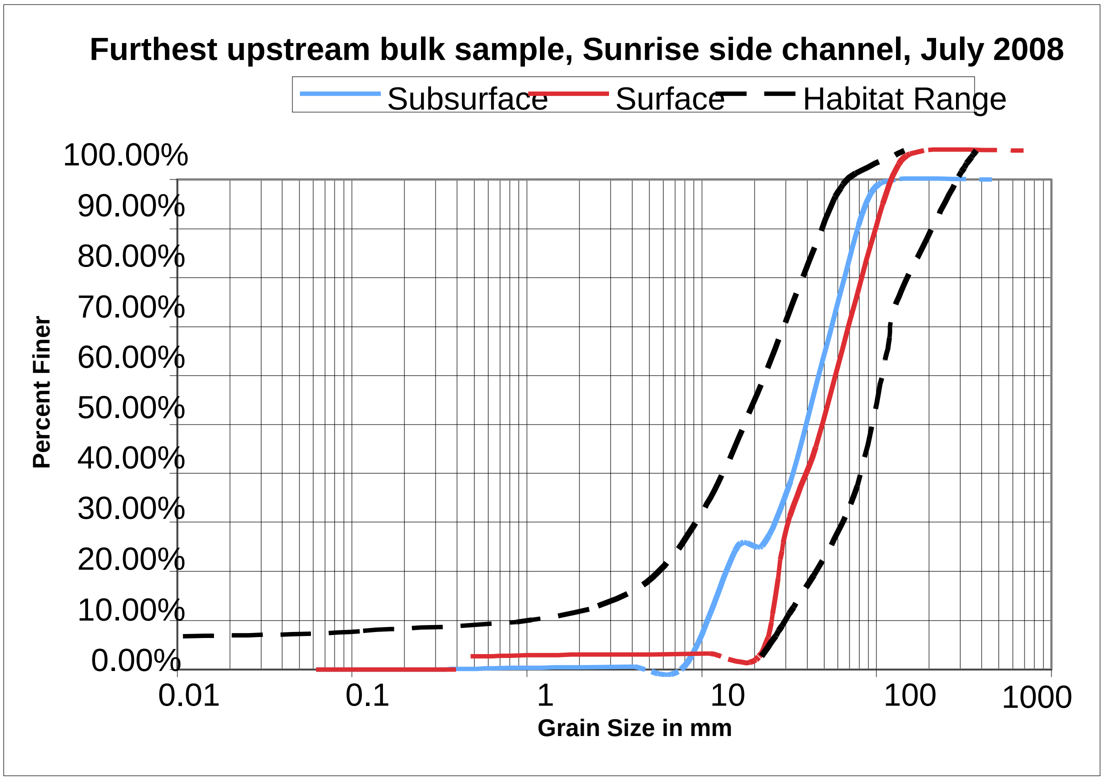
Furthest upstream bulk sample: Surface (7/22/08)

Sieve Size MM	Mass of Sediment Retained (kg)	Percentage of Total Wt	Cumulative Wt %
90 mm	4.20	3.46%	3.46%
64 mm	19.30	15.89%	19.35%
45 mm	24.20	19.93%	39.28%
32 mm	23.50	19.35%	58.64%
22 mm	19.60	16.14%	74.78%
16 mm	30.00	24.71%	99.49%
8.00 mm	0.00	0.00%	99.49%
3.962 mm	0.17	0.14%	99.63%
1.981mm	0.09	0.07%	99.70%
1.00 mm	0.10	0.09%	99.79%
0.425 mm	0.21	0.17%	99.96%
0.250 mm	0.03	0.03%	99.99%
0.12446 mm	0.00	0.00%	100.00%
Residual	0.00	0.00%	100.00%
Total WT.	121.42		

Tables showing the surface values (above) for furthest upstream bulk sample, and the sub surface values (below) for the furthest upstream bulk sample. Data collected July 29, 2008.

Furthest upstream bulk sample: Sub Surface (7/22/08)

Sieve Size MM	Mass of Sediment Retained (kg)	Percentage of Total Wt	Cumulative Wt %
90 mm	2.70	3.78%	3.78%
64 mm	12.60	17.64%	21.42%
45 mm	14.60	20.44%	41.86%
32 mm	14.10	19.74%	61.60%
22 mm	9.50	13.30%	74.89%
16 mm	0.00	0.00%	74.89%
8.00 mm	17.40	24.36%	99.25%
3.962 mm	0.13	0.19%	99.44%
1.981mm	0.08	0.12%	99.56%
1.00 mm	0.09	0.13%	99.69%
0.425 mm	0.17	0.24%	99.93%
0.250 mm	0.04	0.05%	99.98%
0.12446 mm	0.01	0.01%	99.99%
Residual	0.00	0.01%	100.00%
Total WT.	71.43		



Cumulative frequency graph for the furthest upstream bulk sample. Data collected July 2008.

Mid channel (upstream) bulk sample: Surface (7/22/08)

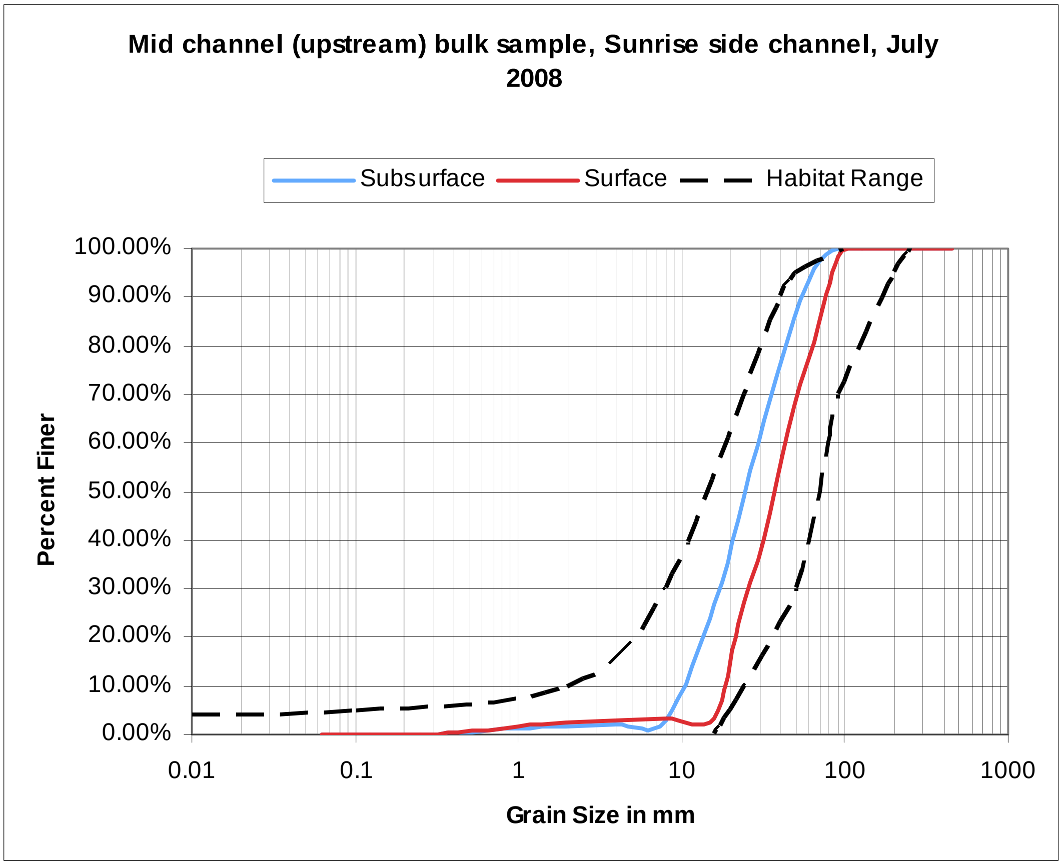
Sieve Size MM	Mass of Sediment Retained (kg)	Percentage of Total Wt	Cumulative Wt %
90 mm	0.40	1.81%	1.81%
64 mm	3.90	17.68%	19.50%
45 mm	4.00	18.14%	37.63%
32 mm	4.90	22.22%	59.85%
22 mm	3.90	17.68%	77.53%
16 mm	4.20	19.04%	96.57%
8.00 mm	0.00	0.00%	96.58%
3.962 mm	0.15	0.67%	97.24%
1.981mm	0.06	0.27%	97.51%
1.00 mm	0.15	0.66%	98.17%
0.425 mm	0.32	1.46%	99.63%
0.250 mm	0.07	0.30%	99.93%
0.12446 mm	0.01	0.05%	99.98%
Residual	0.00	0.02%	100.00%
Total WT.	22.06		

Table showing surface values for mid channel upstream bulk sample. Data collected July 29, 2008.

Mid channel (upstream) bulk sample: Sub surface (7/22/08)

Sieve Size MM	Mass of Sediment Retained (kg)	Percentage of Total Wt	Cumulative Wt %
90 mm	0.00	0.00%	0.00%
64 mm	1.20	4.22%	4.22%
45 mm	4.10	14.41%	18.62%
32 mm	4.80	16.87%	35.49%
22 mm	5.80	20.38%	55.87%
16 mm	4.90	17.22%	73.09%
8.00 mm	6.80	23.89%	96.98%
3.962 mm	0.25	0.87%	97.85%
1.981mm	0.11	0.40%	98.25%
1.00 mm	0.13	0.46%	98.71%
0.425 mm	0.28	1.00%	99.70%
0.250 mm	0.07	0.25%	99.95%
0.12446 mm	0.01	0.04%	99.99%
Residual	0.00	0.01%	100.00%
Total WT.	28.46		

Table showing sub surface values for mid channel upstream bulk sample. Data collected July 29, 2008.



Cumulative frequency graph for the mid channel upstream bulk sample. Data collected July 2008.

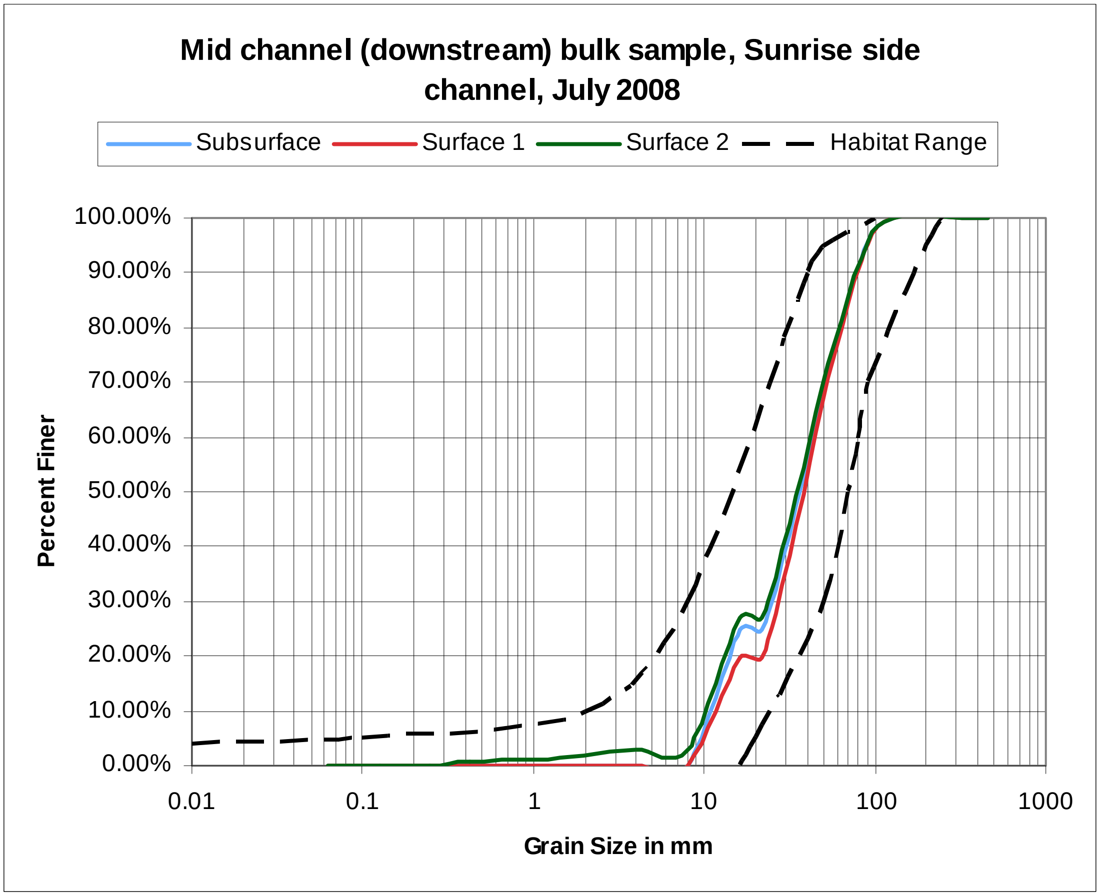
Mid channel (downstream) bulk sample: Surface (7/29/08)

Sieve Size MM	Mass of Sediment Retained (kg)	Percentage of Total Wt	Cumulative Wt %
90 mm	1.2	4.74%	4.74%
64 mm	3.9	15.41%	20.16%
45 mm	4.8	18.97%	39.13%
32 mm	5.7	22.53%	61.66%
22 mm	4.7	18.58%	80.23%
16 mm	0.00	0.00%	80.23%
8.00 mm	5.0	19.76%	100.00%
3.962 mm	0.31	0.00%	100.00%
1.981mm	0.23	0.00%	100.00%
1.00 mm	0.20	0.00%	100.00%
0.425 mm	0.15	0.00%	100.00%
0.250 mm	0.02	0.00%	100.00%
0.12446 mm	0.00	0.00%	100.00%
Residual	0.00	0.00%	100.00%
Total WT.	25.392		

Tables showing the surface values (above) for mid channel downstream bulk sample, and the sub surface values (below) for the mid channel downstream bulk sample. Data collected July 29, 2008.

Mid channel (downstream) bulk sample: Sub Surface (7/29/08)

Sieve Size MM	Mass of Sediment Retained (g)	Percentage of Total Wt	Cumulative Wt %
90 mm	1200.00	4.35%	4.35%
64 mm	4100.00	14.85%	19.20%
45 mm	4800.00	17.39%	36.59%
32 mm	5800.00	21.01%	57.61%
22 mm	4900.00	17.75%	75.36%
16 mm	0.00	0.00%	75.36%
8.00 mm	6800.00	24.64%	100.00%
3.962 mm	0.26	0.00%	100.00%
1.981mm	0.16	0.00%	100.00%
1.00 mm	0.14	0.00%	100.00%
0.425 mm	0.15	0.00%	100.00%
0.250 mm	0.05	0.00%	100.00%
0.12446 mm	0.02	0.00%	100.00%
Residual	0.01	0.00%	100.00%
Total WT.	27600.79		



Cumulative frequency graph for the mid channel downstream bulk sample.

Furthest downstream bulk sample: Surface (7/29/08)

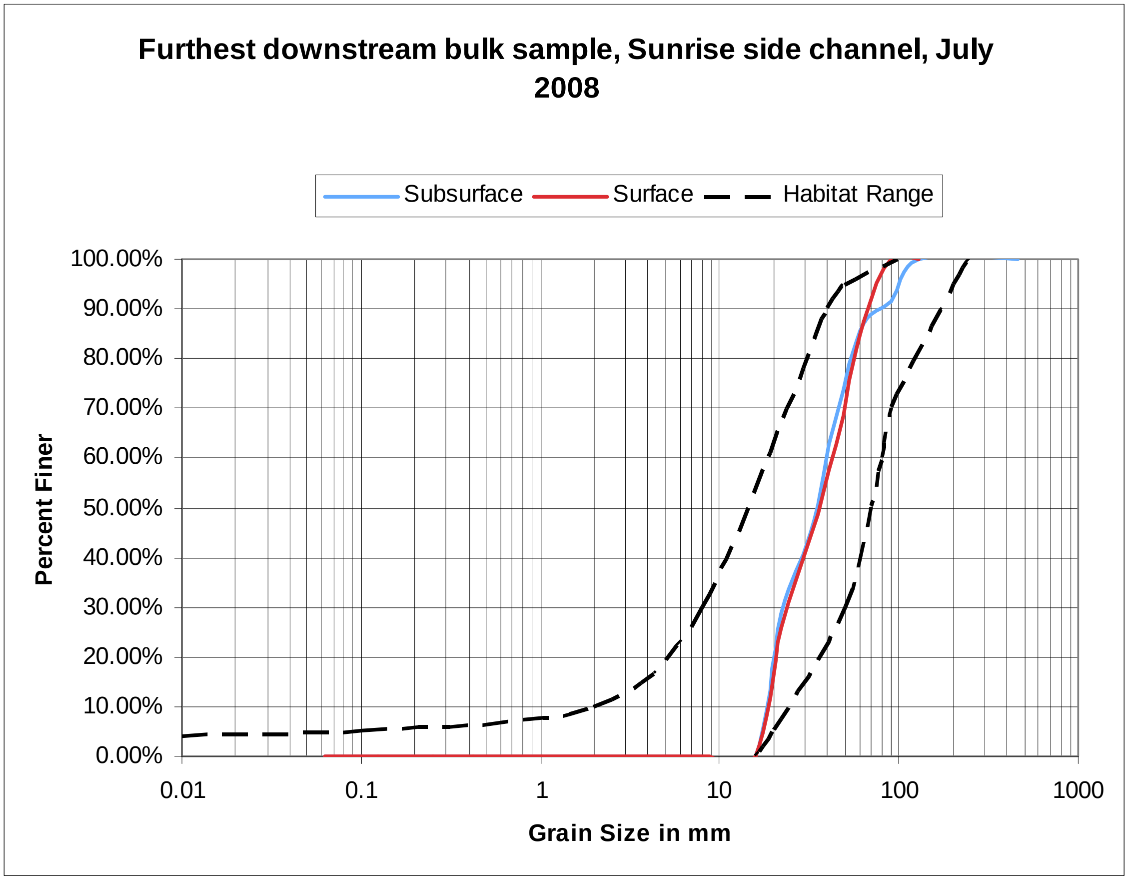
Sieve Size MM	Mass of Sediment Retained (g)	Percentage of Total Wt	Cumulative Wt %
90 mm	1400.00	12.39%	12.39%
64 mm	1100.00	9.73%	22.12%
45 mm	1700.00	15.04%	37.17%
32 mm	2100.00	18.58%	55.75%
22 mm	2100.00	18.58%	74.33%
16 mm	2900.00	25.66%	100.00%
8.00 mm	0.00	0.00%	100.00%
3.962 mm	0.14	0.00%	100.00%
1.981mm	0.11	0.00%	100.00%
1.00 mm	0.13	0.00%	100.00%
0.425 mm	0.12	0.00%	100.00%
0.250 mm	0.02	0.00%	100.00%
0.12446 mm	0.00	0.00%	100.00%
Residual	0.00	0.00%	100.00%
Total WT.	11300.52		

Table showing surface values for furthest downstream bulk sample. Data collected July 29, 2008.

Furthest downstream bulk sample: Sub Surface (7/29/08)

Sieve Size MM	Mass of Sediment Retained (g)	Percentage of Total Wt	Cumulative Wt %
90 mm	1500.00	8.47%	8.47%
64 mm	800.00	4.52%	12.99%
45 mm	3300.00	18.64%	31.64%
32 mm	4100.00	23.16%	54.80%
22 mm	2900.00	16.38%	71.18%
16 mm	5100.00	28.81%	100.00%
8.00 mm	0.00	0.00%	100.00%
3.962 mm	0.18	0.00%	100.00%
1.981mm	0.12	0.00%	100.00%
1.00 mm	0.11	0.00%	100.00%
0.425 mm	0.15	0.00%	100.00%
0.250 mm	0.06	0.00%	100.00%
0.12446 mm	0.02	0.00%	100.00%
Residual	0.01	0.00%	100.00%
Total WT.	17700.64		

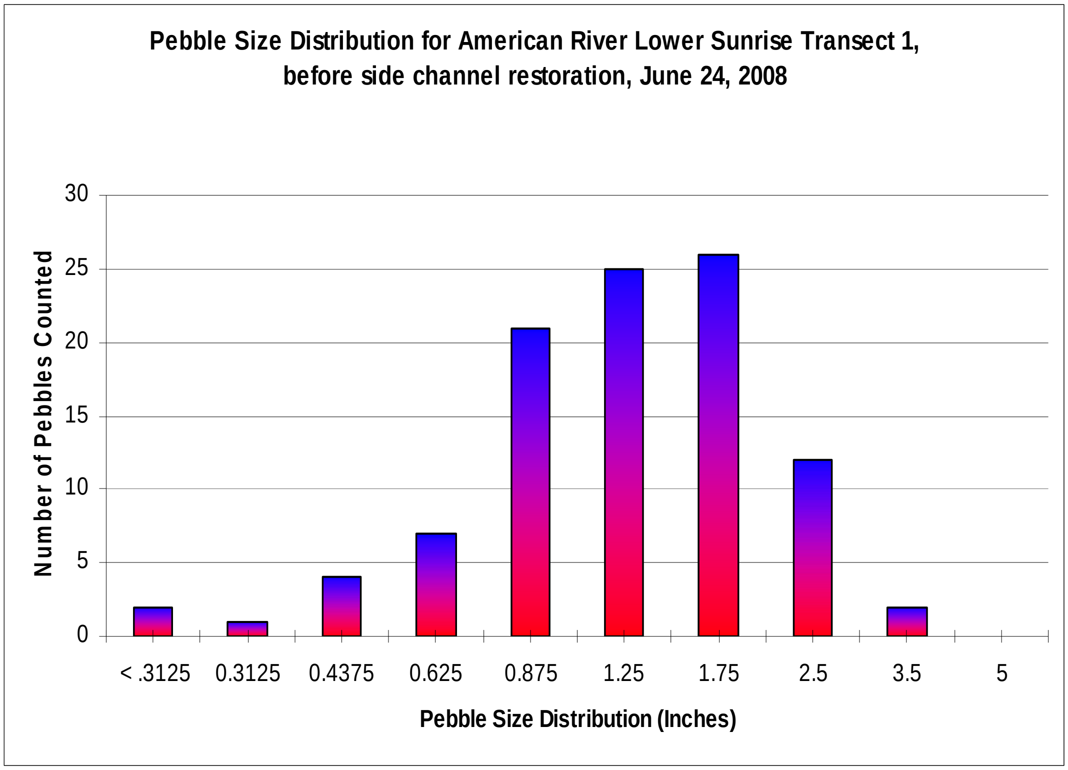
Table showing sub surface values for furthest downstream bulk sample. Data collected July 29, 2008.



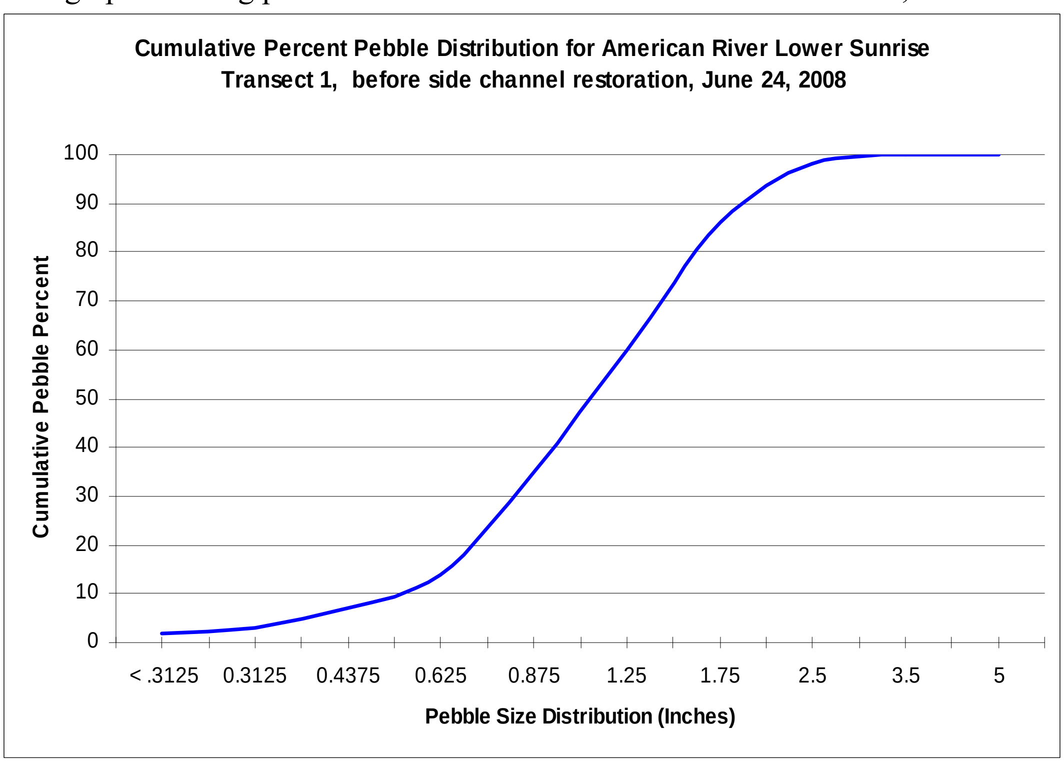
Cumulative frequency graph for the furthest downstream bulk sample. July 2008.

APPENDIX B

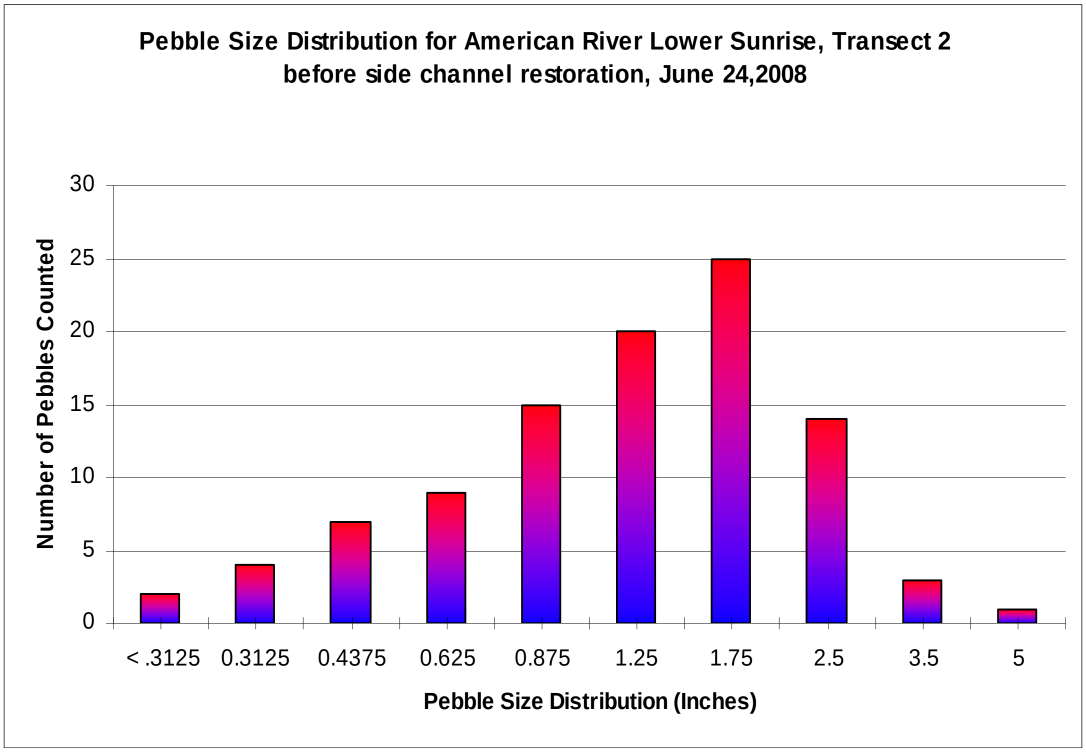
Sunrise Pebble Count: Conducted Before Side Channel Construction



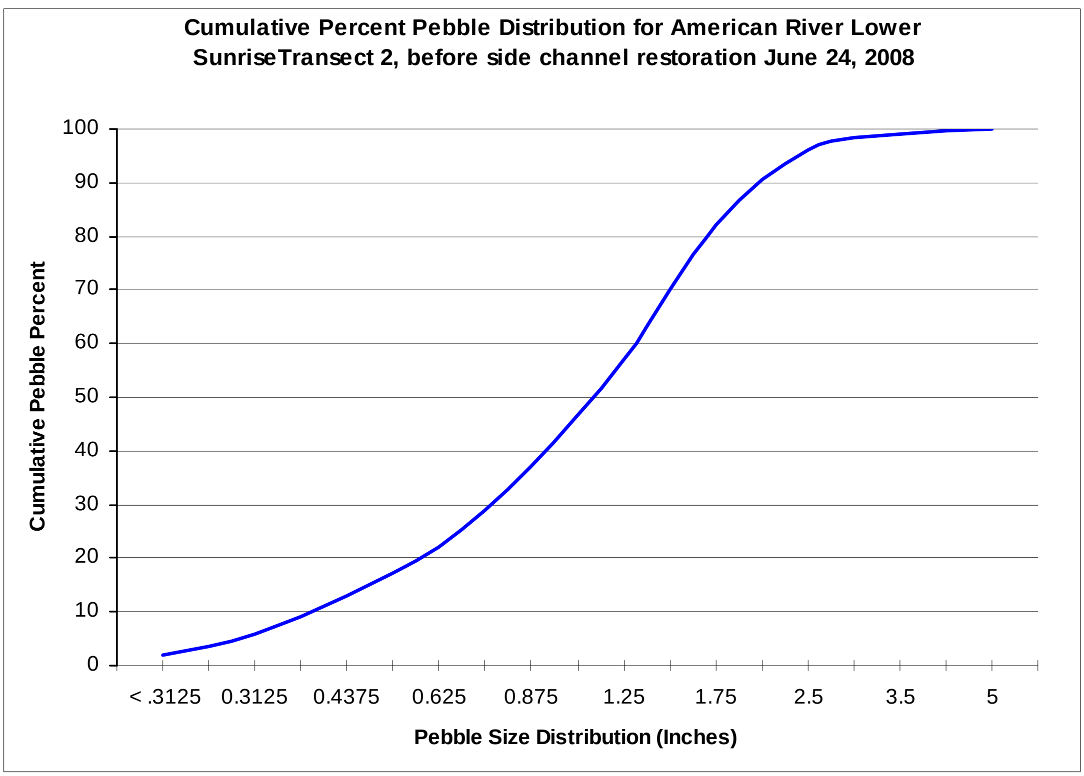
Histograph showing pebble count data Sunrise side channel Transect 1, June 2008.



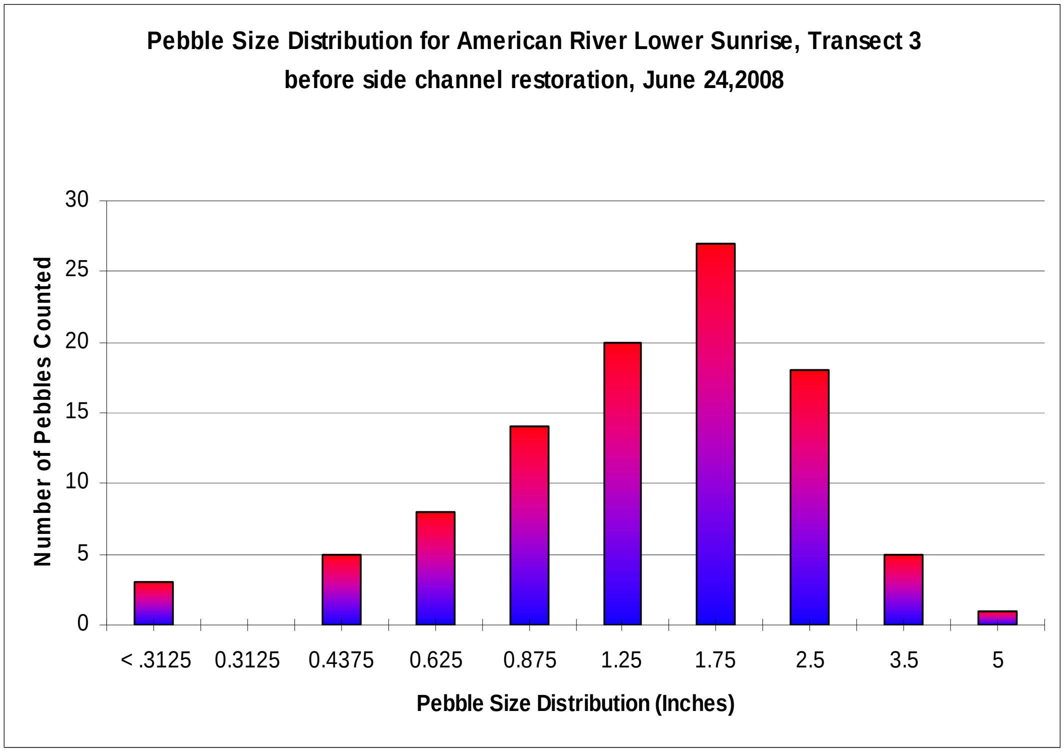
Cumulative frequency graph for Sunrise side channel Transect 1, June 2008.



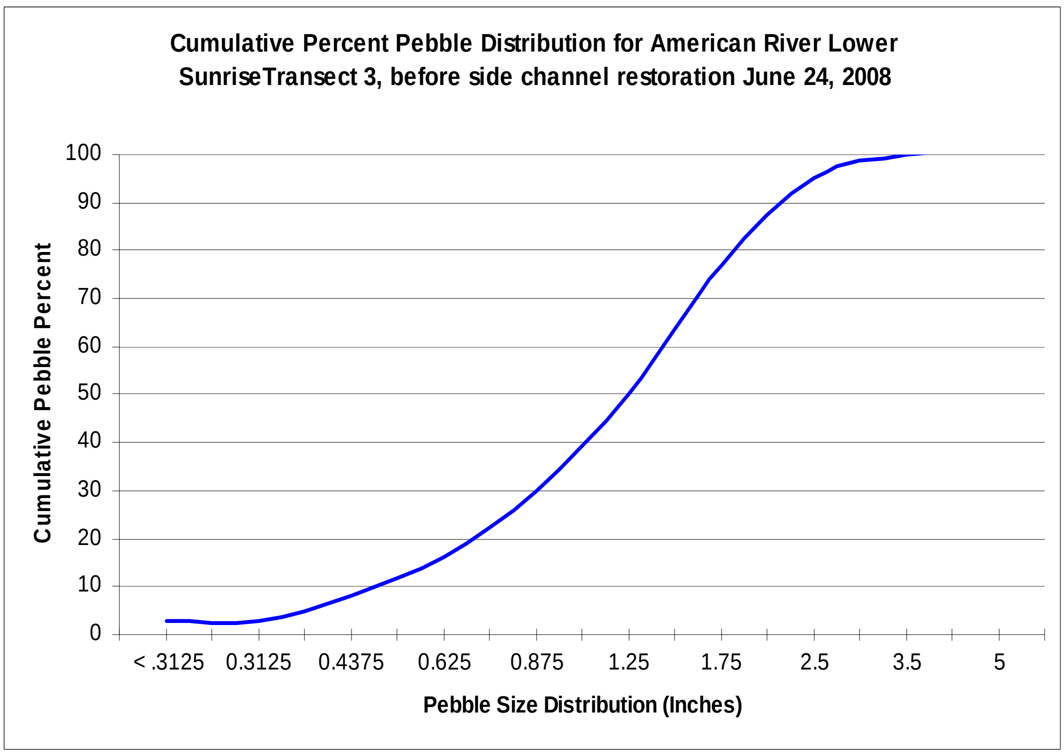
Histograph showing pebble count data Sunrise side channel Transect 2, June 2008.



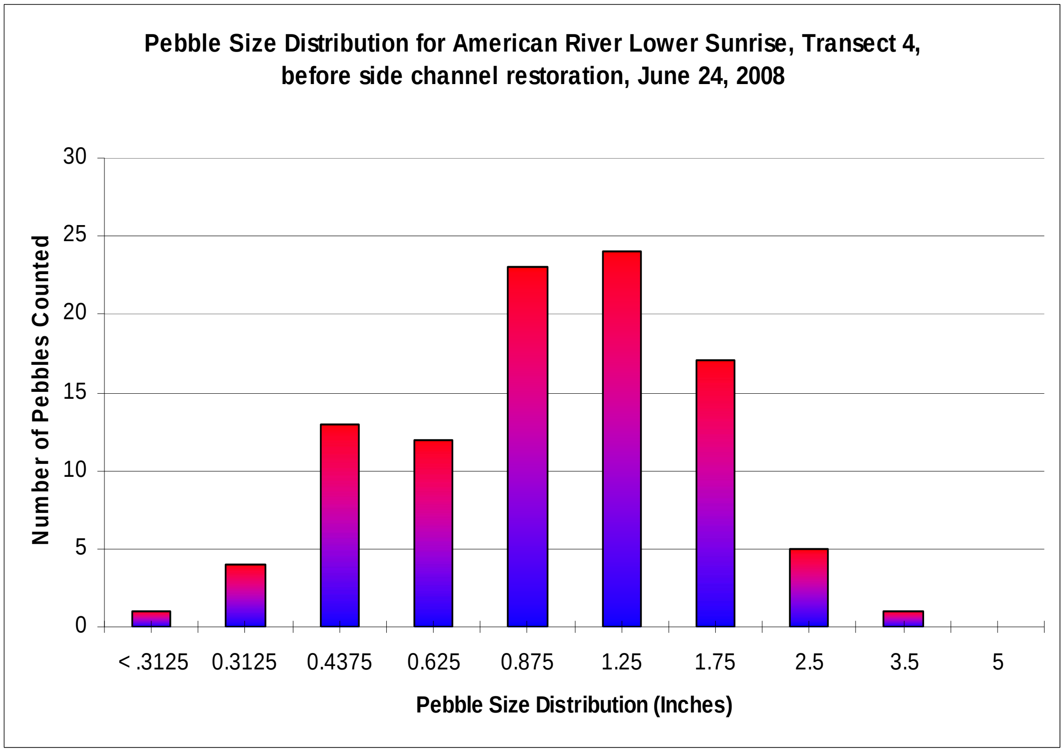
Cumulative frequency graph for Sunrise side channel Transect 2, June 2008.



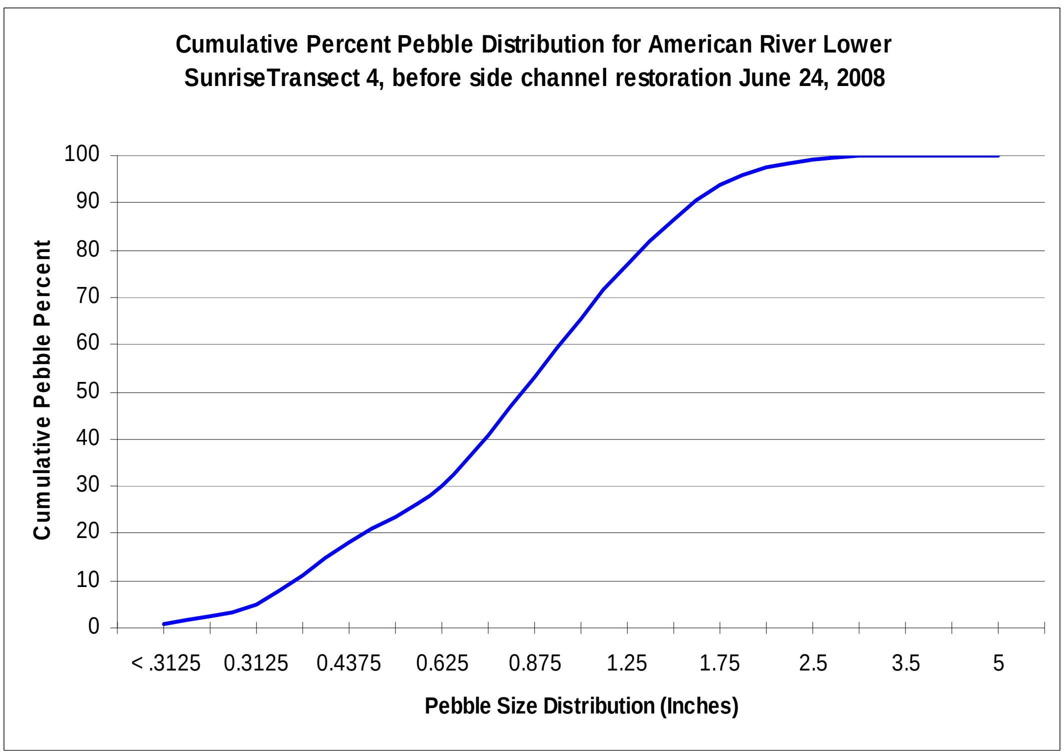
Histograph showing pebble count data Sunrise side channel Transect 3, June 2008.



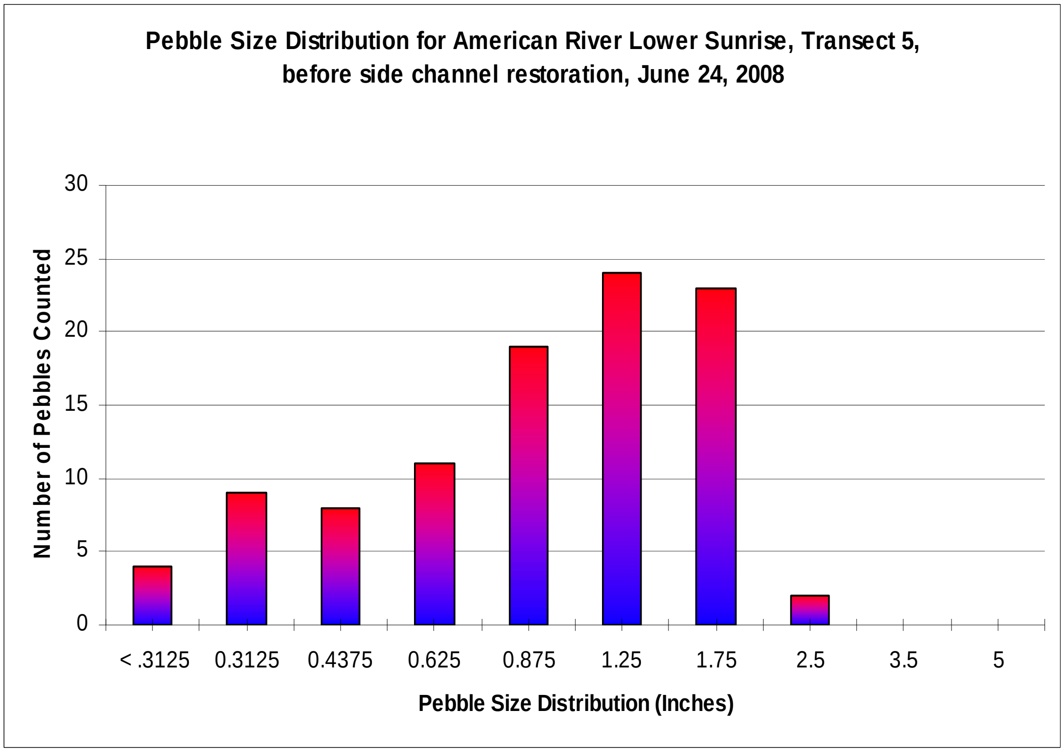
Cumulative frequency graph for Sunrise side channel Transect 3, June 2008.



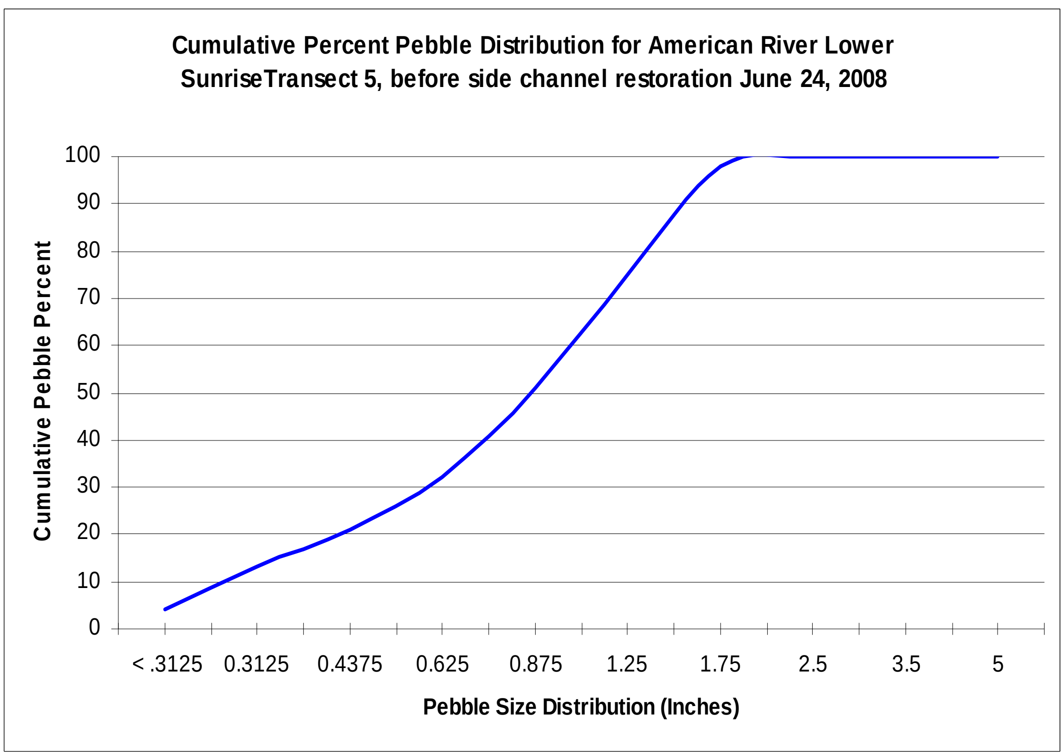
Histograph showing pebble count data Sunrise side channel Transect 4, June 2008.



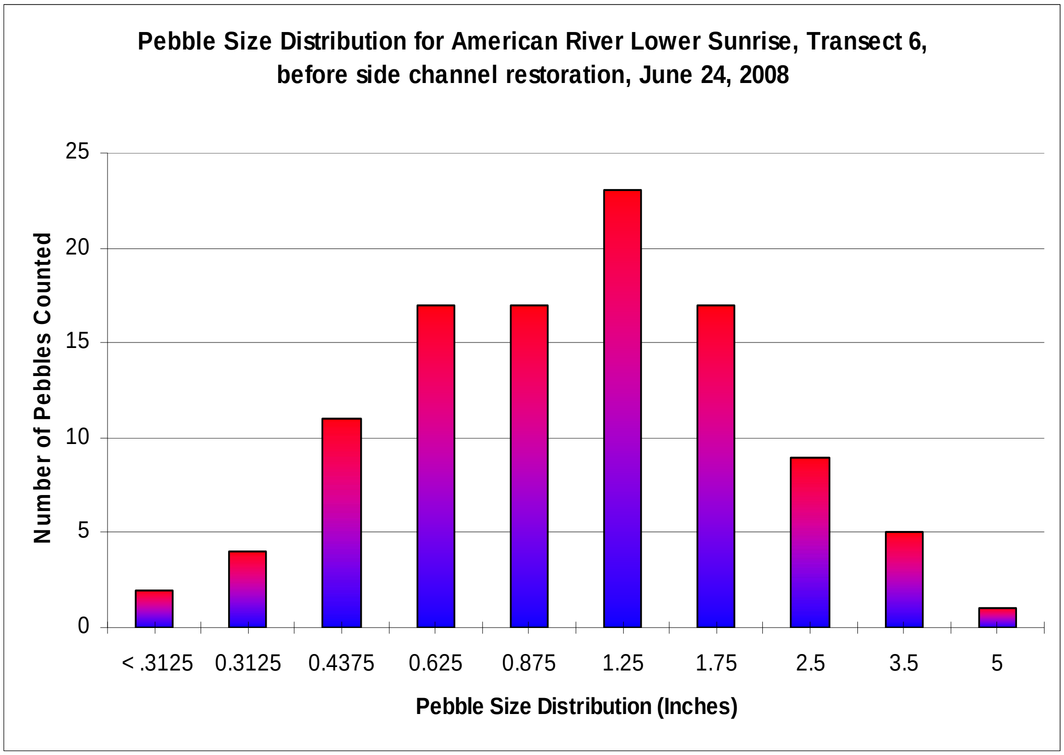
Cumulative frequency graph for Sunrise side channel Transect 4, June 2008.



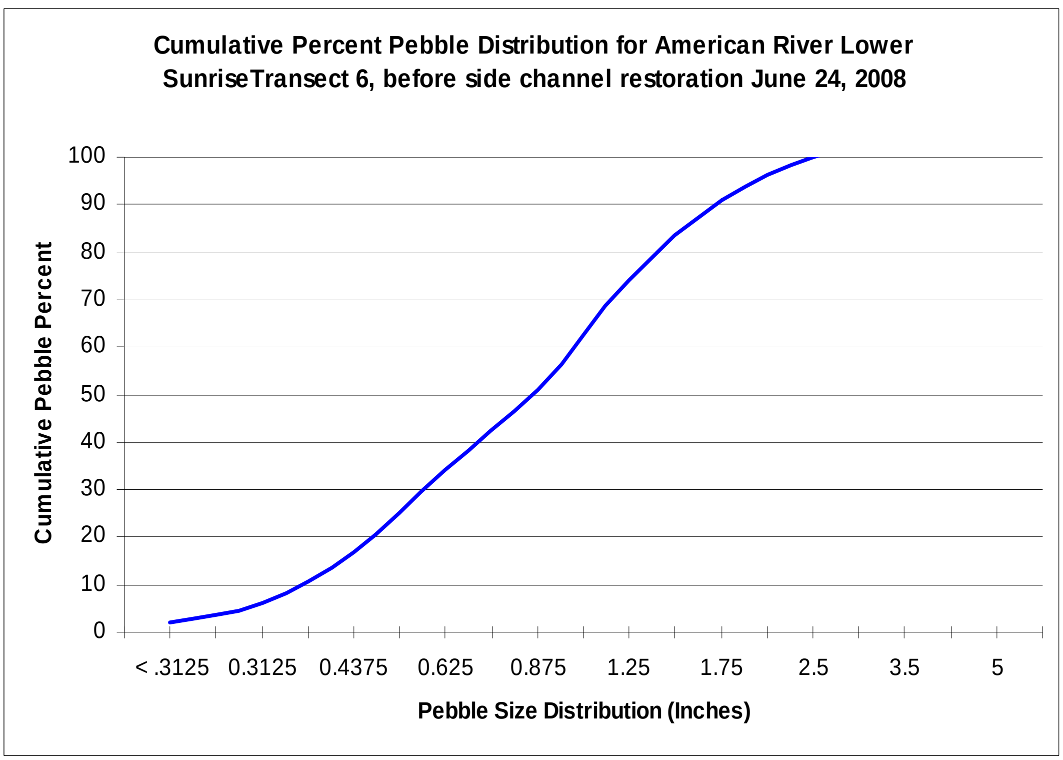
Histograph showing pebble count data Sunrise side channel Transect 5, June 2008.



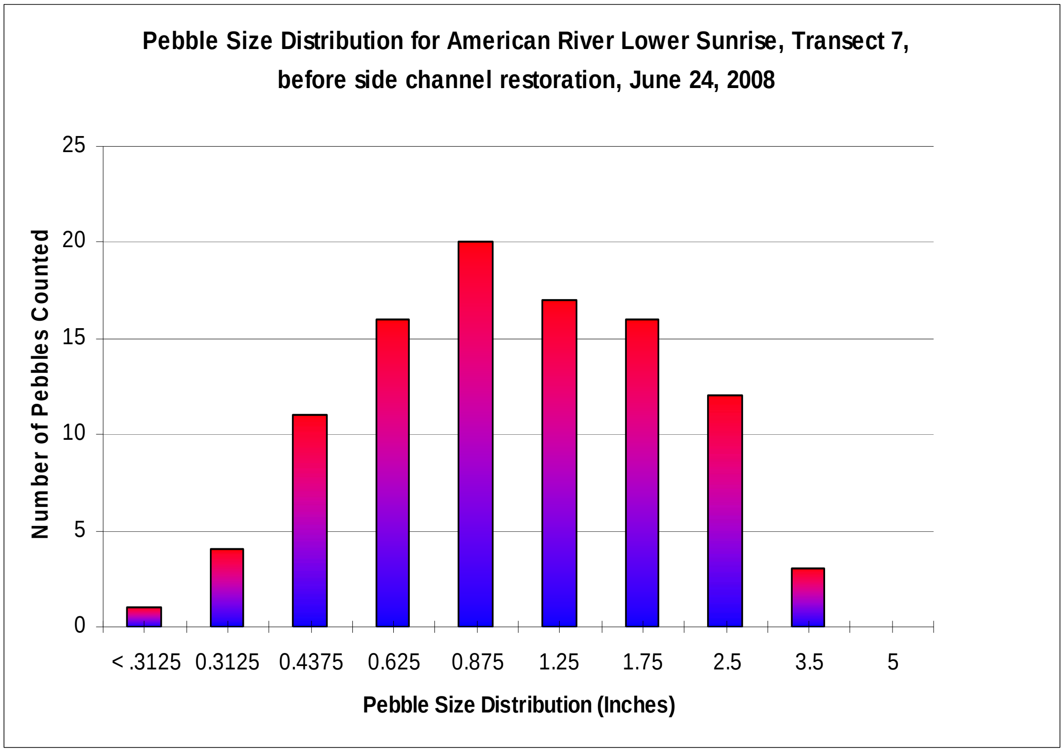
Cumulative frequency graph for Sunrise side channel Transect 5, June 2008.



