American River gravel studies 2005

Physical and geochemical characteristics of American River Spawning Gravels

Second year report (2003/2004 season)

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Sources of text:

Four portions of this text appear in other documents that were written by Tim Horner, Eric Morita, Tim Bishop, or Andrew Head during the course of this project. A brief summary of sources follows:

1) The introductory section that deals with previous work and description of gravel manipulation experiments on the Lower American River (pp. 2-6, this report) was taken from:

Horner, T. C., Titus, R., and Brown, M., 2003 draft report, Phase 3 Gravel Assessment on the Lower American River: California Department of Fish and Game, Stream Evaluation Program Technical Publication Series, 93 pp.

2) Grain size information and cumulative frequency curves (Section V) are from preliminary thesis work by Tim Bishop, and a modified version will appear in his M.S. thesis. (Geology Department, CSU Sacramento, in prep.).

3) Geochemical information and interpretations about geochemical trends (Section VIII) are from preliminary thesis work by Eric Morita, and a modified version will appear in his M.S. thesis (Geology Department, CSU Sacramento, in prep.).

4) Discussion of Steelhead redds in the Lower Sunrise side channel, and substrate modification by spawning steelhead was modified from a B.S. thesis by Andrew Head:

Modification of intergravel dissolved oxygen content by spawning salmonids: Unpublished Bachelors thesis, Geology Department, CSU Sacramento, 17 p.

I. INTRODUCTION AND OBJECTIVES

Results described in this report are a summary of field – based evaluation of Lower American River salmon and steelhead spawning gravels. This work was funded by the U.S. Bureau of Reclamation (Sacramento Office), and is part of the overall Central Valley Project Improvement Act (CVPIA) objective to enhance spawning gravels on the American River.

Field work and analyses carried out during the 2003/2004 field season have six major objectives. These objectives were described as tasks in a gravel evaluation proposal submitted to the U.S. Bureau of Reclamation, Sacramento Office on June 12, 2003, and are summarized below:

- Compile a written report for the 2002/2003 field season (this report).
- Install additional mini-piezometer tips near sites where the California Department of Fish and Game (DFG) performed gravel manipulation experiments in Fall, 1999.
- Measure gravel permeability with the Terhune standpipe (Terhune, 1958) and standard slug test methods.
- Measure current velocity, water depth and vertical gradient at established and new monitoring points.
- Measure field parameters (dissolved oxygen, pH, electrical conductivity, turbidity and temperature) on a quarterly basis or as flows permit.
- Collect pore water samples on a quarterly basis or as flows permit.
- Analyze pore water samples for nutrients and trace metals.
- Analyze gravel temperatures.

This report is a summary of findings based on these objectives, with additional geologic interpretations and comparison to results obtained by Kris Vyverberg (Vyverberg et al., 1997), and our first year study (Horner et al., 2003 draft report).

II. PROJECT OVERVIEW, SUMMARY OF PREVIOUS WORK

II. A. Background and funding

The Lower American River is defined as the 23 miles of unobstructed channel that lie below Nimbus Dam. This portion of the river produces approximately one third of the salmon in northern California, but dams, urbanization, artificial levees, channel modification, and input from the Nimbus Fish Hatchery have altered the natural balance of the system. The lower American River is the site of significant natural spawning activity for Fall run Chinook salmon, with lesser Winter and Spring runs. Salmonid populations on the Lower American River have declined dramatically from historical levels, and there is speculation that the quantity or quality of spawning gravel is a limiting factor. For this reason, significant effort has been made to evaluate and restore habitat quality on the lower American River (Sinder et al., 1992; Snider and Vyverberg, 1996; Vyverberg et al., 1997; DFG Technical Report no. 01-2). Activities described in this report build on existing work by examining spawning gravel quality in and near several sites that were used to test gravel rehabilitation or gravel enhancement methods.

The three phases of gravel assessment and manipulation are described in the next sections. Phases 1 and 2 were partially funded by the U.S. Bureau of Reclamation (BOR) as part of the requirements of the Central Valley Project Improvement Act (CVPIA). This Act requires on-going study of the need and type of physical habitat restoration that would benefit anadromous fish within stream reaches influenced by Central Valley Project facilities. Project facilities on the American River include Folsom Dam and Nimbus Dam, which act as barriers to upstream migration of anadromous fish. Preliminary investigations of salmon spawning habitat conditions, and implementation of an experimental restoration project constructed during Fall 1999, have been primarily supported by funds provided to DFG by the BOR as outlined by the CVPIA.

Work described in this report is the third phase of a concentrated effort to study salmon spawning habitat on the Lower American River. Continued monitoring and evaluation of spawning gravels has been funded since 2002 by BOR, with funds provided to CSUS by CVPIA. The 2002/2003 project received $98,384 in funding from the US Bureau of Reclamation and CVPIA, including the required 32% overhead from CSUS. Total federal funds expended for the 2003/2004 project (this report) were $103.114, including the 32% overhead charged by CSUS.