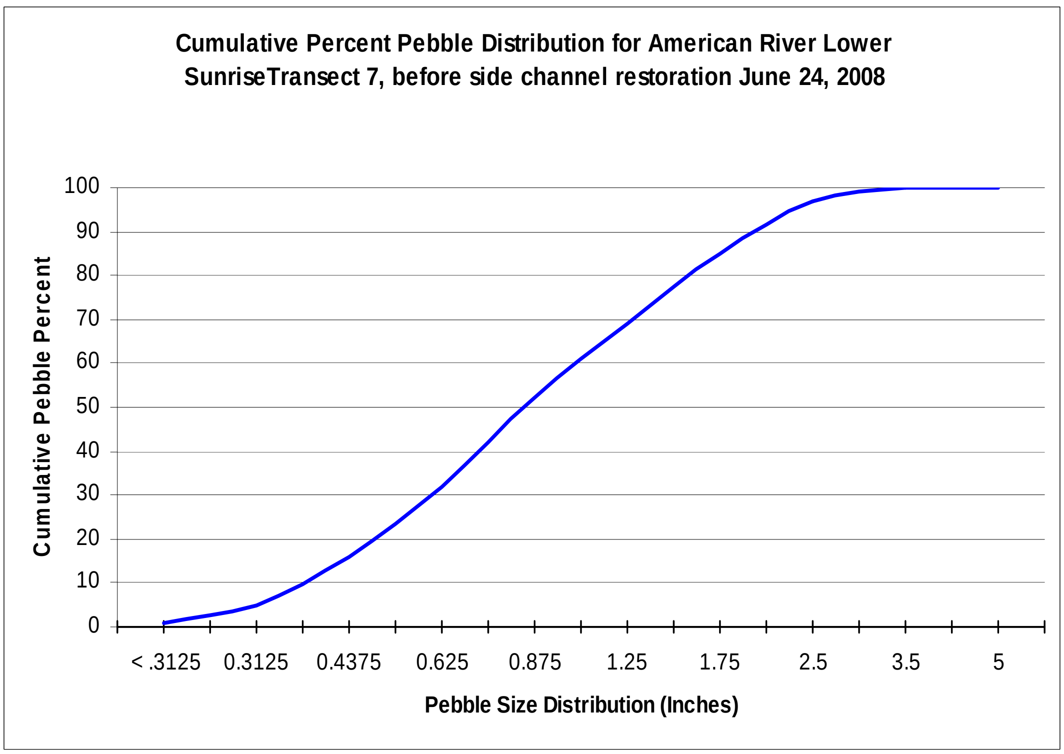
Histograph showing pebble count data Sunrise side channel Transect 6, June 2008.



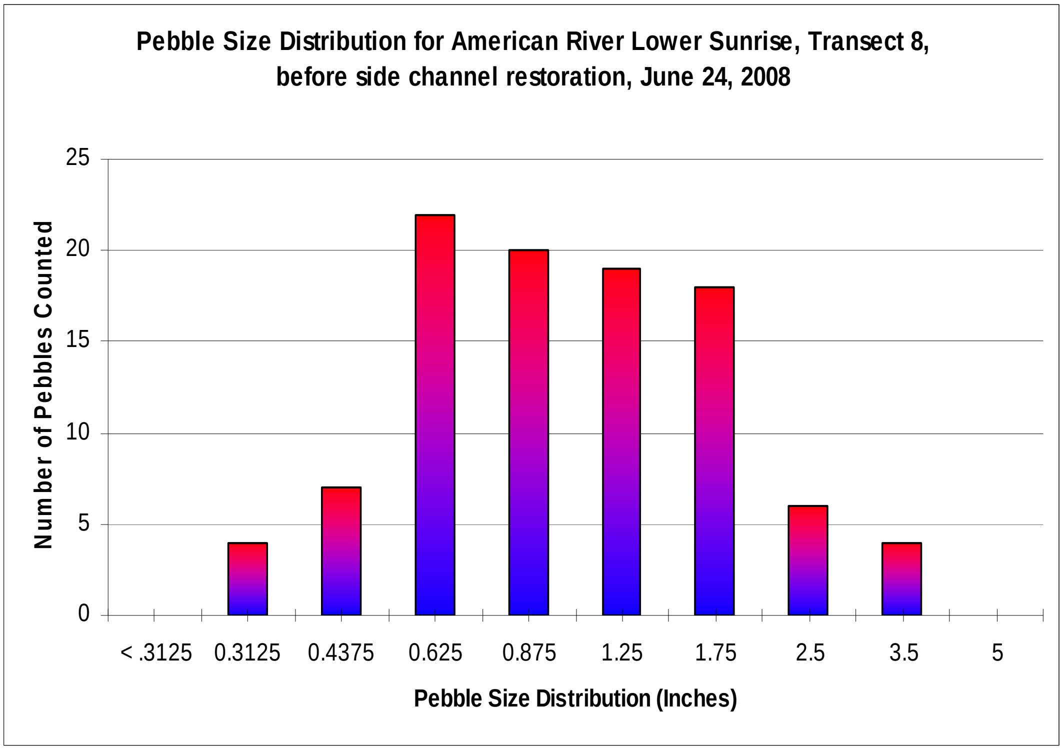
Cumulative frequency graph for Sunrise side channel Transect 6, June 2008.



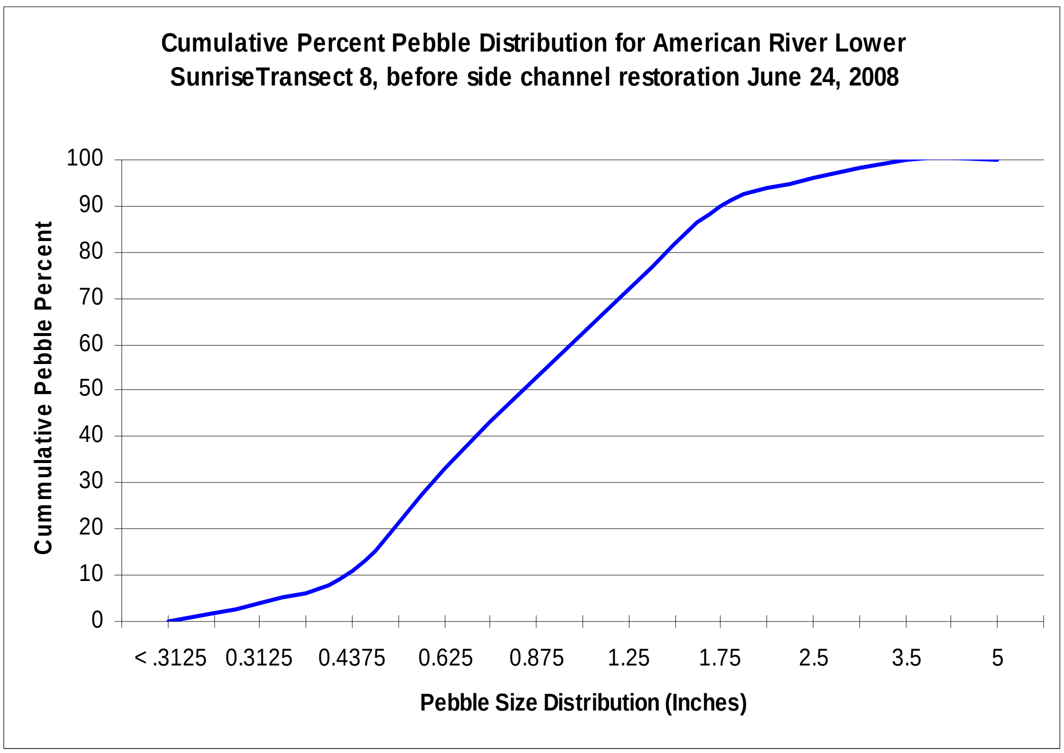
Histograph showing pebble count data Sunrise side channel Transect 7, June 2008.



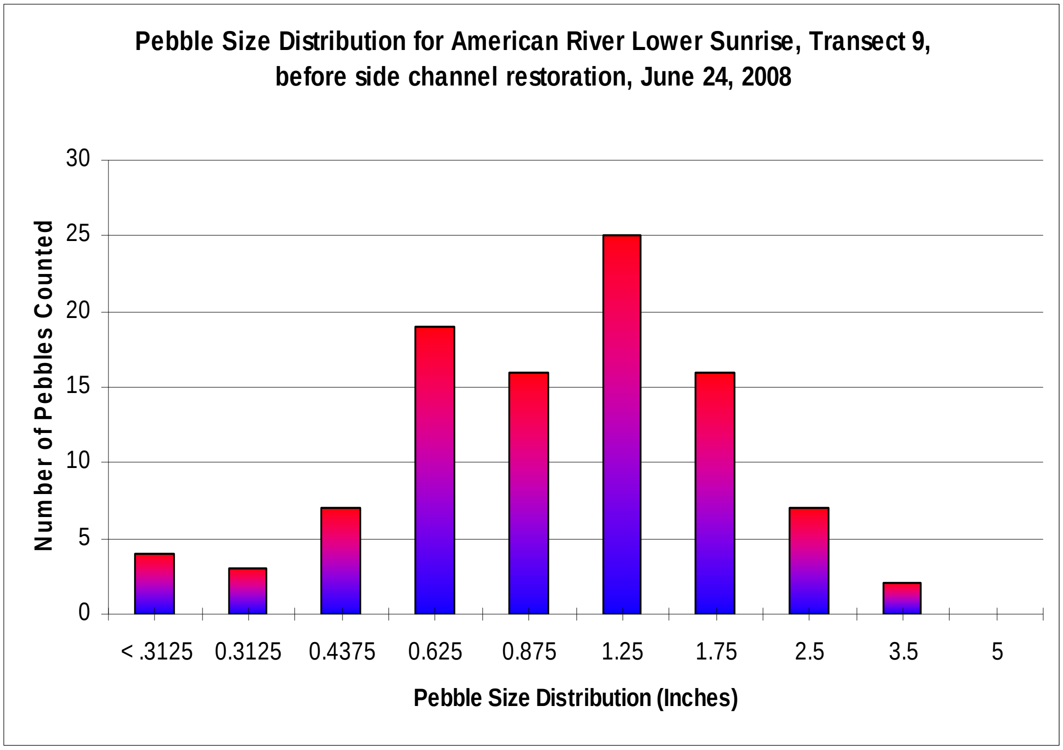
Cumulative frequency graph for Sunrise side channel Transect 7, June 2008.



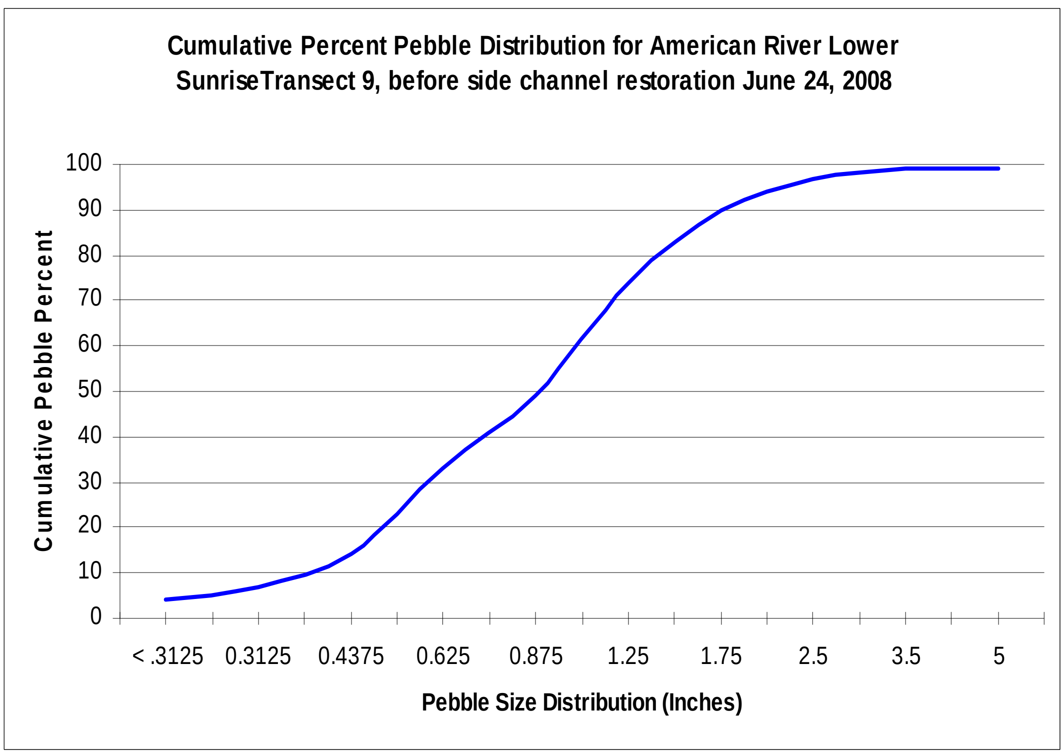
Histograph showing pebble count data Sunrise side channel Transect 8, June 2008.



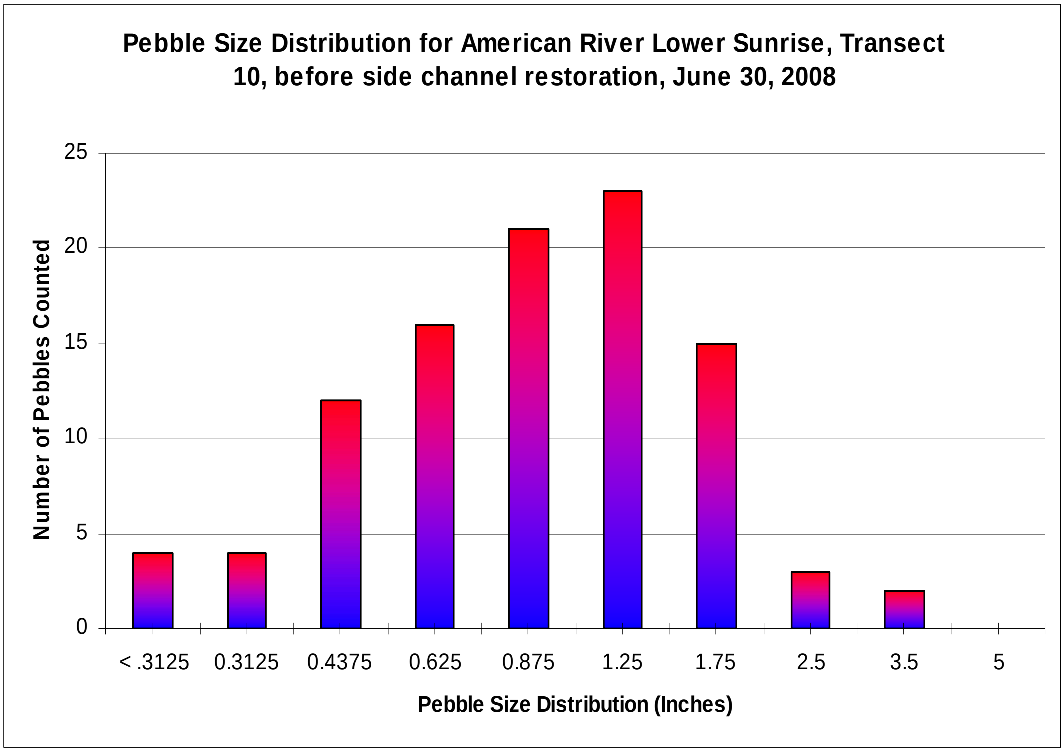
Cumulative frequency graph for Sunrise side channel Transect 8, June 2008.



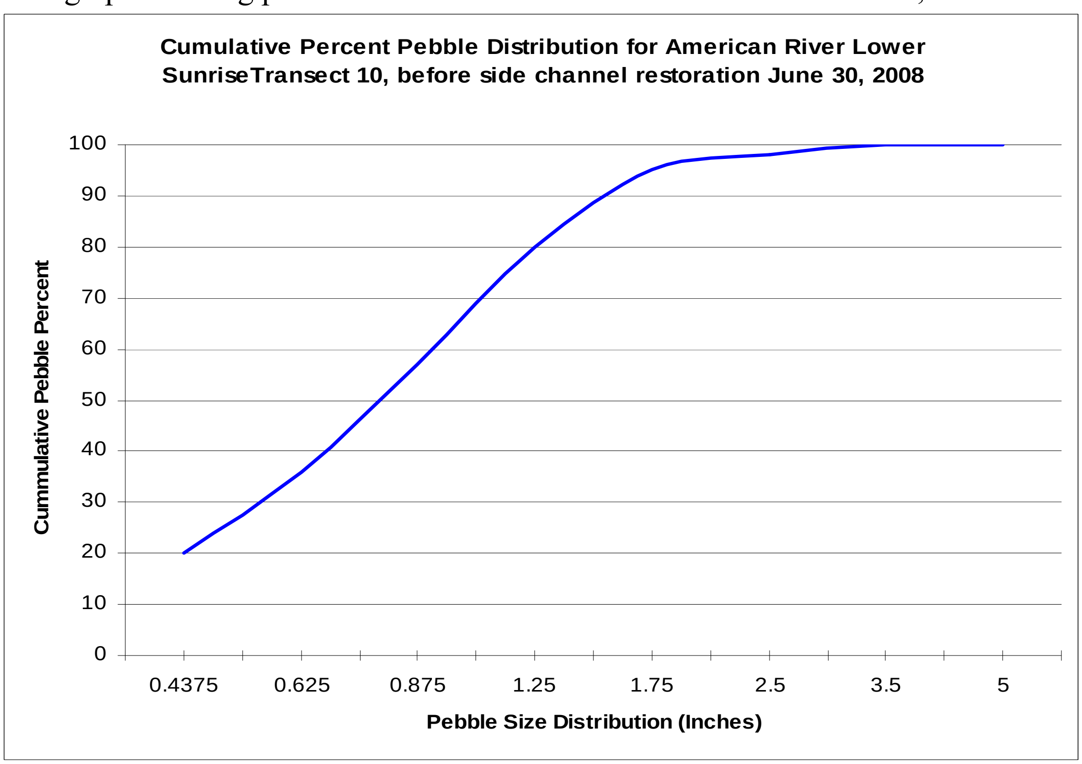
Histograph showing pebble count data Sunrise side channel Transect 9, June 2008.



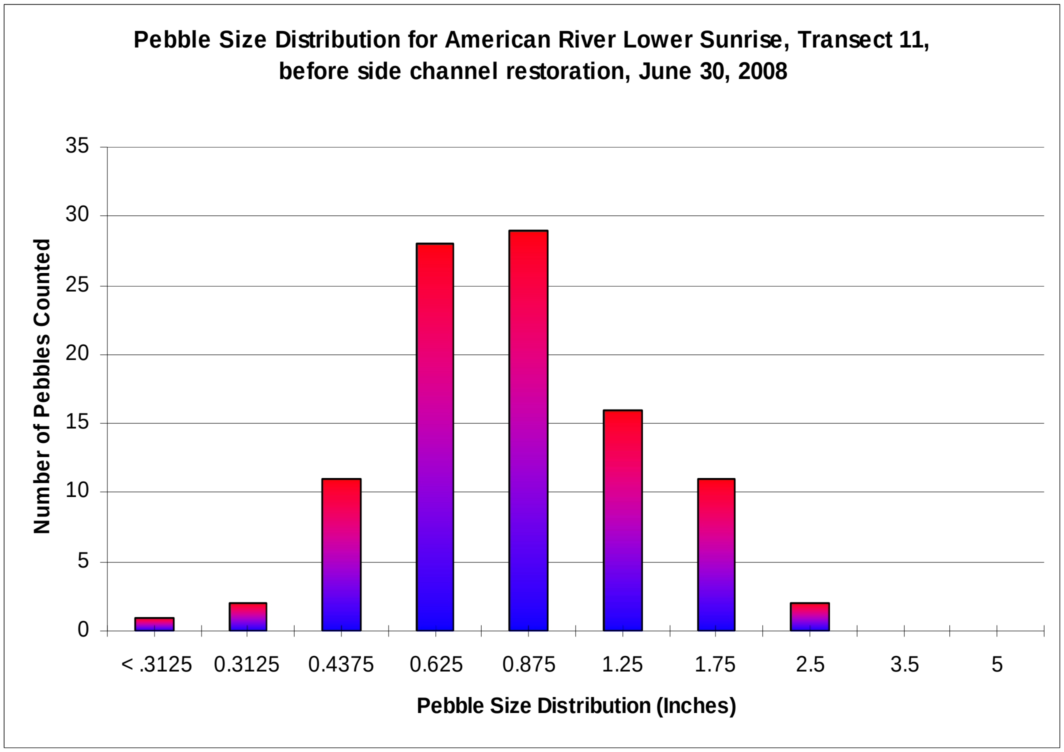
Cumulative frequency graph for Sunrise side channel Transect 9, June 2008.



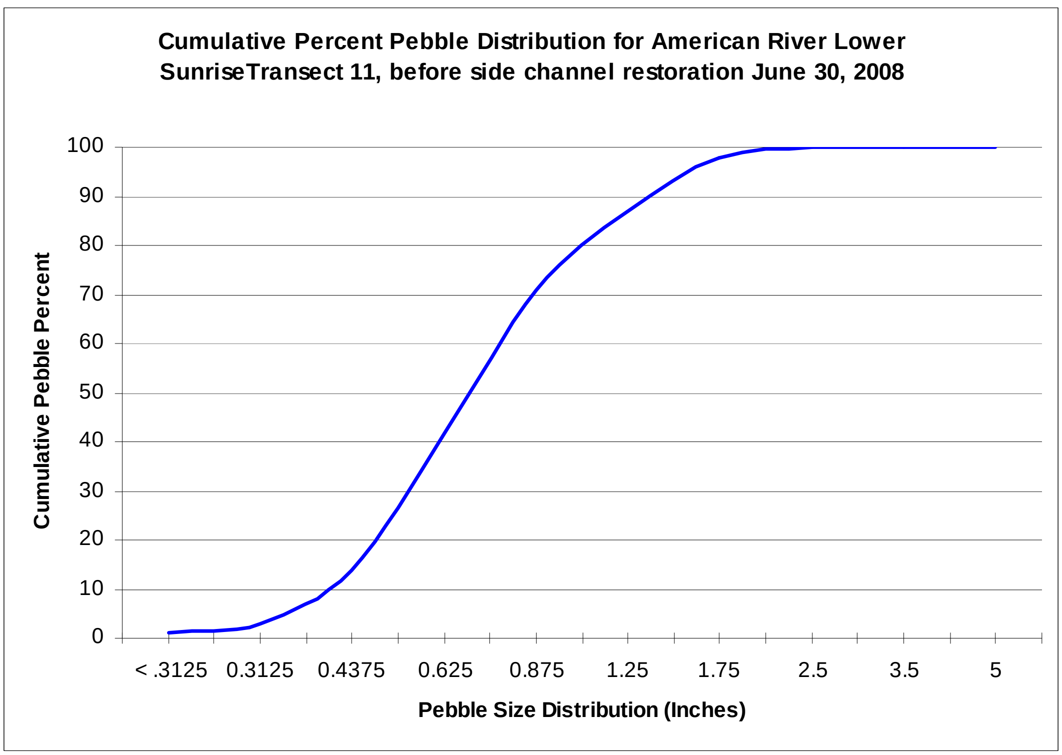
Histograph showing pebble count data Sunrise side channel Transect 10, June 2008.



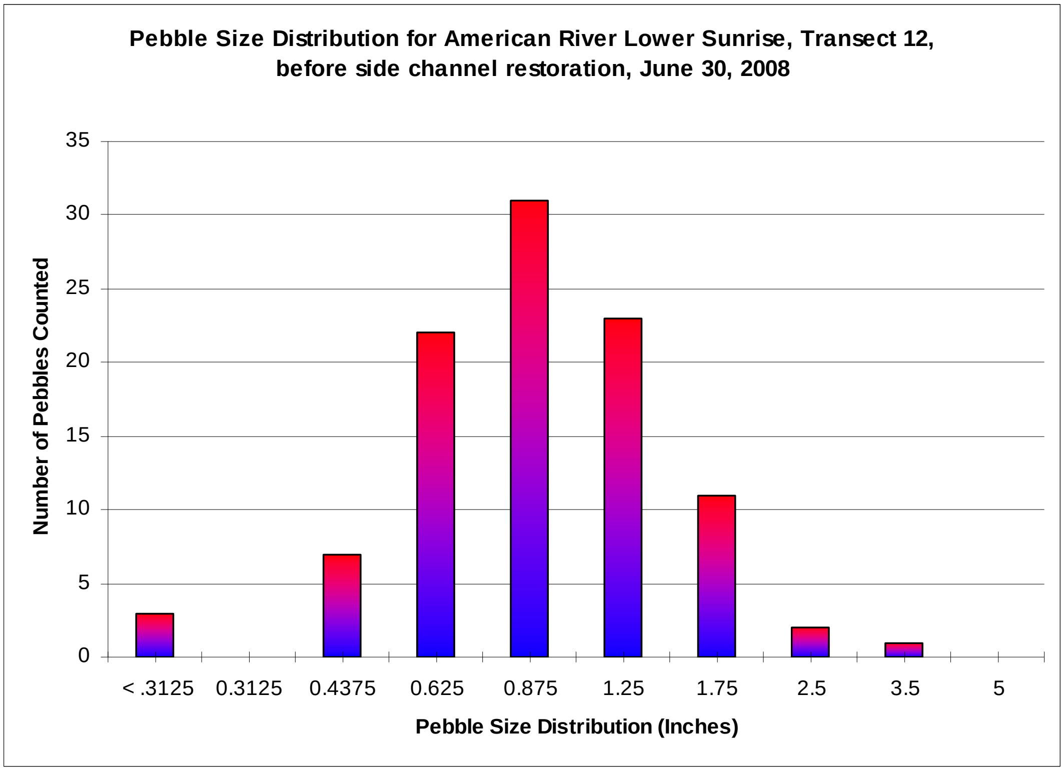
Cumulative frequency graph for Sunrise side channel Transect 10, June 2008.



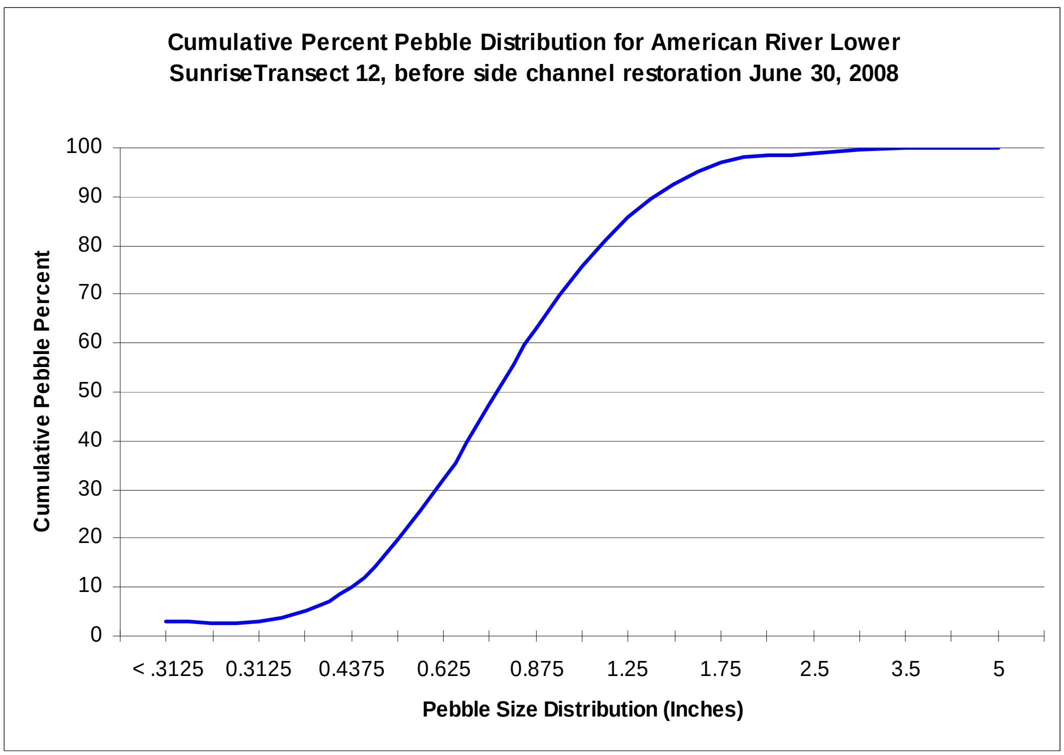
Histograph showing pebble count data Sunrise side channel Transect 11, June 2008.



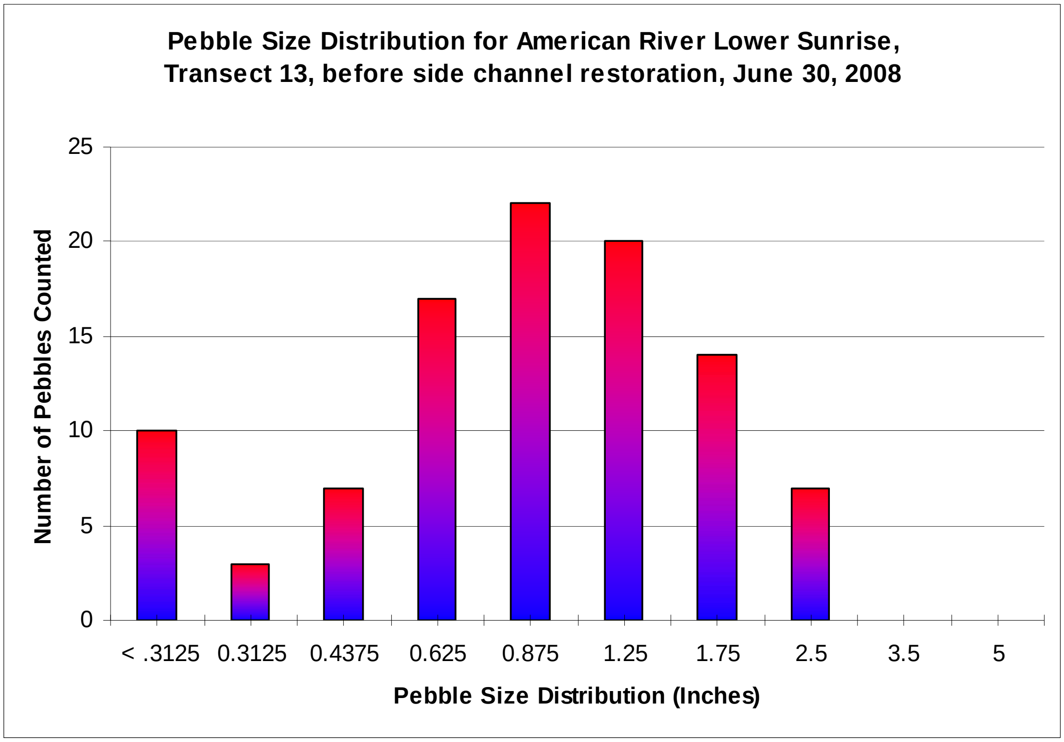
Cumulative frequency graph for Sunrise side channel Transect 11, June 2008.



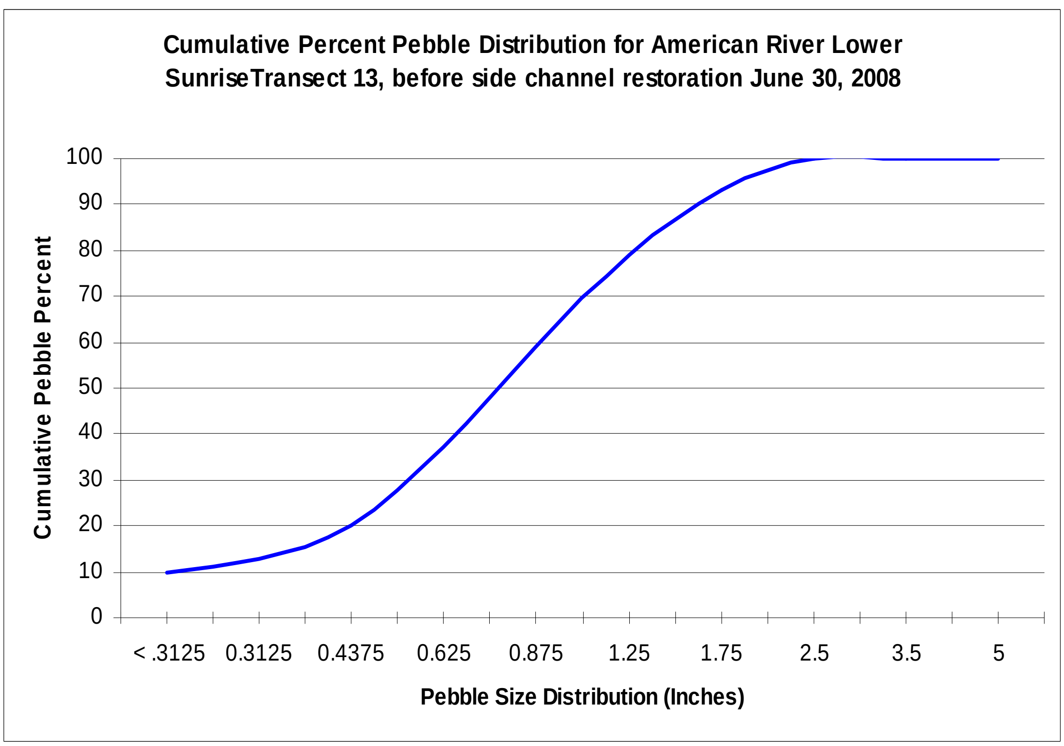
Histograph showing pebble count data Sunrise side channel Transect 12, June 2008.



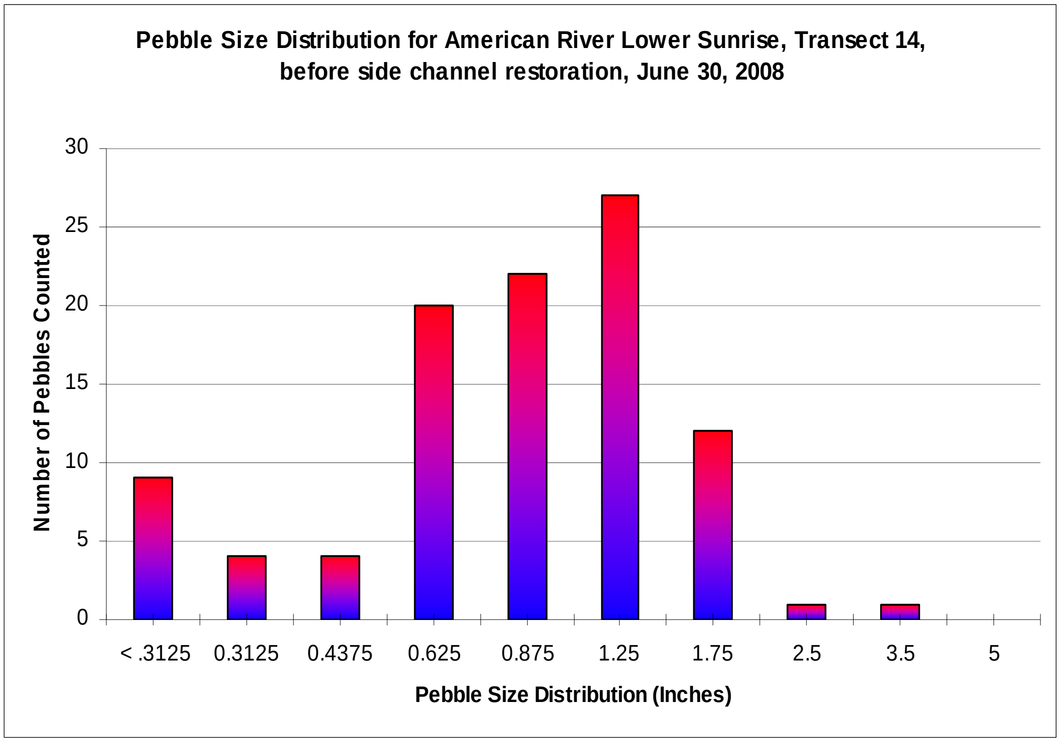
Cumulative frequency graph for Sunrise side channel Transect 12, June 2008.



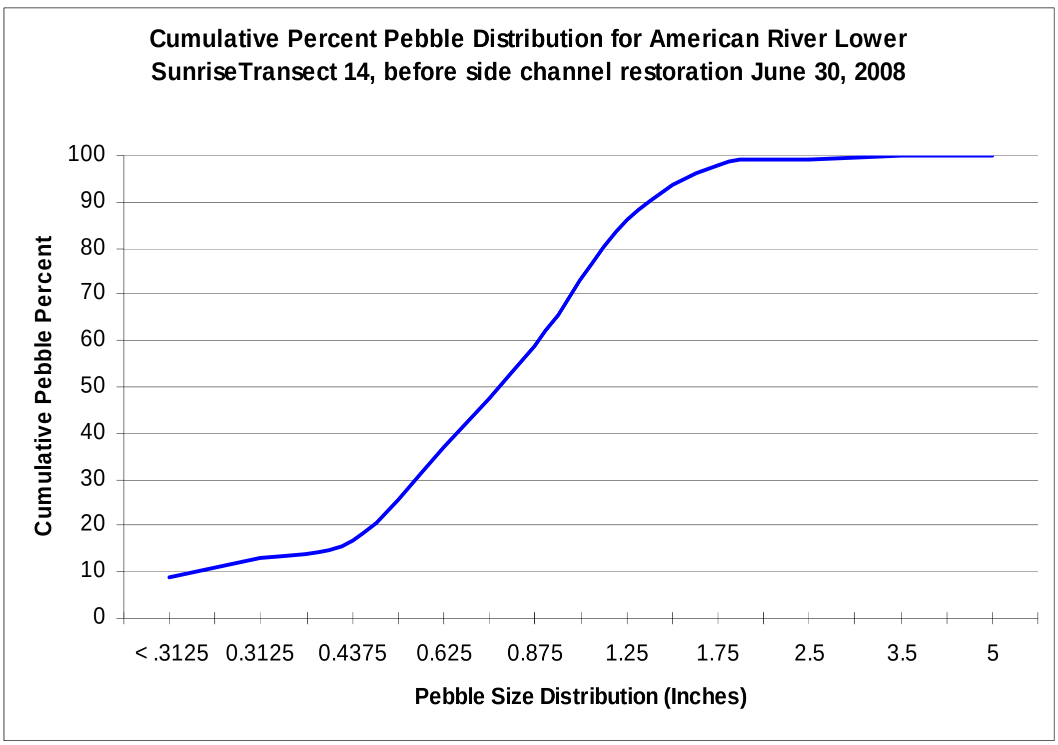
Histograph showing pebble count data Sunrise side channel Transect 13, June 2008.



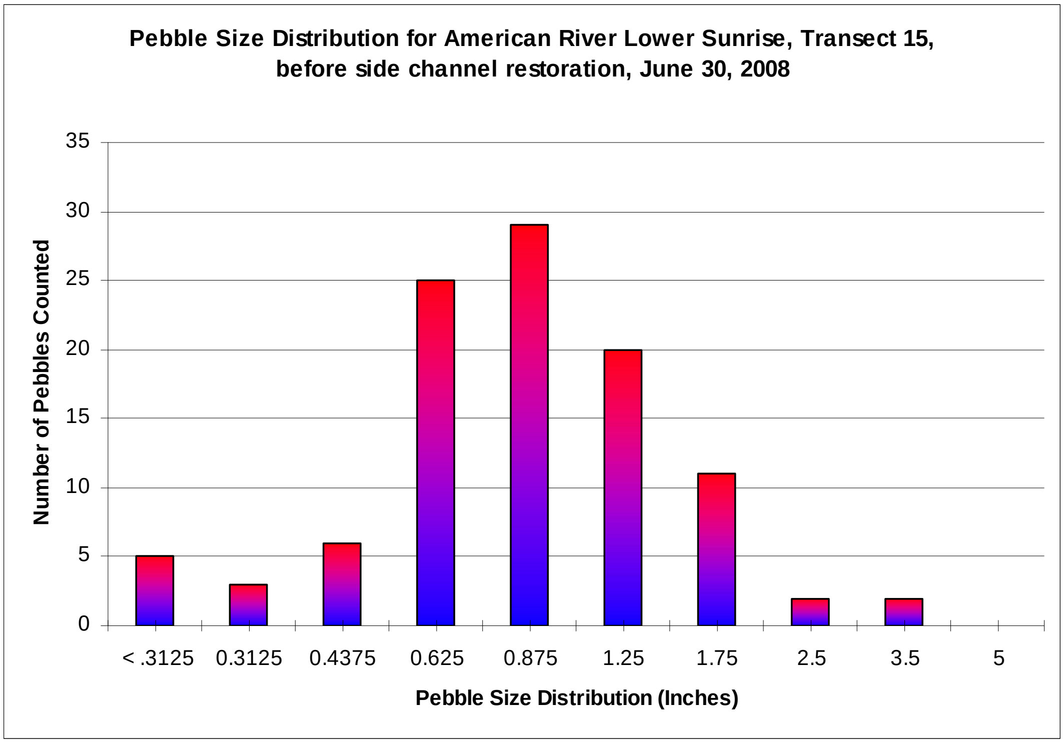
Cumulative frequency graph for Sunrise side channel Transect 13, June 2008.



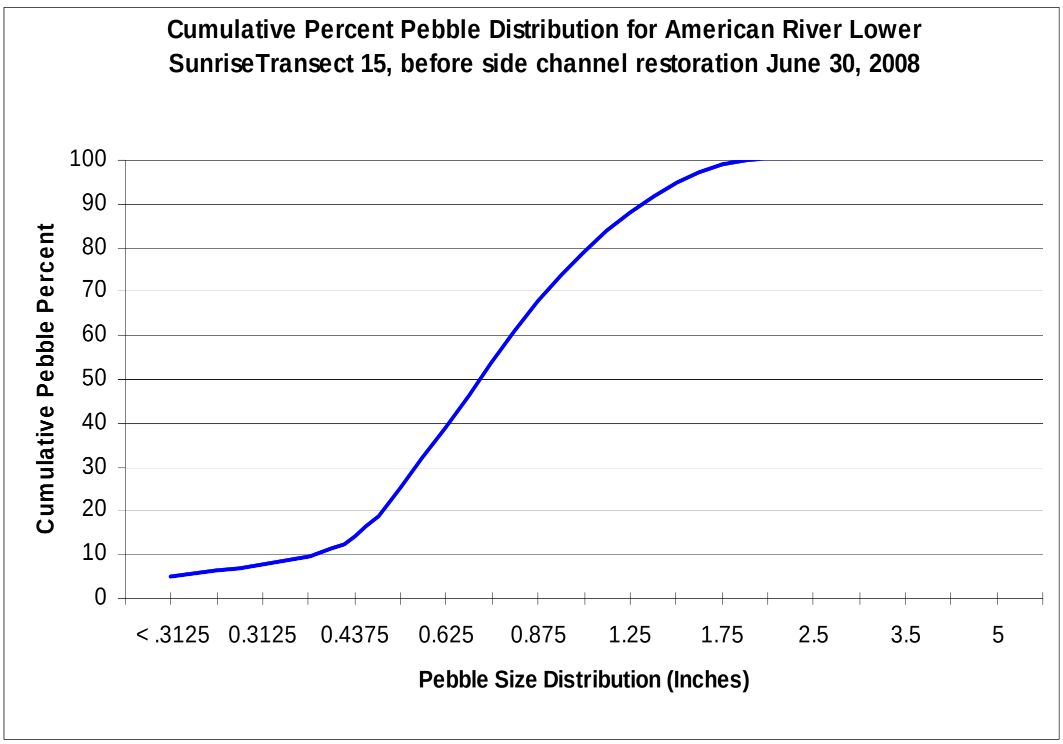
Histograph showing pebble count data Sunrise side channel Transect 14, June 2008



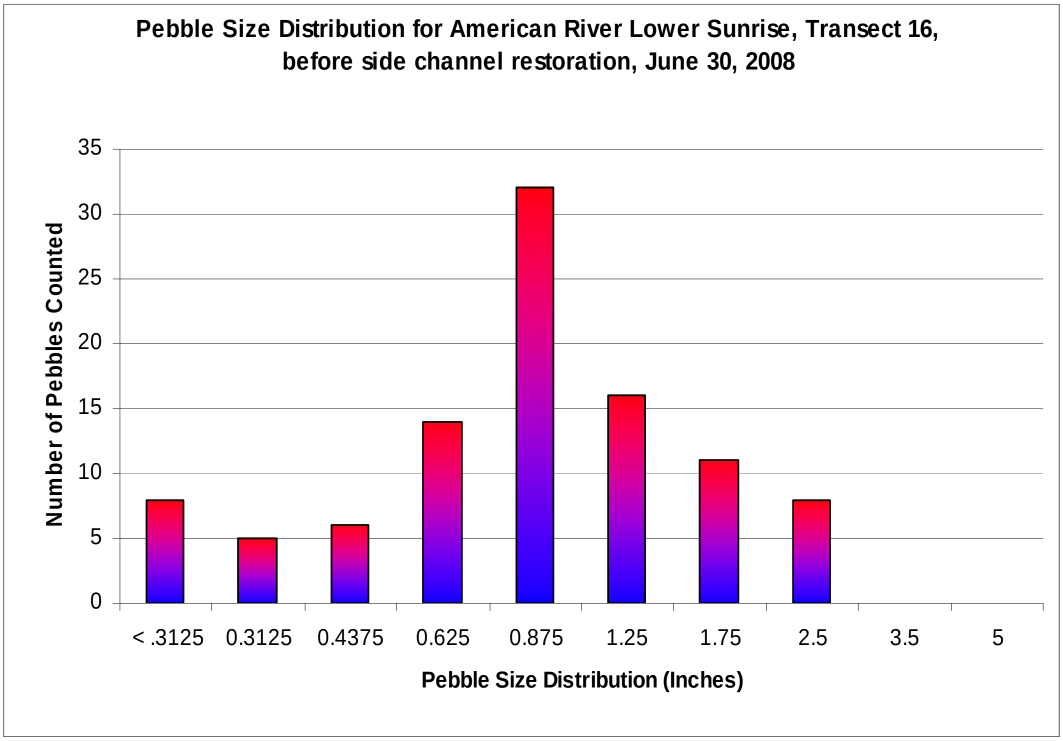
Cumulative frequency graph for Sunrise side channel Transect 14, June 2008.



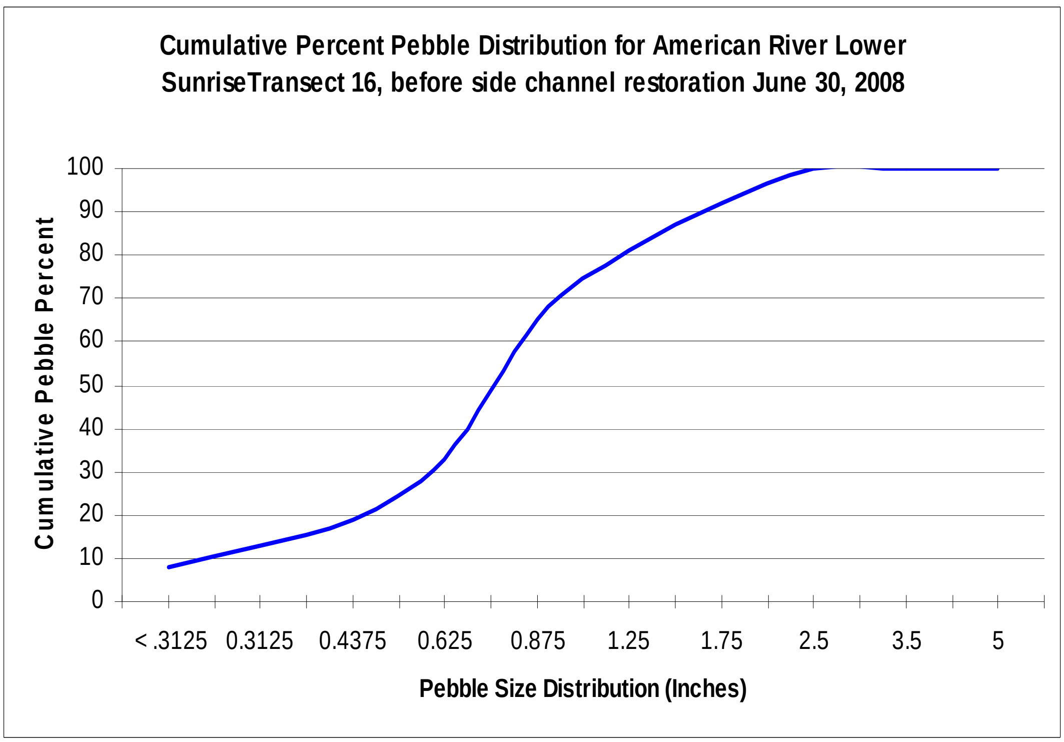
Histograph showing pebble count data Sunrise side channel Transect 15, June 2008



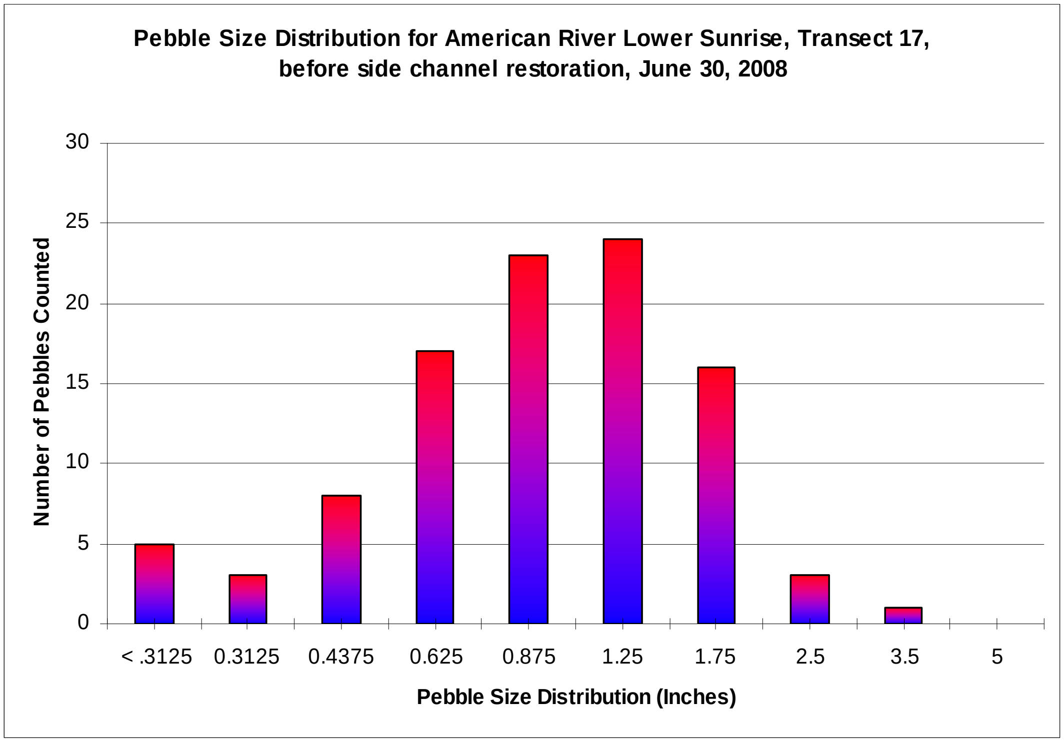
Cumulative frequency graph for Sunrise side channel Transect 15, June 2008.



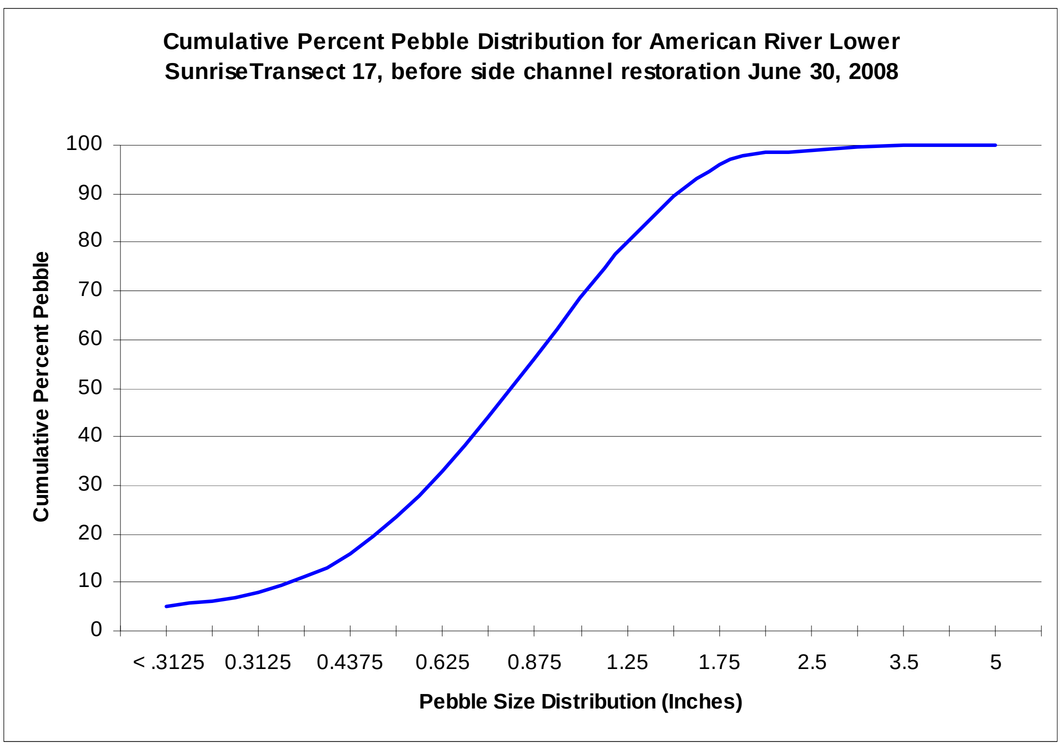
Histograph showing pebble count data Sunrise side channel Transect 16, June 2008



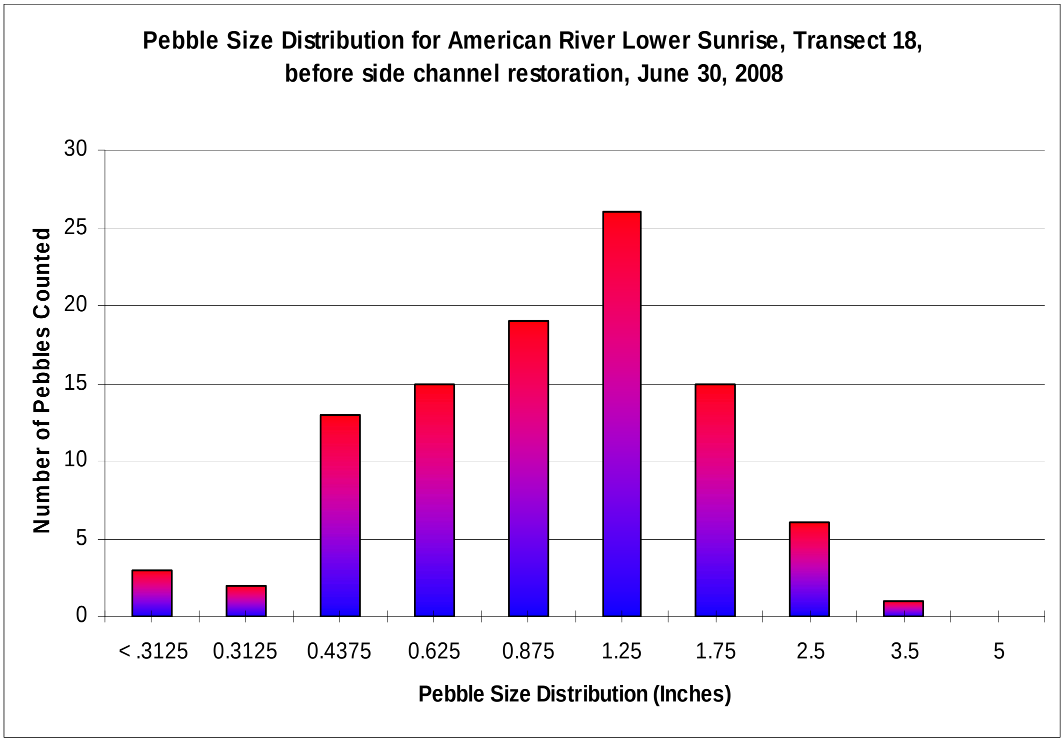
Cumulative frequency graph for Sunrise side channel Transect 16, June 2008.



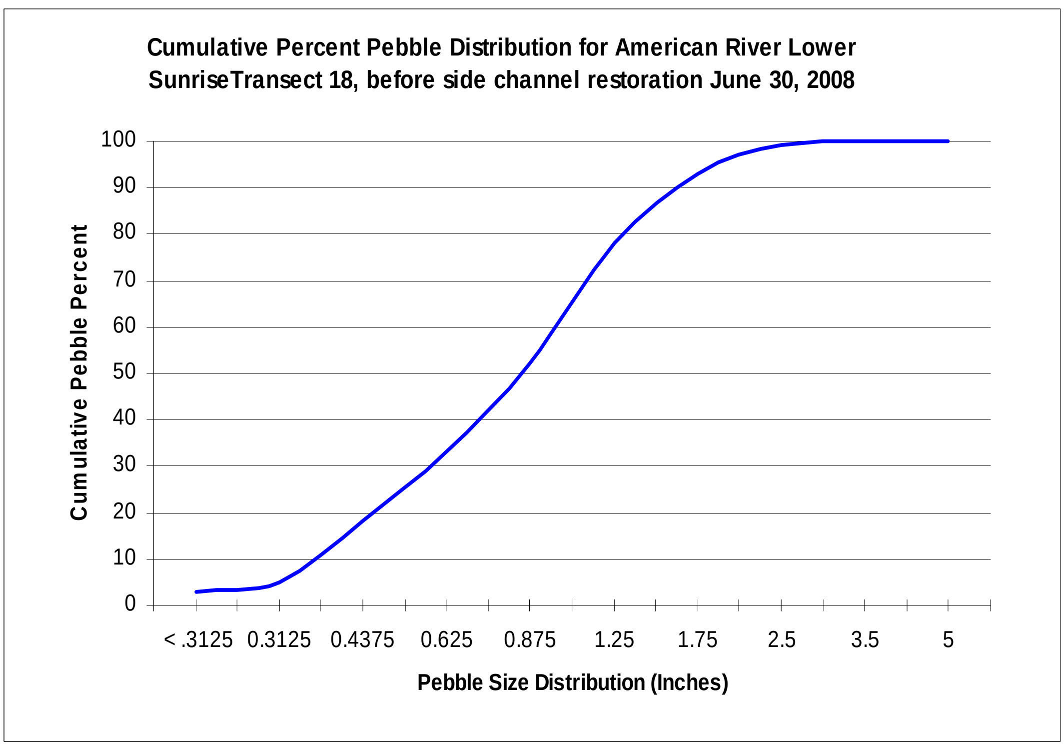
Histograph showing pebble count data Sunrise side channel Transect 17, June 2008



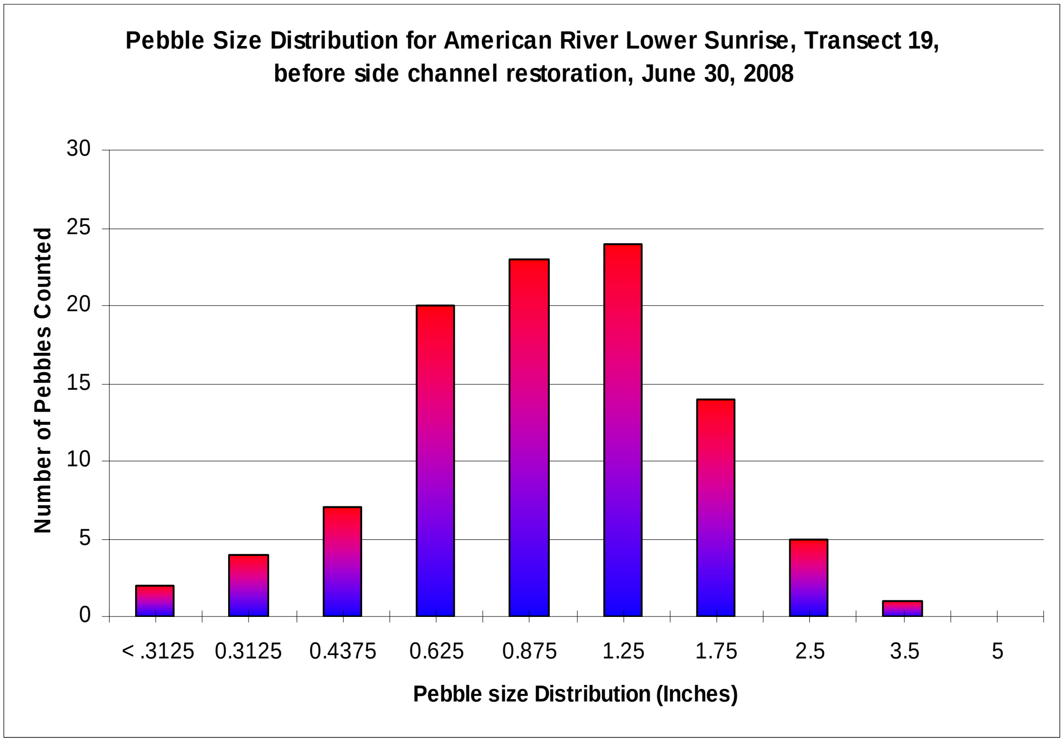
Cumulative frequency graph for Sunrise side channel Transect 17, June 2008.



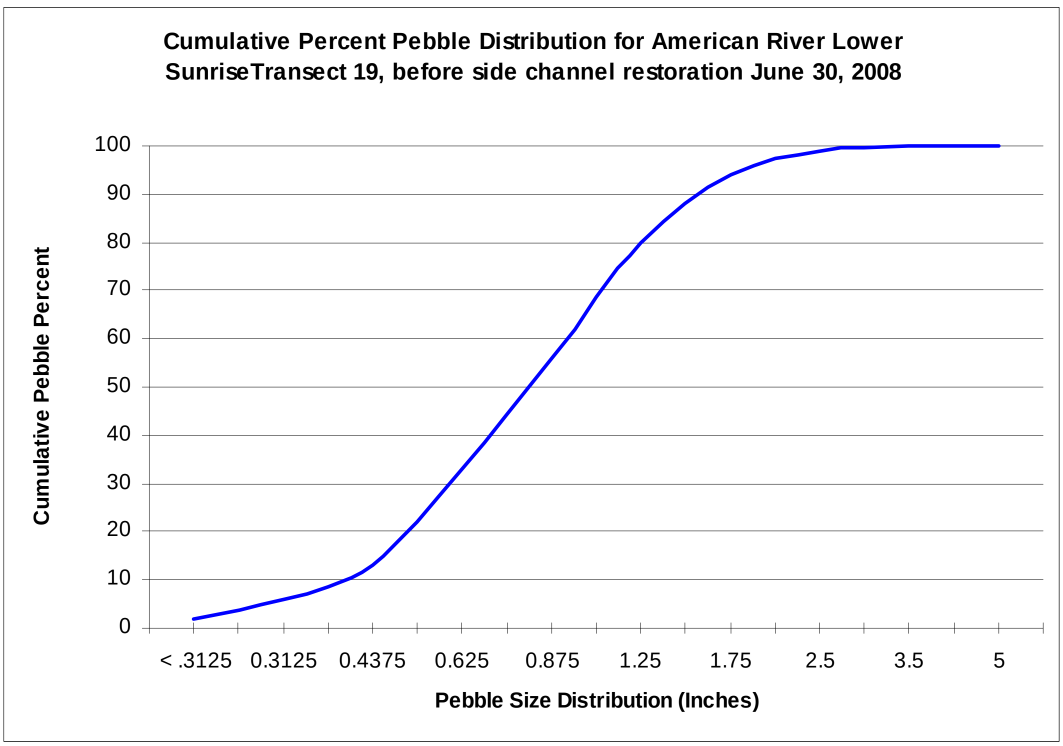
Histograph showing pebble count data Sunrise side channel Transect 18, June 2008



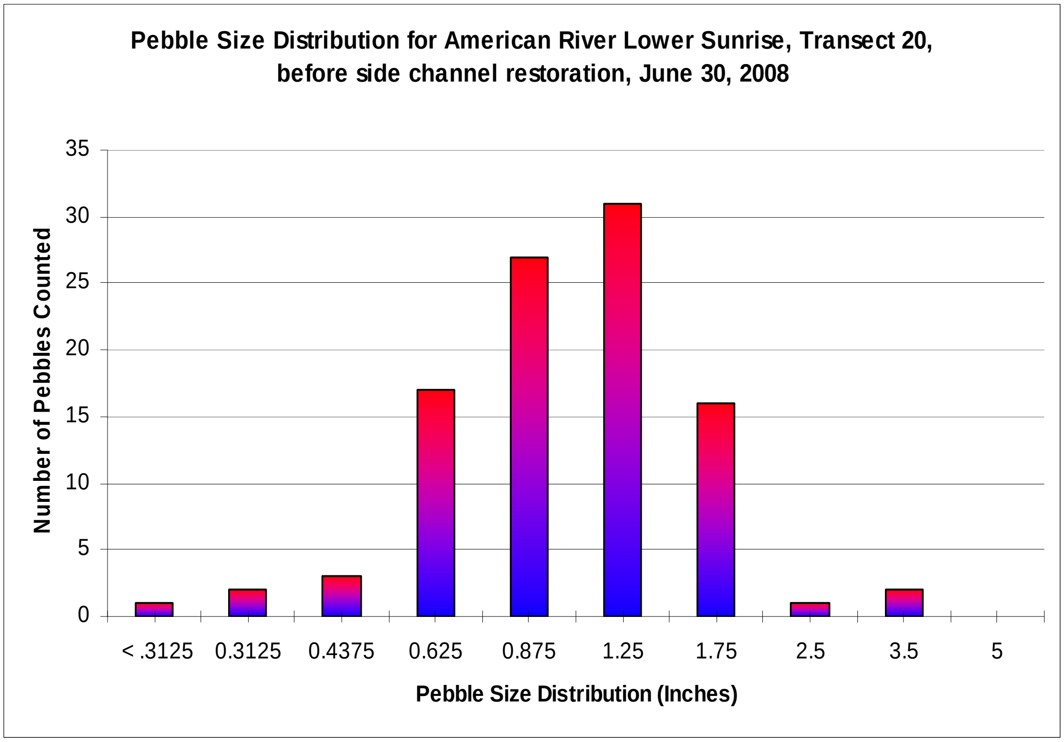
Cumulative frequency graph for Sunrise side channel Transect 18, June 2008.



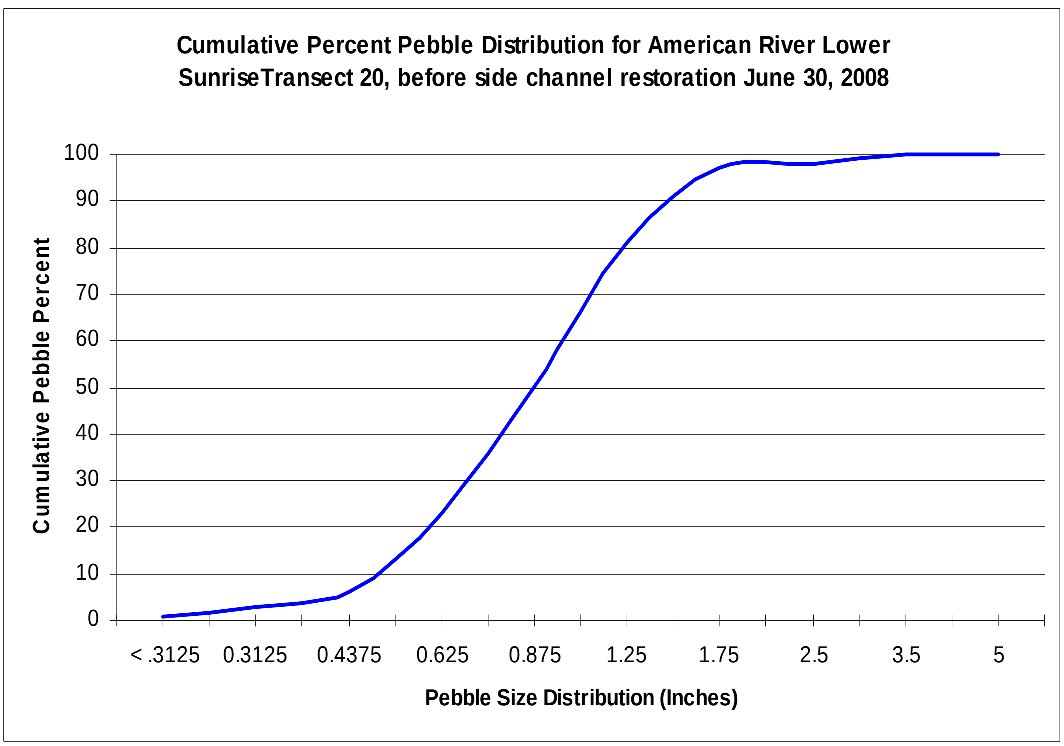
Histograph showing pebble count data Sunrise side channel Transect 19, June 2008



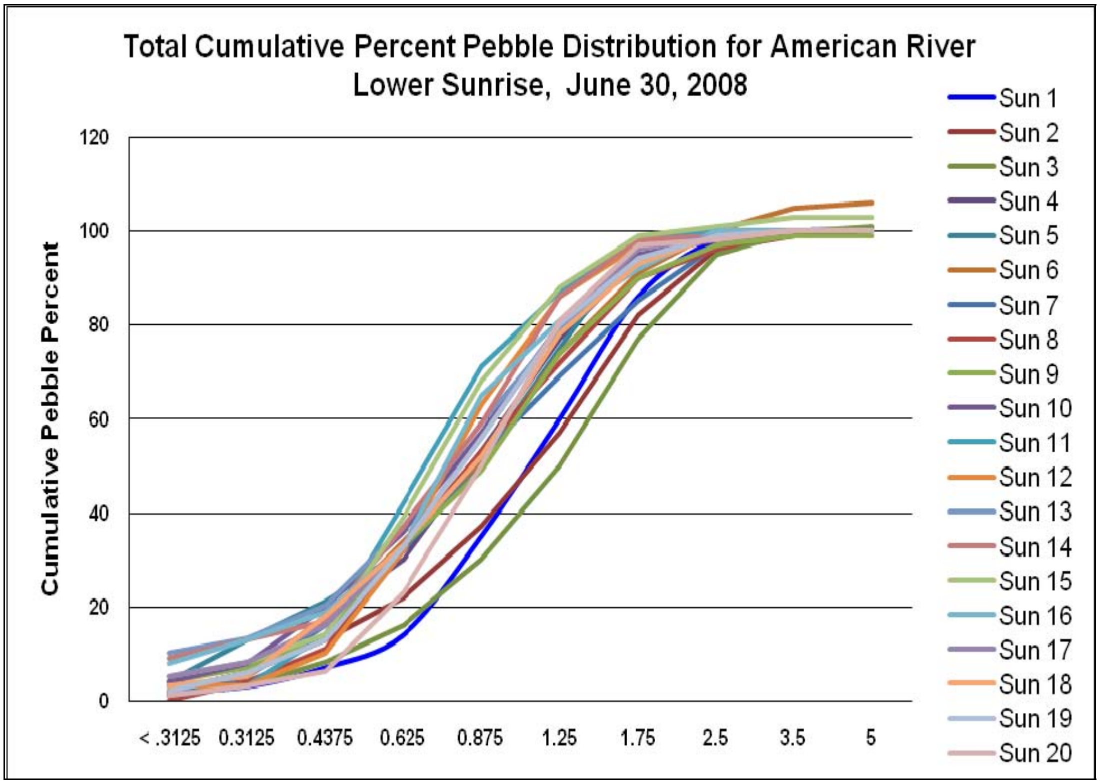
Cumulative frequency graph for Sunrise side channel Transect 19, June 2008.



Histograph showing pebble count data Sunrise side channel Transect 20, June 2008



Cumulative frequency graph for Sunrise side channel Transect 20, June 2008.



Graph showing the cumulative frequency for each pebble count, June 2008.

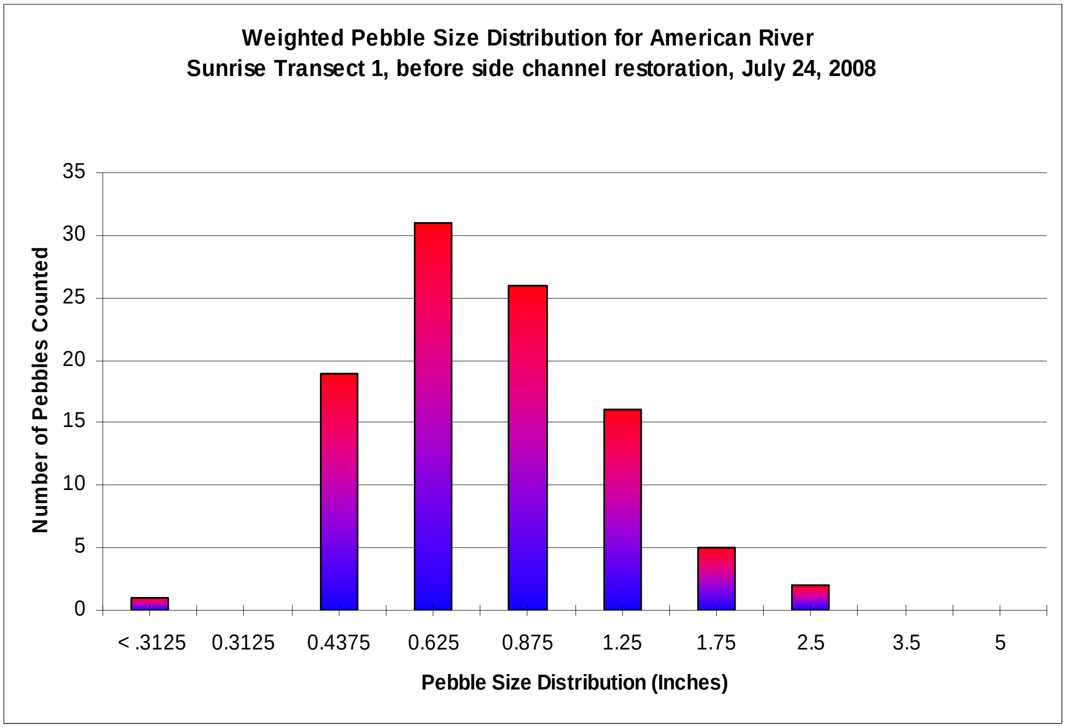
APPENDIX C

Sunrise Weighted Pebble Counts: Conducted Before Side Channel Construction

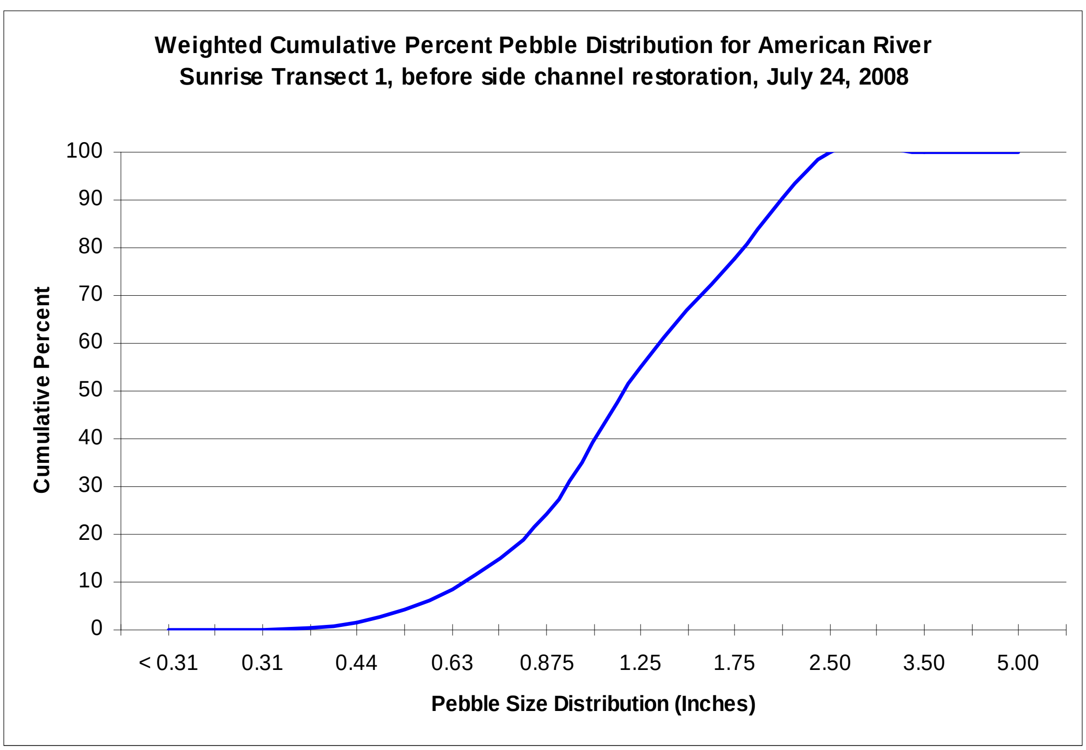
Weighted Pebble Counts from Transect 1, before side channel restoration, July 2008

Pebble Size	Number Counted	Weight	% Total Wt	Cum Wt %
< 0.31	1	0	0	0
0.31	0	0	0	0
0.44	19	0.1	1.72	1.72
0.63	31	0.4	6.9	8.62
0.88	26	0.9	15.52	24.14
1.25	16	1.8	31.03	55.17
1.75	5	1.3	22.41	77.58
2.50	2	1.3	22.41	99.99
3.50	0	0	0	100
5.00	0	0	0	100
Total	100	5.8	99.99	

Data for weighted pebble count 1, Sunrsie side channel, July 2008.



Histograph showing weighted pebble count data, Sunrise Transect 1, July 2008.

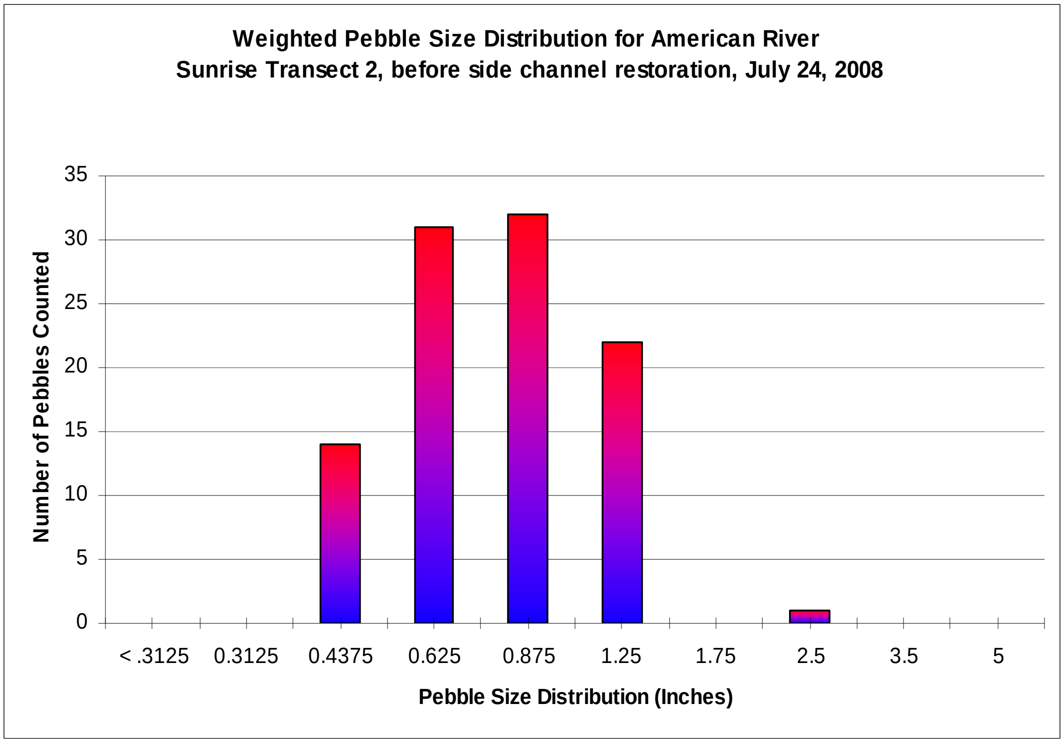


Cumulative frequency graph for Sunrise weighted pebble count Transect 1, July 2008.

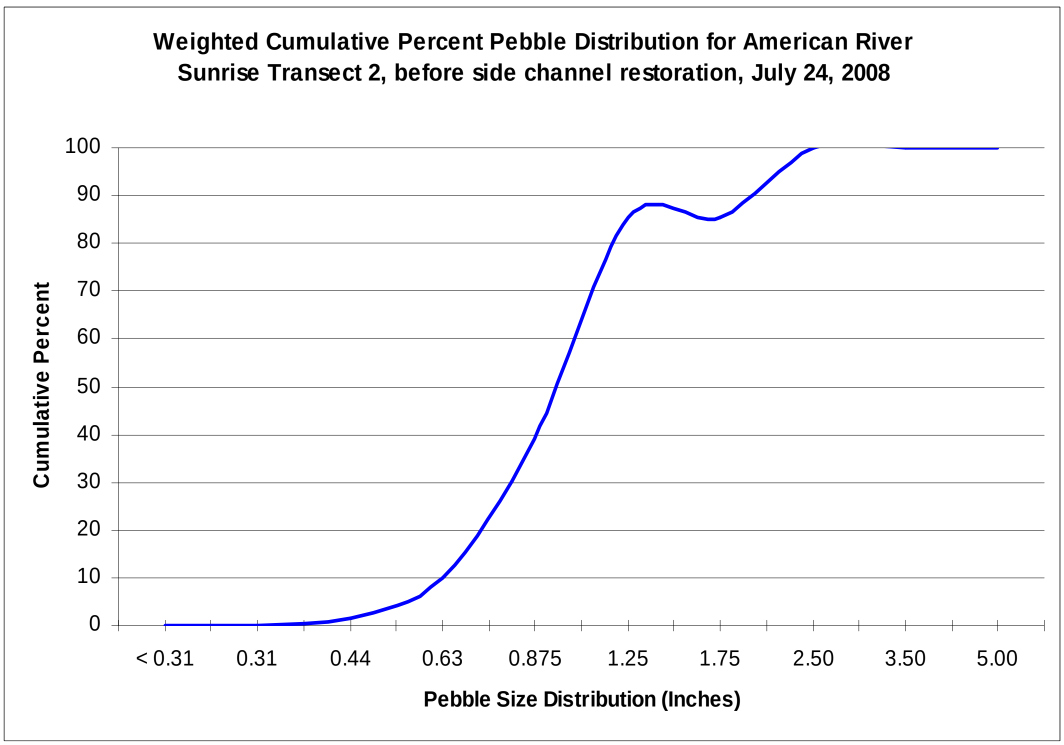
Weighted Pebble Counts from Transect 2, before side channel restoration, July 2008

Pebble Size	Number Counted	Weight	% Total Wt	Cum Wt %
< 0.31	0	0	0	0
0.31	0	0	0	0
0.44	14	0.05	1.45	1.45
0.63	31	0.3	8.70	10.15
0.88	32	1	28.99	39.13
1.25	22	1.6	46.38	85.51
1.75	0	0	0.00	85.51
2.50	1	0.5	14.49	100.00
3.50	0	0	0	100
5.00	0	0	0	100
Total	100	3.45	100.00	

Data for weighted pebble count 2, Sunrsie side channel, July 2008.



Histograph showing weighted pebble count data, Sunrise Transect 2, July 2008.

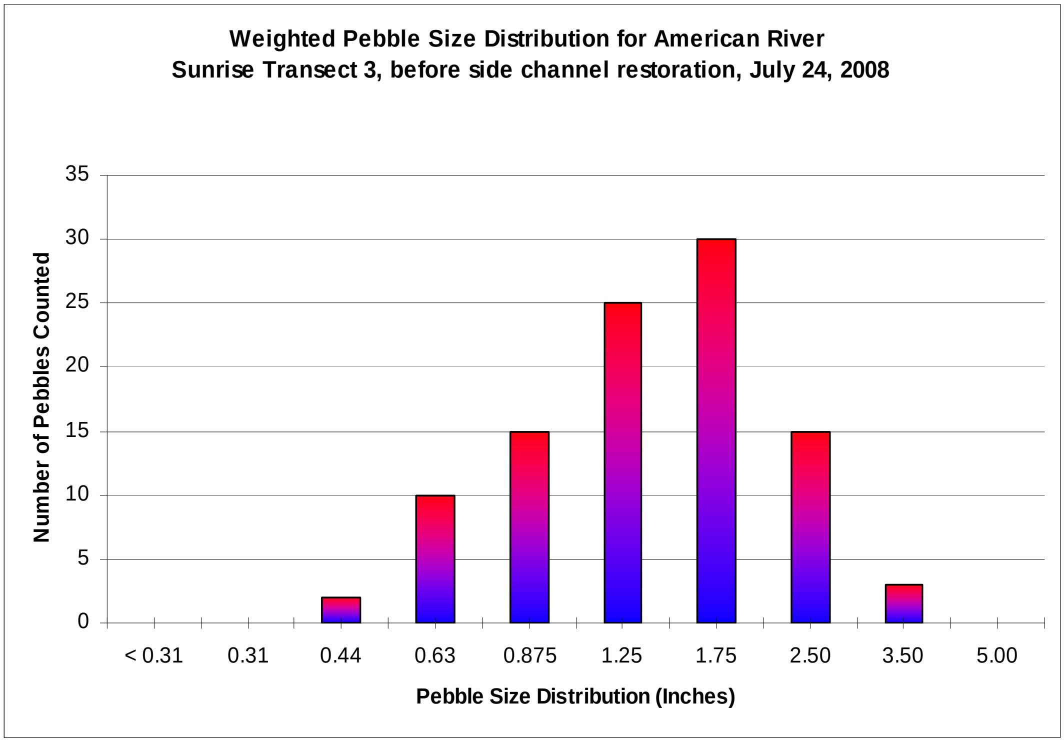


Cumulative frequency graph for Sunrise weighted pebble count Transect 2, July 2008.

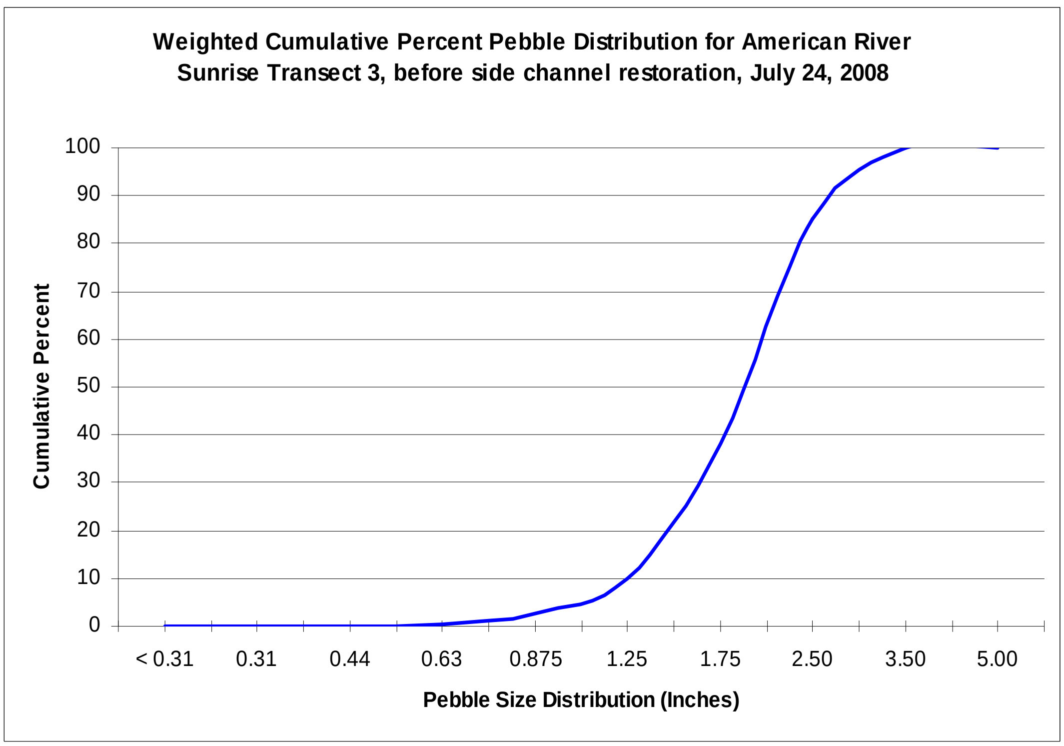
Weighted Pebble Counts from Transect 3, before side channe restoration, July 2008

Pebble Size	Number Counted	Weight	% Total Wt	Cum Wt %
< 0.31	0	0	0	0
0.31	0	0	0	0
0.44	2	0.05	0.19	0.19
0.63	10	0.1	0.38	0.57
0.88	15	0.6	2.26	2.83
1.25	25	1.9	7.16	9.98
1.75	30	7.5	28.25	38.23
2.50	15	12.4	46.70	84.94
3.50	3	4	15.07	100.00
5.00	0	0	0	100
Total	100	26.55	100.00	

Data for weighted pebble count 3, Sunrsie side channel, July 2008.



Histograph showing weighted pebble count data, Sunrise Transect 3, July 2008.

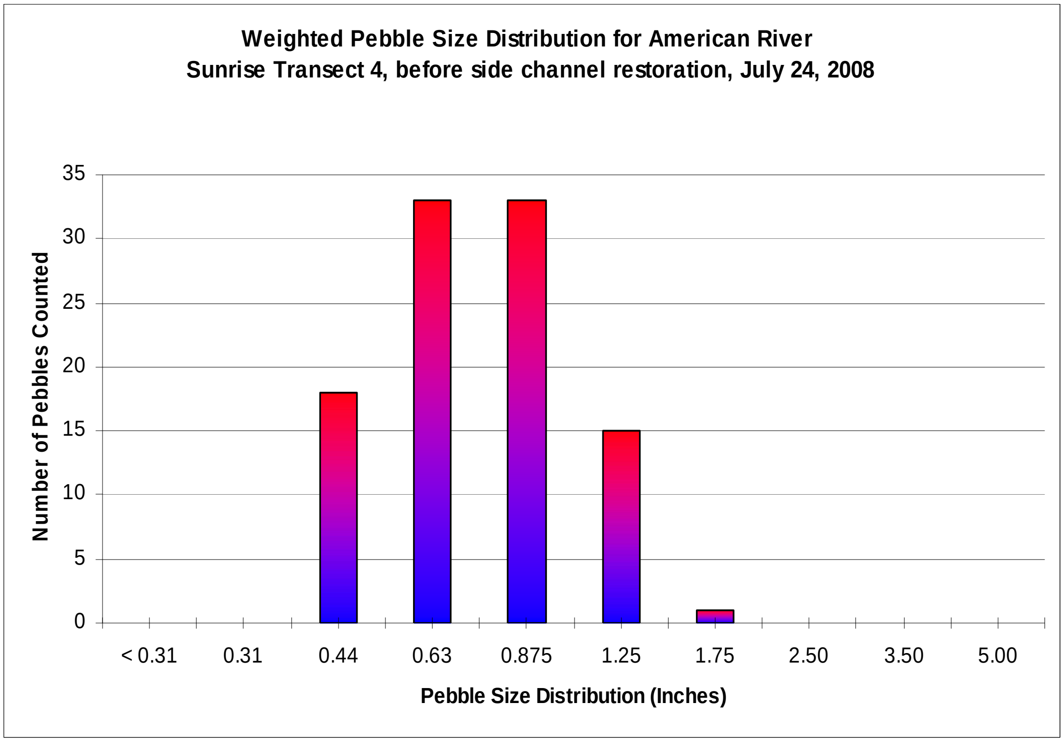


Cumulative frequency graph for Sunrise weighted pebble count Transect 3, July 2008.

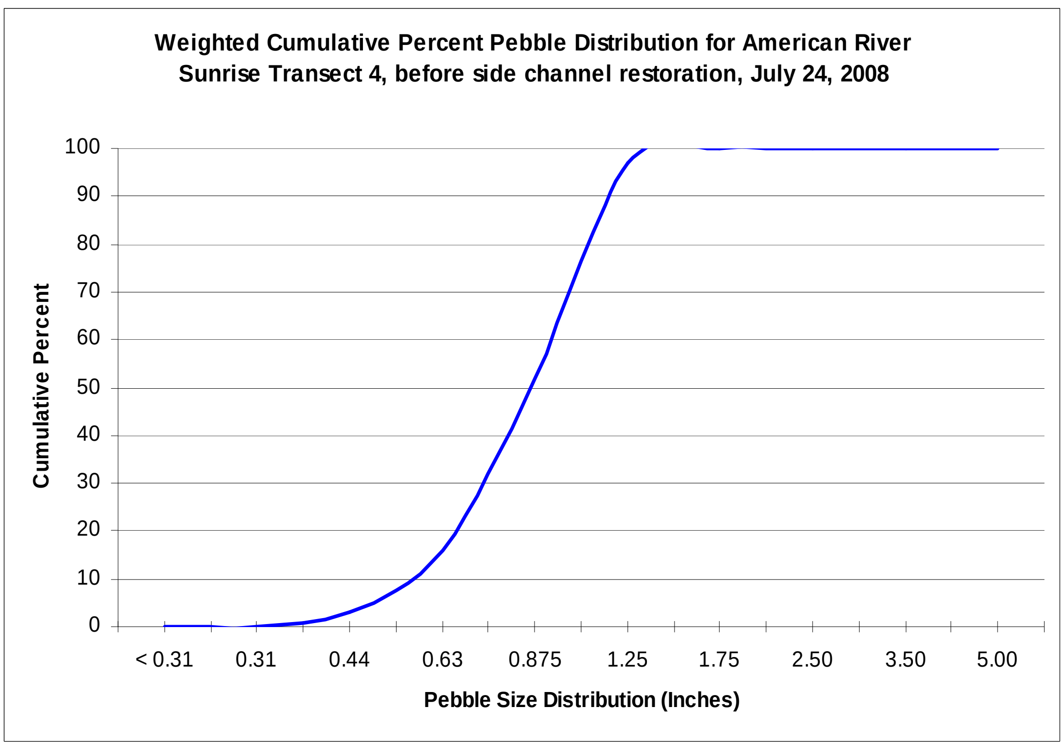
Weighted Pebble Counts from Transect 4, before side channe
restoration, July 2008

Pebble Size	Number Counted	Weight	% Total Wt	Cum Wt %
< 0.31	0	0	0	0
0.31	0	0	0	0
0.44	18	0.1	3.23	3.23
0.63	33	0.4	12.90	16.13
0.88	33	1.1	35.48	51.62
1.25	15	1.4	45.16	96.78
1.75	1	0.1	3.23	100.00
2.50	0	0	0.00	100.00
3.50	0	0	0.00	100.00
5.00	0	0	0	100
Total	100	3.1	100.00	

Data for weighted pebble count 4, Sunrsie side channel, July 2008.



Histograph showing weighted pebble count data, Sunrise Transect 4, July 2008.



Cumulative frequency graph for Sunrise weighted pebble count Transect 4, July 2008.

APPENDIX D

Sunrise Stream Velocity And Stream Depth

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	4.35	1.7	1.67	12.36
2	4.35	2.9	1.78	22.48
3	4.35	2.8	2.19	26.62
4	4.35	2.8	2.41	29.31
5	4.35	2.4	2.33	24.35
6	4.35	2.7	2.15	25.24
7	4.35	2.2	2.37	22.68
8	4.35	2.3	2.59	25.91
9	4.35	2.9	1.97	24.79
10	4.35	0.9	1.08	4.24
			Qtotal =	217.99

Cross Section 1 (11/21/2008), at 1165 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	4.6	0.7	1.82	5.86
2	4.6	1.2	2.55	14.09
3	4.6	1.6	2.66	19.60
4	4.6	1.5	1.89	13.05
5	4.6	1.8	3.47	28.75
6	4.6	1.9	3.69	32.27
7	4.6	1.8	3.77	31.18
8	4.6	1.8	3.55	29.36
9	4.6	1.3	3.66	21.86
10	4.6	0.7	1.93	6.21
			Qtotal =	202.24

Cross Section 2 (11/21/2008), at 1165 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft³/sec)
1	4.56	0.83	1.82	6.91
2	4.56	1.42	2.52	16.26
3	4.56	1.54	2.88	20.27
4	4.56	1.50	2.88	19.73
5	4.56	1.71	2.63	20.46
6	4.56	2.00	3.36	30.66
7	4.56	1.75	3.33	26.53
8	4.56	1.75	3.21	25.65
9	4.56	1.96	2.66	23.79
10	4.56	0.65	NA	0.00
			Qtotal =	190.26

Cross Section 3 (11/21/2008), at 1165 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft³/sec)
1	5.5	0.65	0.20	0.72
2	5.5	1.1	1.82	11.00
3	5.5	2.3	2.26	28.58
4	5.5	2.4	2.22	29.34
5	5.5	2.6	1.97	28.10
6	5.5	2.8	2.00	30.83
7	5.5	2.7	1.89	28.09
8	5.5	2	1.19	13.13
9	5.5	1.6	0.28	2.42
10	5.5	0.7	0.02	0.07
			Qtotal =	172.29

Cross Section 4 (11/24/2008), at 1165 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	5.5	0.70	1.12	4.31
2	5.5	1.60	2.04	17.94
3	5.5	1.80	2.00	19.82
4	5.5	1.90	1.97	20.54
5	5.5	2.10	1.86	21.43
6	5.5	2.40	2.04	26.91
7	5.5	2.10	2.08	23.97
8	5.5	2.30	2.11	26.72
9	5.5	2.20	1.60	19.33
10	5.5	1.00	0.79	4.34
			Qtotal =	185.33

Cross Section 5 (11/24/2008), at 1165 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	5.9	1.3	0.83	6.34
2	5.9	1.9	1.86	20.80
3	5.9	1.9	2.08	23.27
4	5.9	1.9	2.19	24.50
5	5.9	1.9	2.22	24.92
6	5.9	1.8	2.30	24.38
7	5.9	2	2.00	23.63
8	5.9	2	2.04	24.06
9	5.9	1.8	1.05	11.12
10	5.9	0.7	0.20	0.83
			Qtotal =	183.84

Cross Section 6 (11/24/2008), at 1165 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	6.6	1.8	1.34	15.93
2	6.6	1.9	1.23	15.43
3	6.6	2.4	1.45	22.98
4	6.6	2.4	1.74	27.64
5	6.6	2.3	1.60	24.26
6	6.6	2.2	1.49	21.60
7	6.6	2	1.74	23.03
8	6.6	1.5	1.27	12.55
9	6.6	1.5	1.34	13.27
10	6.6	1.1	0.94	6.80
			Qtotal =	183.49

Cross Section 7 (11/24/2008), at 1165 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	6.6	1.3	1.01	8.67
2	6.6	2.5	0.83	13.63
3	6.6	2.4	1.27	20.07
4	6.6	2.3	1.56	23.70
5	6.6	2.4	0.53	8.43
6	6.6	1.9	1.67	20.96
7	6.6	2.2	1.49	21.60
8	6.6	1.9	1.34	16.81
9	6.6	2	1.60	21.09
10	6.6	1.3	1.34	11.50
			Qtotal =	166.47

Cross Section 8 (11/24/2008), at 1165 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	3	0.1	NA	0.00
2	3	0.7	2.00	4.20
3	3	1.8	2.74	14.78
4	3	2.8	2.74	22.99
5	3	4.0	2.96	35.49
6	3	4.4	3.33	43.89
7	3	4.1	3.62	44.51
8	3	4.0	3.40	40.78
9	3	4.0	3.47	41.66
10	3	5.0	NA	0.00
11	3	5.3	NA	0.00
12	3	5.2	NA	0.00
13	3	5.0	NA	0.00
14	3	4.3	3.91	50.48
15	3	4.6	4.43	61.10
16	3	3.0	3.99	35.88
17	3	1.9	3.77	21.47
18	3	1.1	1.86	6.12
19	3	0.3	0.61	0.55
			Q total =	**423.90**

Cross Section 1 (6/11/2009), at 2000 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	2.7	0.4	NA	0.00
2	2.7	0.9	1.34	3.26
3	2.7	1.5	2.00	8.11
4	2.7	2.1	3.03	17.19
5	2.7	2.3	2.52	15.63
6	2.7	2.4	2.88	18.69
7	2.7	2.5	3.10	20.96
8	2.7	2.4	3.69	23.93
9	2.7	2.8	3.10	23.47
10	2.7	3	3.77	30.50
11	2.7	3	3.47	28.12
12	2.7	3.2	3.77	32.54
13	2.7	3	3.33	26.93
14	2.7	2.8	3.77	28.47
15	2.7	2.5	3.99	26.91
16	2.7	2.8	3.62	27.36
17	2.7	2.1	3.40	19.27
18	2.7	1.5	3.40	13.76
19	2.7	0.9	2.30	5.58
20	2.7	0.1	NA	0.00
			Q total =	**370.67**

Cross Section 2 (6/11/2009), at 2000 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	2.5	0.40	NA	0.00
2	2.5	1.20	1.41	4.24
3	2.5	1.90	2.22	10.56
4	2.5	2.30	2.81	16.16
5	2.5	2.40	2.81	16.86
6	2.5	2.60	2.96	19.22
7	2.5	2.70	3.33	22.44
8	2.5	2.60	3.40	22.09
9	2.5	2.80	3.40	23.79
10	2.5	3.30	3.55	29.25
11	2.5	3.20	3.47	27.78
12	2.5	3.20	3.55	28.36
13	2.5	3.10	3.84	29.76
14	2.5	2.90	3.84	27.84
15	2.5	2.80	3.91	27.39
16	2.5	2.60	3.40	22.09
17	2.5	2.30	3.62	20.81
18	2.5	1.90	2.96	14.05
19	2.5	1.40	2.15	7.52
20	2.5	0.50	1.19	1.49
			Q total =	**371.71**

Cross Section 3 (6/11/2009), at 2000 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	2.9	0.4	0.83	0.00
2	2.9	1.4	2.22	9.02
3	2.9	1.9	3.10	17.11
4	2.9	2.6	3.69	27.84
5	2.9	2.8	3.69	29.98
6	2.9	3	3.69	32.12
7	2.9	3.1	3.77	33.86
8	2.9	3.1	3.55	31.87
9	2.9	3.2	3.69	34.27
10	2.9	3	3.25	28.29
11	2.9	2.5	3.40	24.64
12	2.9	2.2	3.47	22.15
13	2.9	1.9	3.33	18.32
14	2.9	1.7	3.25	16.03
15	2.9	1.8	3.03	15.82
16	2.9	1.9	2.44	13.46
17	2.9	1.6	2.37	10.99
18	2.9	1.7	1.71	8.42
19	2.9	1.1	0.09	0.29
20	2.9	0.4	NA	0.00
			Q total =	**374.49**

Cross Section 4 (6/11/2009), at 2000 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	3.2	0.50	NA	0.00
2	3.2	1.50	1.71	8.20
3	3.2	2.10	2.08	13.95
4	3.2	2.40	2.81	21.58
5	3.2	2.60	3.18	26.44
6	3.2	2.60	3.18	26.44
7	3.2	2.60	3.25	27.05
8	3.2	2.60	3.25	27.05
9	3.2	2.50	3.40	27.19
10	3.2	1.80	3.10	17.88
11	3.2	2.50	3.33	26.60
12	3.2	2.50	3.03	24.25
13	3.2	2.80	3.40	30.45
14	3.2	2.80	2.81	25.18
15	3.2	2.80	2.88	25.84
16	3.2	2.60	2.52	20.94
17	3.2	1.10	1.49	5.24
18	3.2	0.80	0.75	1.93
19	3.2	NA	NA	0.00
			Q total =	**356.21**

Cross Section 5 (6/11/2009, at 2000 cfs)

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	3.2	0.6	0.97	0.00
2	3.2	1.7	2.30	12.49
3	3.2	2.6	2.59	21.55
4	3.2	2.8	2.66	23.87
5	3.2	2.8	2.88	25.84
6	3.2	2.8	2.96	26.50
7	3.2	2.6	2.88	24.00
8	3.2	2.6	2.96	24.61
9	3.2	2	2.81	17.99
10	3.2	2	2.88	18.46
11	3.2	2	2.96	18.93
12	3.2	2.1	2.44	16.42
13	3.2	2.1	2.52	16.91
14	3.2	2	2.44	15.64
15	3.2	2	2.37	15.17
16	3.2	2.5	2.15	17.19
17	3.2	2.5	2.37	18.96
18	3.2	2	1.49	9.52
19	3.2	1.4	0.53	2.38
20	3.2	0.2	NA	0.00
			Q total =	**326.41**

Cross Section 6 (6/11/2009), at 2000 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	6.6	1.8	1.34	15.93
2	6.6	1.9	1.23	15.43
3	6.6	2.4	1.45	22.98
4	6.6	2.4	1.74	27.64
5	6.6	2.3	1.60	24.26
6	6.6	2.2	1.49	21.60
7	6.6	2	1.74	23.03
8	6.6	1.5	1.27	12.55
9	6.6	1.5	1.34	13.27
10	6.6	1.1	0.94	6.80

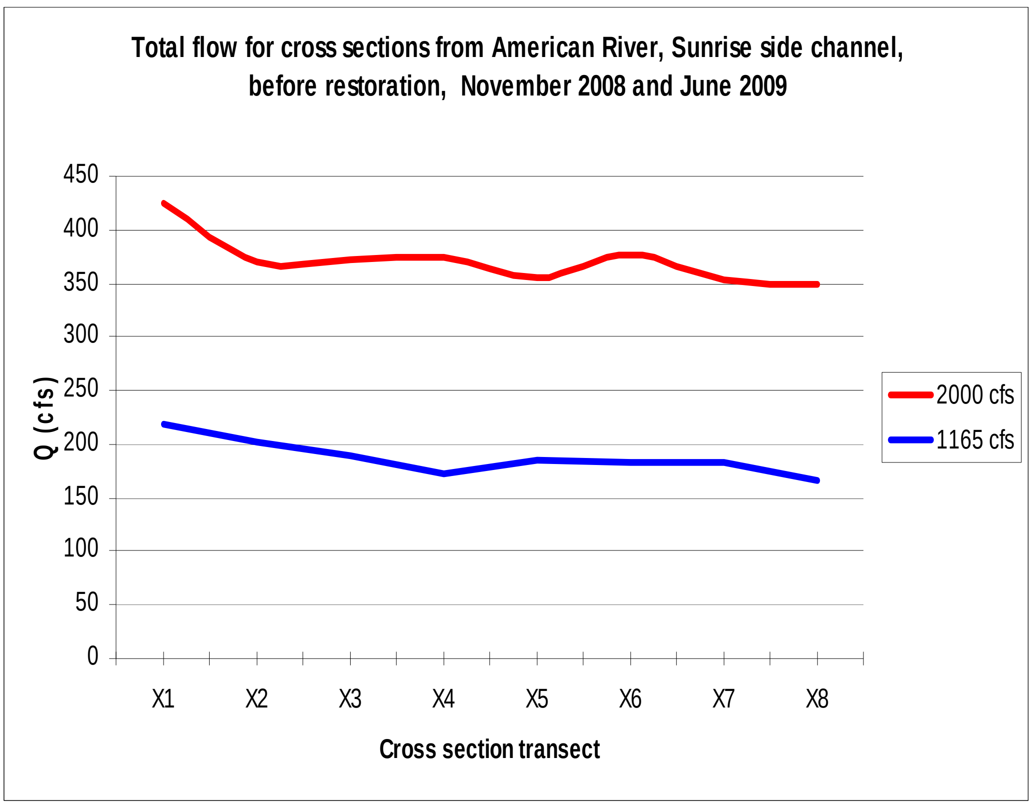
Q total = 351.49

Cross Section 7 (6/11/2009), at 2000 cfs

River Segment	Width (ft)	Water Depth (ft)	V at the 0 .6 depth (ft/sec)	Q (ft^3/sec)
1	6.6	1.3	1.01	8.67
2	6.6	2.5	0.83	13.63
3	6.6	2.4	1.27	20.07
4	6.6	2.3	1.56	23.70
5	6.6	2.4	0.53	8.43
6	6.6	1.9	1.67	20.96
7	6.6	2.2	1.49	21.60
8	6.6	1.9	1.34	16.81
9	6.6	2	1.60	21.09
10	6.6	1.3	1.34	11.50

Q total = 348.47

Cross Section 8 (6/11/2009), at 2000 cfs



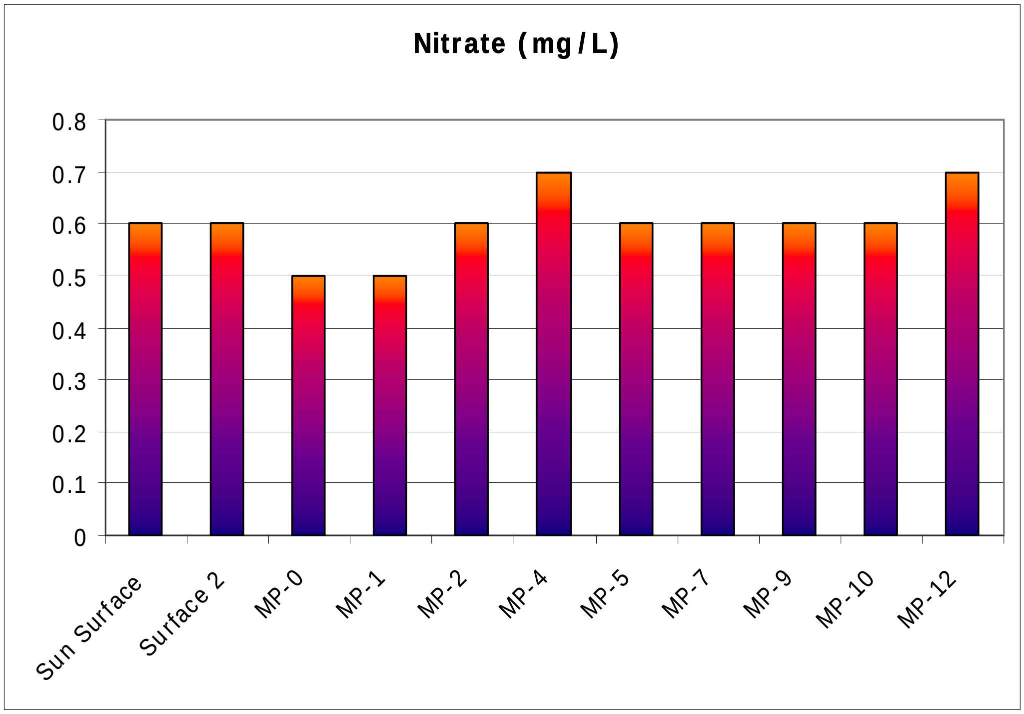
Graph showing differnces in measured flow in the side channel from November 2008 and June 2009.

APPENDIX E

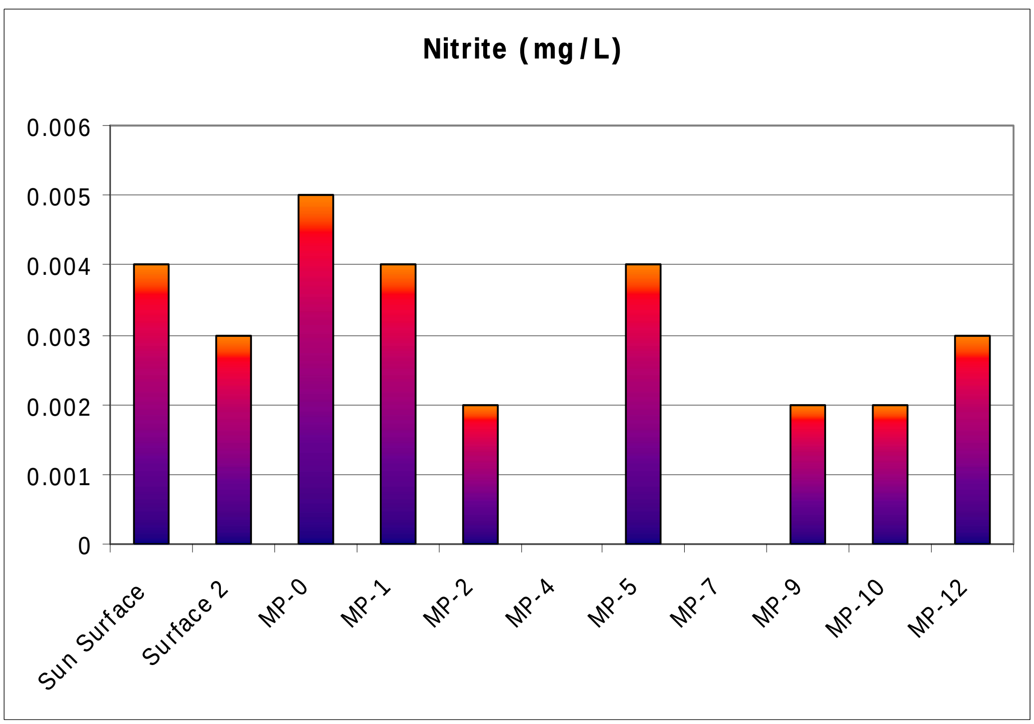
Hach Water Chemistry

Location	Date Sampled	Sample ID	Nitrate, mg/L	Nitrite, mg/L	Ammonia, mg/L	Phosphate, mg/L
Sunrise	2/21/2009	Sun Surface	0.6	0.004	0	0.1
Sunrise	2/21/2009	Surface 2	0.6	0.003	0	0.13
Sunrise	2/21/2009	MP-0	0.5	0.005	0	0.1
Sunrise	2/21/2009	MP-1	0.5	0.004	-	0.18
Sunrise	2/21/2009	MP-2	0.6	0.002	0.2	0.24
Sunrise	2/21/2009	MP-4	0.7	-	0.17	0.12
Sunrise	2/21/2009	MP-5	0.6	0.004	0.1	0.1
Sunrise	2/21/2009	MP-7	0.6	-	0.1	0.01
Sunrise	2/21/2009	MP-9	0.6	0.002	0.02	0.13
Sunrise	2/21/2009	MP-10	0.6	0.002	0.1	0.03
Sunrise	2/21/2009	MP-12	0.7	0.003	0.07	0.1

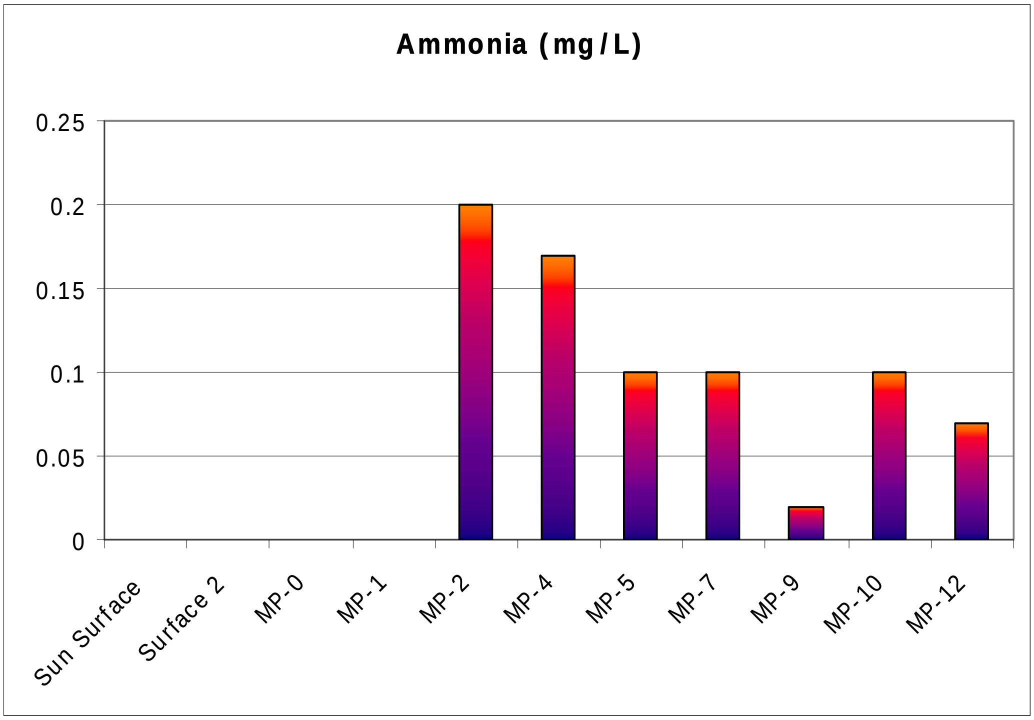
HACH Chemistry data for the Sunrise side channel, data collected February 2009.



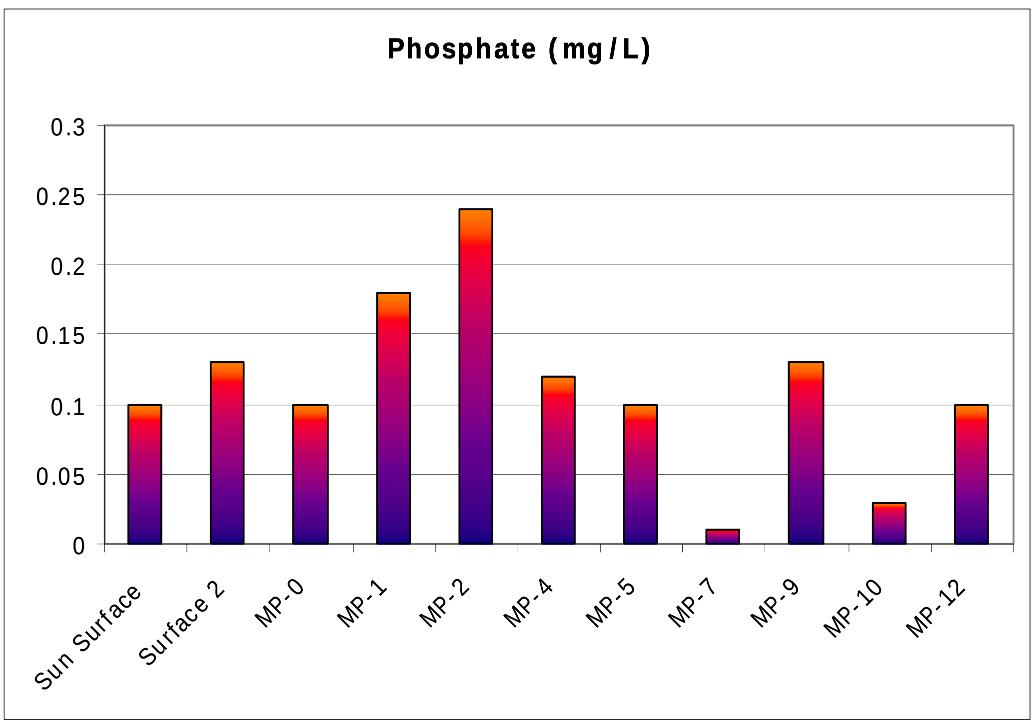
Graph showing amount of Nitrate detected in the Sunrise side channel, February 2009.



Graph showing amount of Nitrite detected in the Sunrise side channel, February 2009.



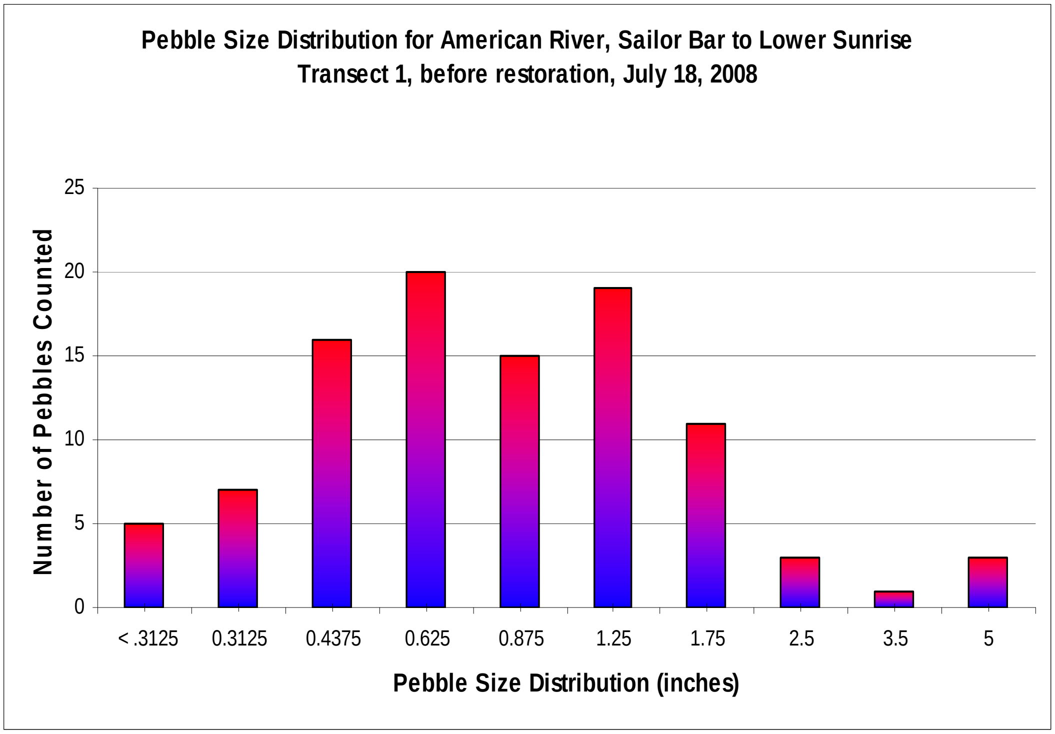
Graph showing amount of Ammonia detected in the Sunrise side channel, February 2009.



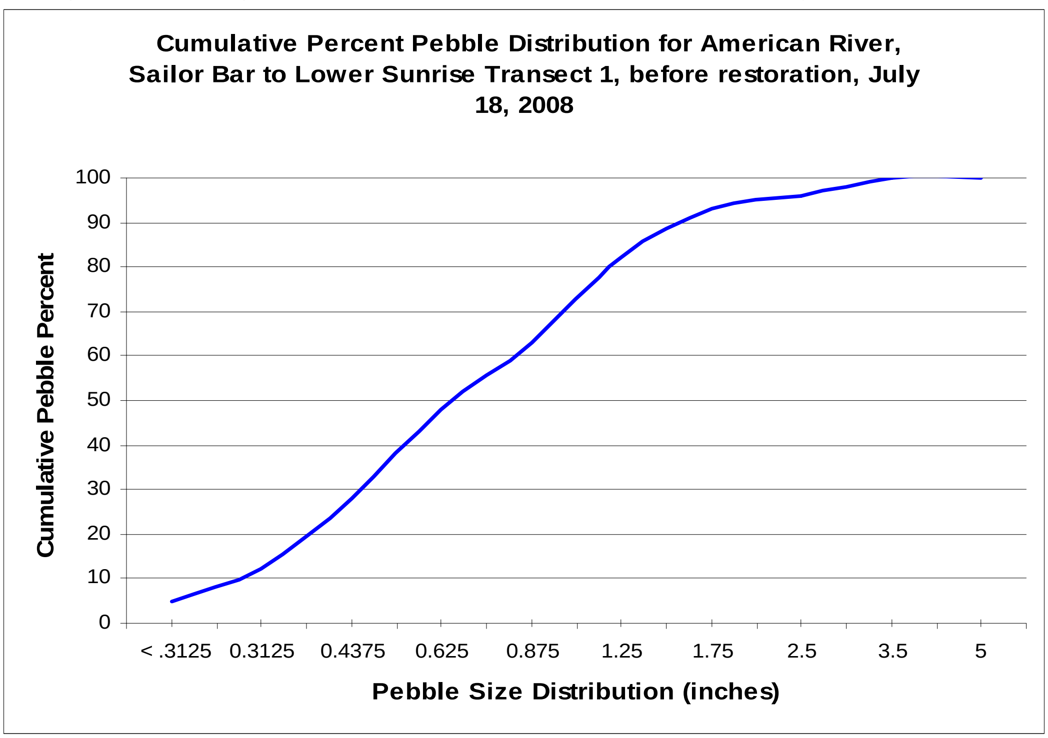
Graph showing amount of Phosphate detected in the Sunrise side channel, February 2009.

APPENDIX F

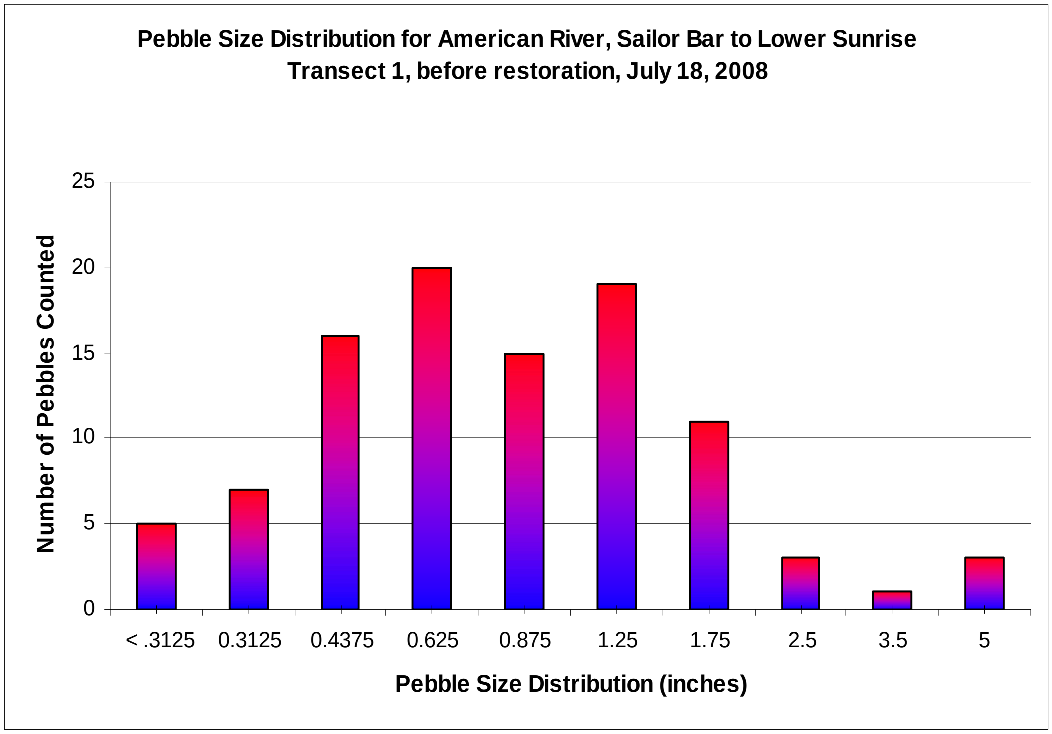
Before Gravel Addition Downstream Pebble Counts



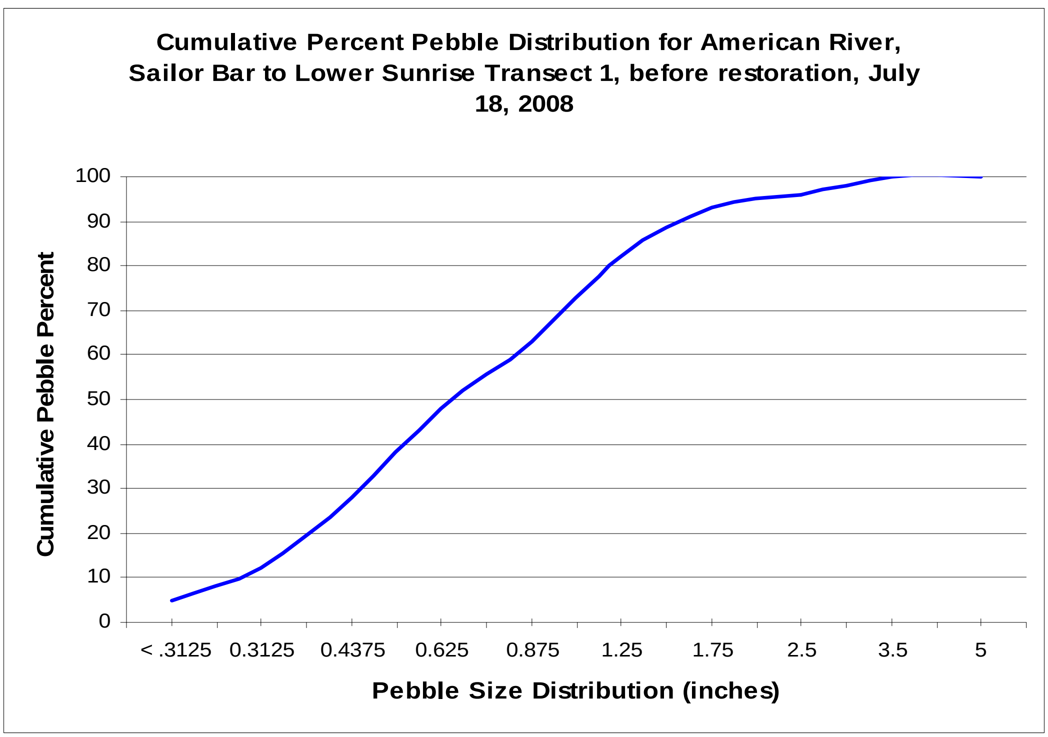
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



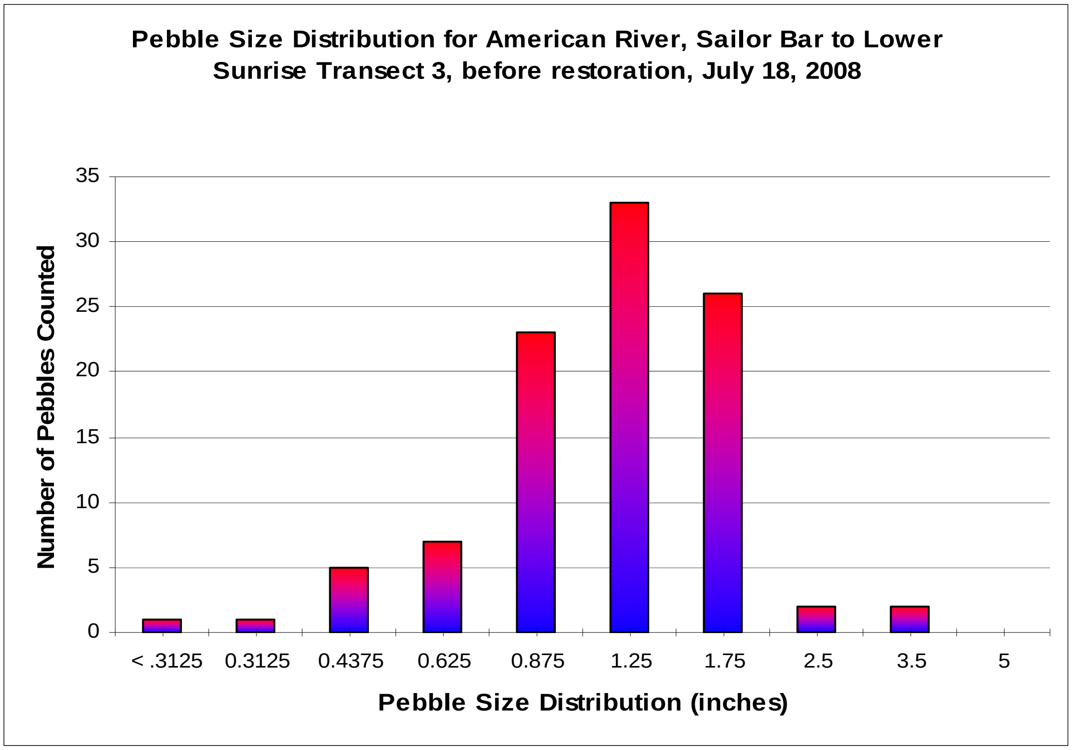
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



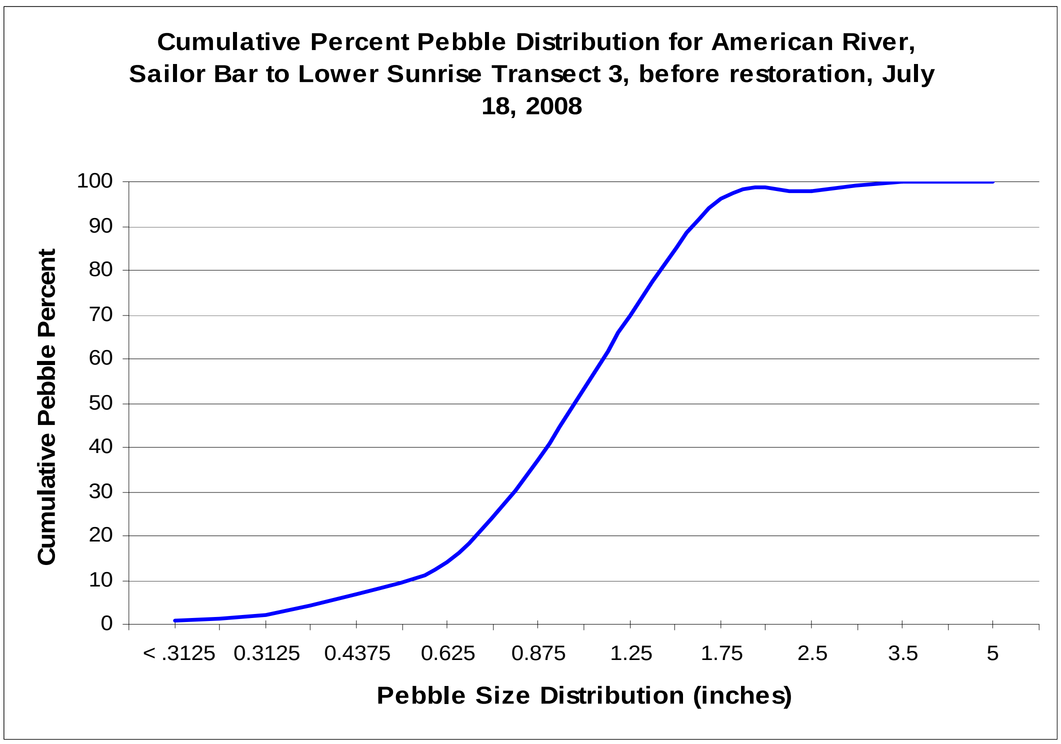
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



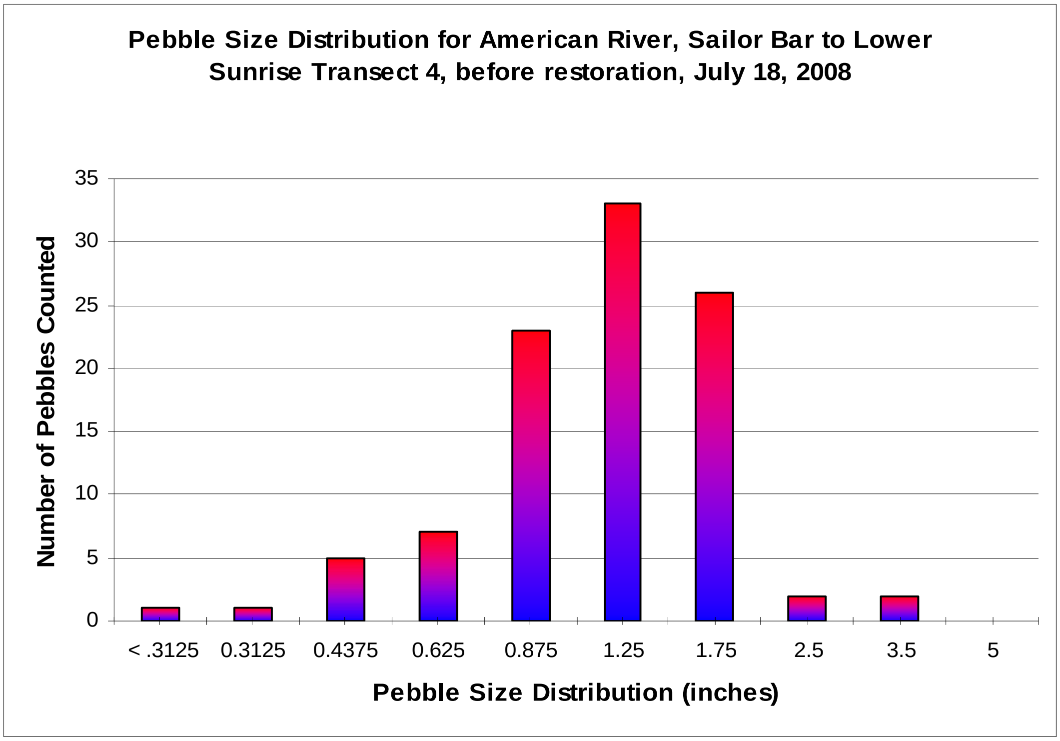
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



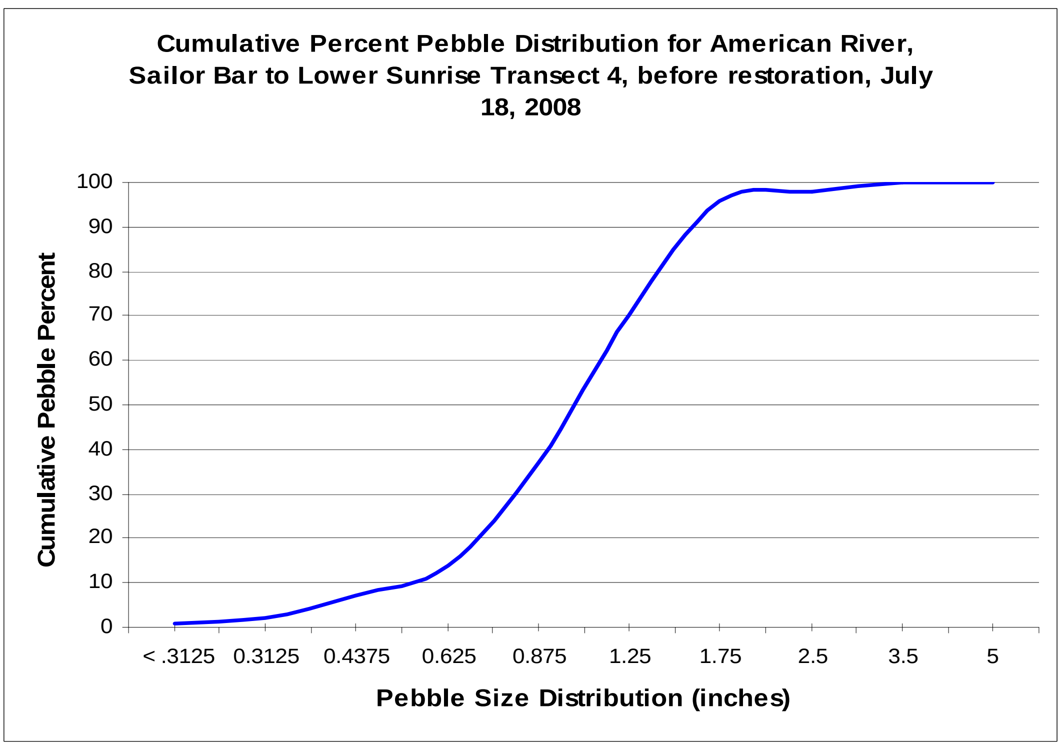
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



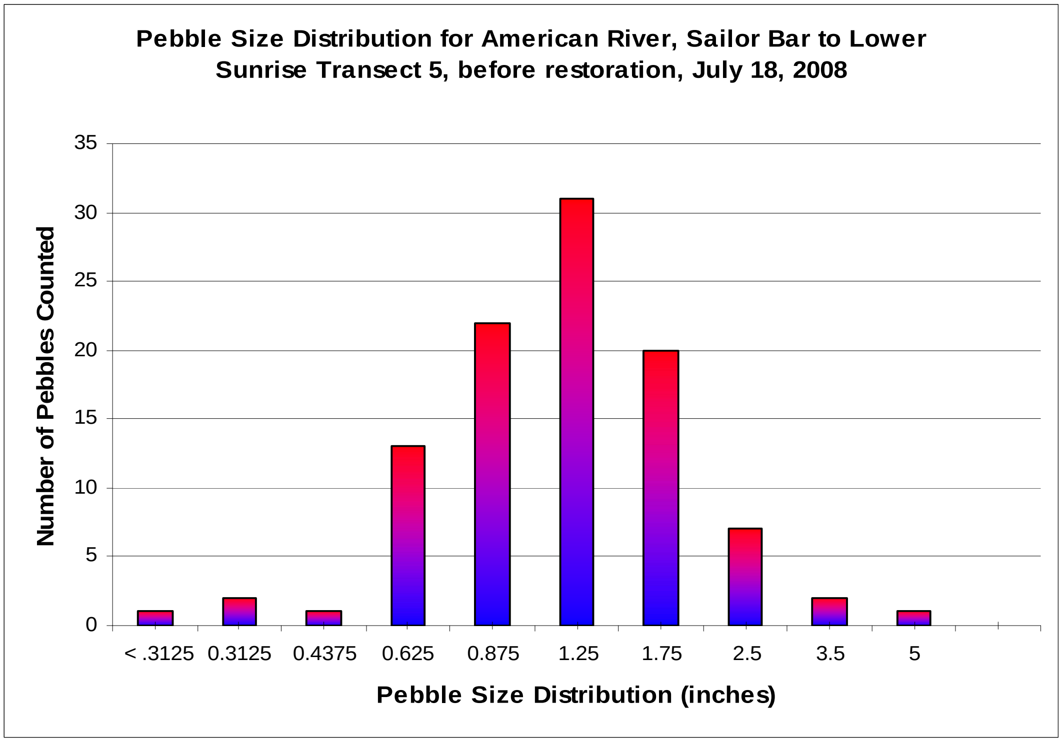
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



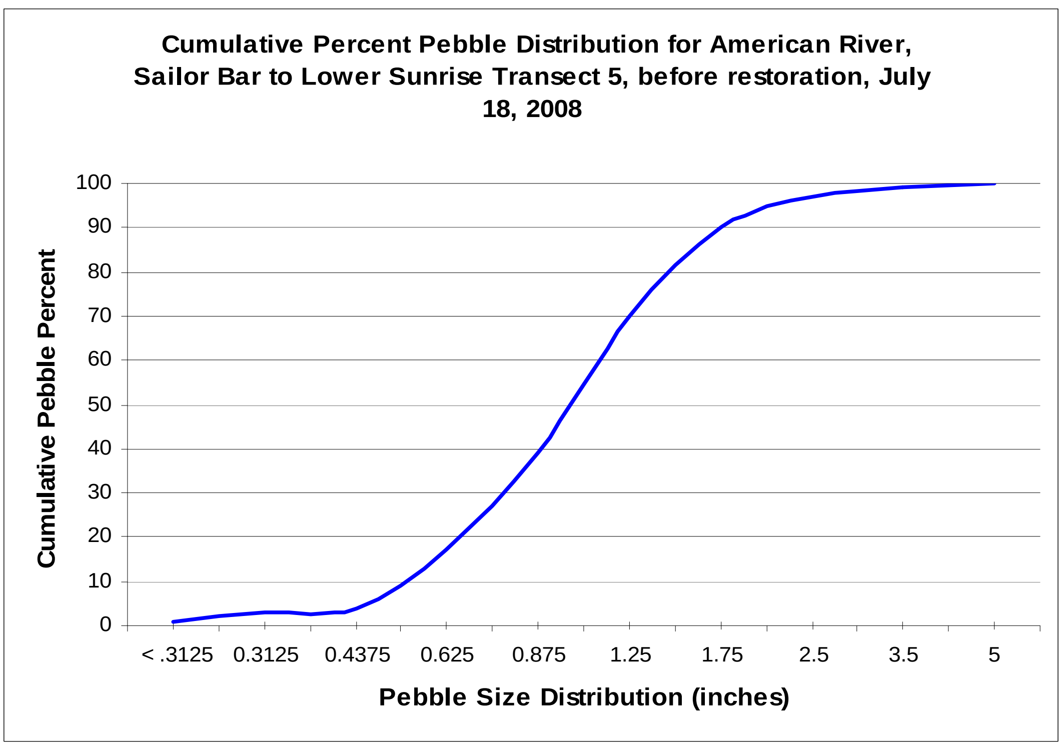
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



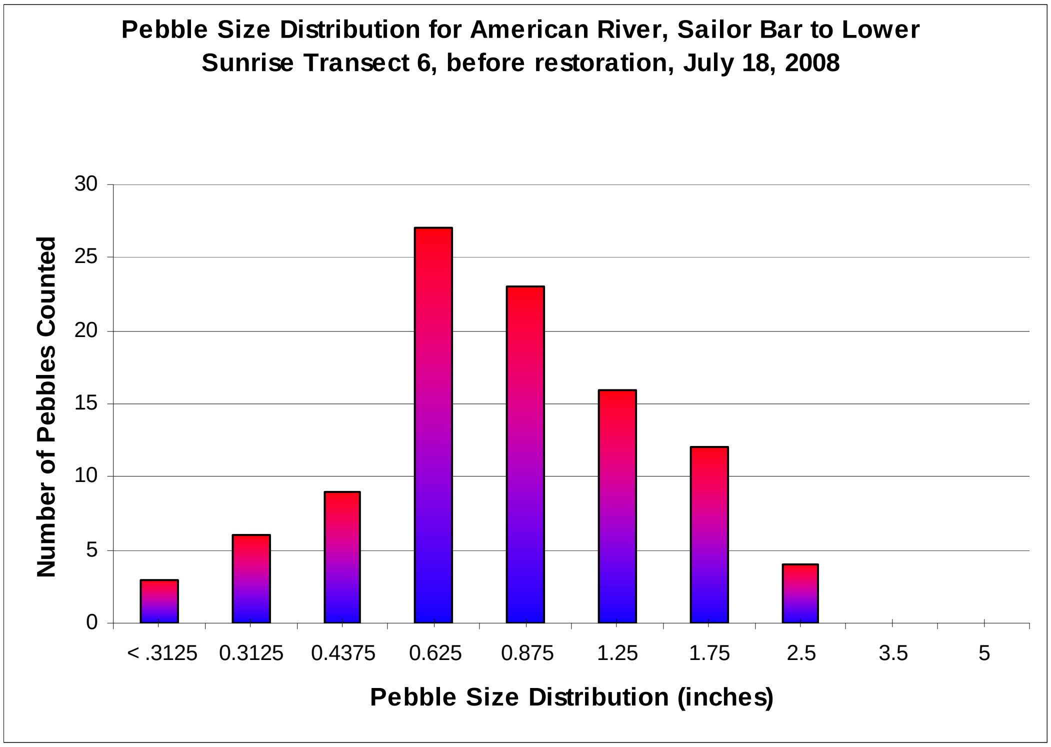
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



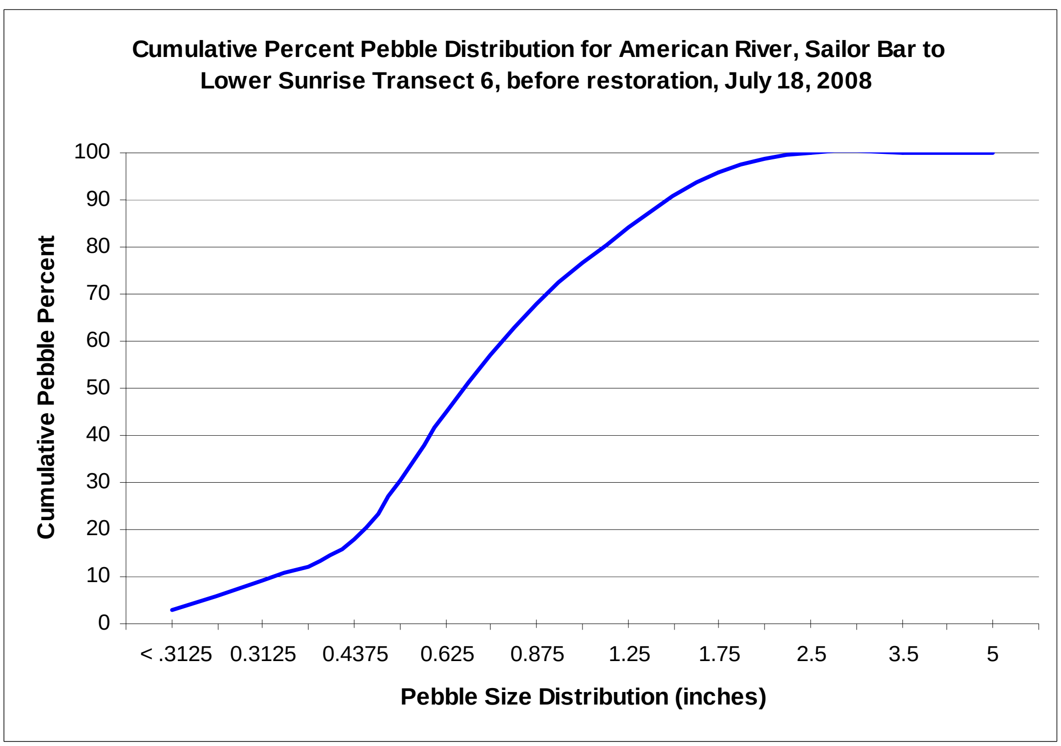
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



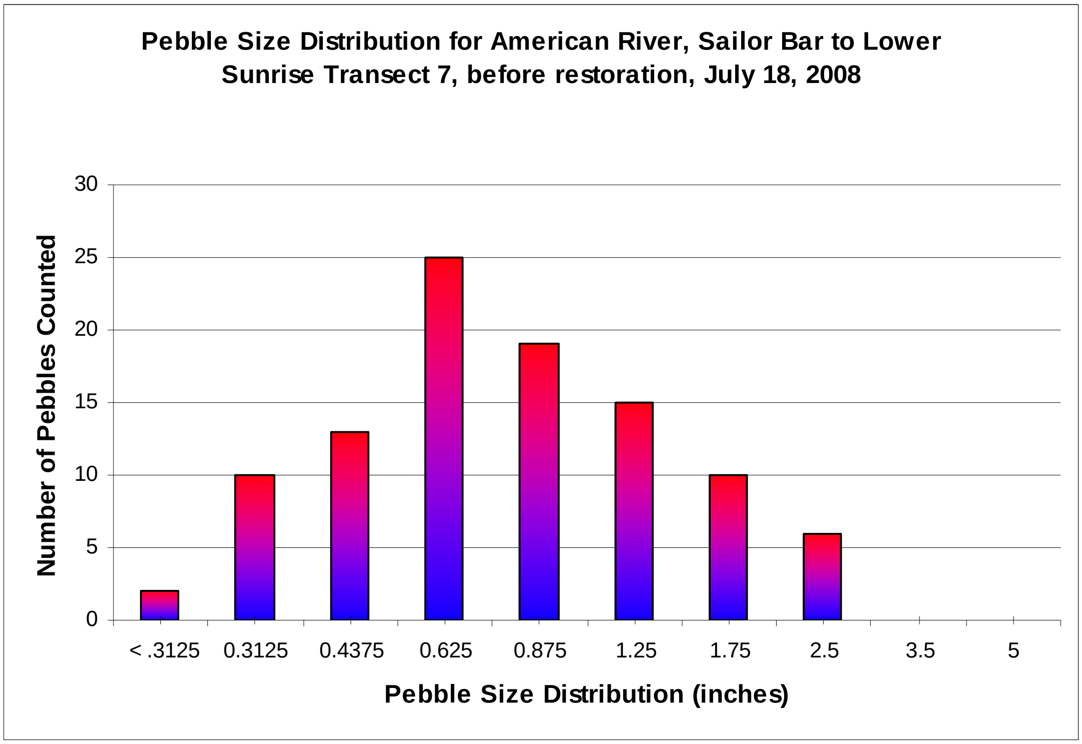
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



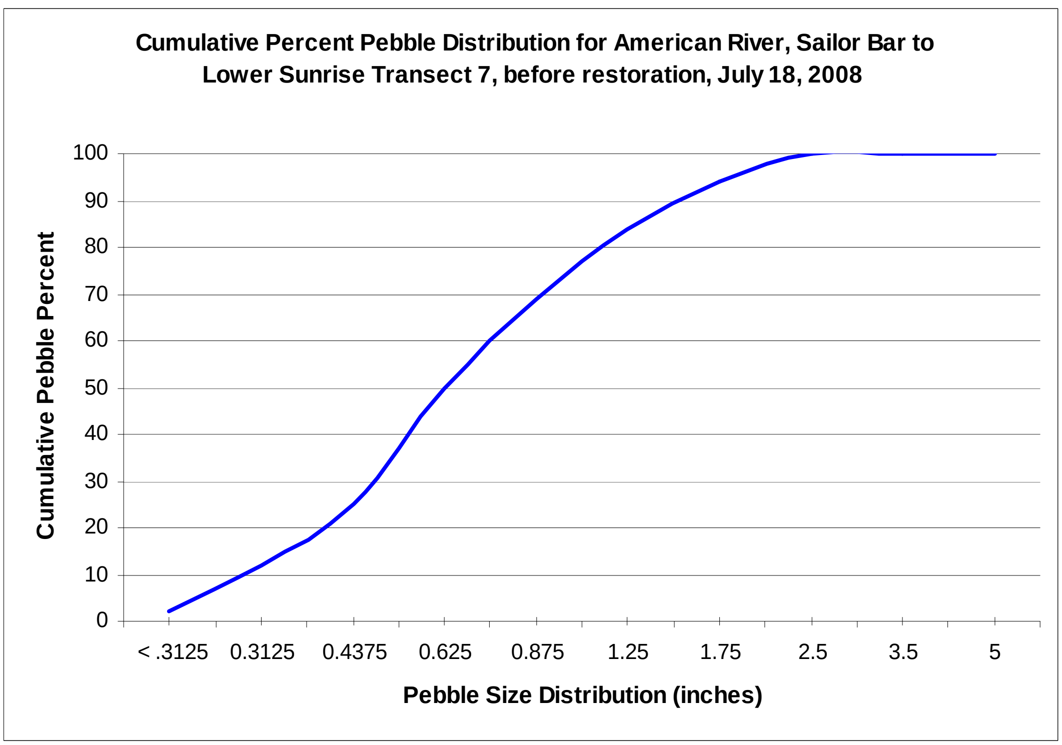
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



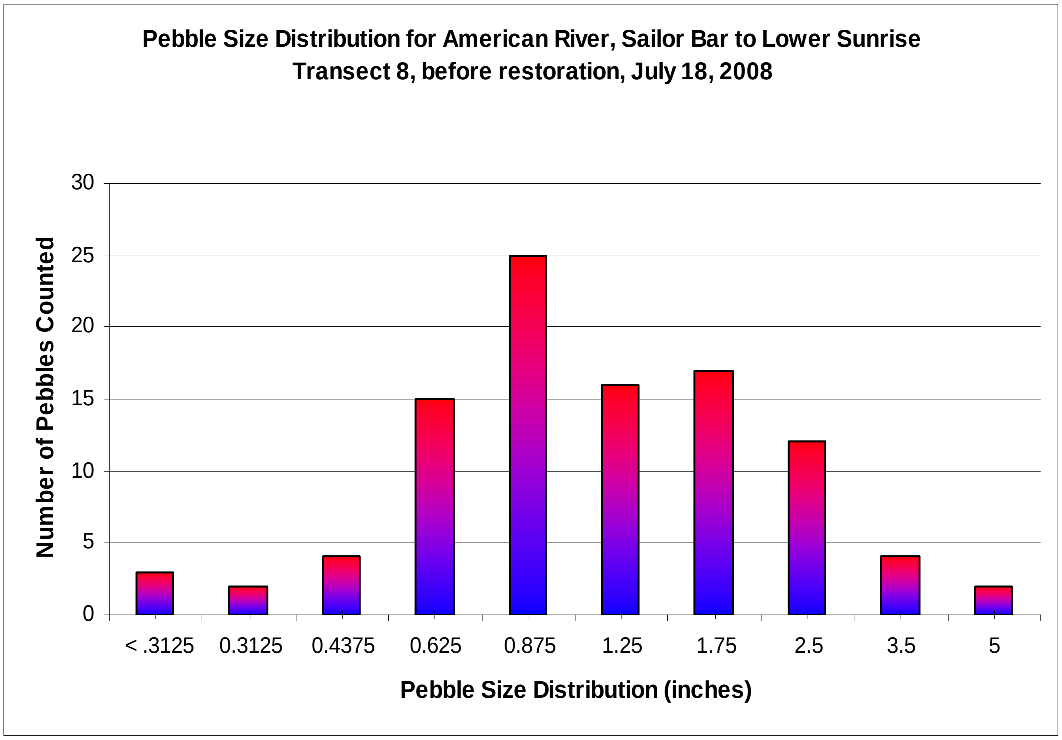
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



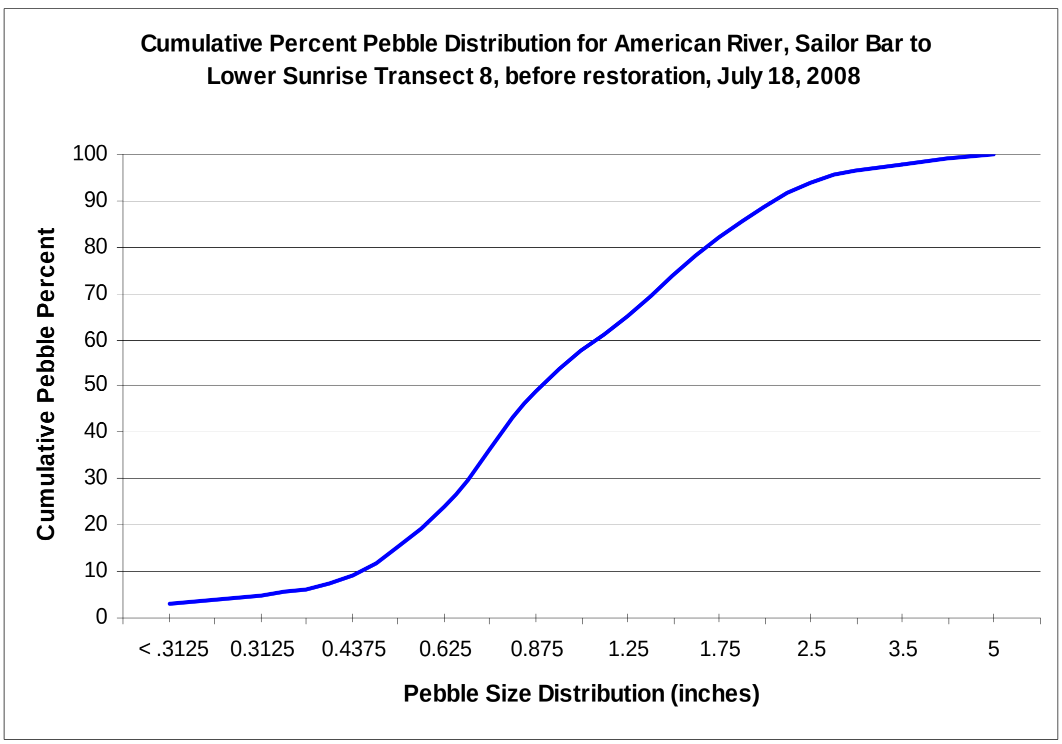
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



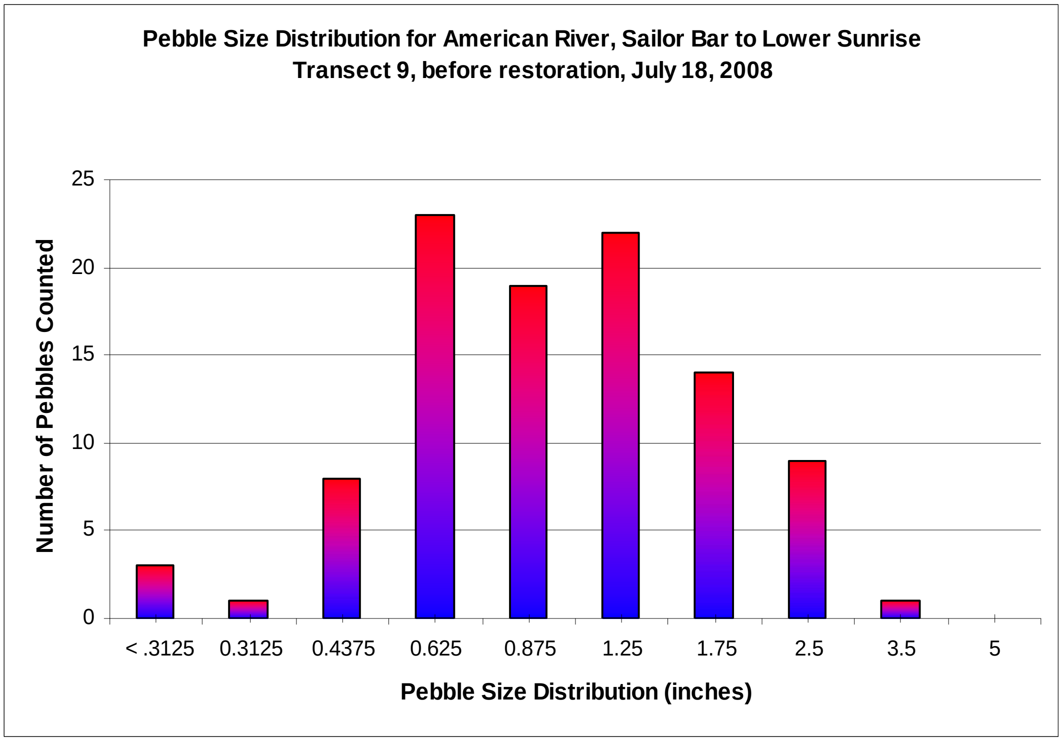
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



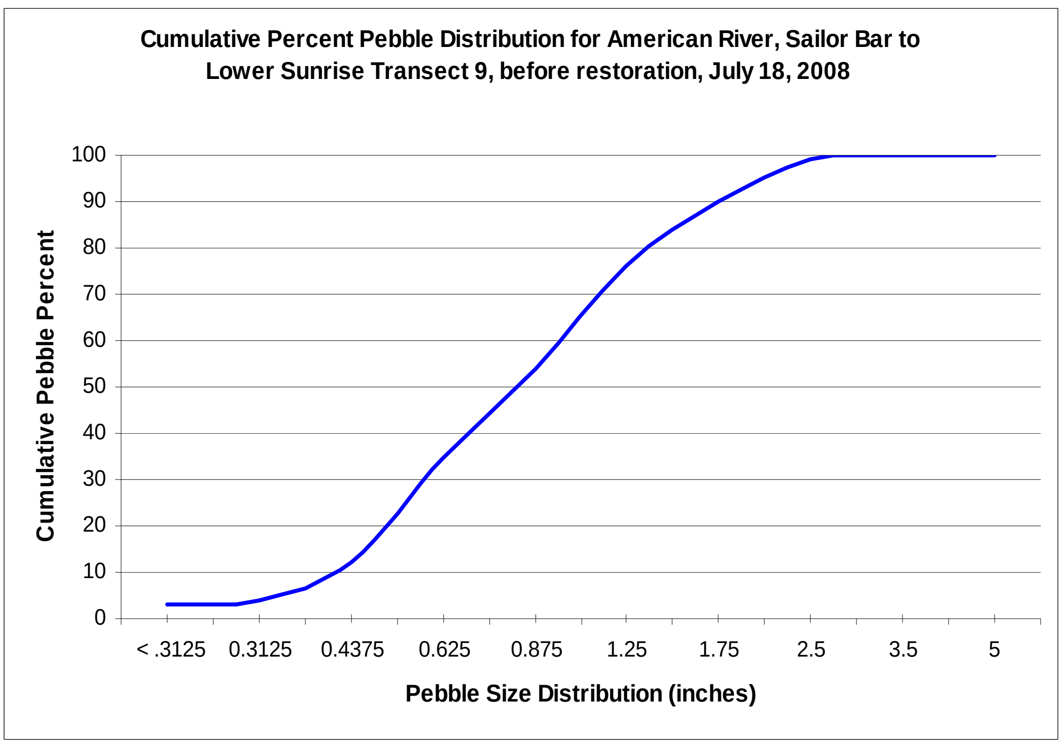
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



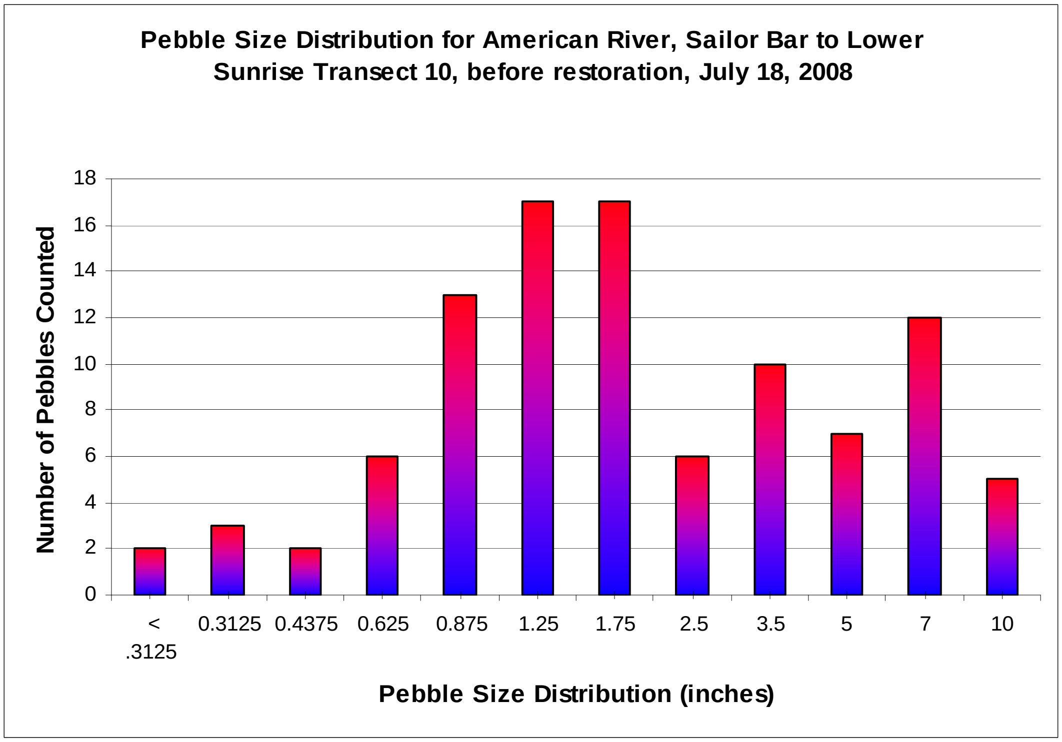
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



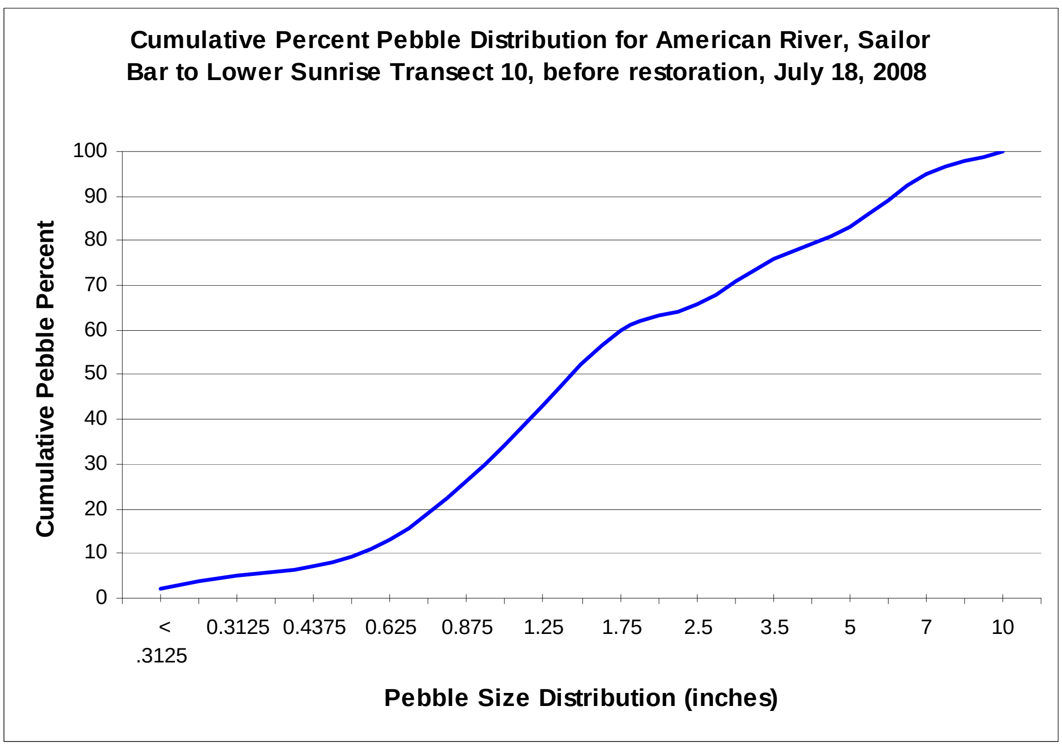
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



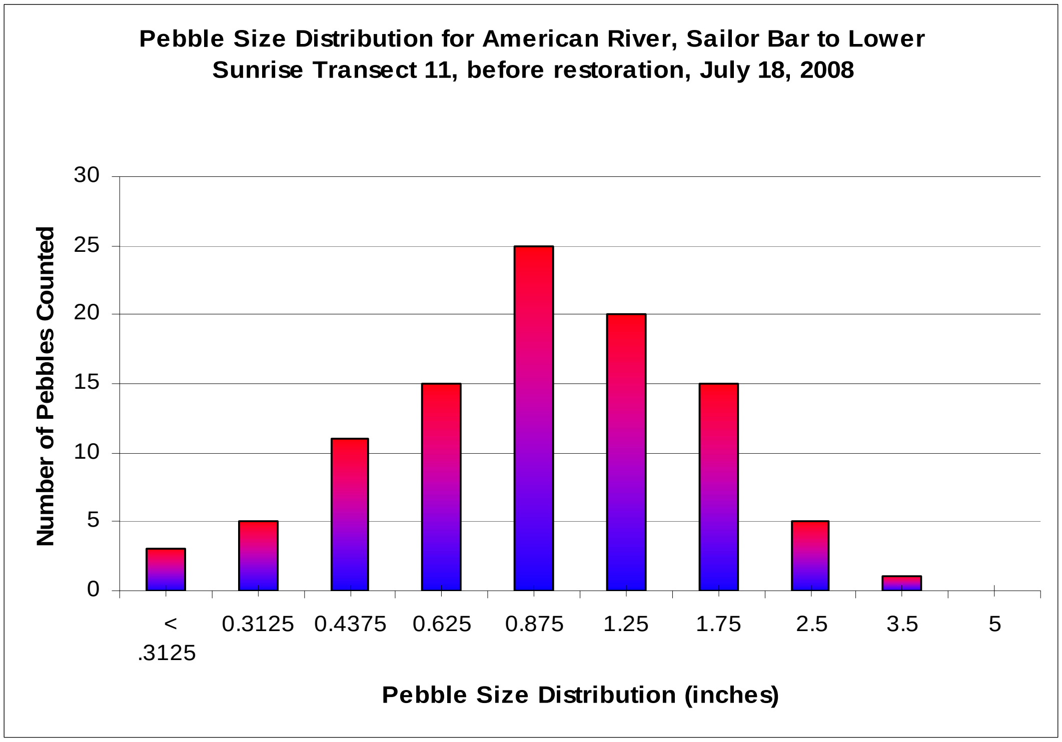
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



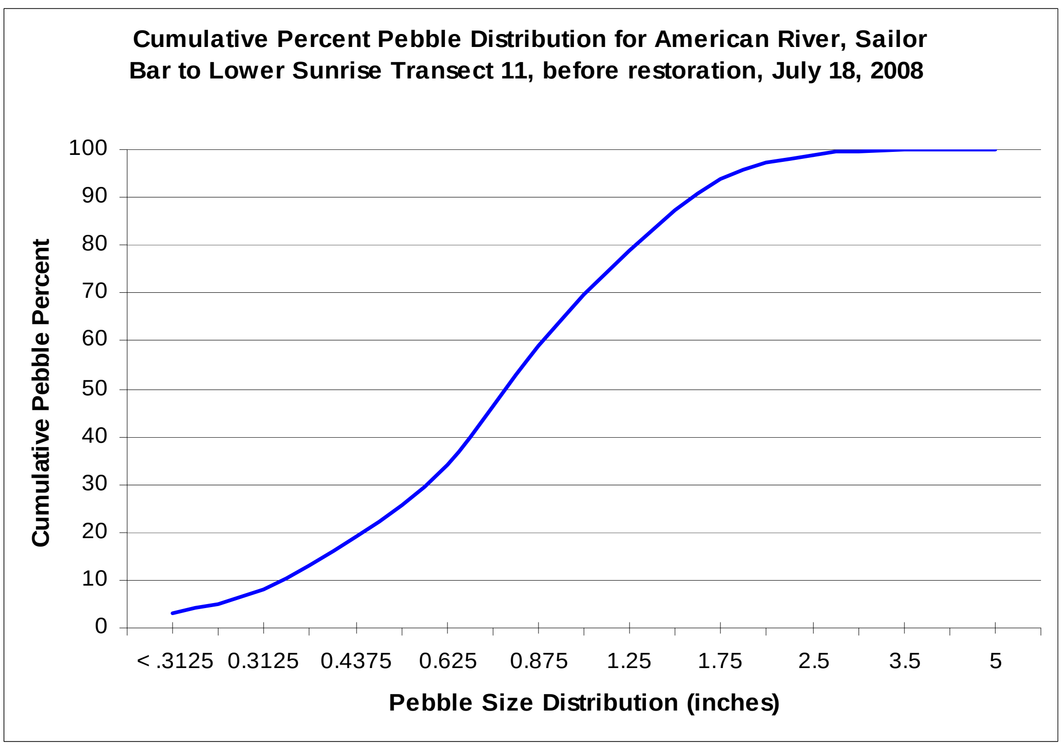
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



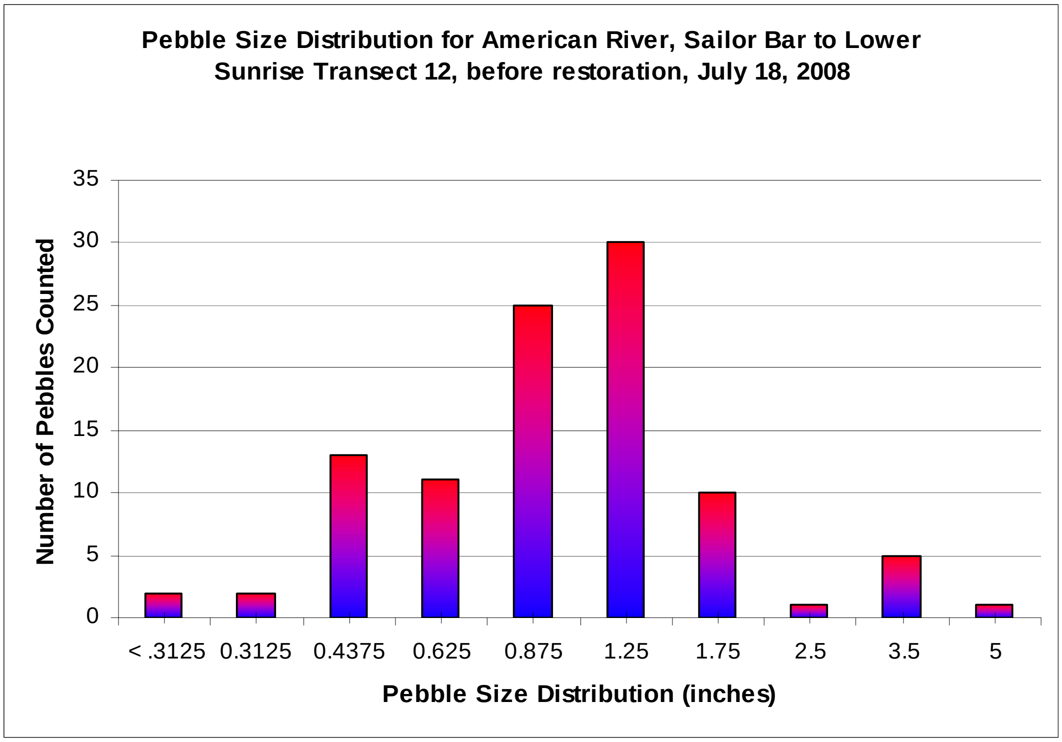
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



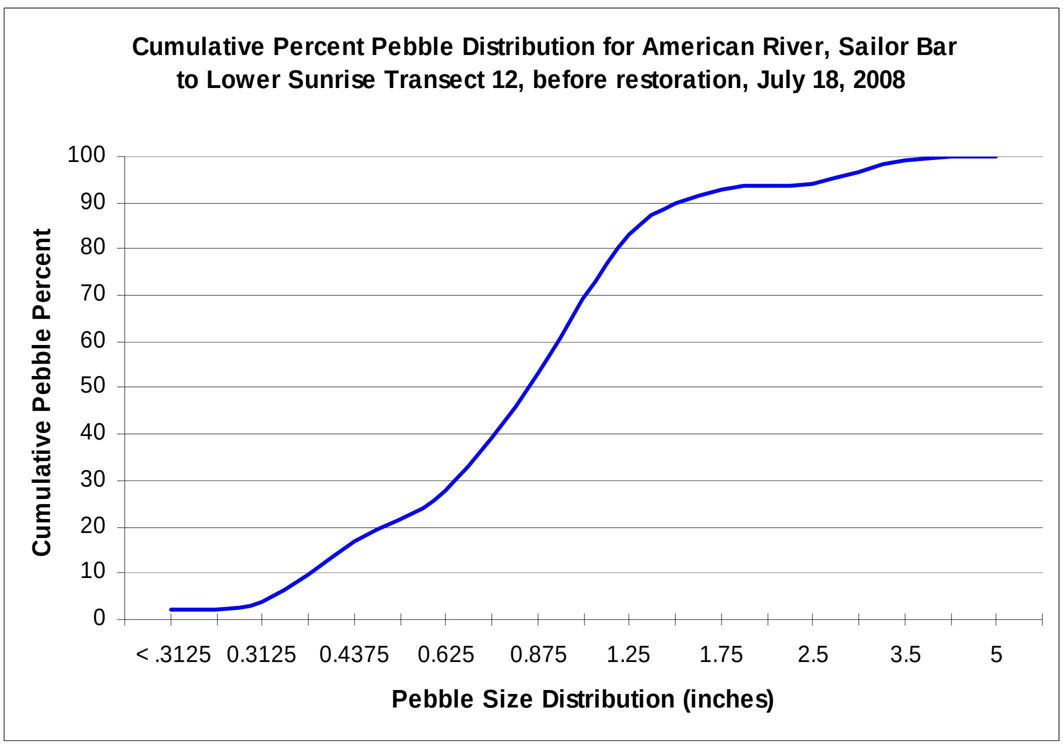
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



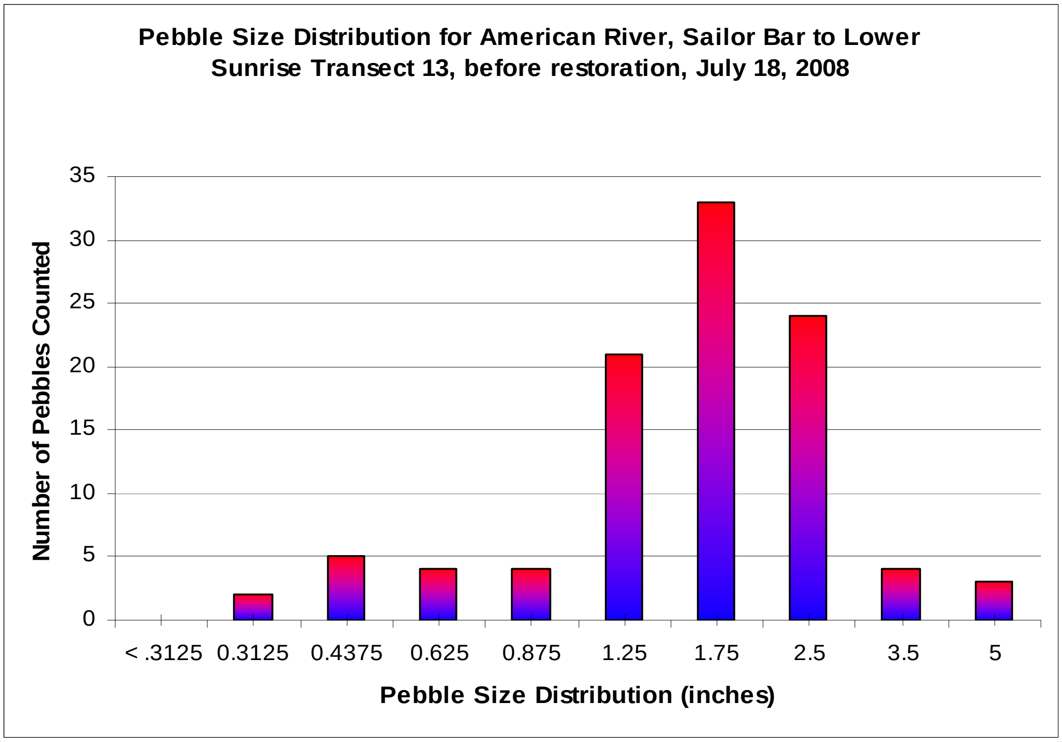
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



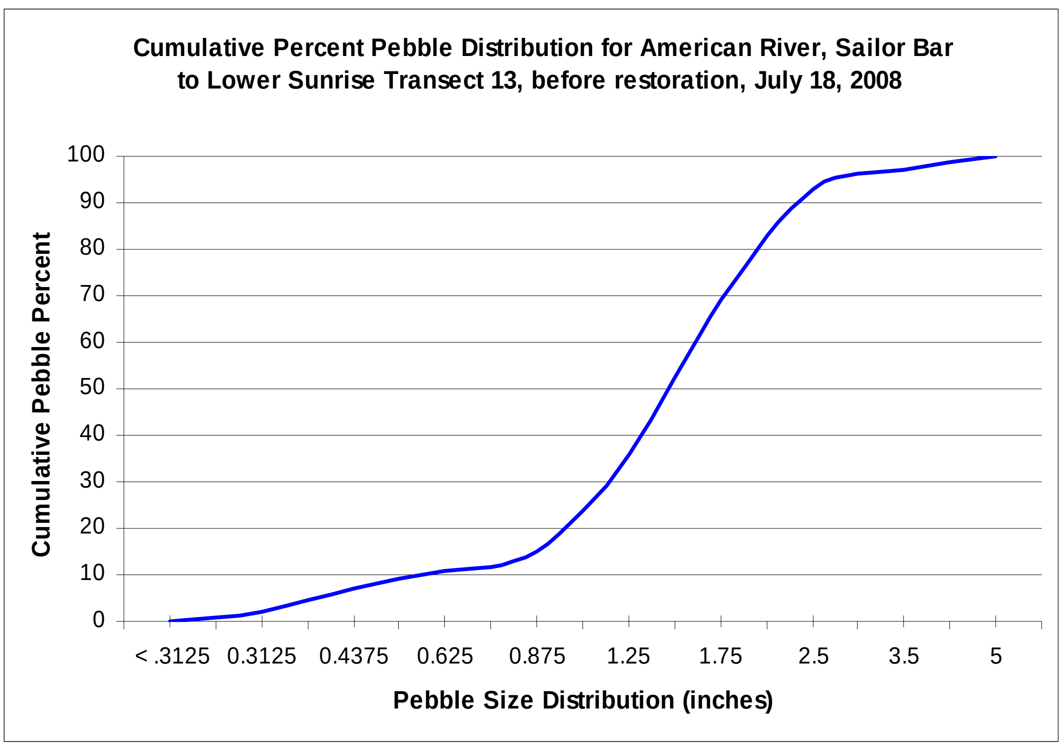
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



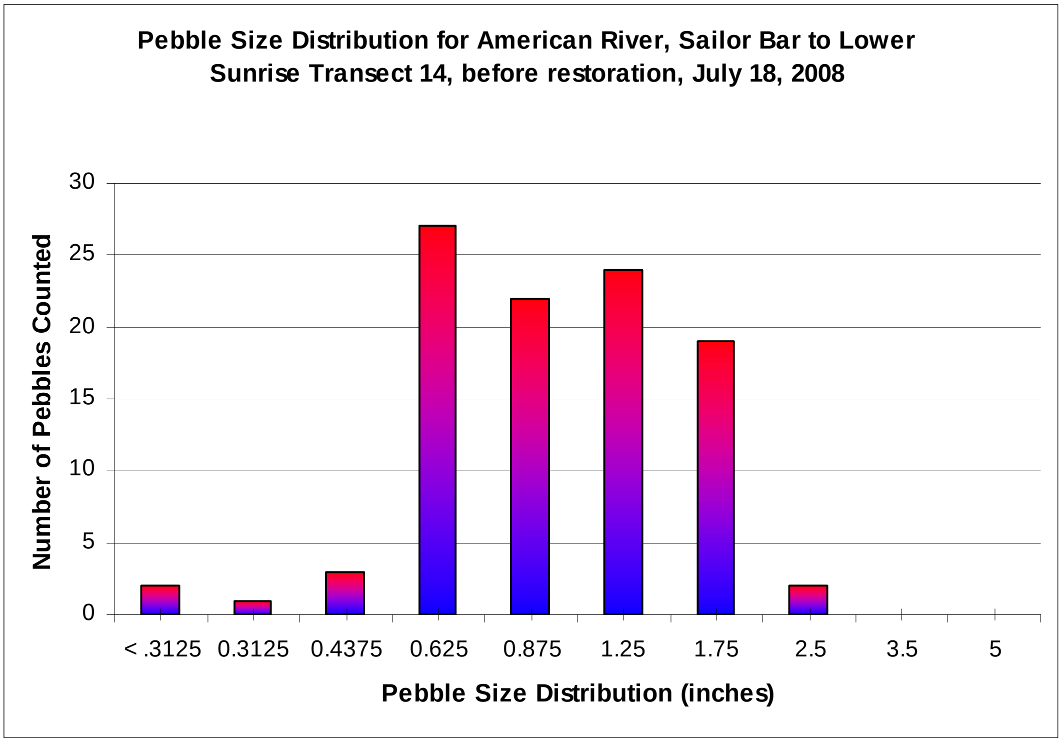
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



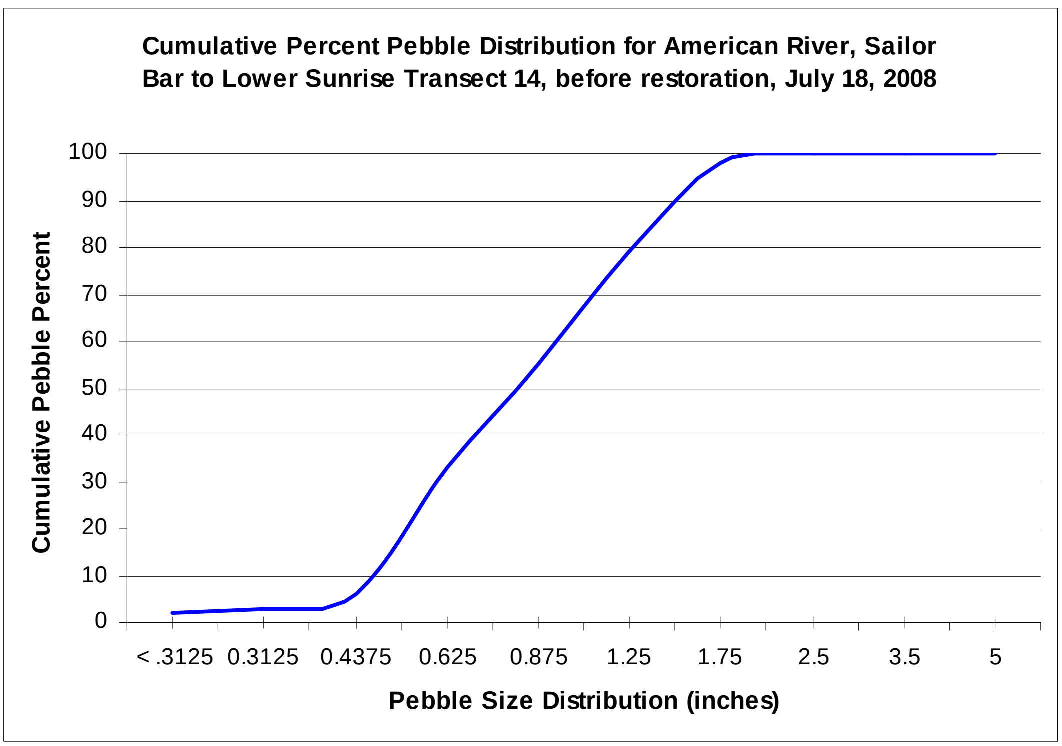
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



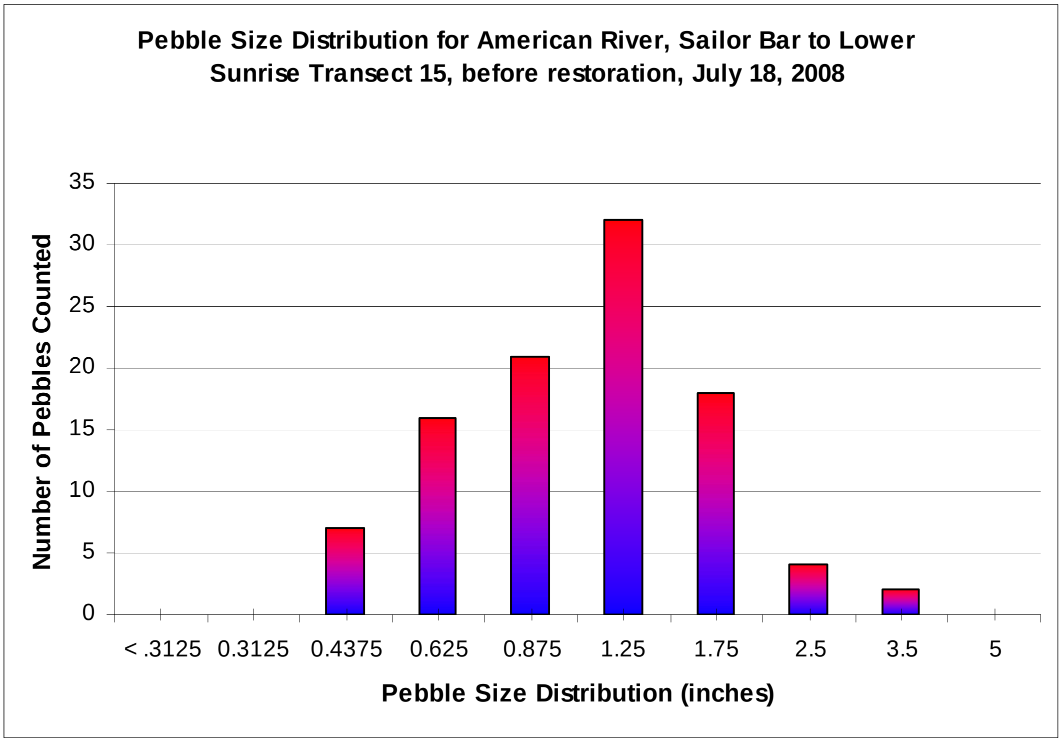
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



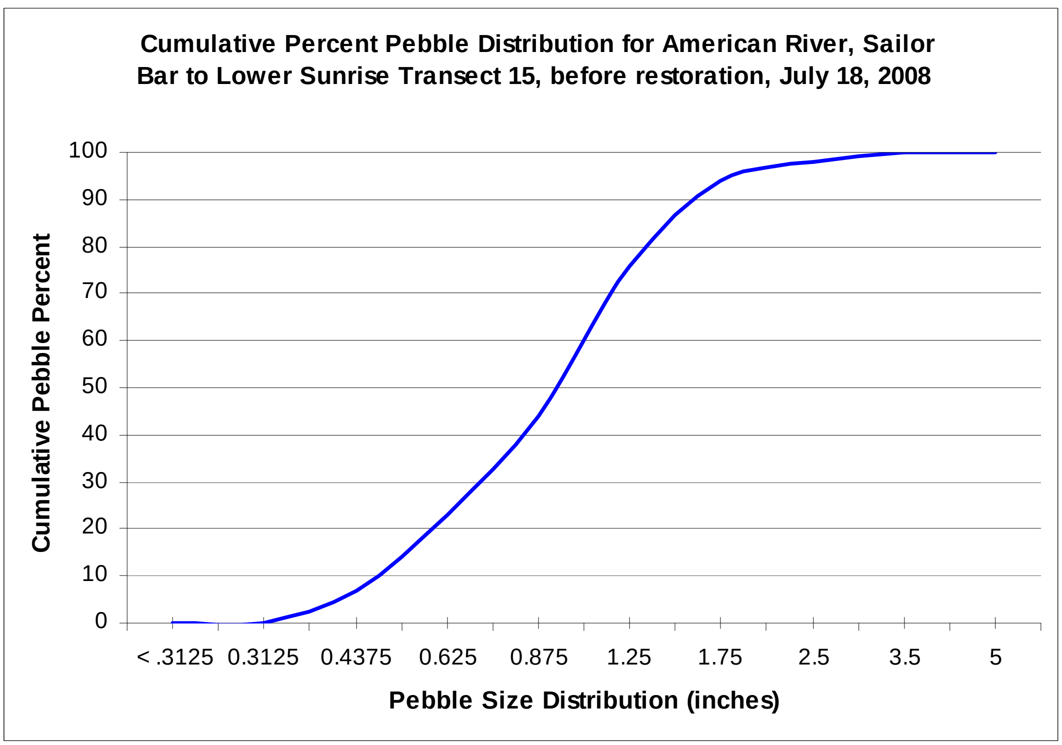
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



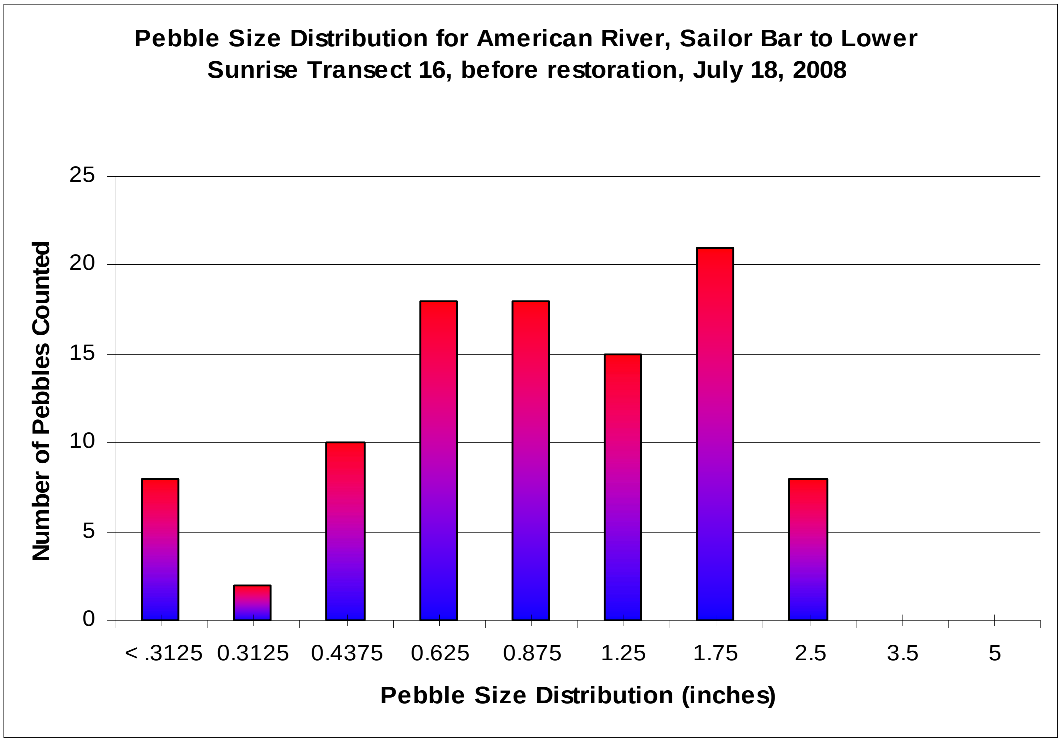
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



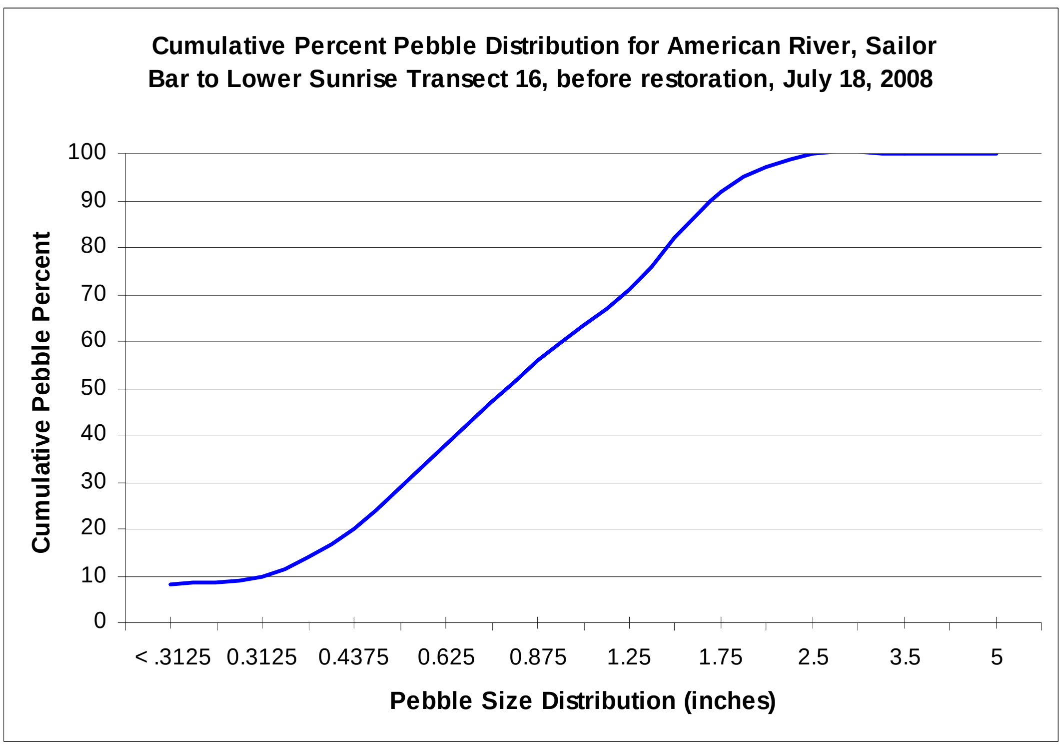
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



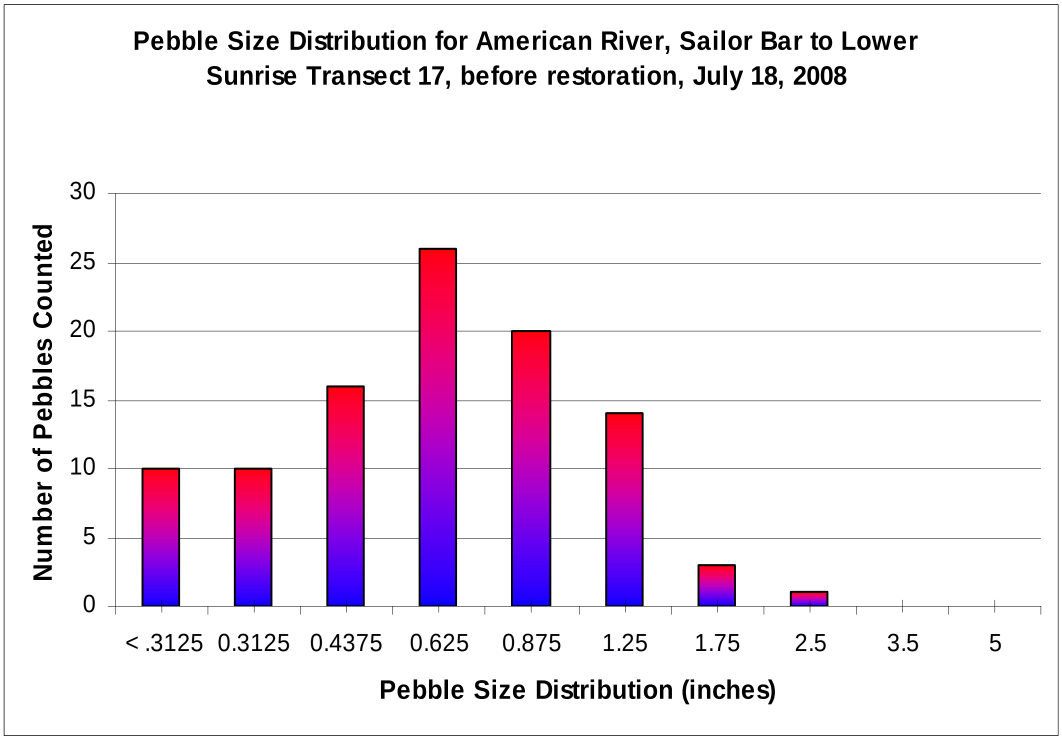
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



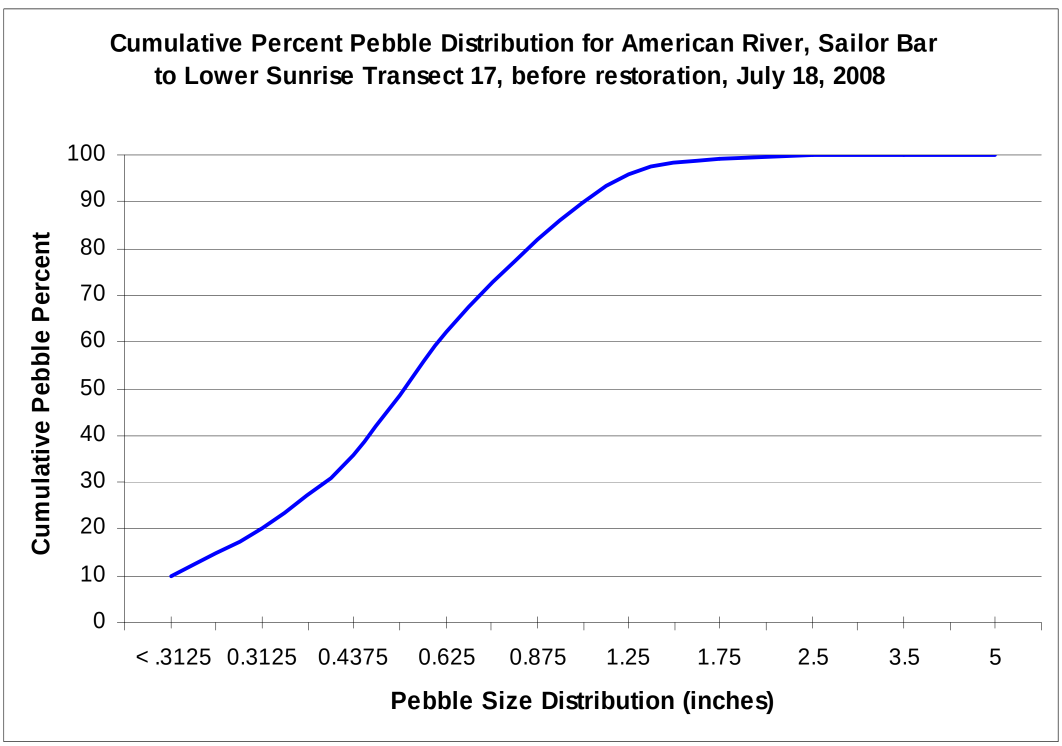
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



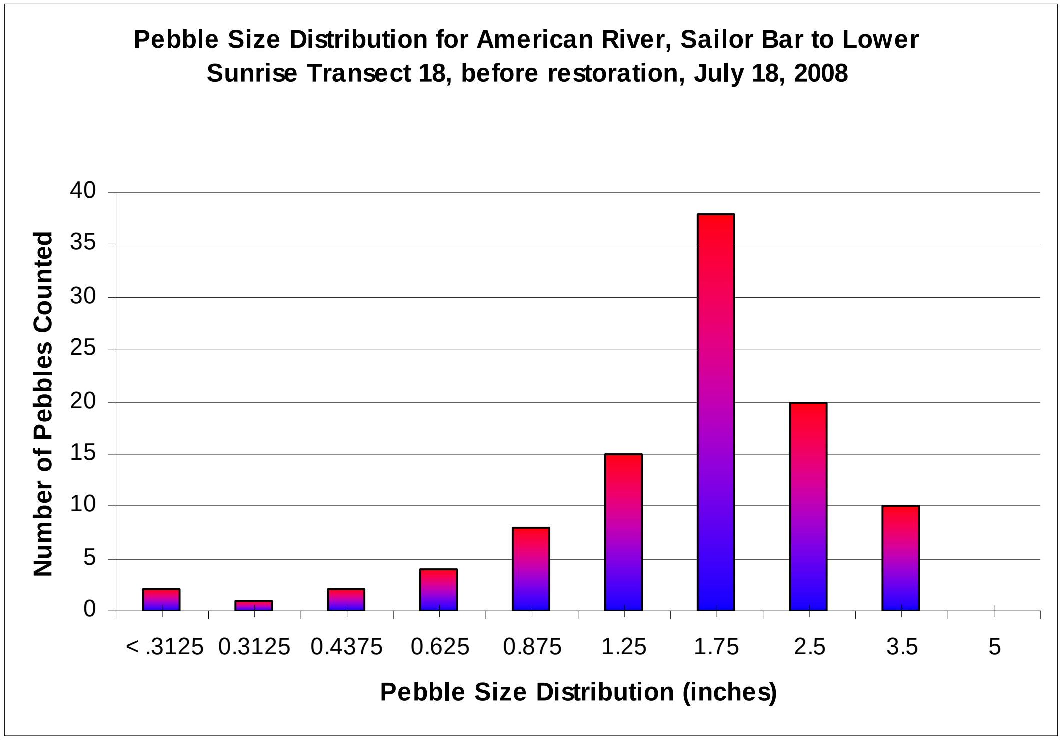
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



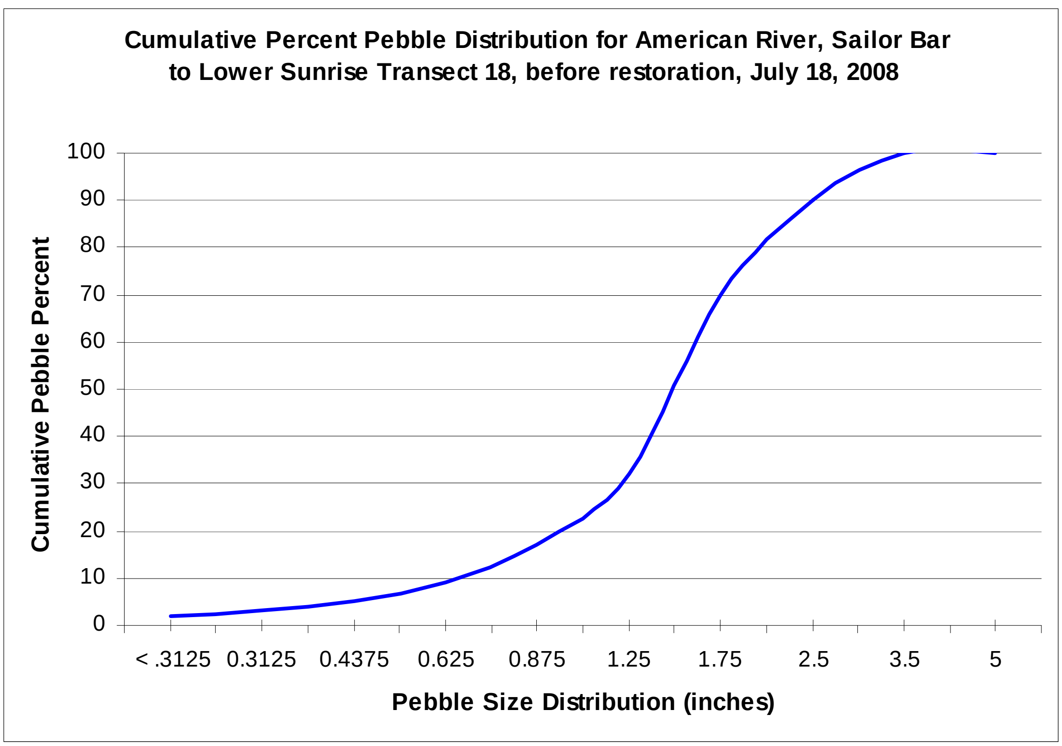
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



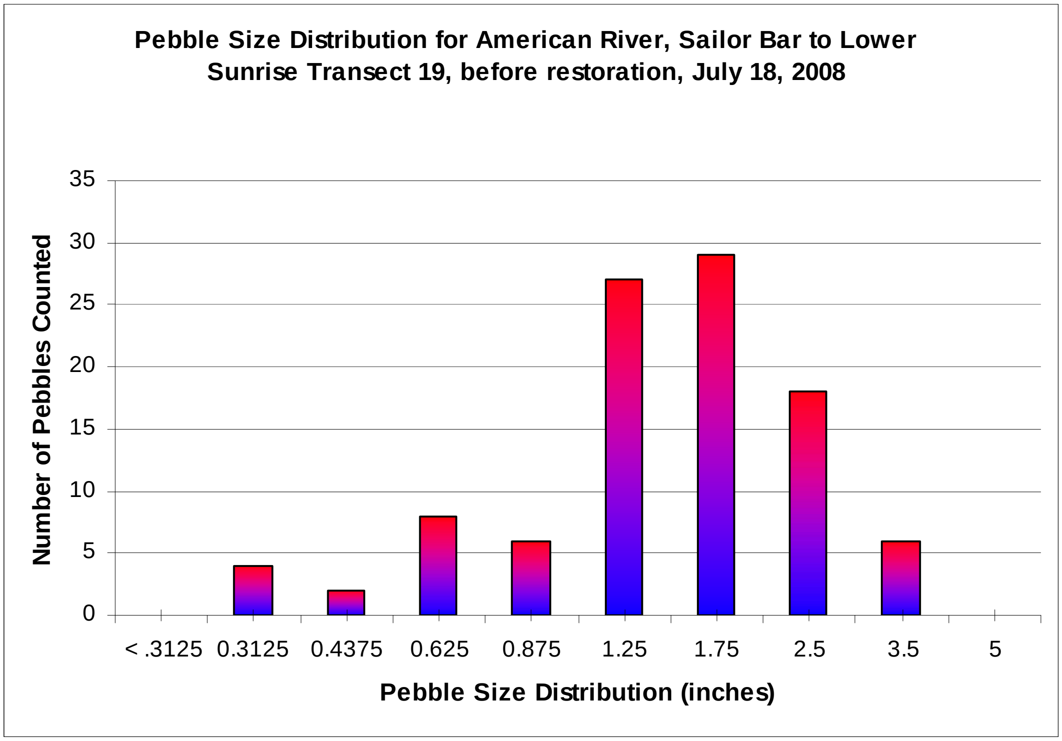
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



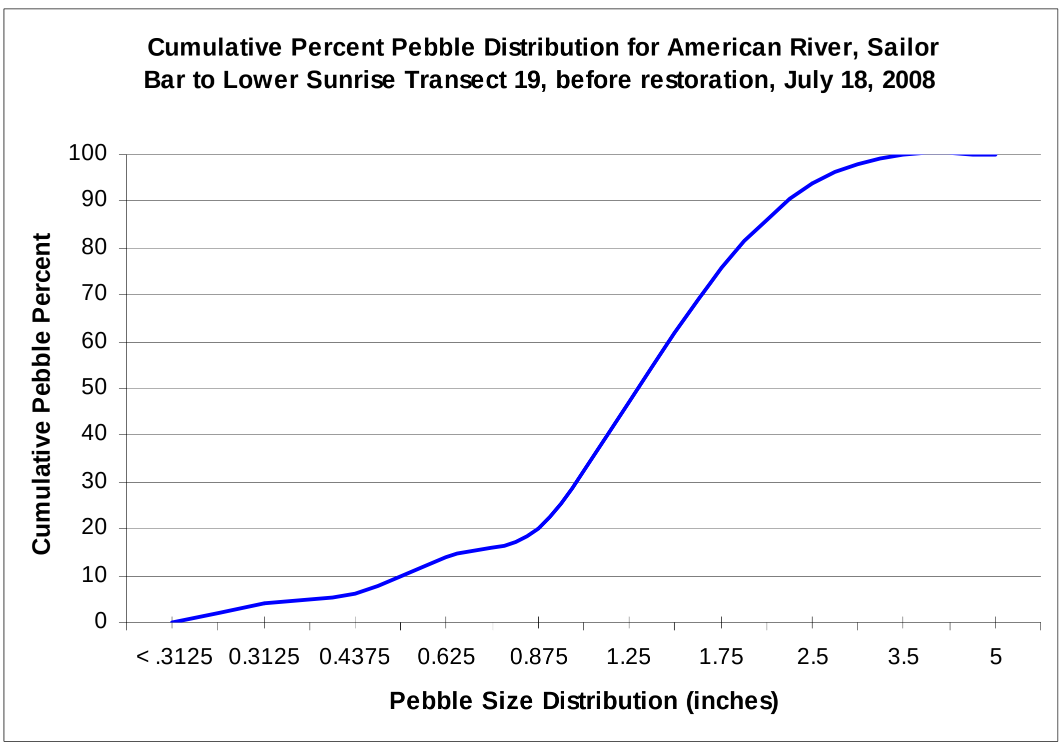
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.



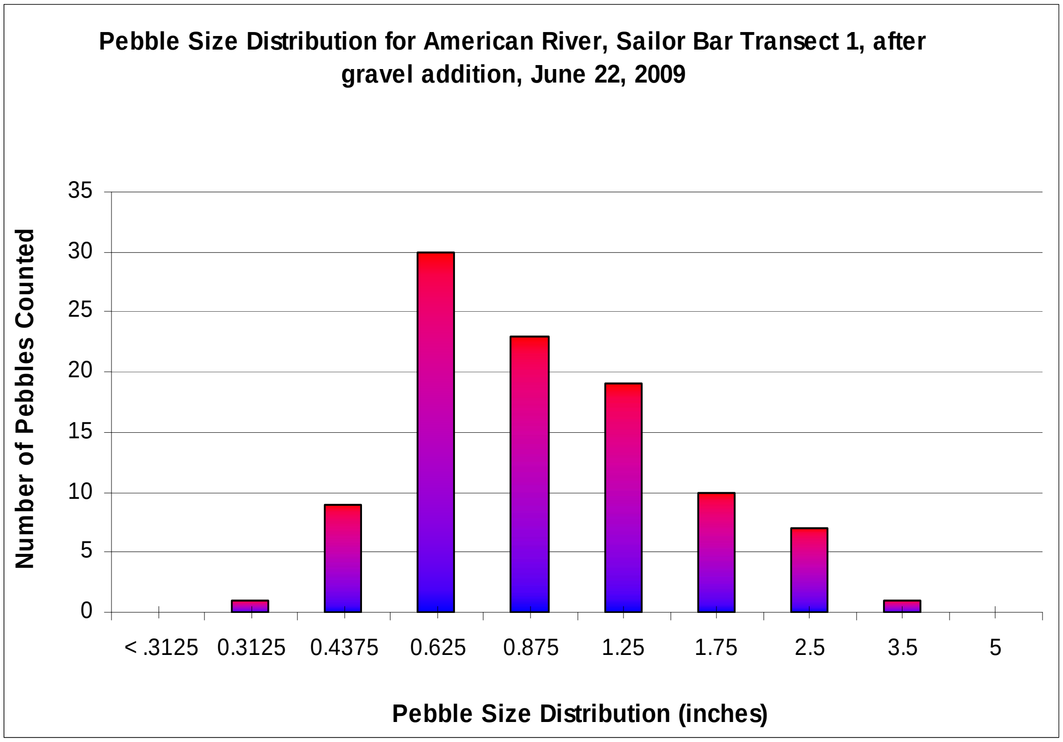
Histograph showing the pebble count data, Sailor bar 2008, July 2008.



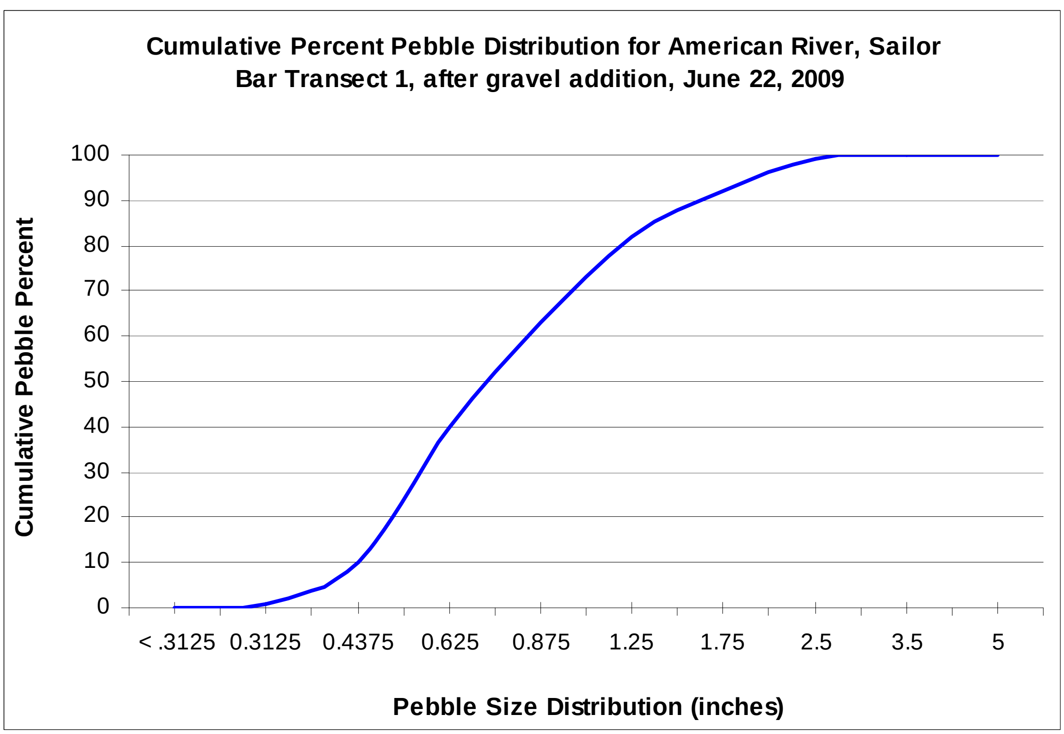
Graph showing the cumulative frequency data for Sailor bar 2008, July 2008.

APPENDIX G

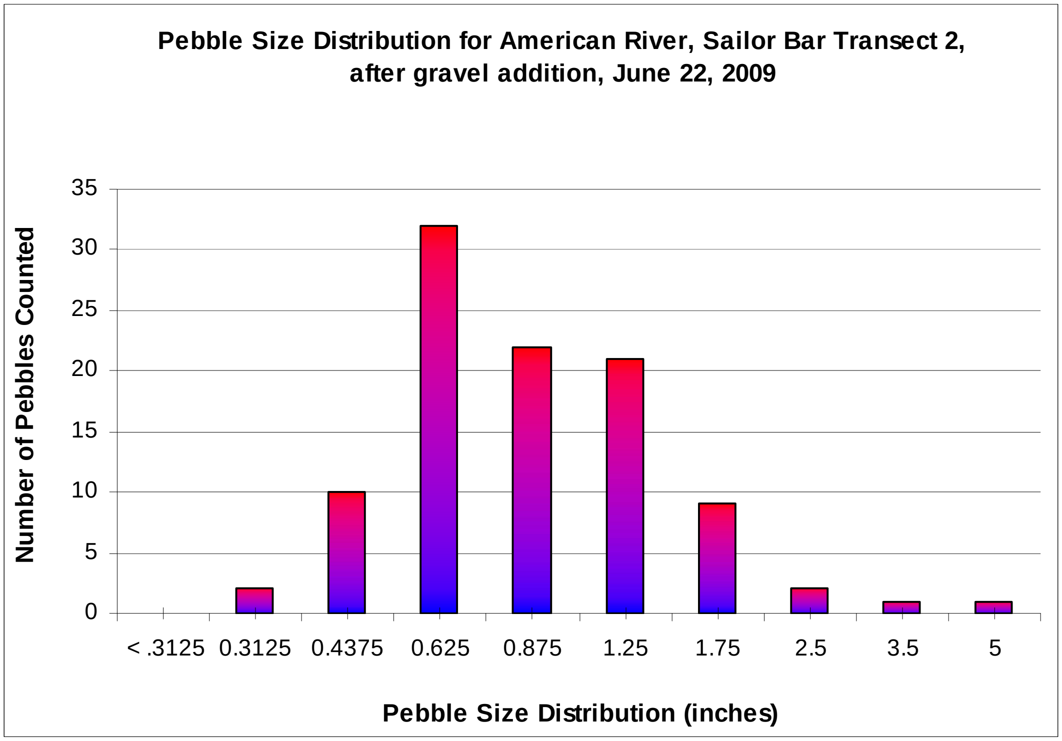
Sailor Bar 2008 After Gravel Addition Pebble Counts



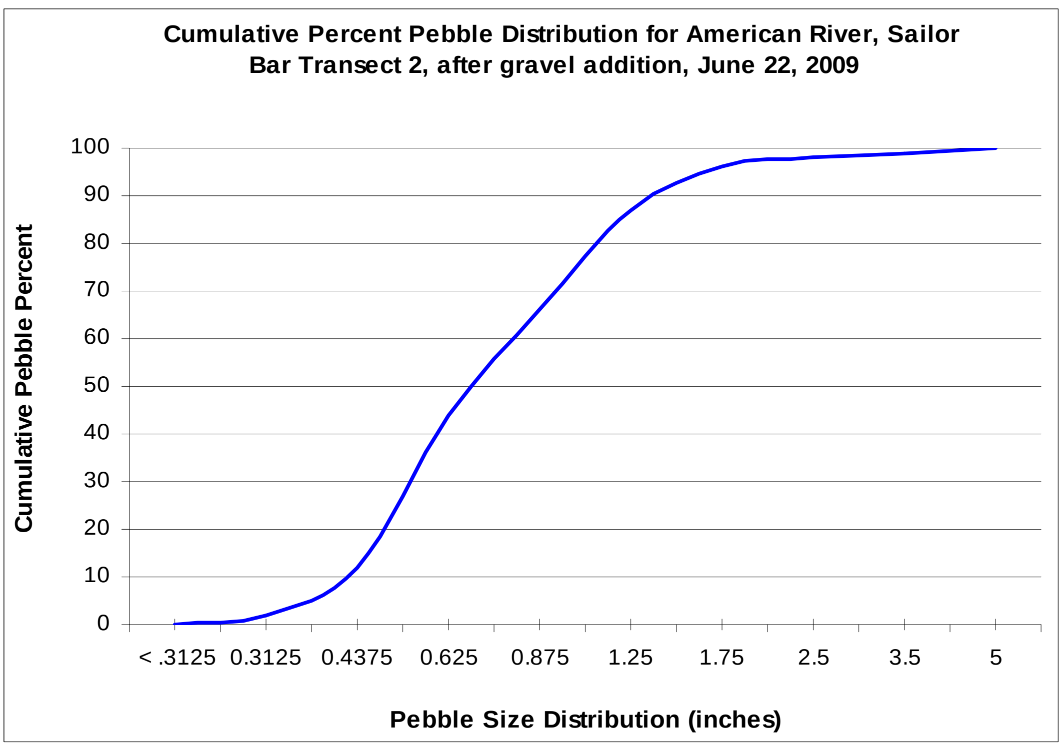
Histograph showing the after gravel addition pebble count data, June 2009.



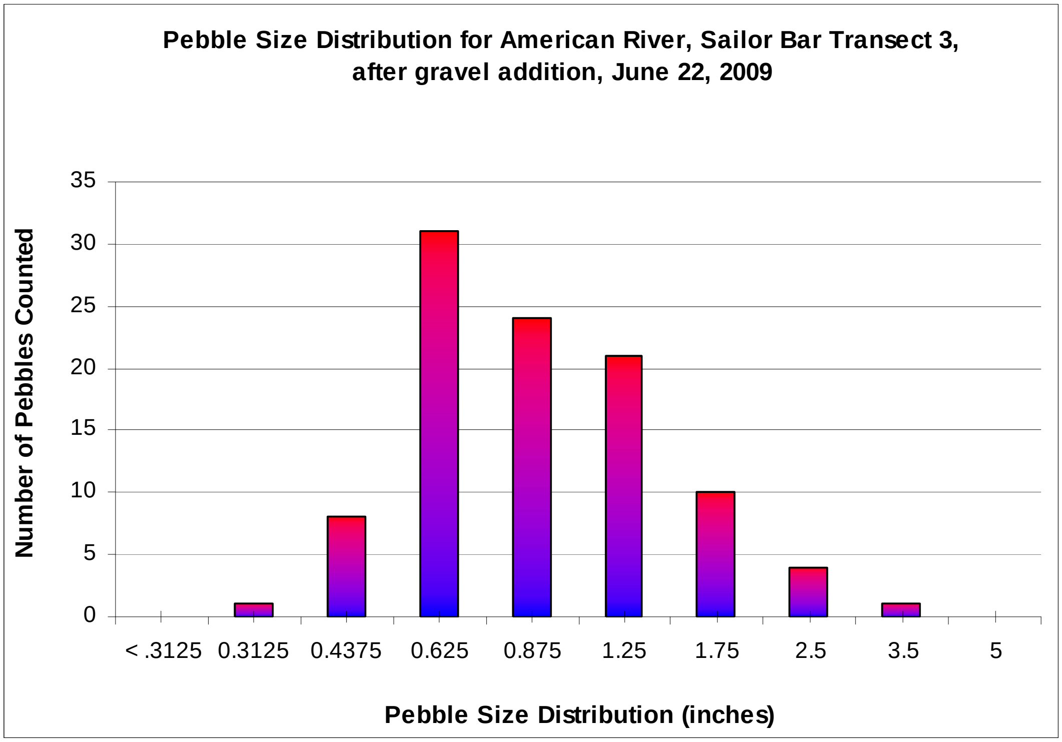
Cumulative frequency graph for after gravel addition pebble count, June 2009.



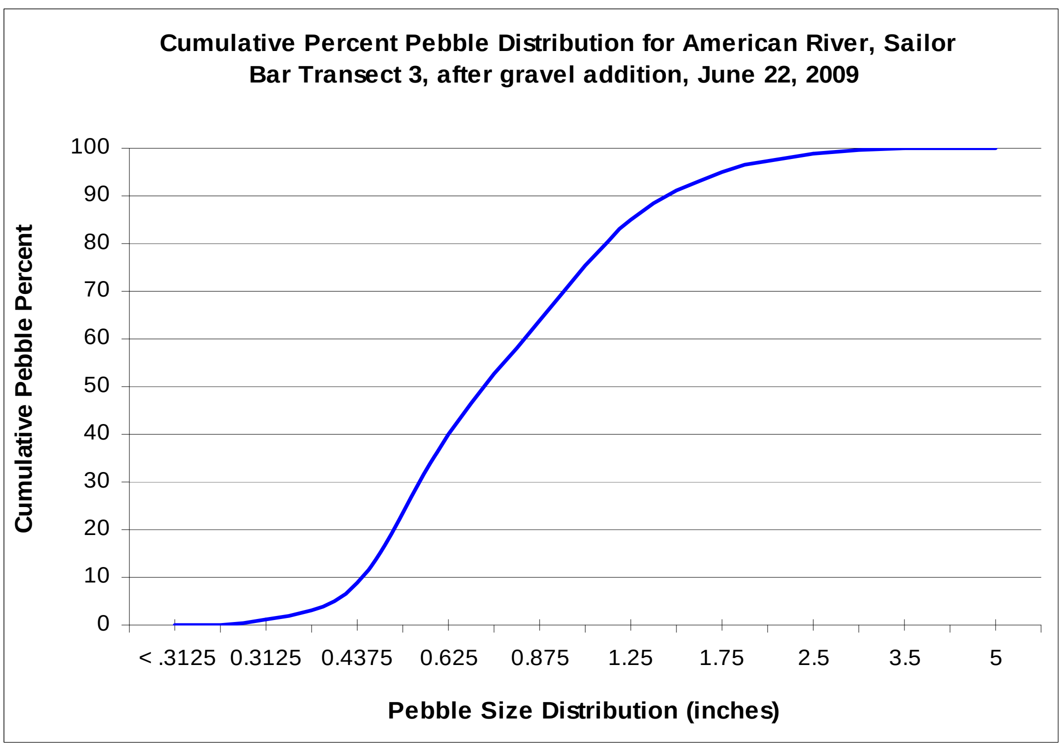
Histograph showing the after gravel addition pebble count data, June 2009.



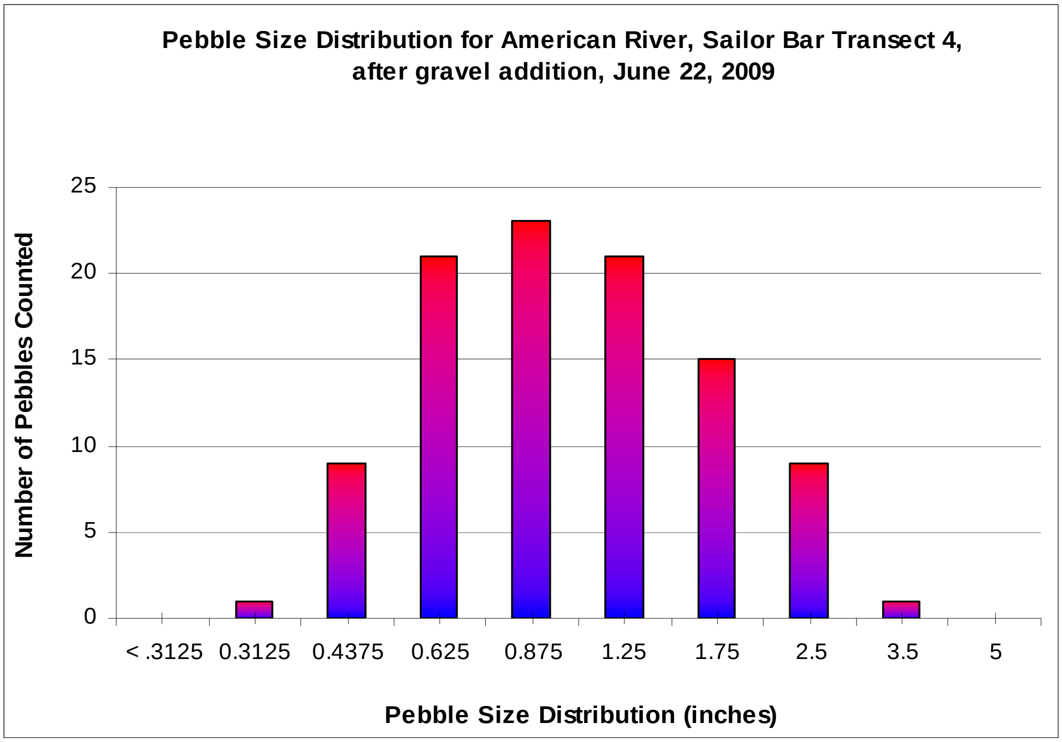
Cumulative frequency graph for after gravel addition pebble count, June 2009.



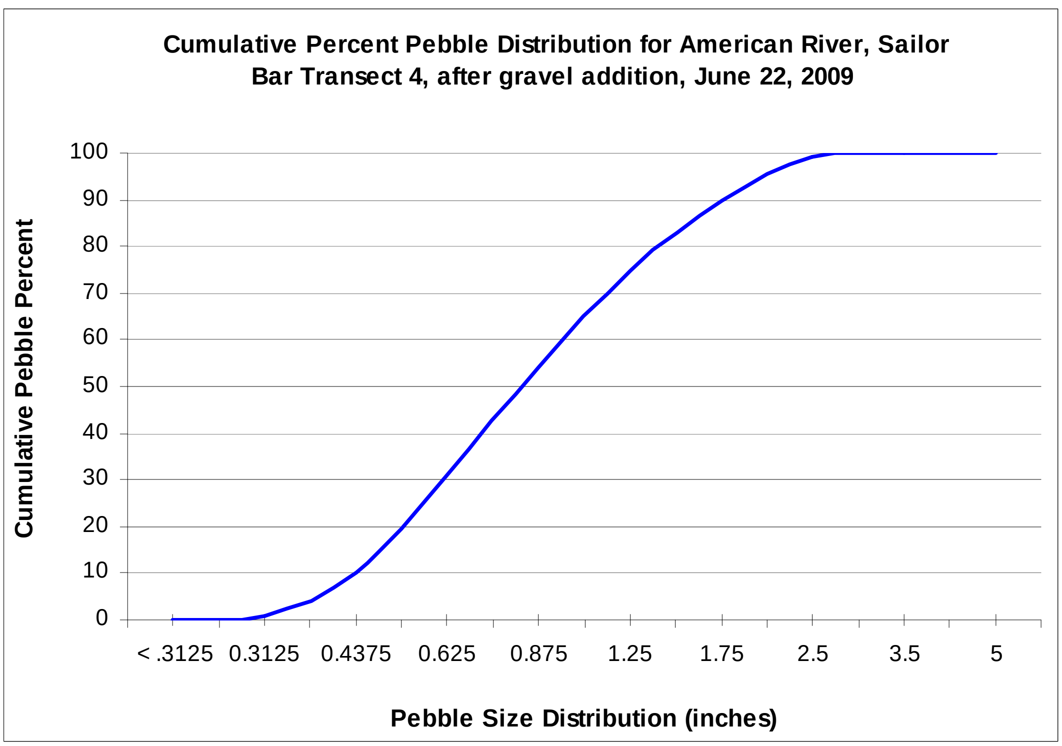
Histograph showing the after gravel addition pebble count data, June 2009.



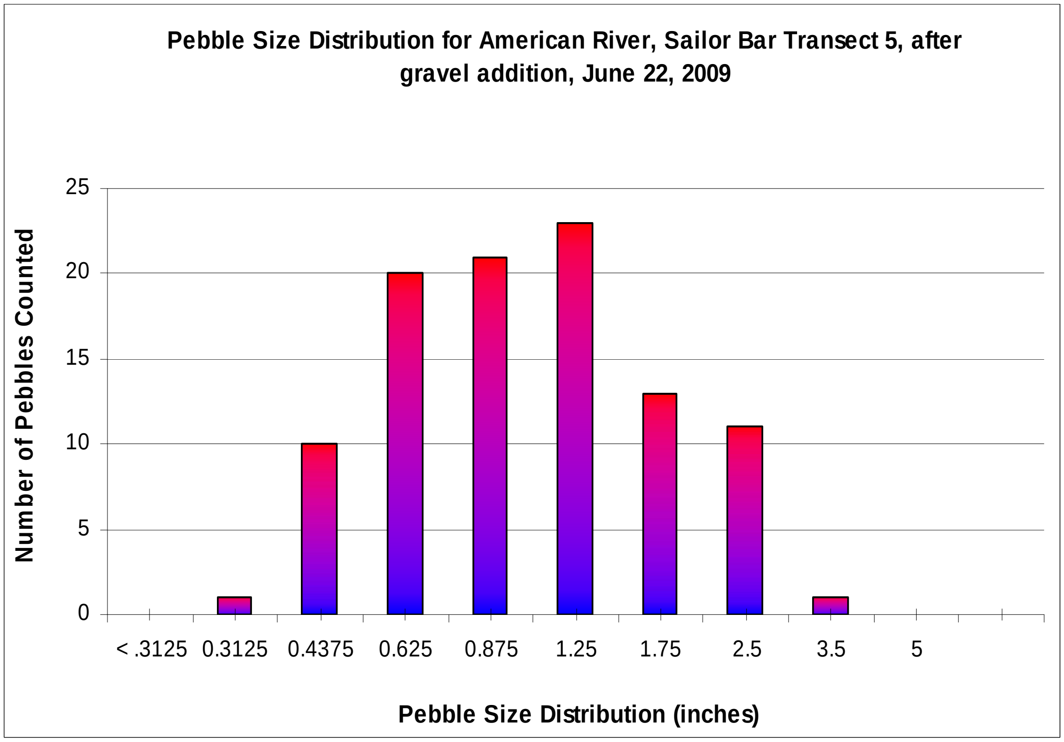
Cumulative frequency graph for after gravel addition pebble count, June 2009.



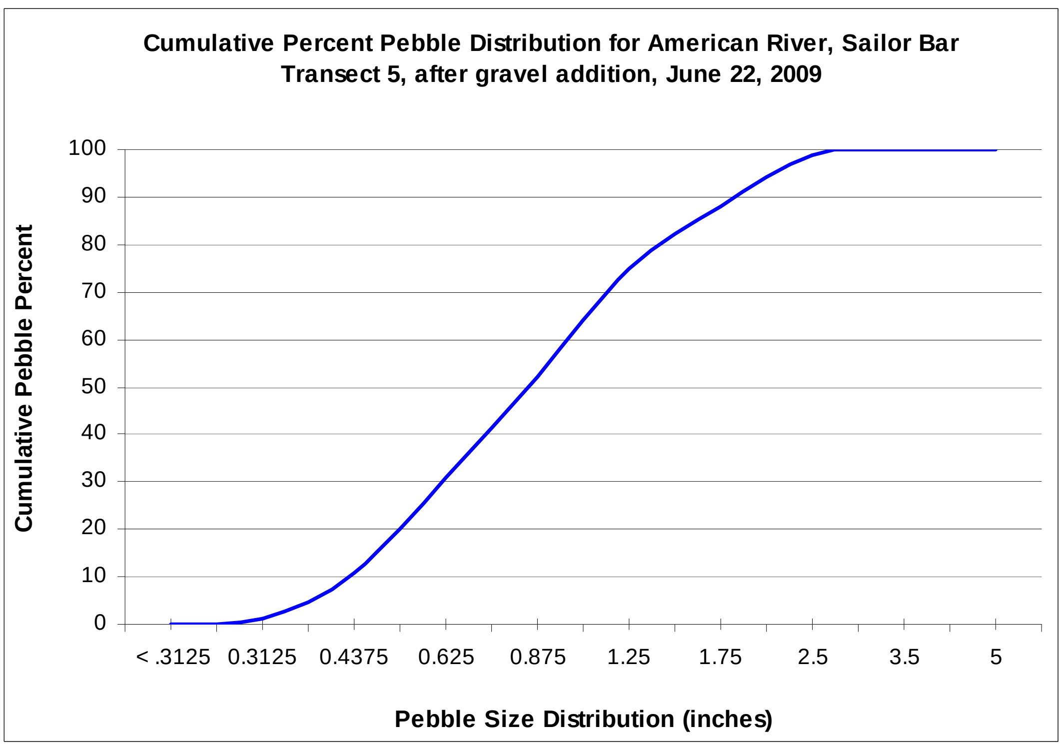
Histograph showing the after gravel addition pebble count data, June 2009.



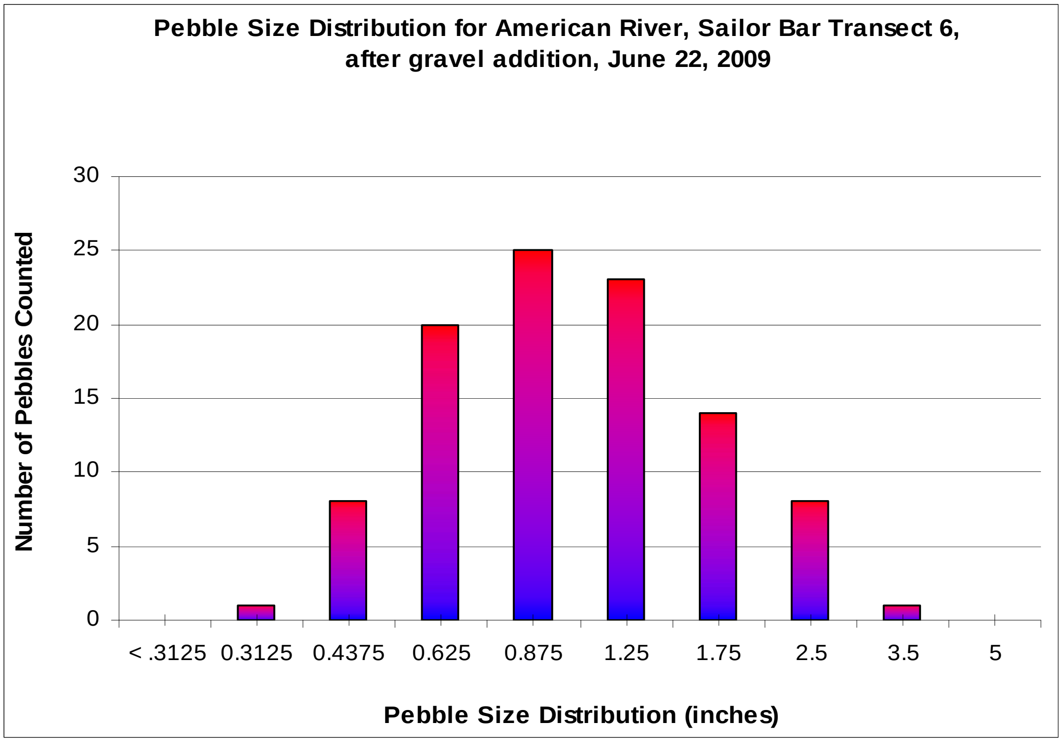
Cumulative frequency graph for after gravel addition pebble count, June 2009.



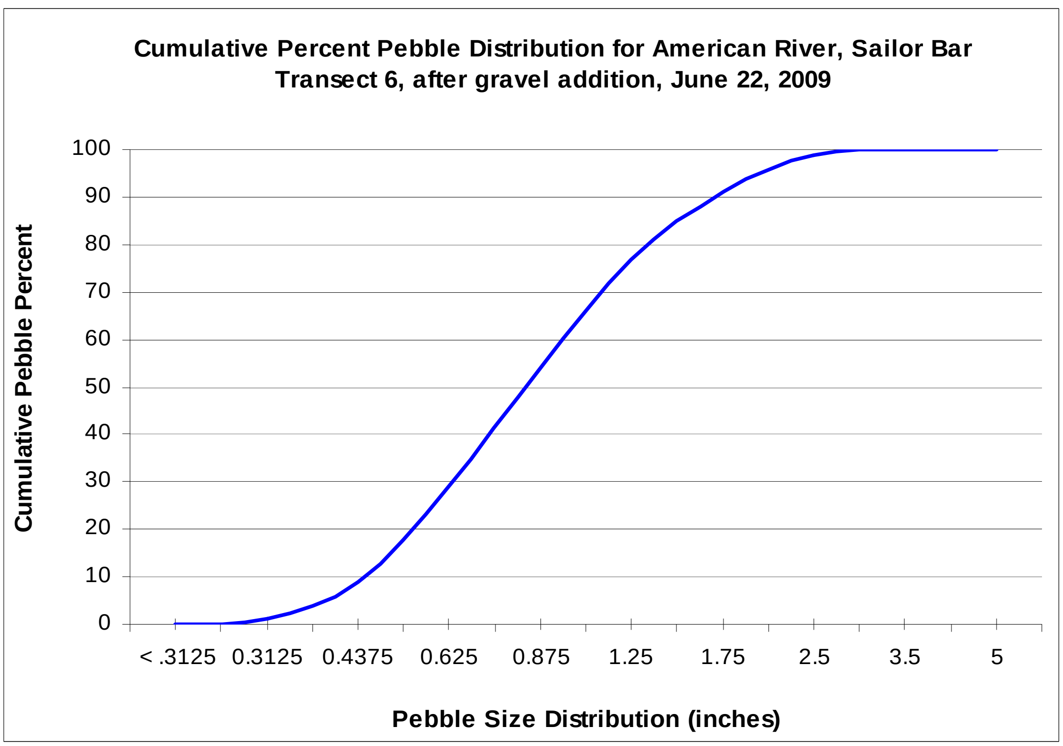
Histograph showing the after gravel addition pebble count data, June 2009.



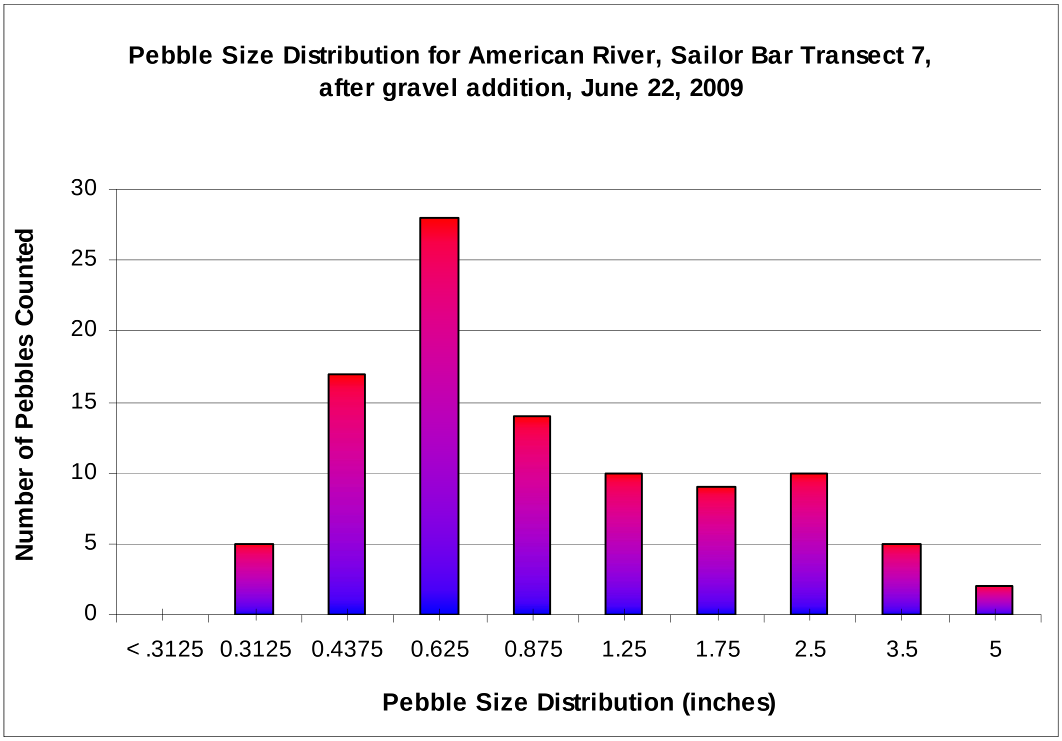
Cumulative frequency graph for after gravel addition pebble count, June 2009.



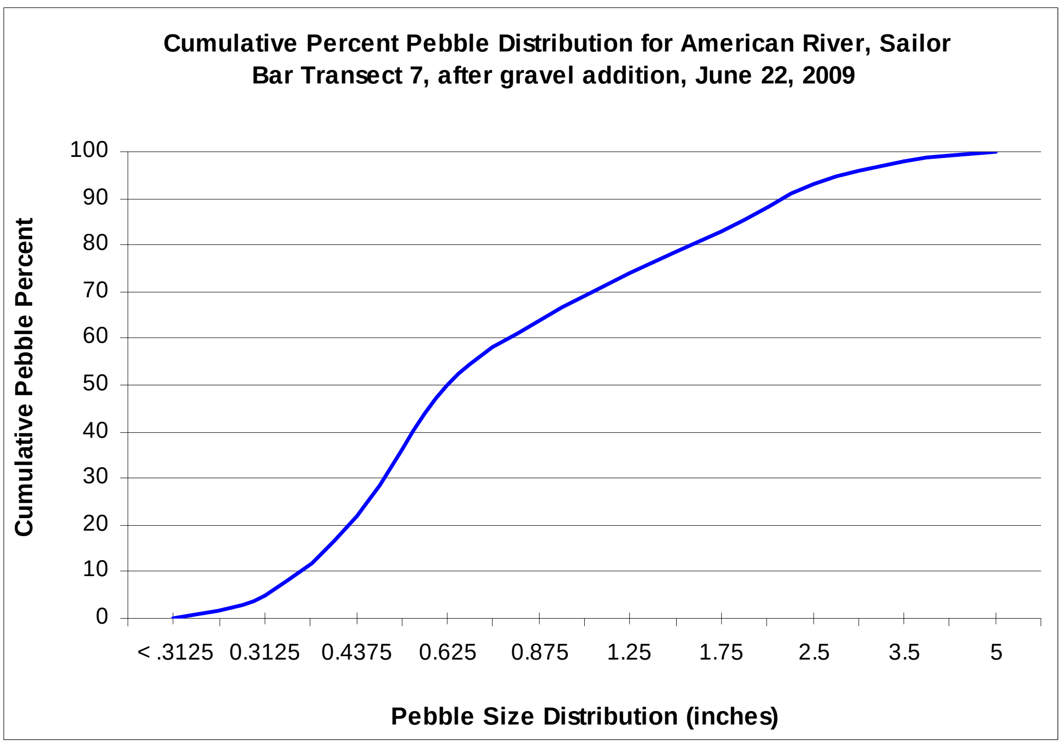
Histograph showing the after gravel addition pebble count data, June 2009.



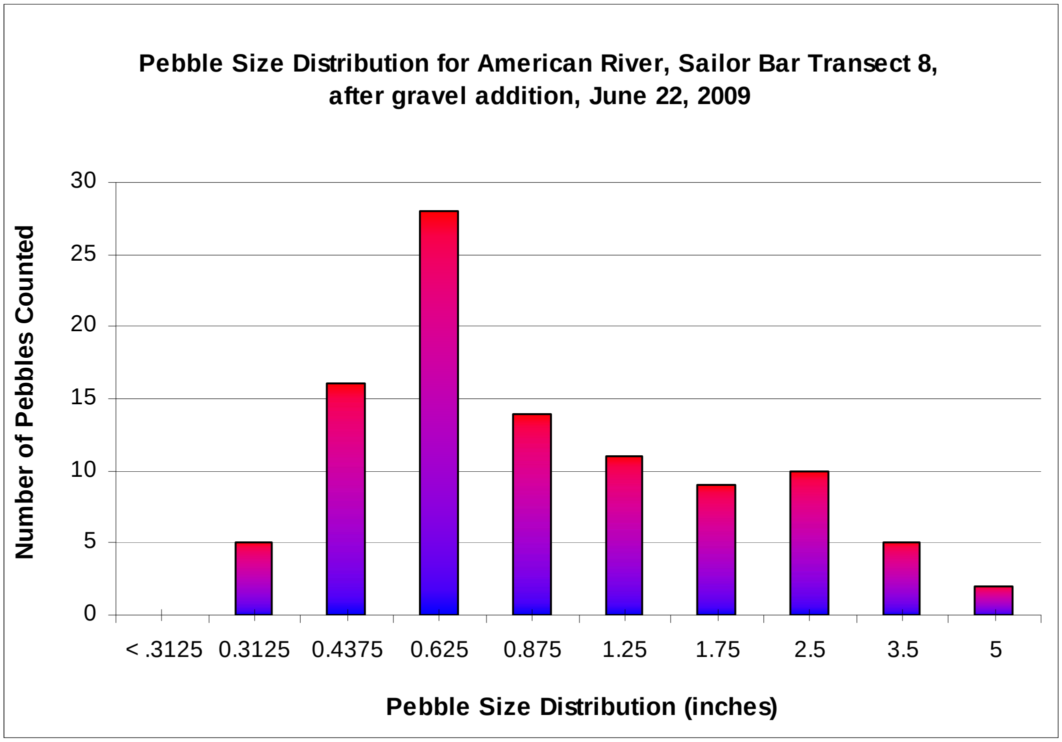
Cumulative frequency graph for after gravel addition pebble count, June 2009.



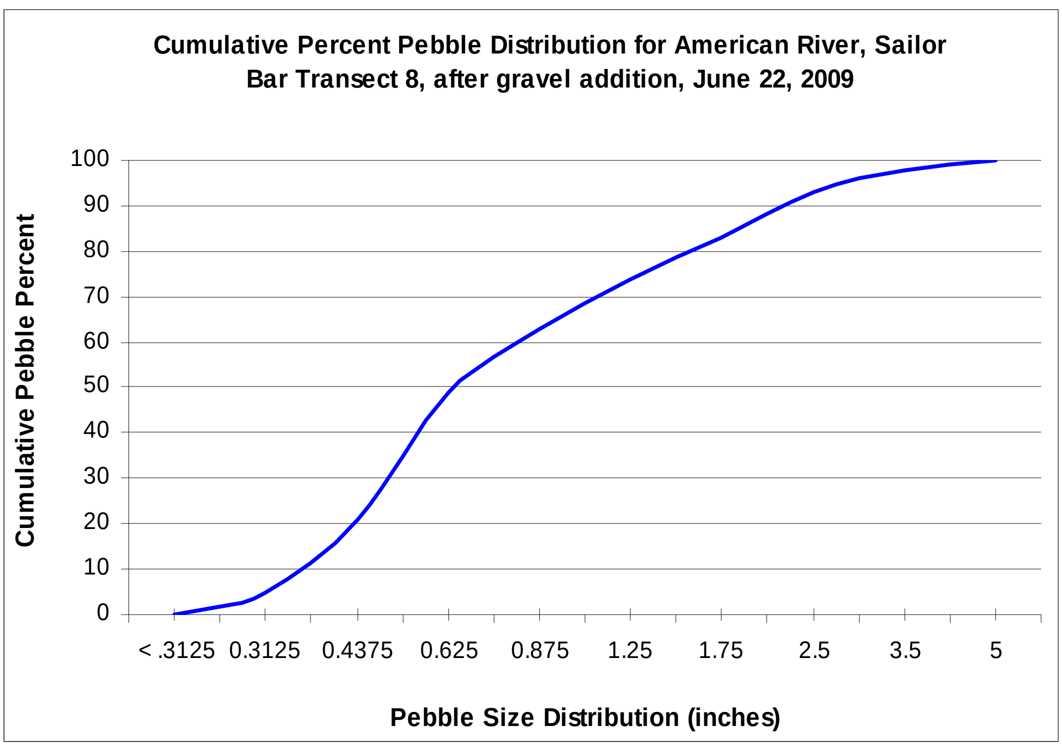
Histograph showing the after gravel addition pebble count data, June 2009.



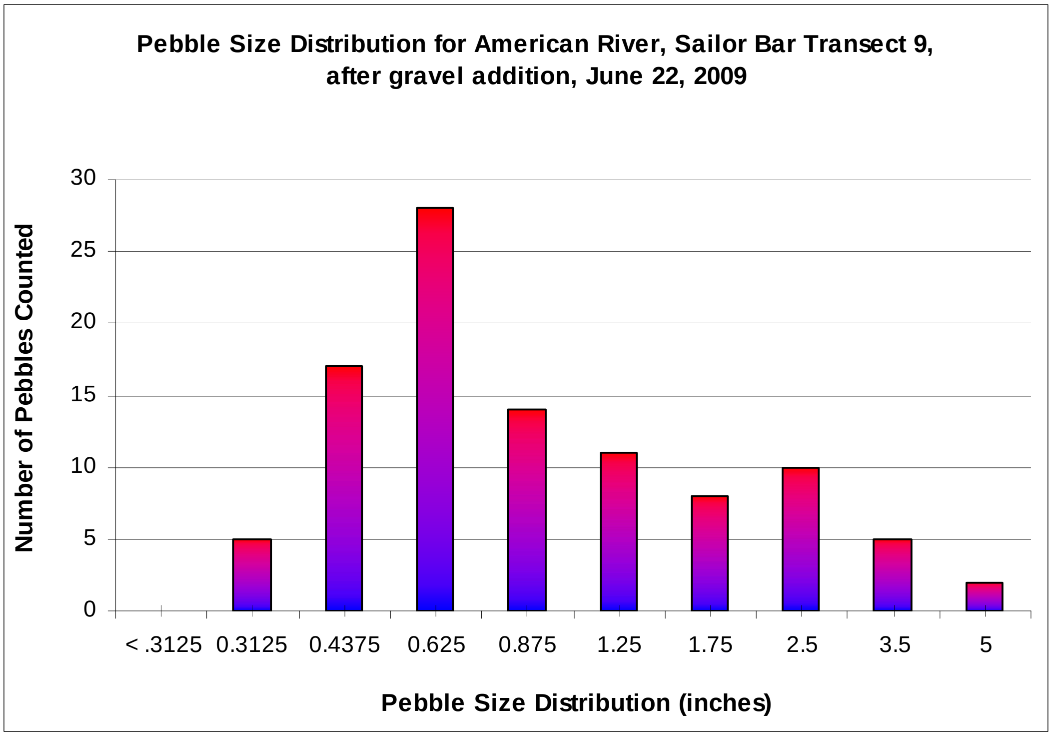
Cumulative frequency graph for after gravel addition pebble count, June 2009.



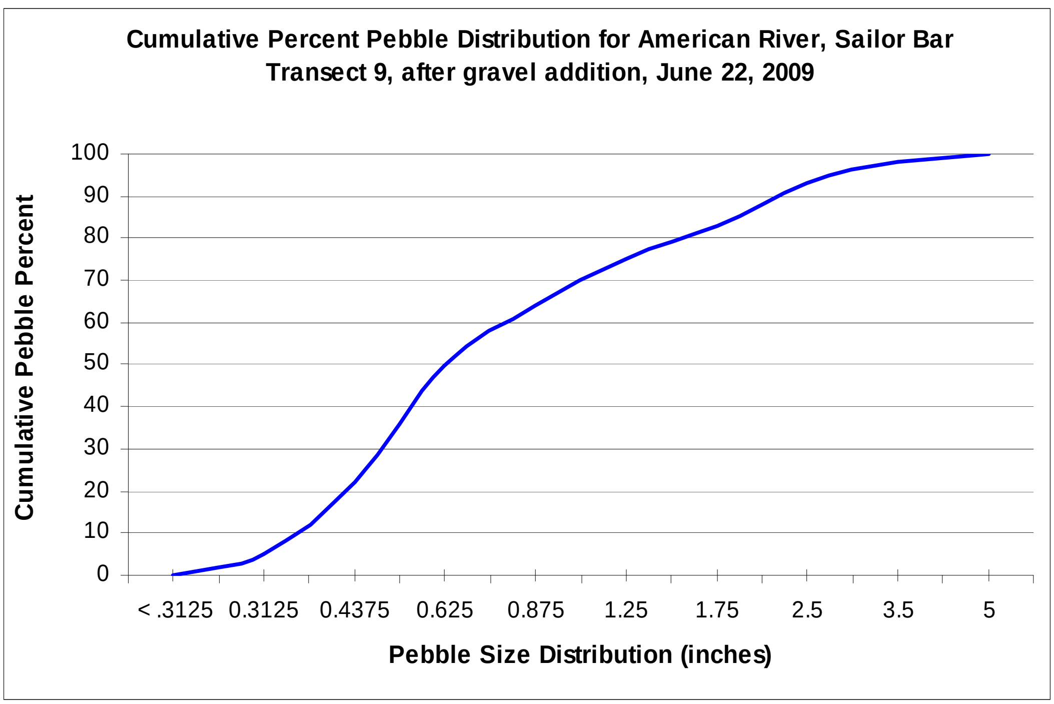
Histograph showing the after gravel addition pebble count data, June 2009.



Cumulative frequency graph for after gravel addition pebble count, June 2009.



Histograph showing the pebble count data, Sailor bar 2008, June 2009



Cumulative frequency graph for after gravel addition pebble count, June 2009.

APPENDIX H

Sailor Bar 2008 Hach Chemistry

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

HACH chemistry data for the before gravel addition Sailor bar 2008, data collected in June 2008.

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

HACH chemistry data for the after gravel addition Sailor bar 2008, data collected in February 2009.

APPENDIX I

Sailor Bar 2008 Inter gravel Velocity Test Data

	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

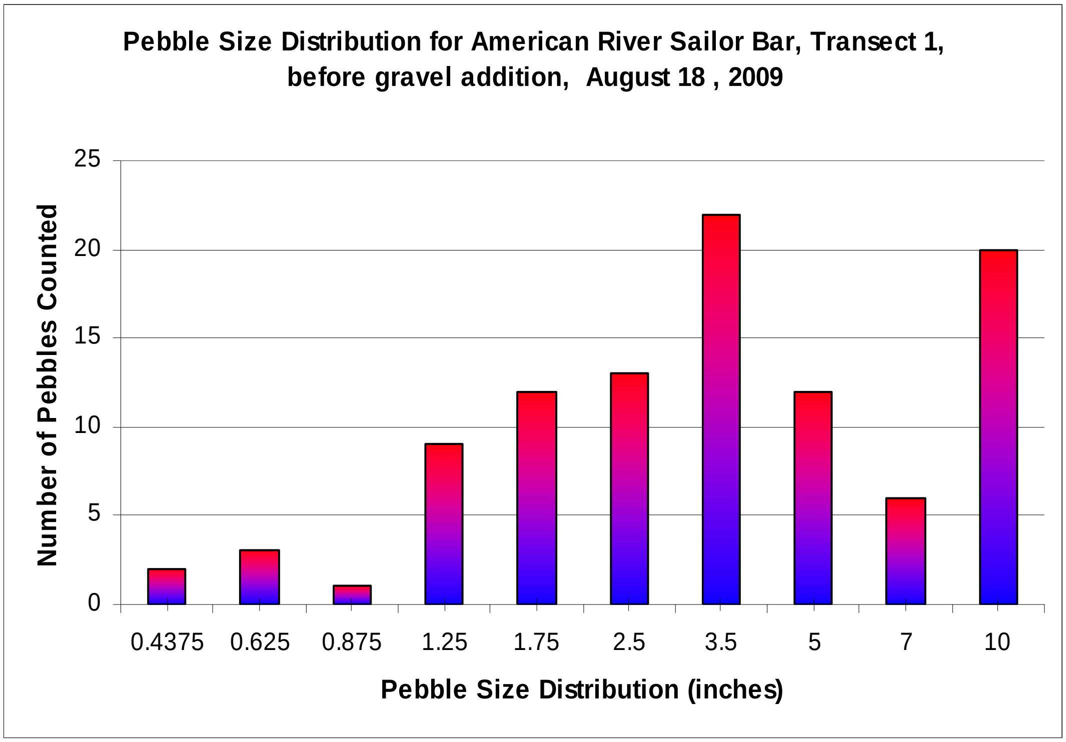
Tracer test 3 time and electrical conductivity data, after gravel addition, March 2010.

	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

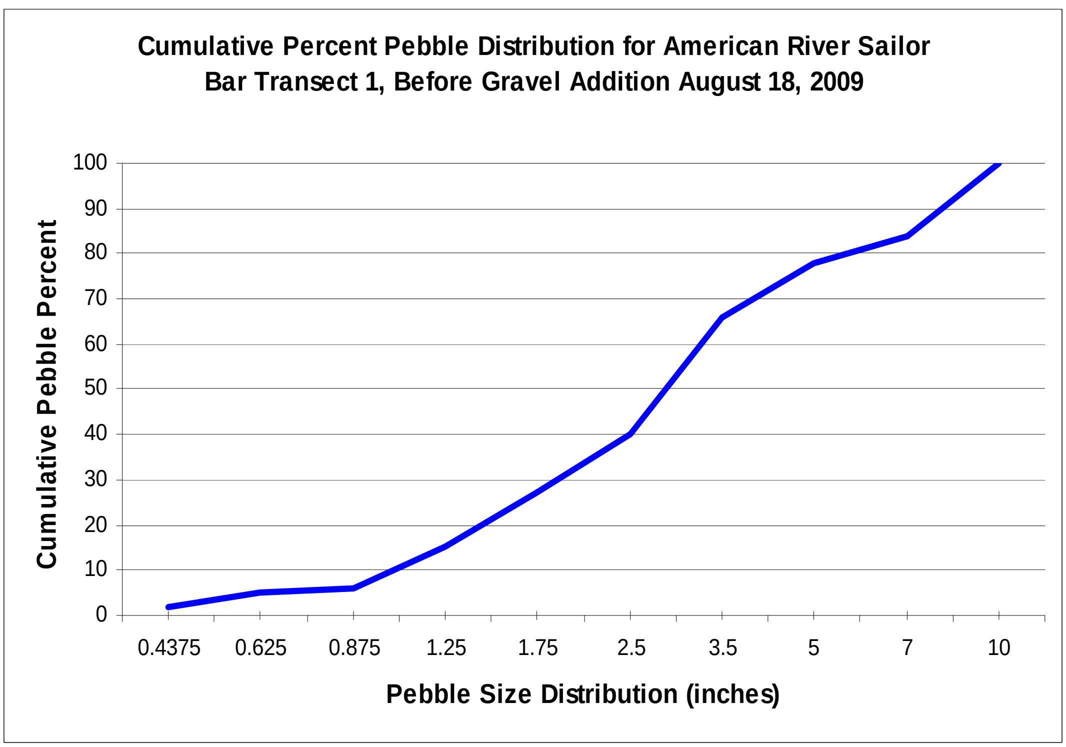
Tracer test 4 time and electrical conductivity data, after gravel addition, March 2010.

APPENDIX J

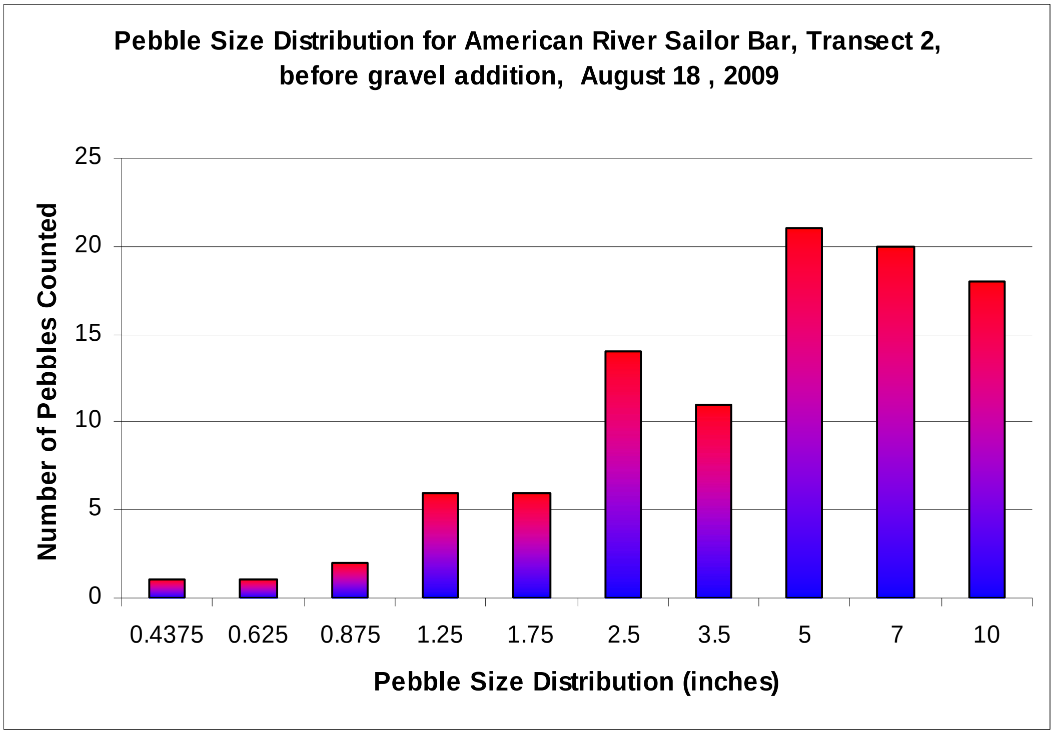
Sailor Bar 2009 Before Gravel Addition Pebble Count



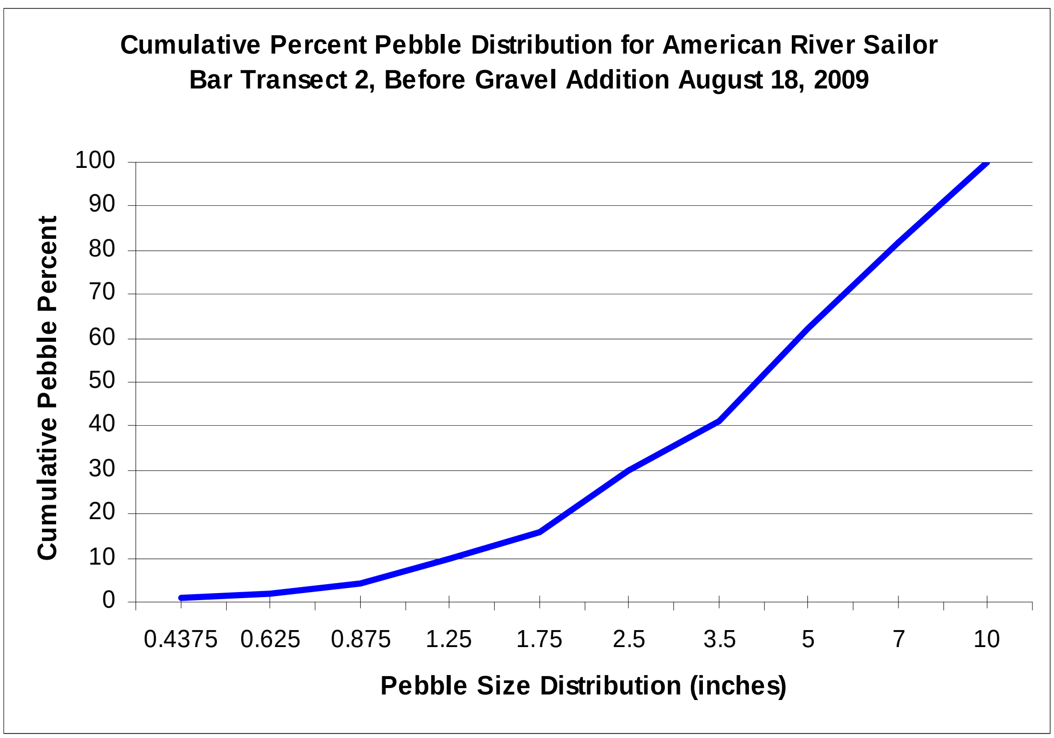
Histograph showing the pebble count data, Sailor bar 2009, August 2009



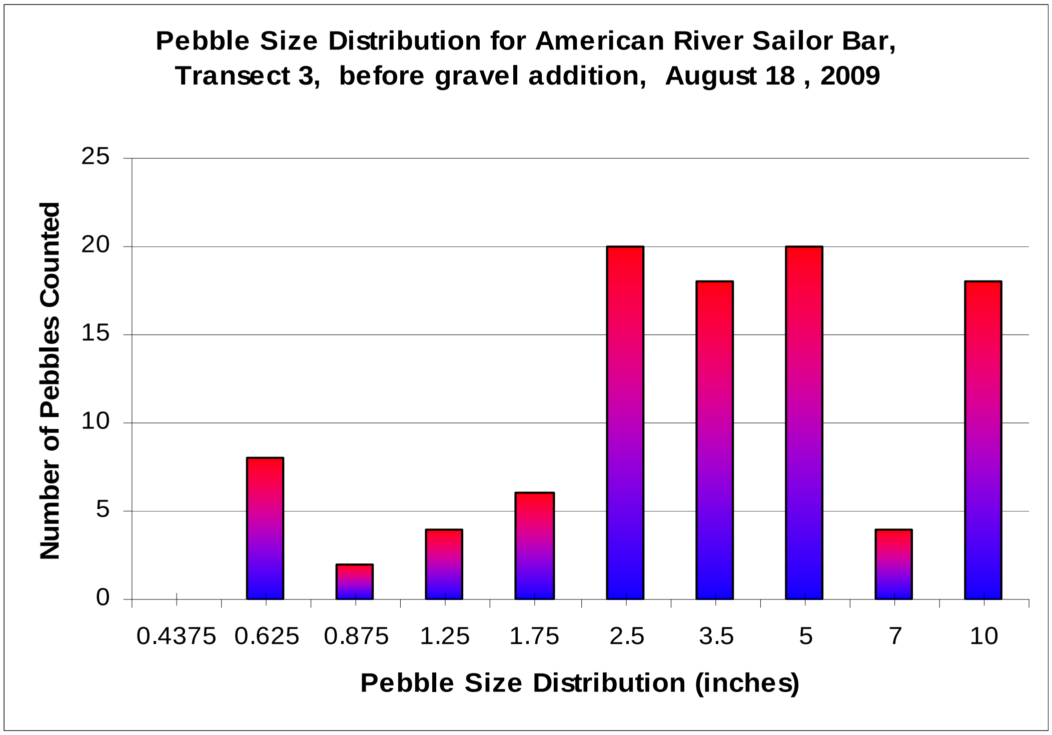
Graph showing the cumulative frequency data for Sailor bar 2009, August 2009.



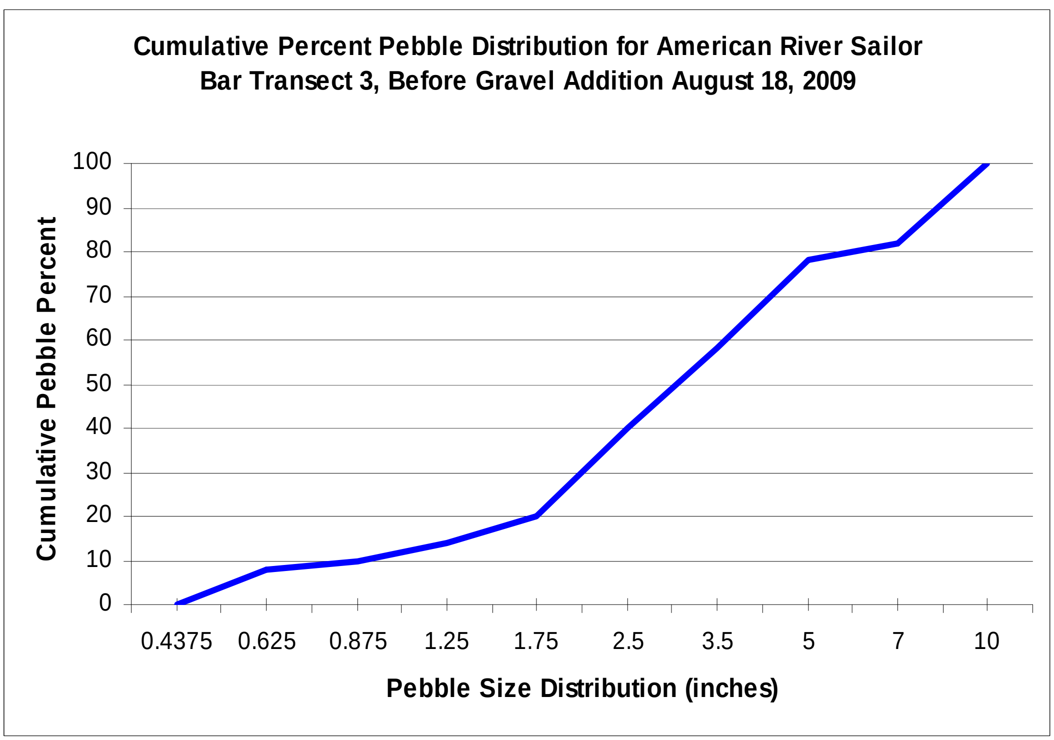
Histograph showing the pebble count data, Sailor bar 2009, August 2009



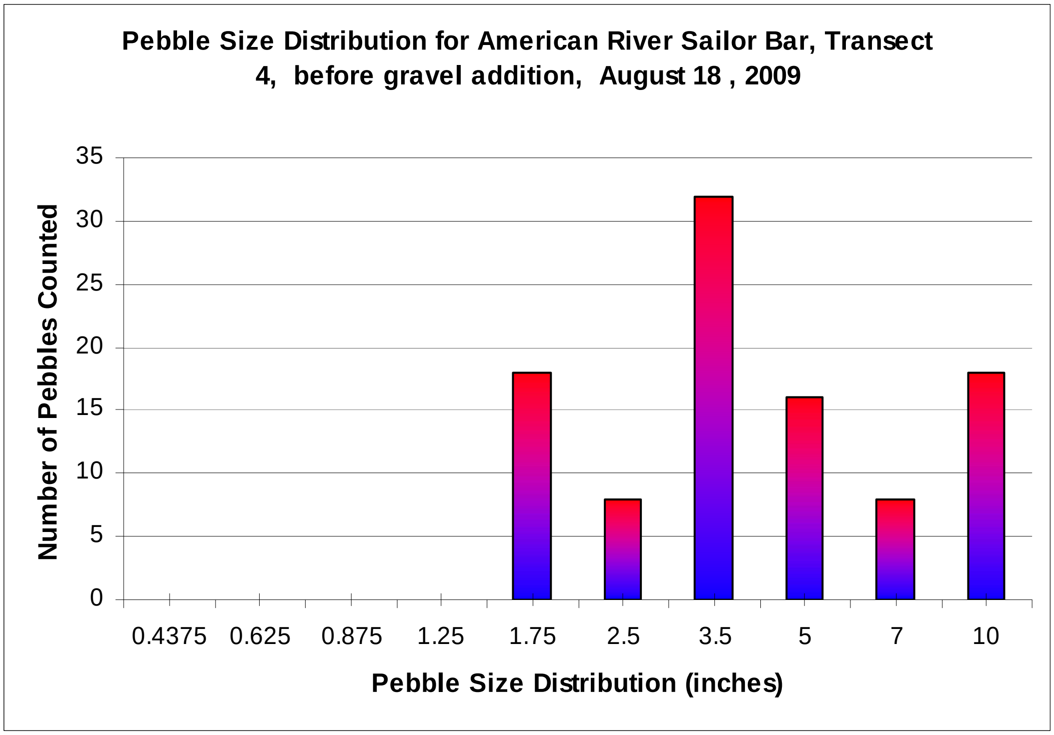
Graph showing the cumulative frequency data for Sailor bar 2009, August 2009.



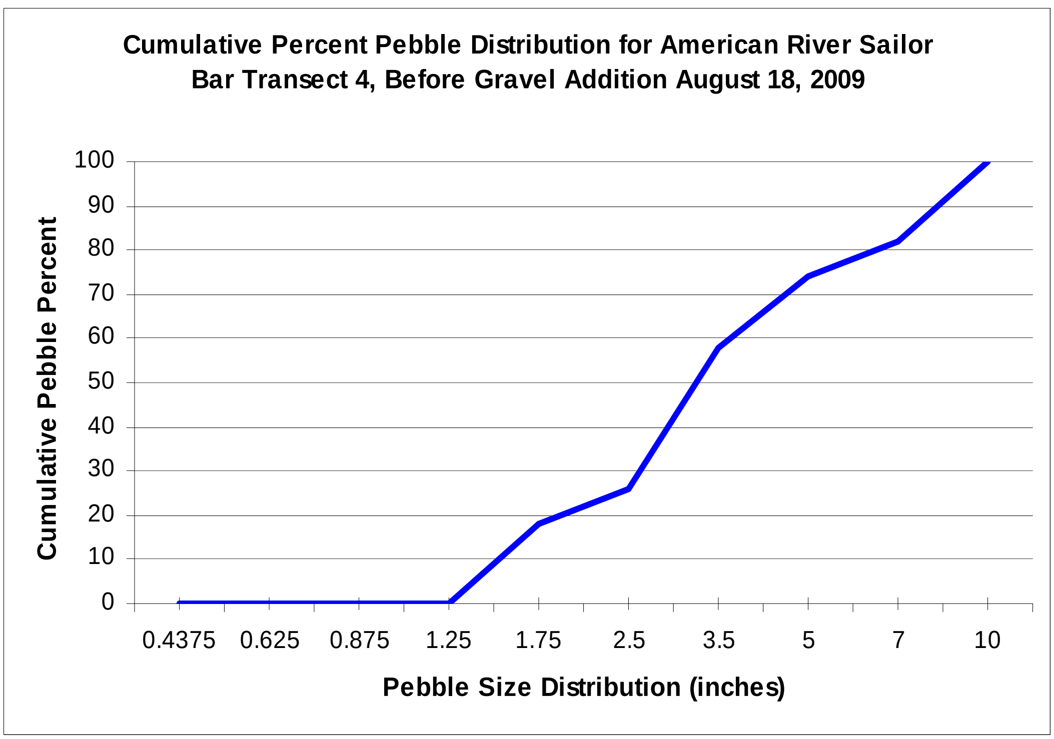
Histograph showing the pebble count data, Sailor bar 2009, August 2009



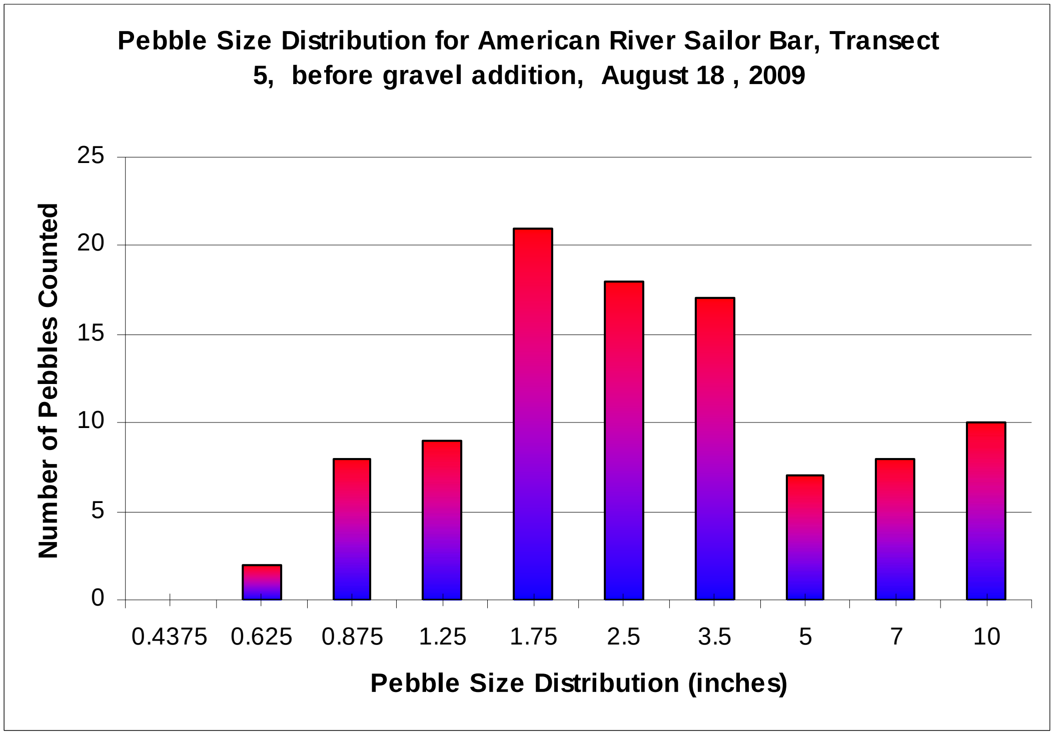
Graph showing the cumulative frequency data for Sailor bar 2009, August 2009.



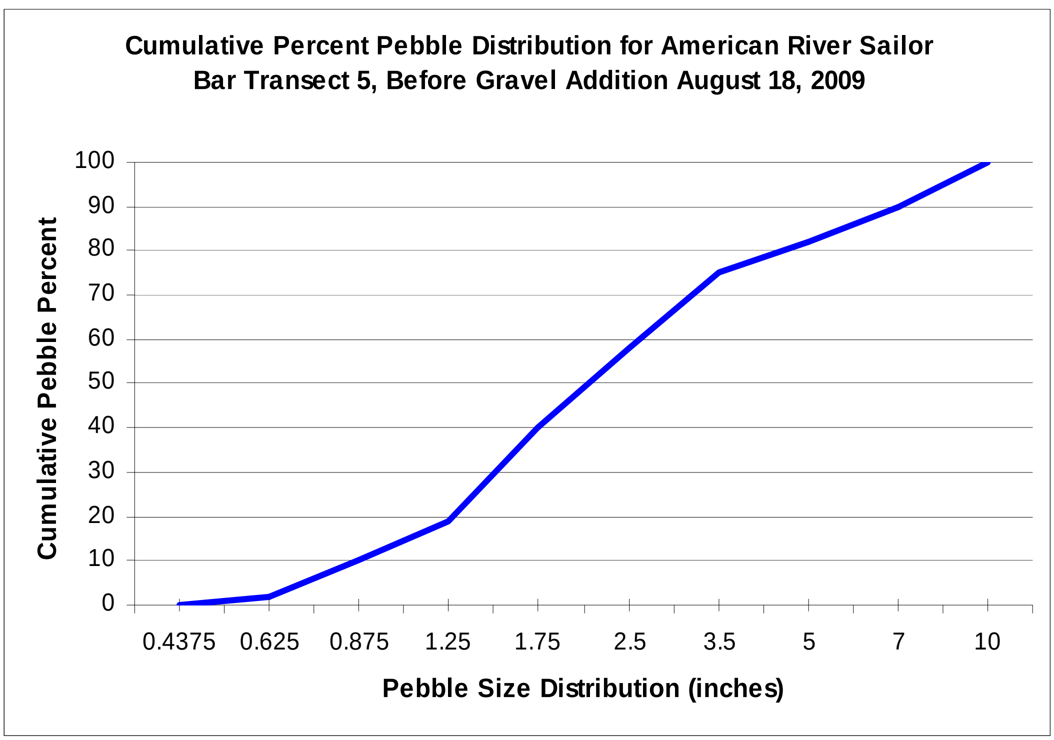
Histograph showing the pebble count data, Sailor bar 2009, August 2009



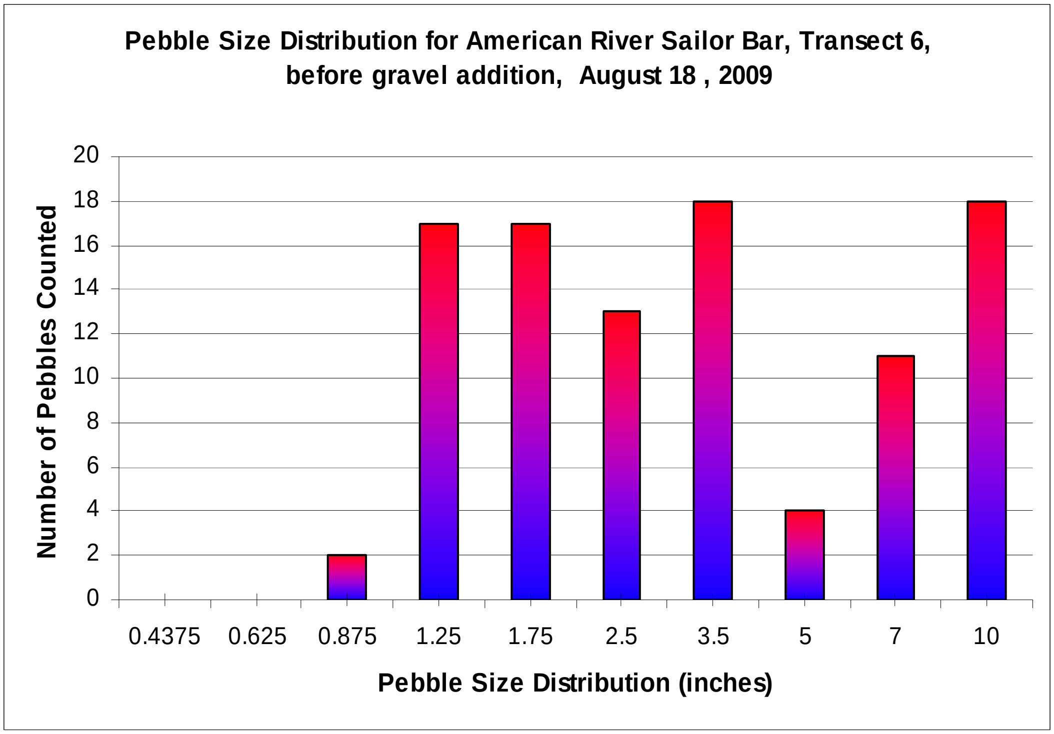
Graph showing the cumulative frequency data for Sailor bar 2009, August 2009.



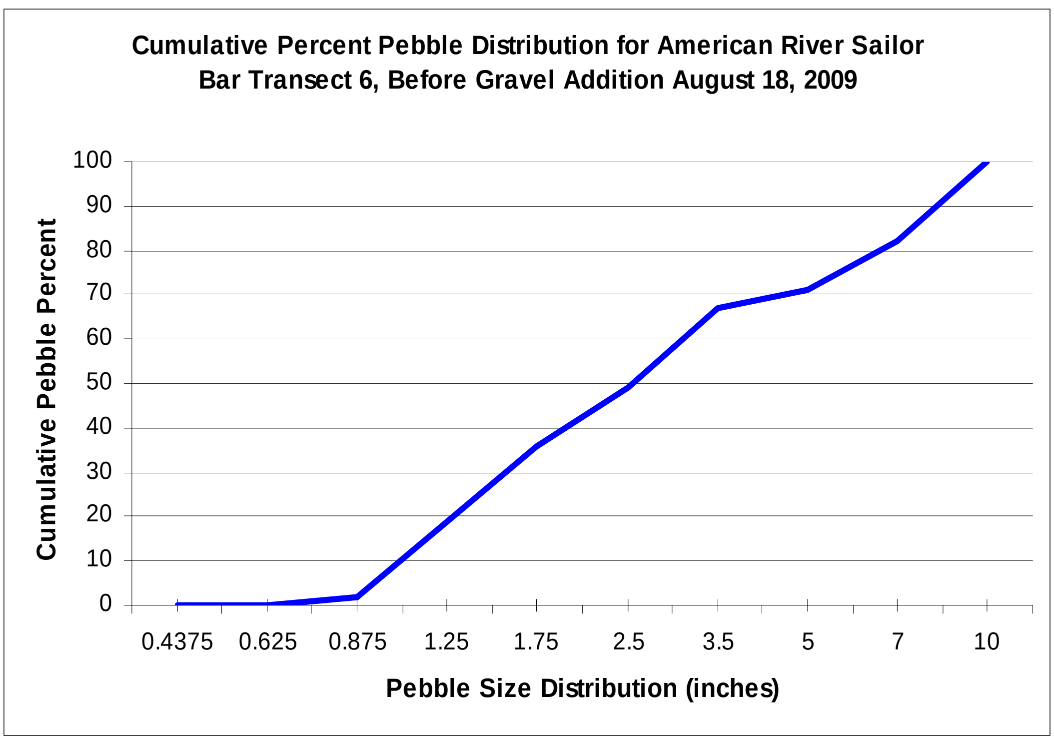
Histograph showing the pebble count data, Sailor bar 2009, August 2009



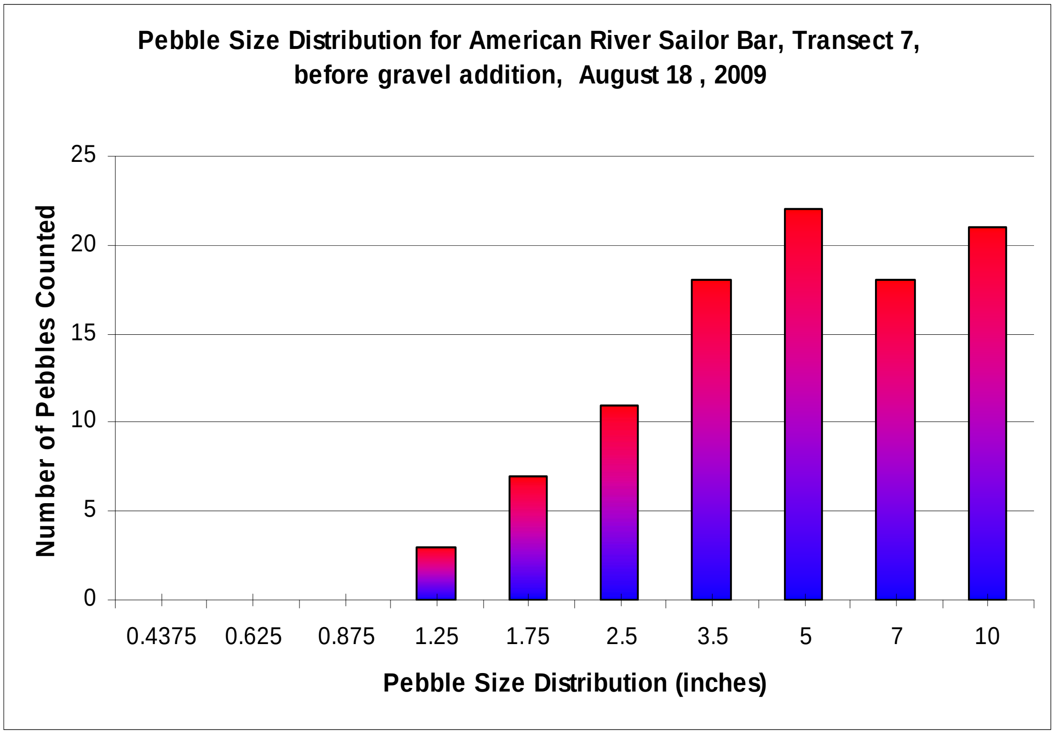
Histograph showing the pebble count data, Sailor bar 2009, August 2009



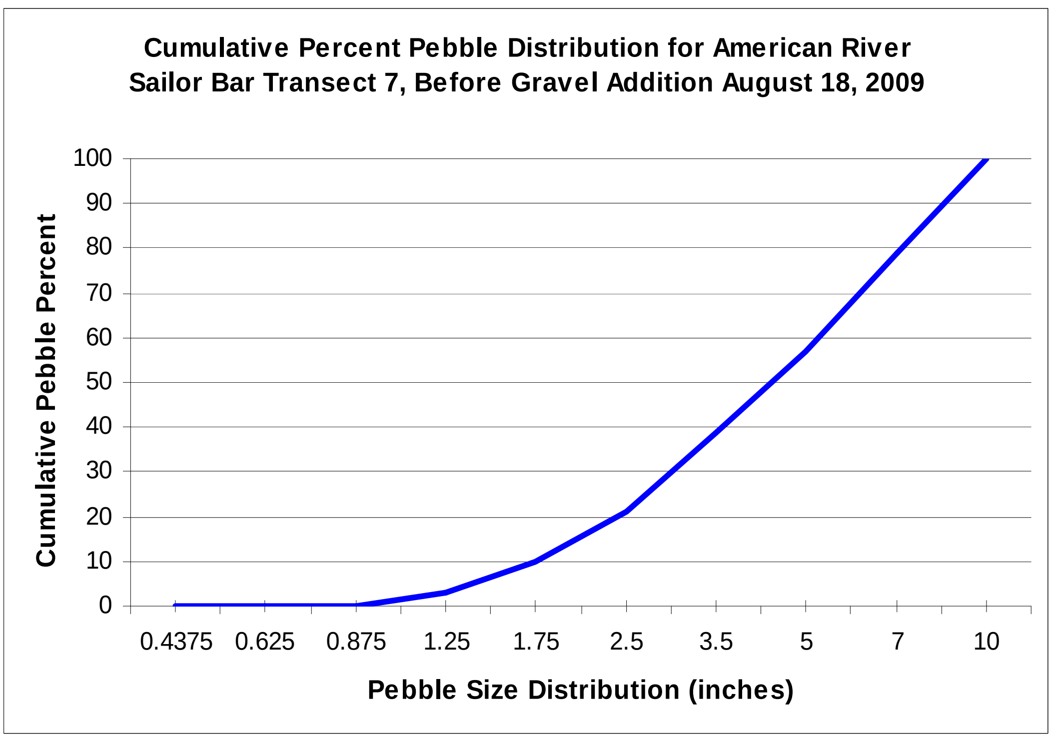
Histograph showing the pebble count data, Sailor bar 2009, August 2009



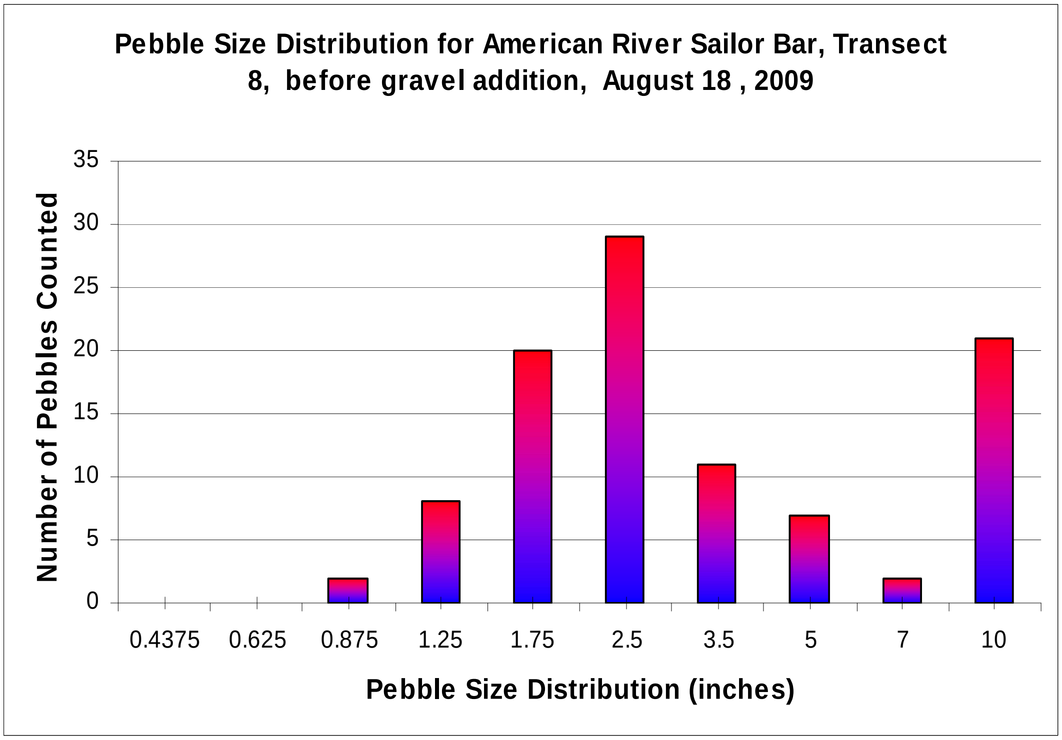
Histograph showing the pebble count data, Sailor bar 2009, August 2009



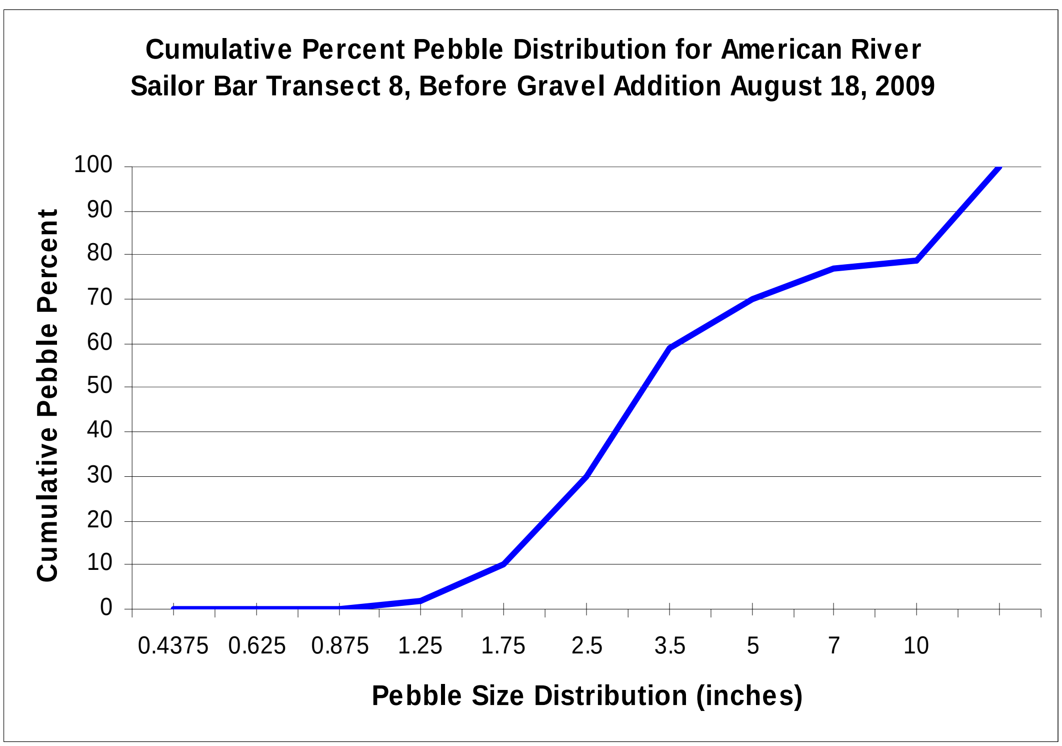
Histograph showing the pebble count data, Sailor bar 2009, August 2009



Histograph showing the pebble count data, Sailor bar 2009, August 2009



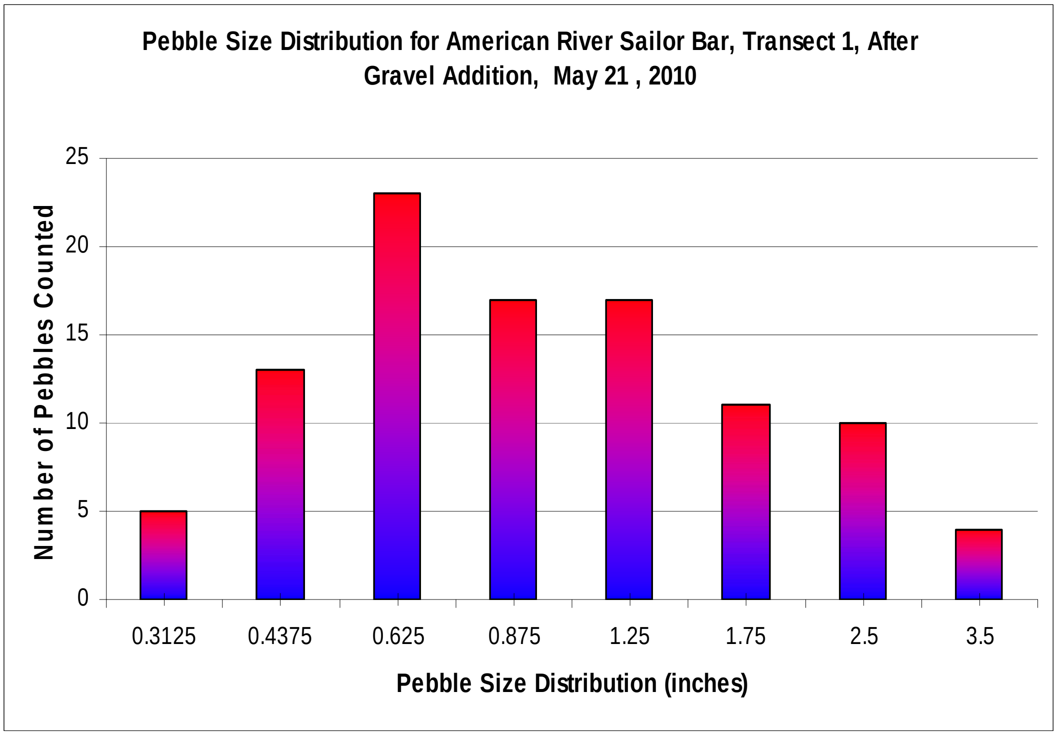
Histograph showing the pebble count data, Sailor bar 2009, August 2009



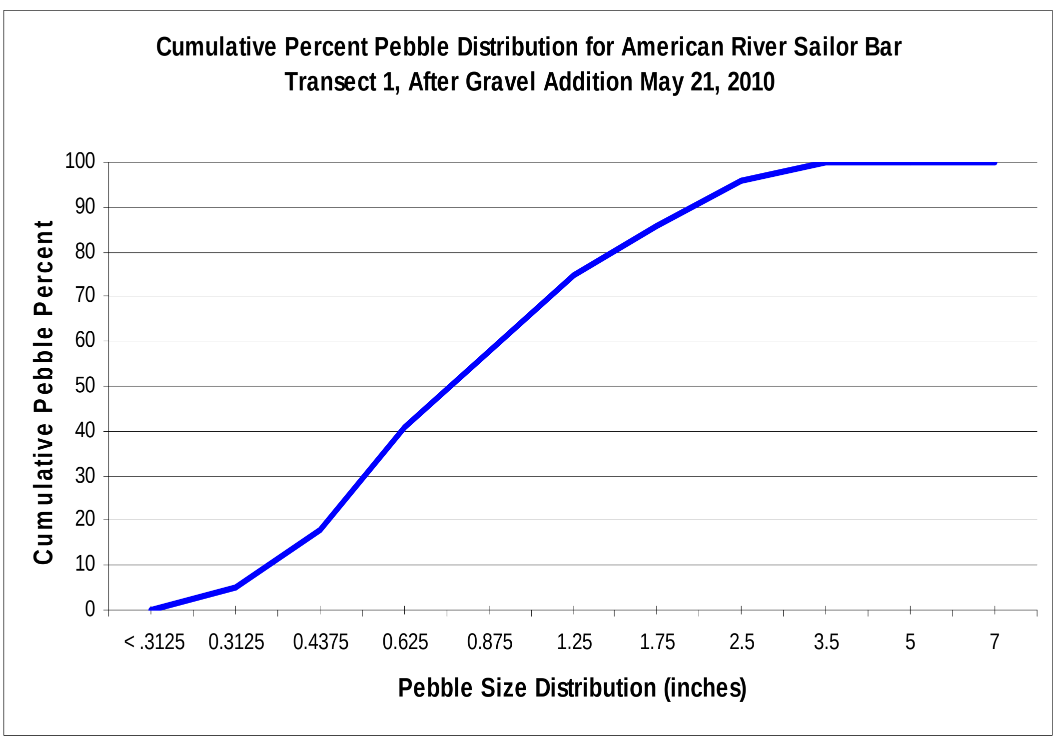
Histograph showing the pebble count data, Sailor bar 2009, August 2009

APPENDIX K

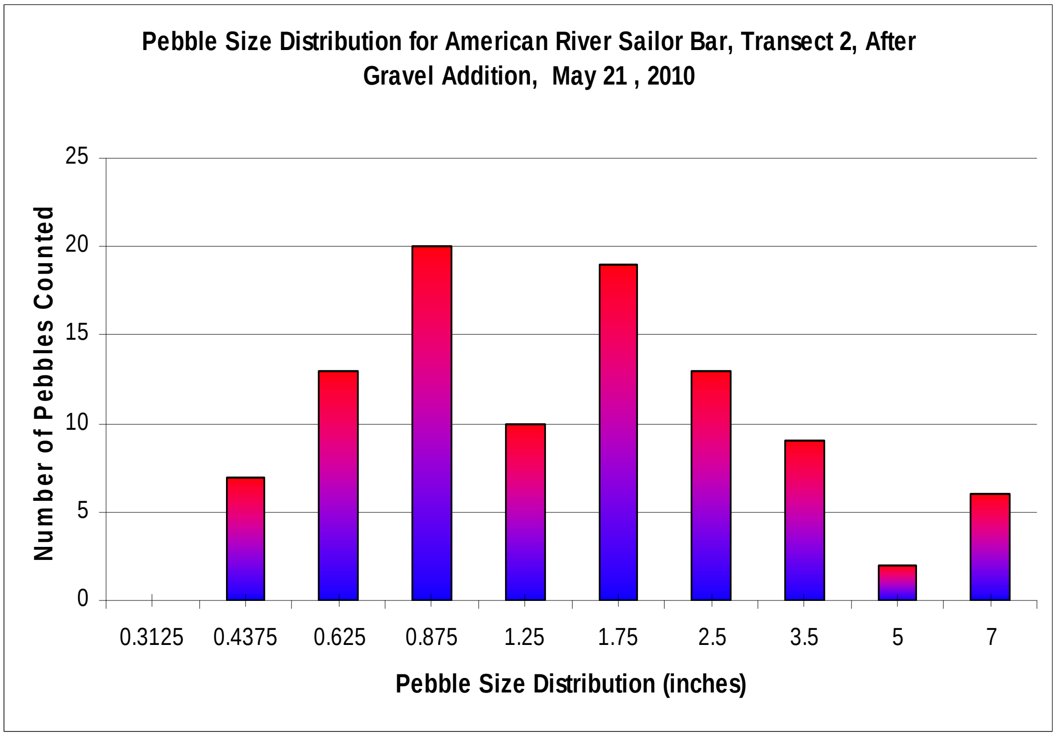
Sailor Bar 2009 After Gravel Addition Pebble Count Data



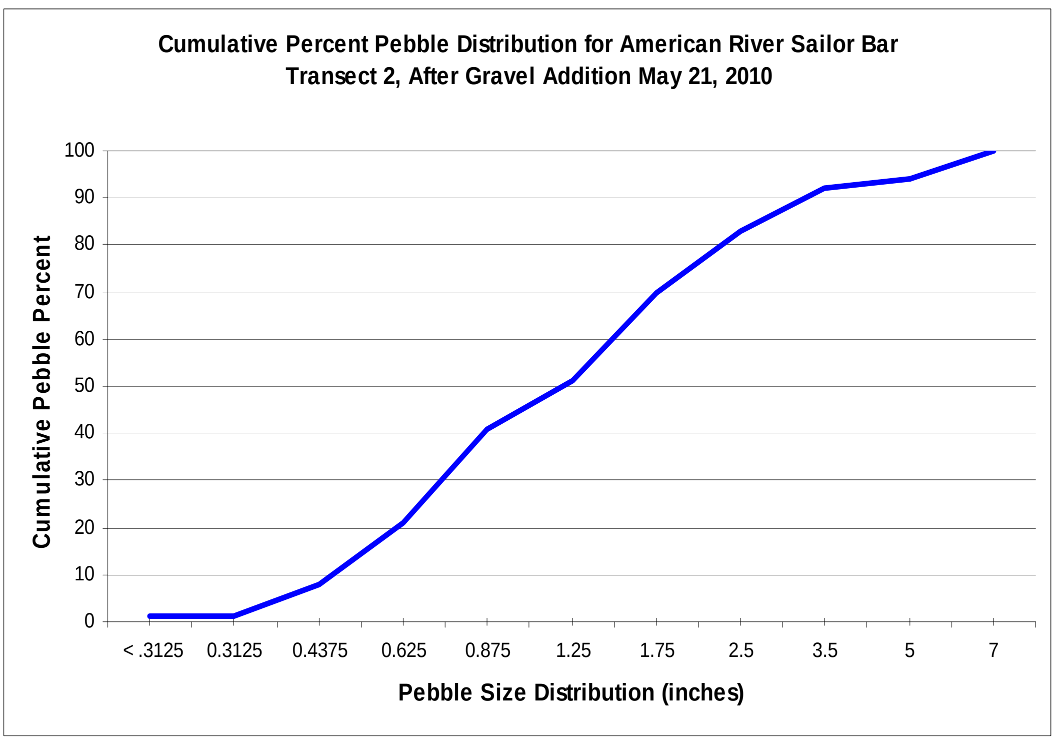
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



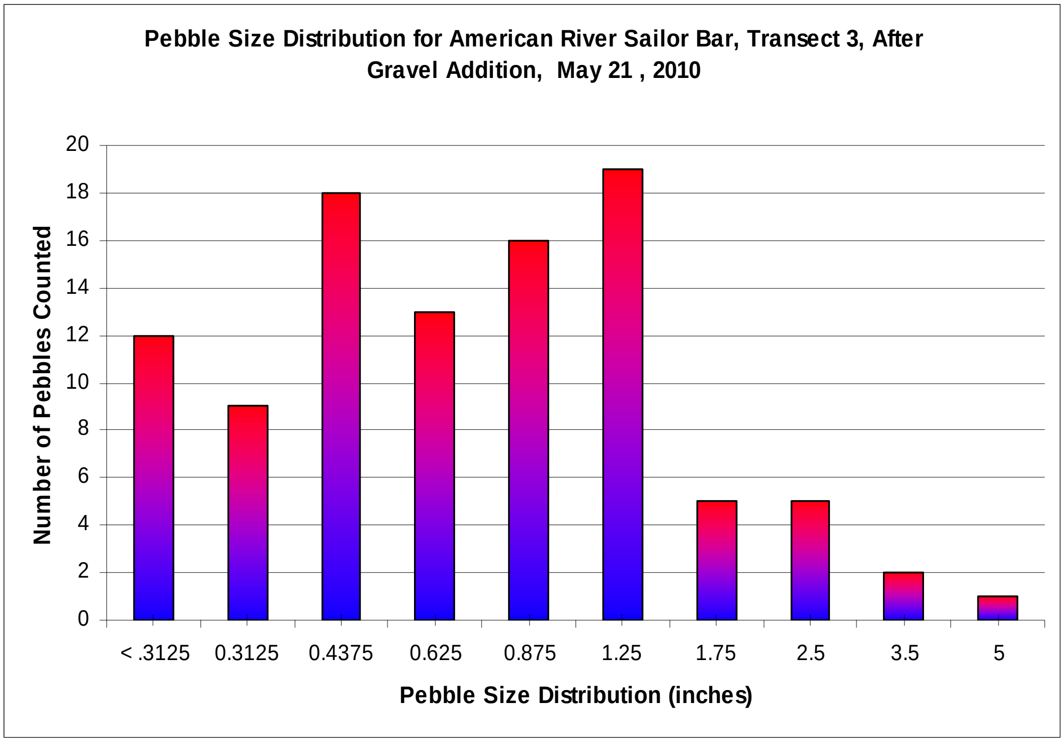
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



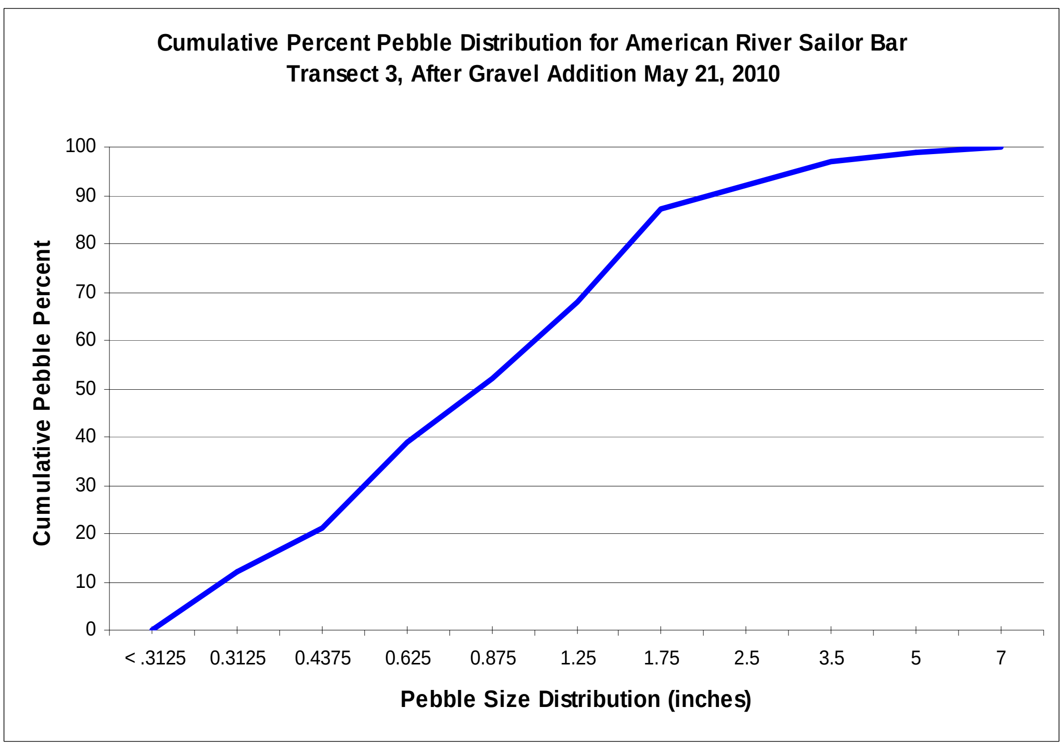
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



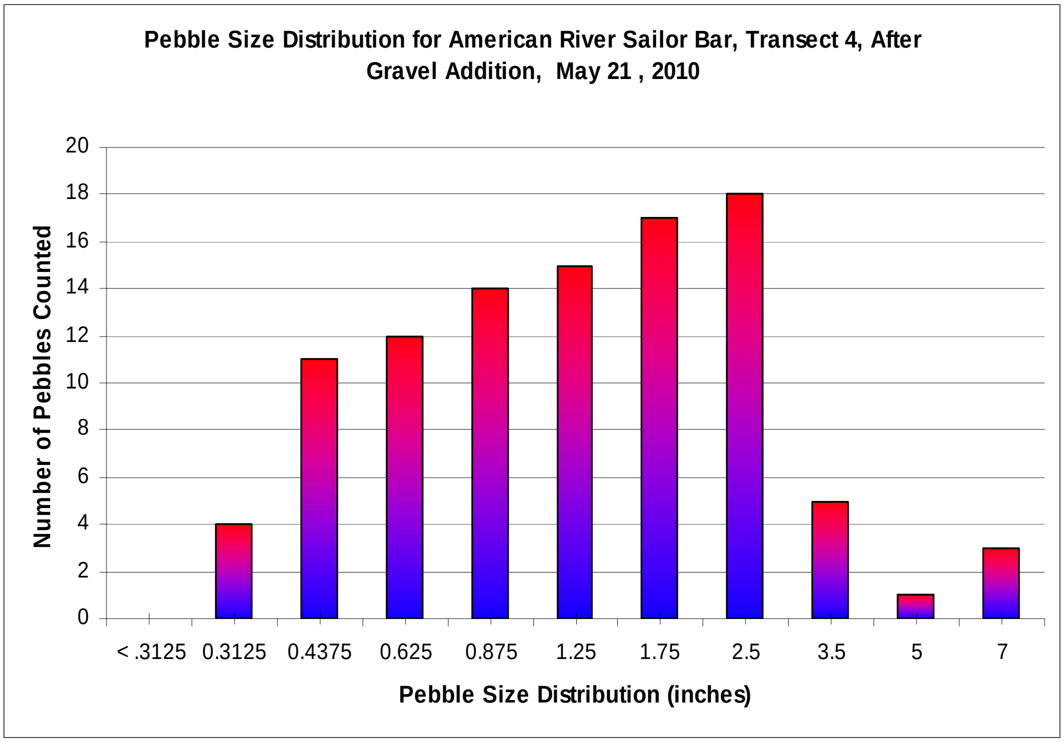
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



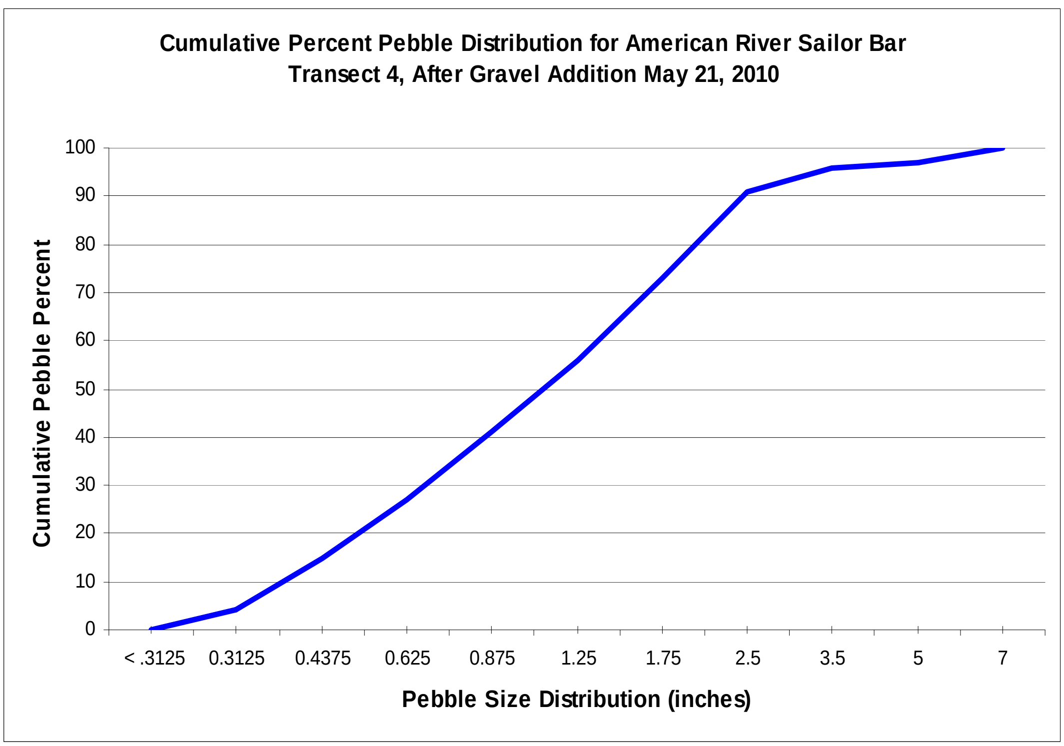
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



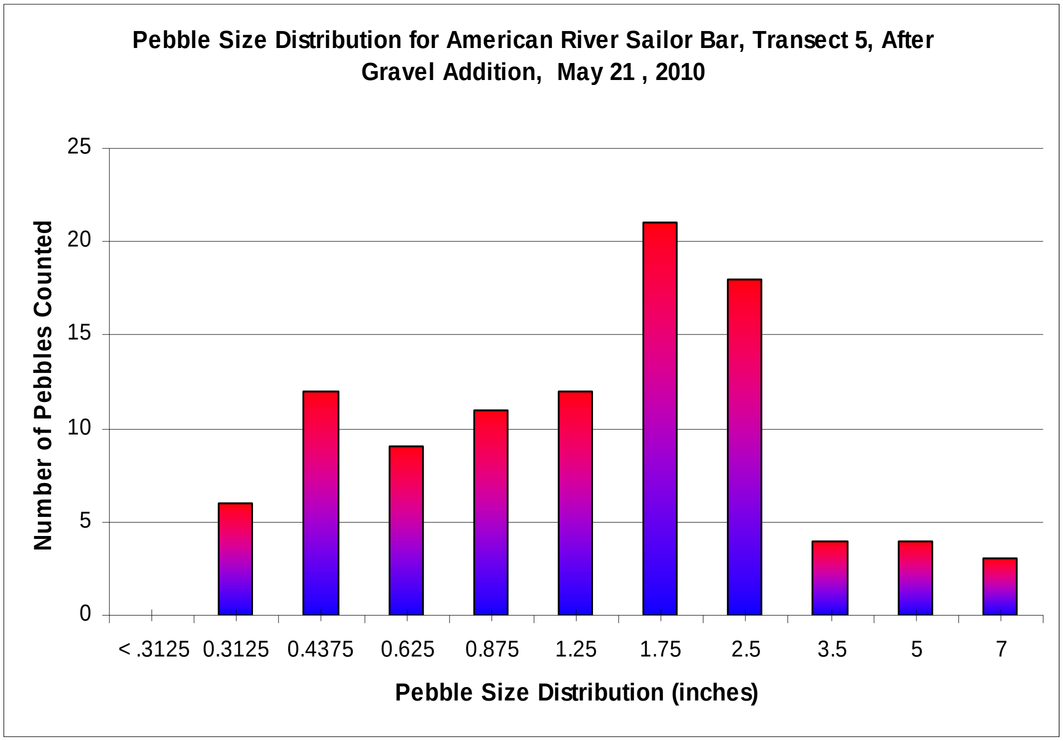
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



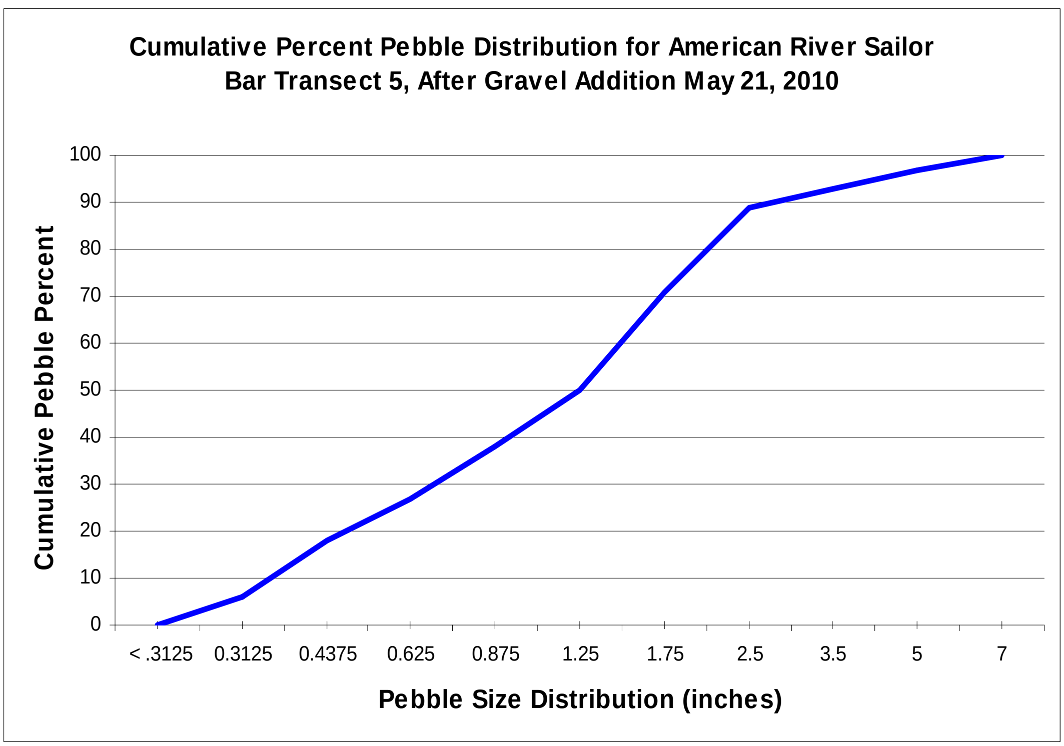
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



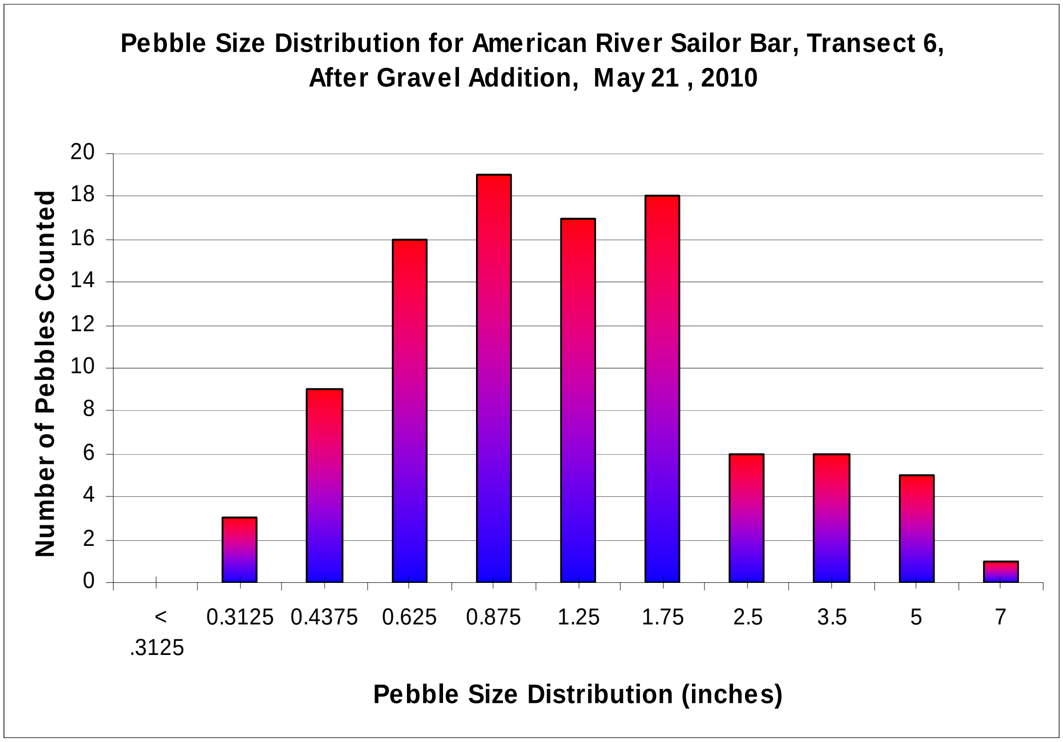
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



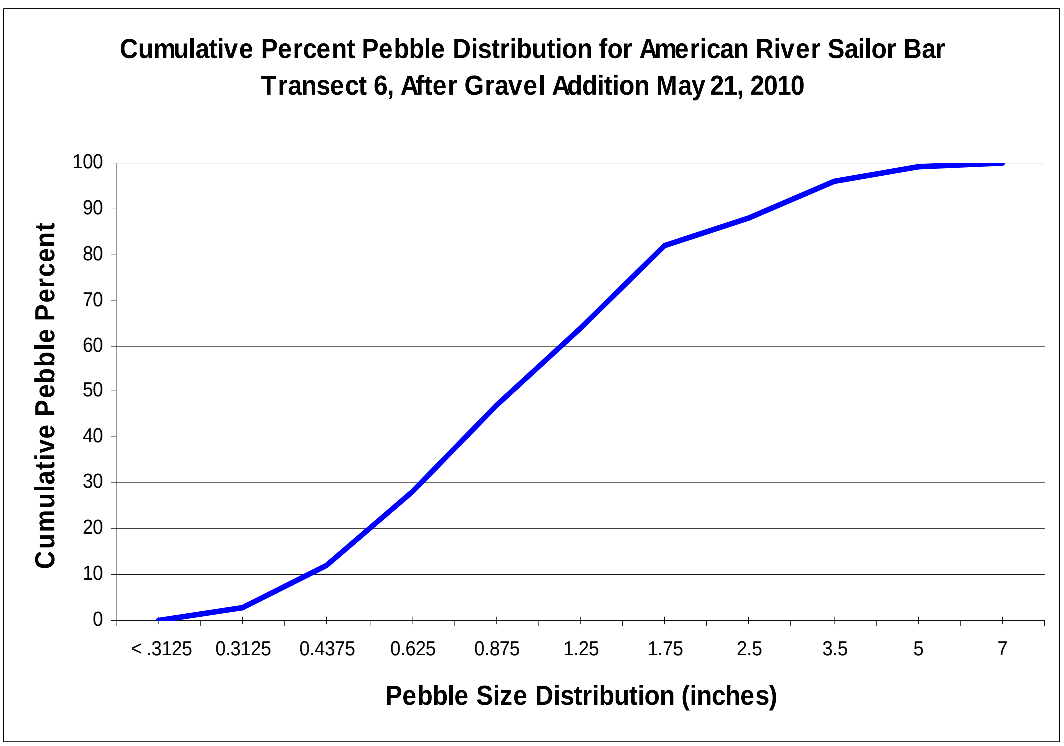
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



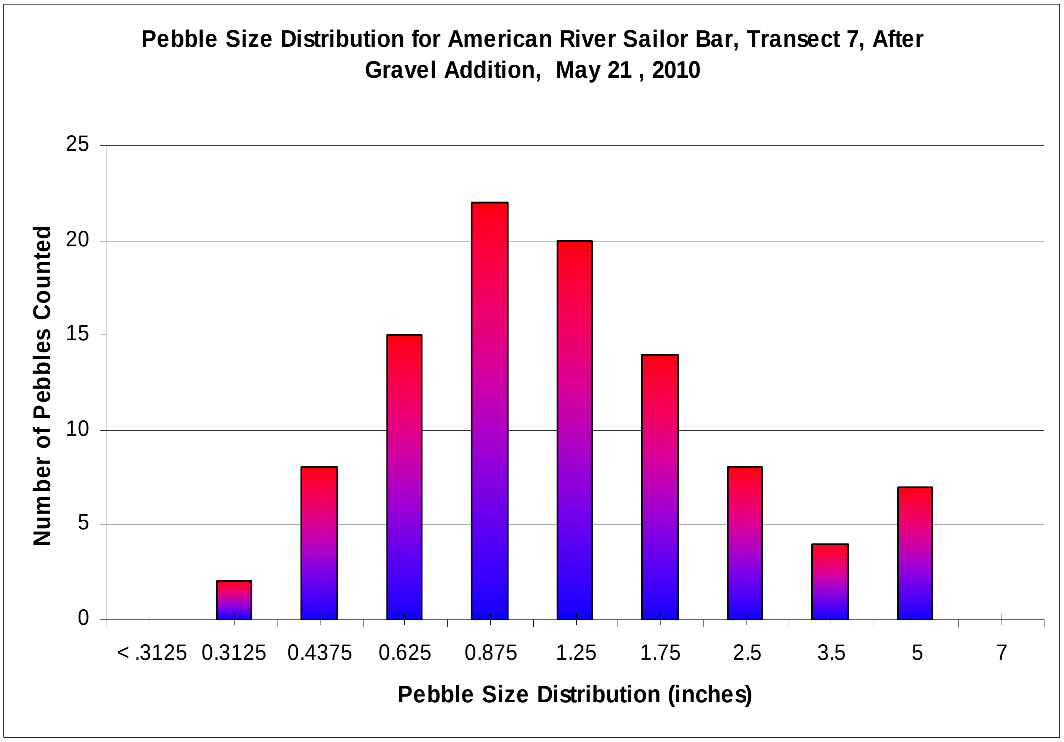
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



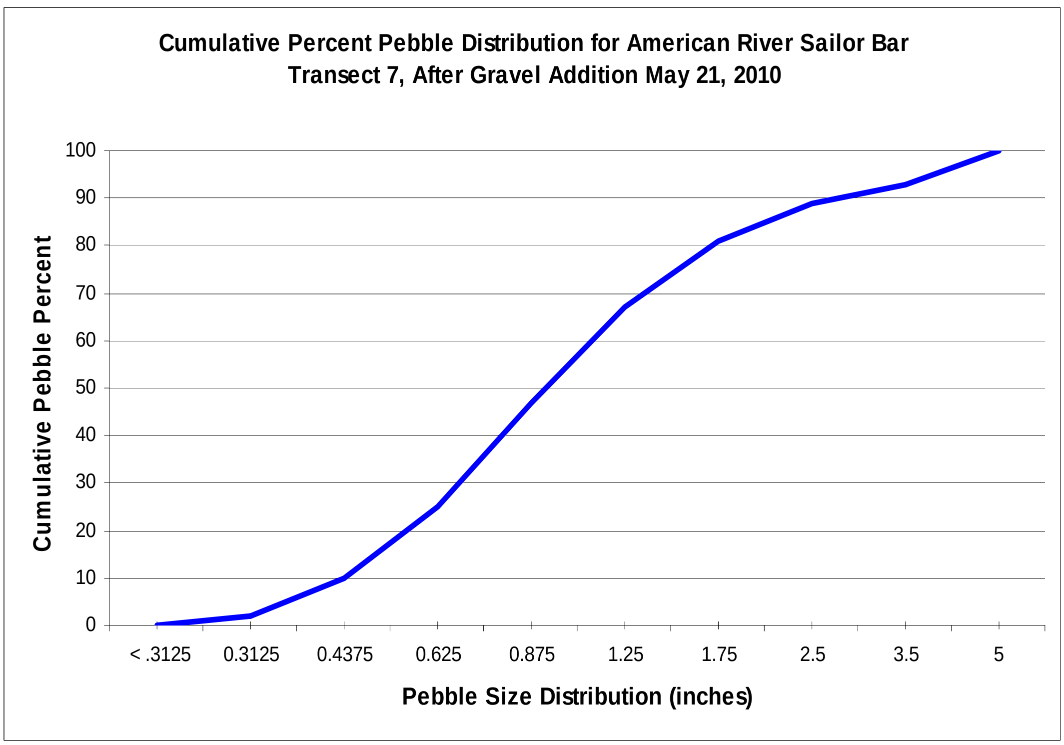
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



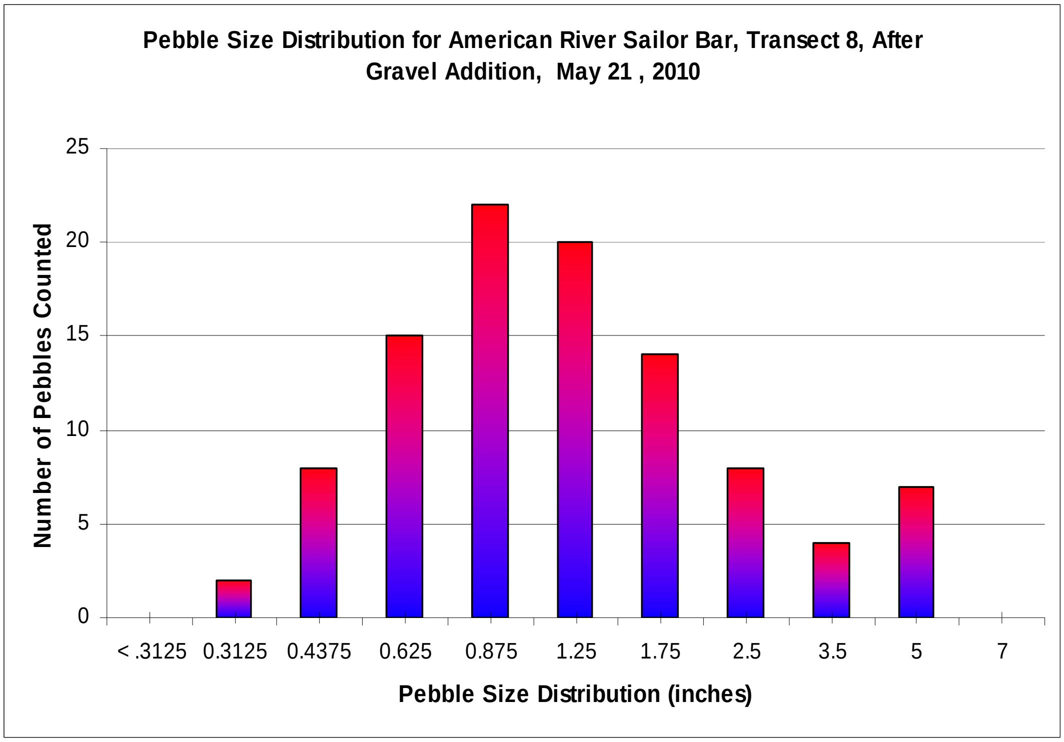
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



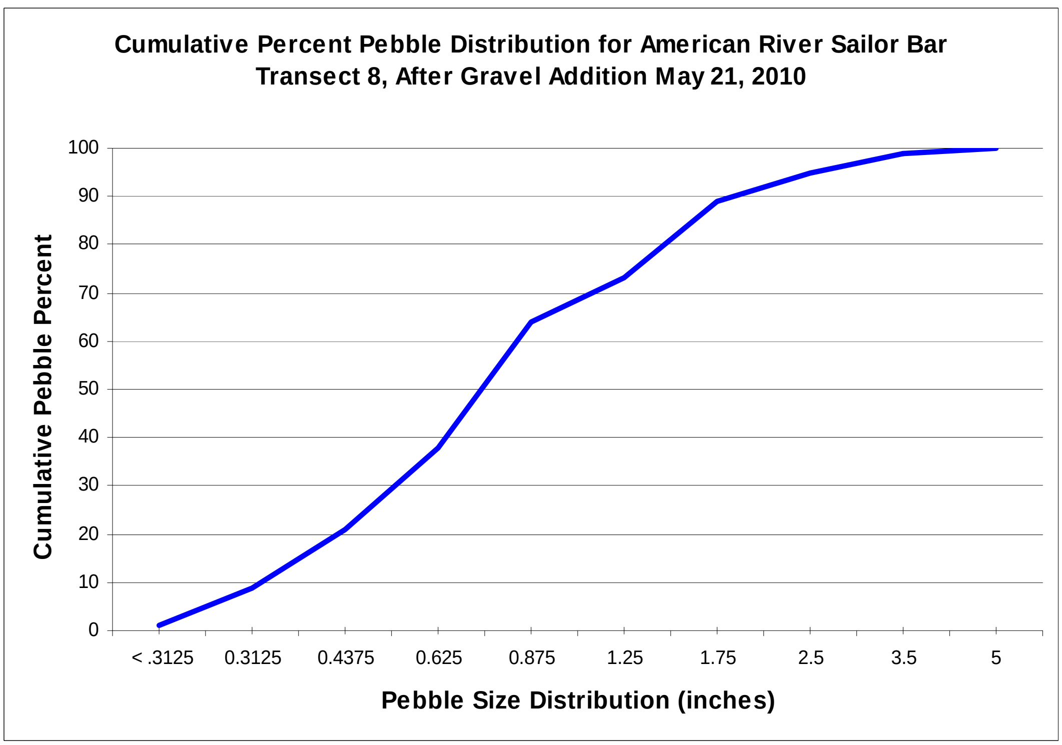
Histograph showing the pebble count data, Sailor bar 2009, May 2010.



Histograph showing the pebble count data, Sailor bar 2009, May 2010.



Histograph showing the pebble count data, Sailor bar 2009, May 2010.



Histograph showing the pebble count data, Sailor bar 2009, May 2010.

APPENDIX L

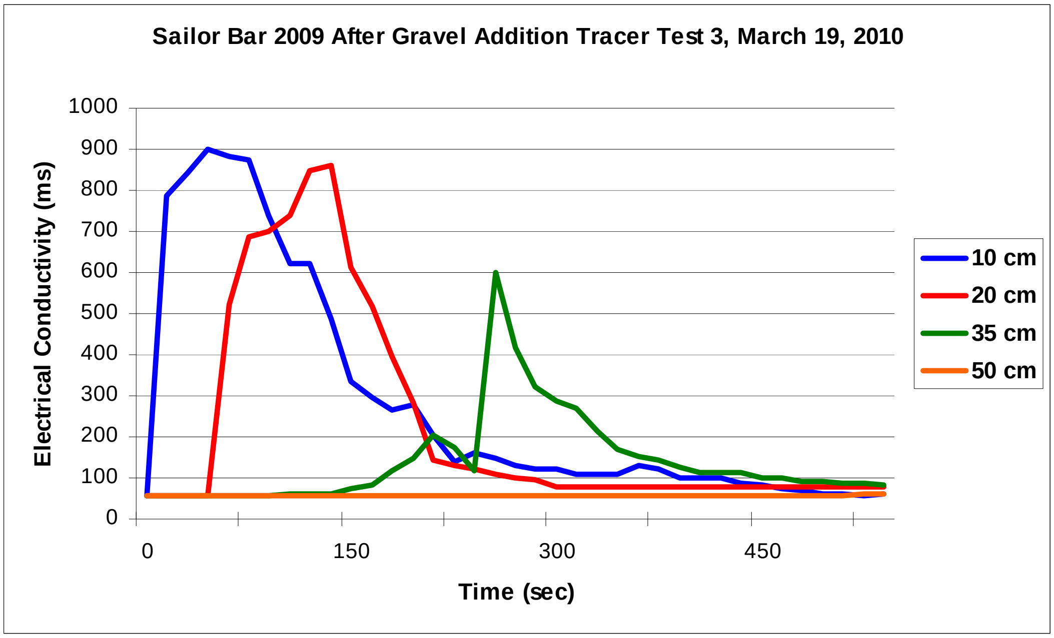
Sailor Bar 2009 After Gravel Addition Inter Gravel Velocity

	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

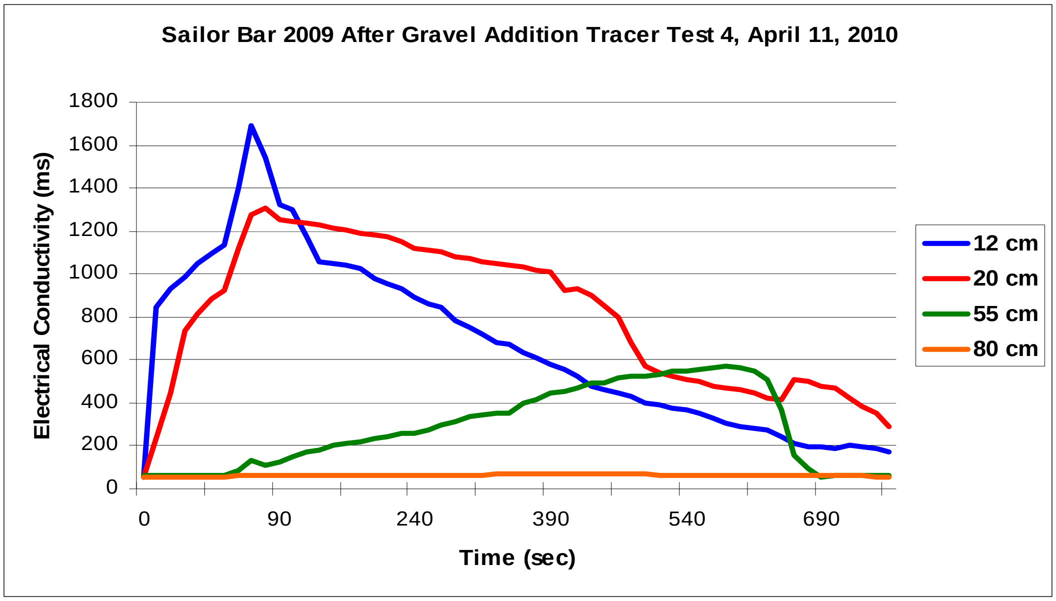
After gravel addition tracer test 2data, March 2010



Graph showing conductivity versus time for tracer test 3, Sailor bar 2009 gravel addition, data collected 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

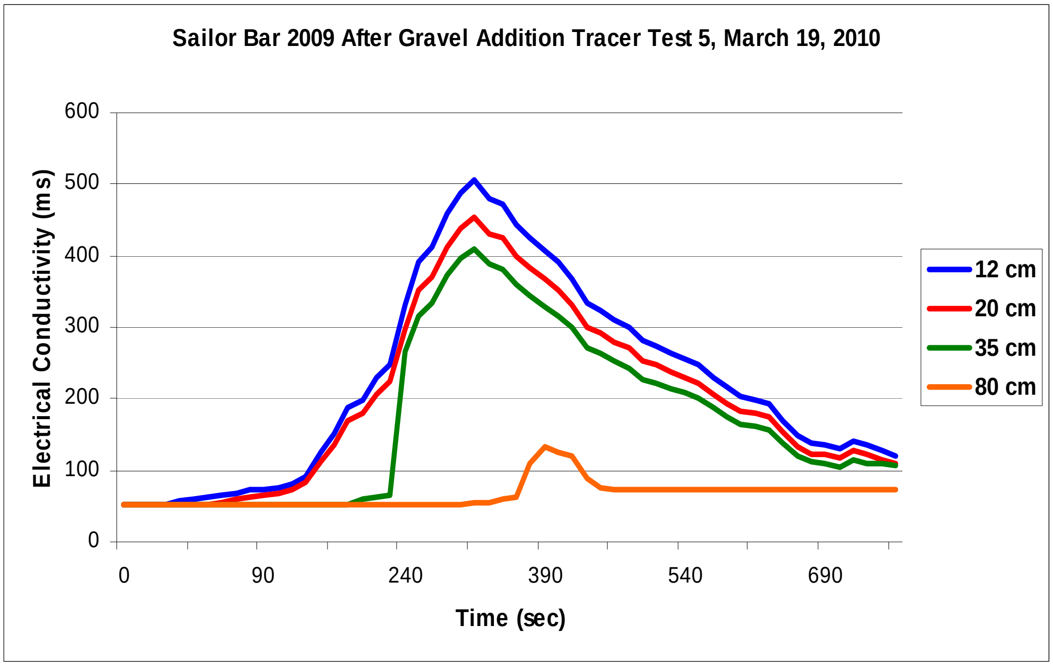
After gravel addition tracer test 3data, March 2010



Graph showing conductivity versus time for tracer test 4, Sailor bar 2009 gravel addition, data collected 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



Graph showing conductivity versus time for tracer test 5, Sailor bar 2009 gravel addition, data collected March 2010

	12 cm	20 cm	40 cm	70 cm
Time (sec)	EC 1	EC 2	EC 3	EC 4
0	52	53	53	53
5	52	53	53	53
10	53	53	53	53
15	53	53	53	53
20	57	53	53	53
25	59	53	53	53
30	62	53	53	53
45	65	56	53	53
60	69	60	53	53
75	72	63	53	53
90	73	65	53	53
105	76	68	53	53
120	80	72	53	53
135	92	83	53	53
150	124	112	53	53
165	150	135	53	53
180	189	170	53	53
195	199	179	60	53
210	230	207	63	53
225	248	223	65	53
240	330	297	267	53
255	391	352	317	53
270	411	370	333	53
285	459	413	372	53

After gravel addition tracer test 5 data, April 2010

APPENDIX M

Sailor Bar 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

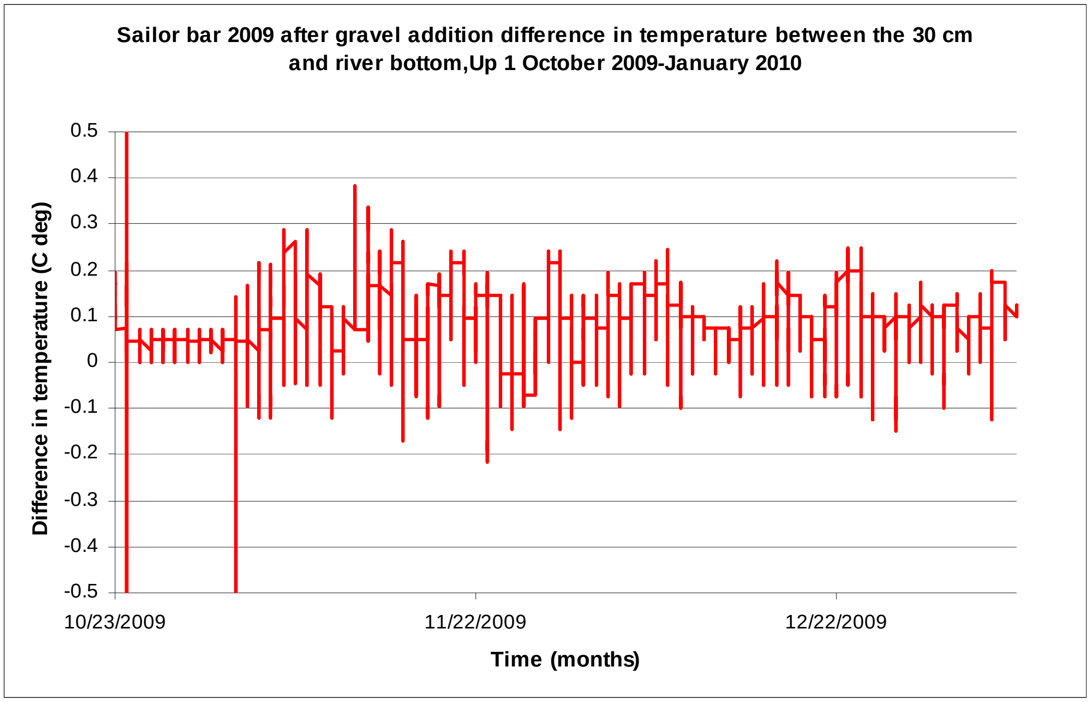
2008 Gravel Addition Tracer Test Data T-1, April 2010

	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

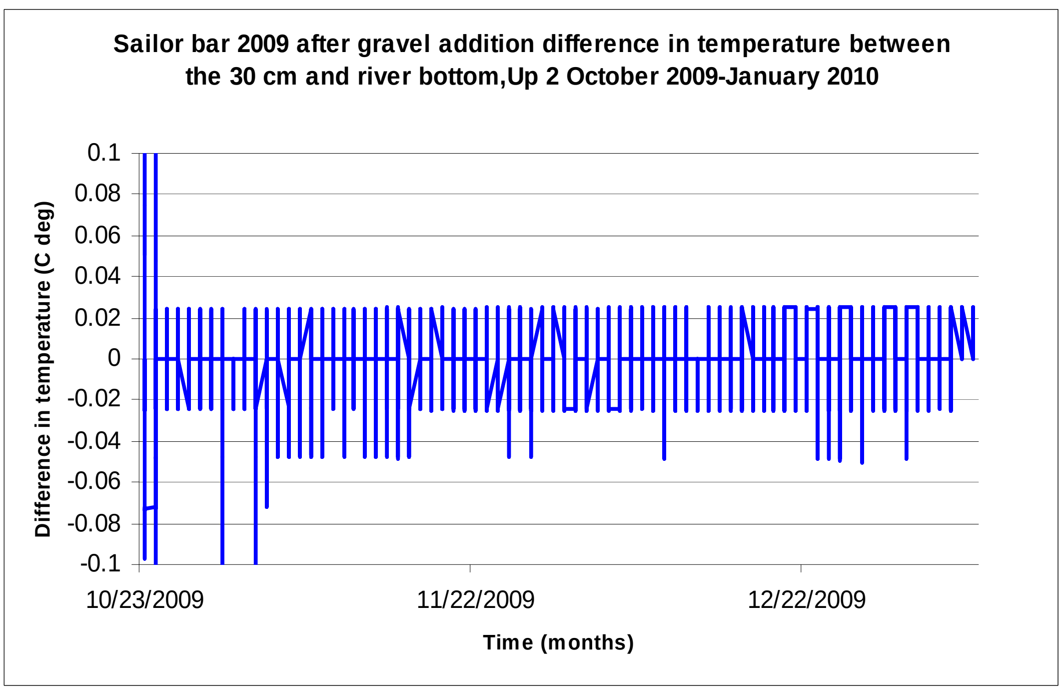
2008 Gravel Addition Tracer Test Data T-2, April 2010

APPENDIX N

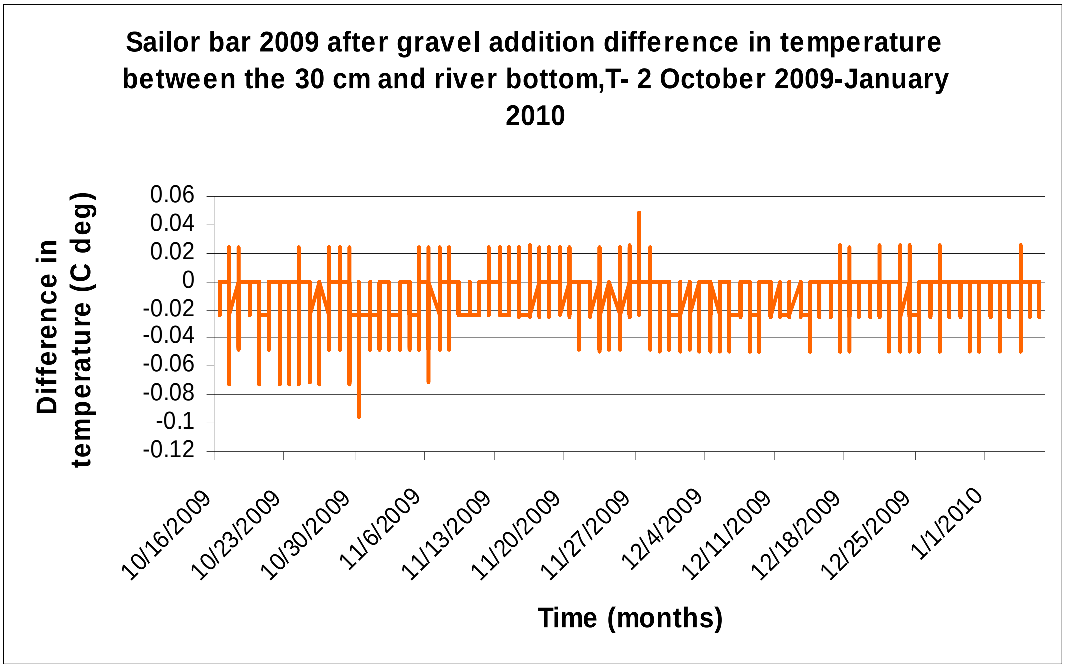
Sailor Bar 2009 Temperature



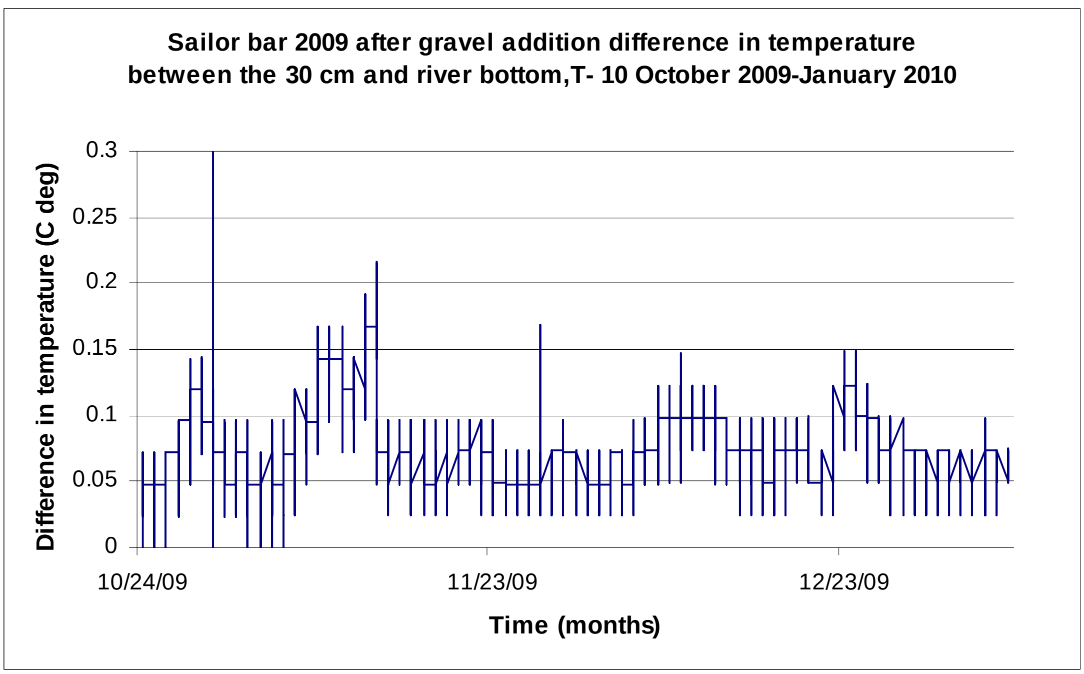
Graph showing 2009 Sailor bar after gravel addition temperature difference between the 30 cm depth logger and the river bottom logger. Data collected October 2009 to January 2010.



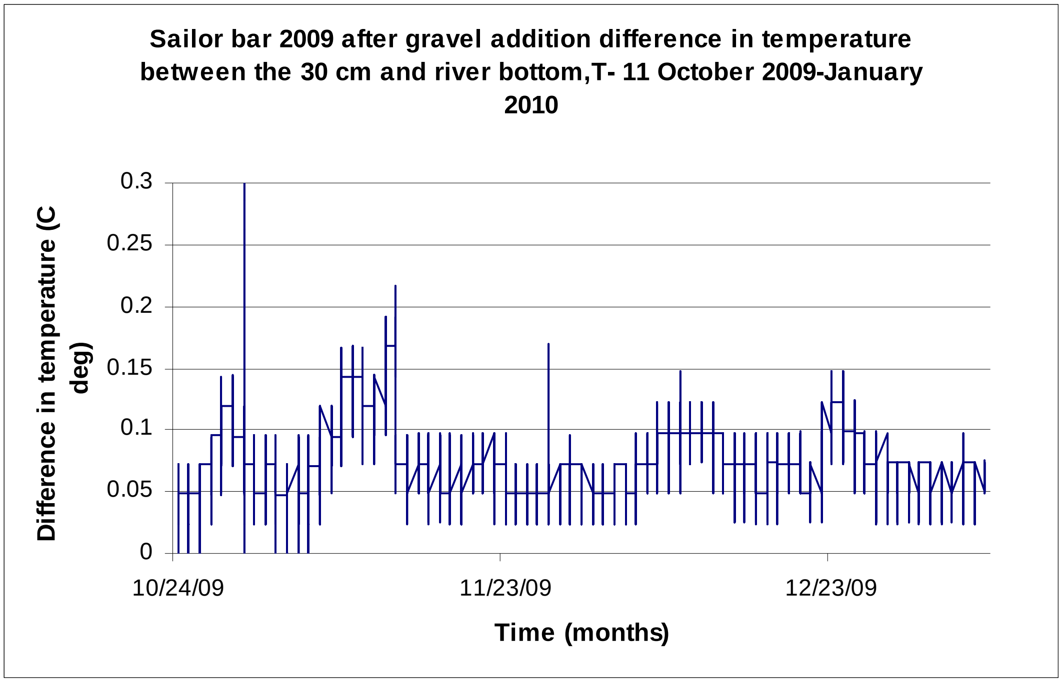
Graph showing 2009 Sailor bar after gravel addition temperature difference between the 30 cm depth logger and the river bottom logger. Data collected October 2009 to January 2010.



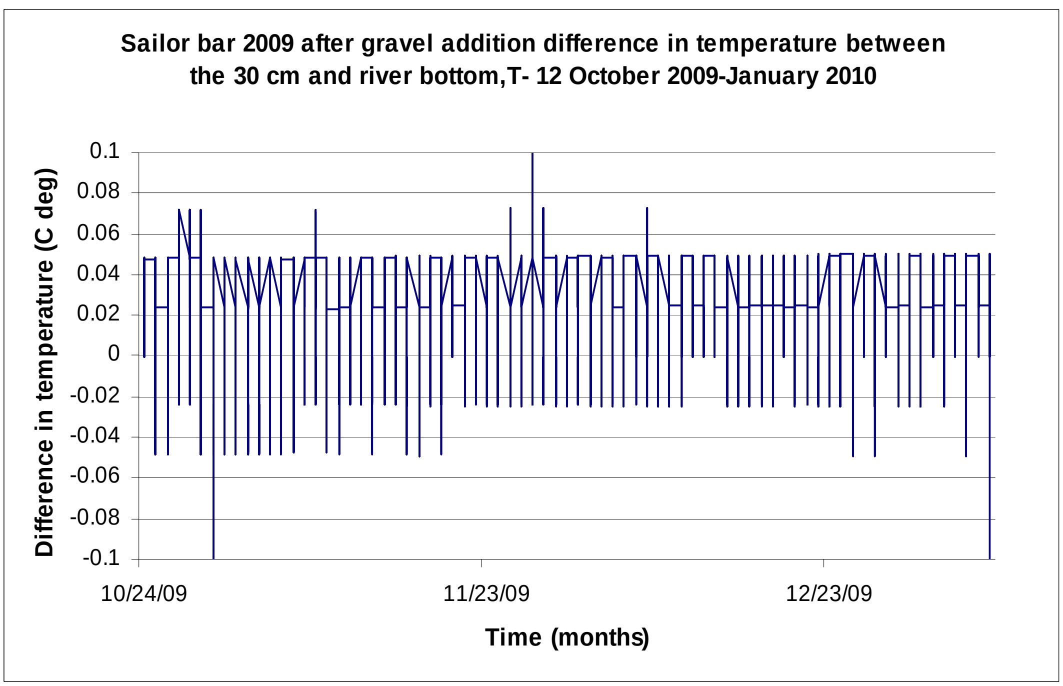
Graph showing 2009 Sailor bar after gravel addition temperature difference between the 30 cm depth logger and the river bottom logger. Data collected October 2009 to January 2010.



Graph showing 2009 Sailor bar after gravel addition temperature difference between the 30 cm depth logger and the river bottom logger. Data collected October 2009 to January 2010.



Graph showing 2009 Sailor bar after gravel addition temperature difference between the 30 cm depth logger and the river bottom logger. Data collected October 2009 to January 2010.



Graph showing 2009 Sailor bar after gravel addition temperature difference between the 30 cm depth logger and the river bottom logger. Data collected October 2009 to January 2010.

REFERENCES

Adams, J. N., and R. L. Beschta. 1980. Gravel bed composition in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 37:1514-1521

Bams, R.A. 1969. Adaptations in sockeye salmon associated with incubation in stream gravels. Pages 71-88 in Symposium on salmon and trout in streams. University of British Columbia, Vancouver.

Barnard, K, and S McBain. 1994. Standpipe to determine permeability; dissolved oxygen, and vertical particle size distribution in salmonid spawning gravels. USFS Region 5, Fish habitat relationships technical bulletin 15, Eureka, California.

Bovee, K.D. 1982. A guide to stream habitat analysis using instream flow incremental methodology. U.S. Fish and Wildlife Service, Instream flow information paper 12, Fort Collins, Colorado.

Briggs, J.C. 1953. The behavior and reproduction of salmonid fishes in small coastal stream. CA Dept of Fish and Game Bulletin 1994.

Buer, K., R. Scott, D. Parfitt, G.Serr, J. Haney, and L. Thompson. 1981. Salmon spawning gravel enhancement studies on Northern CA. Humboldt State University.

Bunte, K. and S.R. Abt. 2001. Sampling surface and subsurface particle size distributions in wadable gravel and cobble bed streams for analysis in sediment transport, hydraulics, and streambed monitoring. USFS Rocky Mountain Research Station, Fort Collins CO.

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.

Carbonneau, P.E., N.E. Bergaron, and S.N. Lane. 2005. Texture-based segmentation applied to a quantification of superficial sand in salmonid river gravels. Earth Surface and Landforms 30:121-127.

Carling, P.A., and C.P. McMahon. 1987. natural siltation of brown trout spawning gravels during low flow conditions. Pages 229-244 in J.F. Craig and J.B. Kemper editors. Regulated streams. Plenum press, new York.

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.

Cederholm, C. J.. and E. 0. Salo. 1979. The effects of logging road landslide siltation on the salmon and trout spawning gravels of Stequaleho Creek and the Clearwater River basin, Jefferson County, Washington, 1972-1978. University of Washington, Fisheries

Chambers, J. S. R. T. Pressey, J. R. Donaldson. and W. R. McKinley**.** 1954. Research relating to study of spawning grounds in natural areas. Annual report to US Army Corps of Engineers, Contract DA-35026-Eng- 20572. (Available from State of Washington. Department of Fisheries. Olympia.)

Chapman. D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 1 17:1-21.

Chow, V.T. 1959. Open-channel hydraulics. McGraw Hill, New York.

Church. M. A., D. G. McLean, and J. F. Wolcott. 1987. River bed gravels: sampling and analysis. Pages 43-79 *in C. R.* Thorne, J. C. Bathurst, and R. D. Hey. editors. Sediment transport in gravel bed rivers. Wiley, New York.

Constanz, J., A.E. Stewart, R. Niswonger, and L. Sarma. 2002. Analysis of temperature profiles for investigating stream losses beneath ephemeral channels. Water Resources Research 38:52-1-52-13.

Cooper, A. C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. International Pacific Salmon Committee, Bulletin 18. New Westminster. British Columbia.

Crisp, D.T. 1993. The ability of U.K. salmonid alevins to emerge through a sand layer. Journal of Fish Biology 43:656-658.

Everest, F. L., R. L. Beschla. J. C. Scrivener. K. V. Koski. J.R. Sedell, and C. J. Cederholm**.** 1987. Fine sediment and salmonid production—a paradox. Pages 98-142 *in* E. 0. Salo and T W. Cundy. editors. Streamside management: forestry and fishery interactions.University of Washington. College of Forest Resources.Seattle.

Everest, F. L.. C. E. McLemore, and J. F. Ward. 1980. An improved tri-tube cryogenic gravel sampler. U.S. Forest Service Research Note PNW-350.

Flosi, G.S. Downie, J. Hopelain, M. Bird, R. Coey, and B. Collins. 1998. CA salmonid stream habitat restoration manual. CA Dept of fish and Game, Inland Fisheries Division, Sacramento.

Freeze, R. A., and J. A. Cherry. 1979. Groundwater. Prentice Hall. Inc. Englewood Cliffs, New Jersey.

Fripp, J.B., and P.Diplas. 1993. Surface sampling in gravel streams. Journal of Hydraulic Engineering 119:473-490.

Geist, D.R. and D.D. Dauble. 1998. Redd site selection and spawning habitat use by fall run Chinook salmon: the importance of geomorphic features in large rivers. Environmental Management 22:655-669.

Greig, S. M., D. A. Sear, and P.A. Carling. 2007. A review of the factors influencing the availability of dissolved oxygen to incubating salmonid embryos. Hydrological Process 21:323-334.

Greig, S. M., D. A. Sear, and P.A. Carling. 2005. The impact of fine sediment accumulation on the survival of incubating salmon progeny; implications for sediment management. Science of the Total Environment 344:241-258

Gustafson-Marjanen, K.I., and J.R. Moring. 1984. Construction of artificial redds for evaluating survival of Atlantic salmon eggs and alevins. North American Journal of Fisheries Management 4:445-461.

Harvey, J.W., and B.J. Wagner. 2000. Quantifying hydrologic interactions between streams and their subsurface hyporheic zones. Pages 3-44 in J.B. Jones and P. J. Mulholland, editors. Streams and ground waters. Academic Press, San Diego CA.

Harvey, J.W., B.J. Wagner, and K.E. Bencala.1996**.** Evaluating the reliability of the stream tracer approach to characterize stream-subsurface water exhchange. Water Resources Research 32:2441-2451.

Hey, R.D.., and C.R. Thorne. 1983. Accuracy of surface samples from gravel bed material. Journal of Hydrologic Engineering 109:842-851.

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.

Horton. J. L.. and D. W. Rogers. 1969. The optimum streamflow requirements for king salmon spawning in the Van Duzen River, Humboldt County, California. California Department of Fish and Game, Water Projects Branch. Administrative Report 69-2, Sacramento.

Inman, D. L. 1952. Measures for describing the size distribution of sediments. Journal of Sedimentary Petrology 22:125-145.

Kondolf. G. M. 1988. Salmonid spawning gravels: a geomorphic perspective on their distribution, size modification by spawning fish. and application of criteria for gravel quality. Doctoral dissertation. Johns Hopkins University, Baltimore, Maryland.

Kondolf. G. M**.** 1997. Application of the pebble count: reflections on purpose, method, and variants. Journal of the American Water Resources Association (formerly Water Resources Bulletin) 33:79-87.

Kondolf. G. M., S. S. Cook. H. R. Maddux, and W. R. Persons**.** 1989. Spawning gravels of rainbow trout in the Grand Canyon. Arizona. Journal of the Arizona-Nevada Academy of Science 23:19-28.

Kondolf. G. M.. and S. Li**.** 1992. The pebble count technique for quantifying surface bed material in in-stream flow studies. Rivers 3:80-87.

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.

Lane, S.N. 2001. The measurement of gravel bed river morphology. Pages 291-320 in M.P. Mosley, editor. Gravel bed rivers V. New Zealand Hydrological Society, Wellington.

Lee, D.R., and J.A. Cherry. 1978. A field exercise on groundwater flow using seepage meters and minipiezometers. Journal of Geological Education 27:6-10.

Levasseur, M.,F. Berube, and N.E. Bergeron. 2006. A field method for the concurrent measurement of fine sediment content and embryo survival in artificial salmonid redds. Earth Science Processes and Landforms 31:526-530.

Libelo, E.L., and W.G. MacIntyre. 1994. Effects of surface-water movement on seepage meter measurements of flow through the sediment-water interface. Applied Hydrogeology. 2:49-54.

Lisle, T. E.. and R. E. Eads. 1991. Methods to measure sedimentation of spawning gravels. U.S. Forest Service. Research Note PSW -411.

Lorenz, J.M., and J.H. Eiler. 1989. Spawning habitat and redd characterization of sockeye salmon in the glacial Taku river, British Columbia and Alaska. Transactions of the American Fisheries Society 118:495-502.

MacFarlane, R.B., and E.C. Norton. 2002. Physiological ecology of juvenile Chinook salmon at the southern end of their distribution, the San Francisco Estuary and the Gulf of the Farallones, CA. Fishery Bulletin 100:244-257.

Malcom, I.A., C. Soulsby, A. F. Youngston, and J. Petry.2003. Heterogeneity in ground water-surface water interactions in the hyporheic zone of a salmonid spawning stream. Hydrologic Processes 17:601-617.

Malcom, I.A., C. Soulsby, and A. F. Youngston. 2006. High-frequency logging technologies reveal state-dependent hyporheic process dynamics: implications for hydrogeological studies. Hydrological Processes 20:615-622.

McNeil. W. J., and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service. Special Scientific Report-Fisheries 469.

Meehan. W. R. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society. Special Publication 19. Bethesda. Maryland.

Merz, J.J., J.D. Setka, G.B. Pasternack, and J.M. Wheaton. 2004 Predicting benefits of spawning habitat rehabilitation to salmonid fry production on a regulated CA river. Canadian Journal of Fisheries and Aquatic Sciences. 61:1433-1446.

Meyer, C.B., M.D. Sparkman, and B.A. Klatte. 2005. Sand seals in coho salmon redd; do they improve egg survival? North American Journal of Fisheries Management 25:105-121.

Milan, D. J., G.L. Heritage, A.R.G. large, and C.F. Brunsdon. 1999. Influence of particle shape and sorting upon sample size estimates for a coarse-grained upland stream. Sedimentary Geology 128:85-100.

Milan, D. J., G.L. Heritage, A.R.G. large, and M.E. Charlton. 2001. Stage-dependant variability in shear stress distribution through a riffle pool sequences. Catena 44:85-109.

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.

Murdoch, L.C., and S.E. Kelly. 2003. Factors affecting the performance of conventional seepage meters. Water Resources Research. 39:2-1-2-10

Nicola, G.G., and A. Almodovar. 2004. Growth pattern of stream-dwelling brown trout under contrasting thermal conditions. Transactions of the American Fisheries Society 133: 66-78.

Orcutt, D. R., B. R. Pulliam, and A. Arp. 1968. Characteristics of steelhead trout redds in Idaho streams. Transactions of the American Fisheries Society 97: 42-45.

Parfitt, D., and K. Buer. 1980. Upper Sacramento River spawning gravel study. California Department of Water Resources, Northern Division, Red Bluff.

Peterson, R. H. 1978. Physical characteristics of Atlantic salmon spawning gravels in some New Brunswick streams. Fisheries and Oceans Canada, Biological Station. Fisheries and Marine Service Technical Report.

Petts, G.E. 1987. Accumulation of fine sediment within substrate gravels along two regulated rivers, UK. Regulated Rivers 2:141-362.

Pollard, W.P..1955. The oxygen supply to salmon eggs in spawning beds. Journal of Fisheries Research Board of Canada 12:706-741.

Powers, E.B., 1941, Physico-chemical behaviors of waters as factors in the "homing" of the salmon: Ecology, v. 22, p. 1-16.

Radtke, D.B., J.K. Kurkin, and F.D. Wilder, editors. 1998. Techniques of water-resources investigations, book 9, handbooks for water resources investigations, section 6.2 National Field manual for the collection of water-quality data. USGS, Reston VA.

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. USFS Pacific Northwest Forest , Portland OR.

Rice, S. 1995. The spatial variation and routine sampling of spawning gravels in small coastal streams. British Columbia Ministry of Forests , Research Branch Working Paper 06/1995, Victoria.

Rice, S., and M Church. 1996. Sampling surficial gravels: the precision of size distribution percentile estimates. Journal of Sedimentary Research 66:654-665.

Rombough, P.J. 1988. Growth, aerobic metabolism, and dissolved oxygen requirements of embryos and alevins of steelhead. Canadian Journal of Zoology 66:651-660.

Rubin, J.F. 1995. Estimating the success of natural spawning of salmonids in streams. Journal of Fish Biology 46:603-622

Savant, S.A., D.D. Reibleand, and L.J. Thibideaux. 1987. Convective transport within stable river sediments. Water Resources Research 23:1763-1768.

Sear, D.A. 1993. Fine sediment infiltration into spawning beds within a regulated river experiencing floods: ecological implications for salmonids. Regulated Rivers Research and Management 8:373-390.

Sear, D.A. 1995. Morphological and sedimentological changes in a gravel-bed river following 12 years of flow regulation from hydropower. Regulated Rivers Research and Management 10:247-264.

Shaw, R.D., and E.E. Prepas. 1989. Anomalous, short-term influx of water into seepage meters. Limnology and Oceanography 34:1343-1351

Shiancariol, R.A., and J.D. McNeil. 2002. Errors with small volume elastic seepage meter bags. Groundwater 40:649.

Shinn, E.A., C.D. Reich, and T.D. Hickey. 2002. Seepage meters and Bernoulli's revenge. Estuaries 25:126-132.

Silver, S.J., C.E. Warren, and P. Doudoroff. 1963. Dissolved Oxygen requirements of developing steelhead trout and Chinook salmon embryos and different water velocities. Transactions of the American Fisheries Society 92:327-343.

Silver, J., C. E. Warren, and P. Duodoroff. 1965. Dissolved oxygen requirements of developing steelhead and chinook salmon embryos at different water velocities. Transactions of the American Fisheries Society 92:327-343.

Springer, A.E., W.D. Petroutson, and B.A. Semmens. 1999. Spatial and temporal variability of hydraulic conductivity in active reattachment bars of the Colorado River, Grand Canyon. Groundwater 37:338-344

Stonestrom, D.A., and J. Constanz, 2003. Heat as a tool for studying the movement of groundwater near streams. USGS Circular, Denver, Colorado.

Terhune, L. B. D. 1958. The Mark VI groundwater standpipe for measuring seepage though salmon spawning gravel. Journal of the Fisheries Research Board of Canada 15:1027-1063.

Theurer, F.D., Harrod, T.R. and M. Theurer. 1998. Sedimentation and salmonids in England and Wales. Environment Agency, R&D Technical Report P194, Bristol, England.

Thibodeaux, L.J., and J.D. Boyle. 1987. Bedform-generated convective transport in bottom sediment. Nature (London) 325:341-343.

Thoms, M.C. 1992. A comparison of grab and freeze sampling in the collection of gravel-bed river sediment. Sedimentary Geology 78:191-202.

Vanoni, V. A. 1975. Sedimentation engineering. American Society of Civil Engineers, New York.

Vaux, W. G. 1968. The flow and interchange of water in a streambed. U.S. Fish and Wildlife Service Fishery Bulletin 66:479-489.

Von Schalburg, K.R., M.L. Rise, G.D. Brown, W.S. Davidson, and B.F. Koop. 2005. A comprehensive survey of the genes involved in the maturation and development of the rainbow trout ovary. Biological Reproduction 72:687-699.

Weight, D., and J.L. Sonderegger. 2001. Manual of applied hydrogeology. McGraw- Hill, New York.

Wilcock, P. R., G. M. Kondolf, W. V. G. Matthews, and A. F. Barta. 1996. Specification of sediment maintenance flows for a large gravel-bed river. Water Resources Research 32:2911-2921.

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

Young. M. **K.,** W. A. Hubert, and T. A. Wesche. 1990. Fines in redds of large salmonids. Transactions of the American Fisheries Society 119:156-162.

Young, M. K., W. A. Hubert, and T. A. Wesche. 1991. Biases associated with four stream substrate samplers. Canadian Journal Fisheries and Aquatic Sciences 48:1882- 1886.

Zamora, C. 2006. Estimating rates of exchange across sediment/water interface in the lower Merced River, CA. Master's s thesis. California State University Sacramento.

Zellweger, G.W. 1994. Testing and comparison of four ionic tracers to measure stream flow loss by multiple tracer injection. Hydrologic Processes 8:155-165.

Zimmerman, A.E., and M. Lapointe. 2006. Intergranular flow velocity through salmonid redds; sensitivity to fines infiltration from low intensity sediment transport events. River Research and Applications 21:865-881.