II. B. Phase 1- Spawning Gravel Studies

Phase 1 of this project started in 1994, when DFG began a quantitative evaluation of spawning gravel on the Lower American River. In this initial phase, 18 study sites were chosen to represent a variety of spawning use and geomorphic conditions. Selection was based on previous work by Snider et al. (1992), who divided the 18 river miles directly below Nimbus Dam into four river reaches based on gradient, bed material and tidal influence. Redd surveys indicated that approximately 90% of the natural spawning occurred in reach three and reach four, so these upper reaches became the focus of more intensive study. Reaches three and four are the six miles of river directly below Nimbus Dam, and contain coarse gravel bed material, with gradient ranging from 0.06 to 0.8. This stretch of river was further subdivided into 75 habitat units based on the morphology of in-stream channel features (bar forms) and channel flow characteristics. 18 of these habitat units were randomly chosen as study sites for the Phase 1 analysis, with distribution representing 6 riffles, 6 runs and 6 glides.

Within each set of riffles, runs and glides, three of the selected sites were characterized as having high spawning use, and three sites were described has having low or no spawning use. This distinction was based on aerial photograph sets taken between 1996 and 1998. In these photographs, Fall-run Chinook salmon spawning activity and distribution was monitored at different intervals during the typical salmon spawning period (November–December). Ground surveys were conducted concurrent with the aerial surveys to verify distribution and abundance of salmon redds recorded by aerial photography.

Phase 1 also included assessment of juvenile salmonid rearing (distribution and abundance) and Chinook salmon emigration (index of production). These data were developed to evaluate the response of juvenile salmon and steelhead to restoration-associated channel modifications (project level) and to identify relative changes in salmon spawning success (production index at the system scale).

Intensive physical investigations were carried out at each of the 18 habitat areas. Physical measurements focused on parameters that other studies have identified as factors for spawning site selection, including substrate composition, permeability, and intragravel conditions (e.g., dissolved oxygen, compaction). Permeability and dissolved oxygen content proved difficult to measure, so the final suite of measured physical attributes included gravel size distribution, water depth, water velocity, and substrate permeability. Physical conditions were then compared to spawning activity to identify those parameters that may be influencing spawning use (Vyverberg et al., 1997).

Results of physical and habitat use studies suggested that areas of low or no spawning use consistently contained poor intragravel conditions, primarily associated with 1) low permeability (inferred by the presence of excess fine material) 2) cemented or interlocking substrate materials, and 3) excess coarse material. The Phase 1 project served as the groundwork for later gravel manipulation experiments, and allowed direct comparison of spawning use, river morphology, and physical characteristics of the river system.

II.C. Phase 2- Gravel Manipulation Experiments

In Phase 2 of the project, three impacted sites were selected from among the 18 intensively studied habitat areas described in Phase 1 (Vyverberg et al., 1997). All impacted sites are located in reach 4 of the Lower American River to minimize differences in substrate and gradient. Impacted areas all had low permeability and marginal quality spawning gravel, but the physical conditions responsible for poor quality gravel were different at each site. Low permeability and low suitability for spawning were due to combinations of excess fine sediment, excess coarse sediment, surficial armoring, clay layers, or the presence of coarse lag deposits. Treatments were designed to address the specific problems at each site, with the ultimate goal of improving spawning use. Construction was completed during low flow conditions in September 1999 at a cost of approximately $250,000.

At Sailor Bar, habitat sites 2, 3 and 7 were selected for gravel enhancement. Phase 1 analysis showed low spawning use, low permeability, gravel armoring, coarse lag deposits, and variable grain size distribution that ranged from excess fine material to excess coarse material. Gravel at this site was generally coarser than the optimal spawning grain size. Treatment at this location (habitat sites two, three and seven) included addition of finer gravel to a depth of 60 cm (two ft) and redistribution of coarse surface gravel layers using a heavy ripping blade.

At Lower Sunrise Access habitat sites 37 and 39 were selected for gravel enhancement. Phase 1 analysis showed spawning use ranging from low to high, with consistently low permeability, some coarse lag deposits, some armoring, and subsurface clay layers. This site (habitat sites 37 and 39) was treated by loosening the substrate to a depth of 60 cm (2 ft) using a ripping blade and adding gravel of intermediate size to a depth of 30 cm (one ft).

At Sacramento Bar, habitat site 42 was chosen as part of the gravel manipulation experiment. Phase 1 analysis showed high spawning use, but low permeability and some excess fine material. Gravel at habitat site 42 was treated by loosening the substrate to a depth of 60 cm (2 ft) with a ripping blade, and lowering the gradient of the point bar to allow spawning fish more access to shallow, near-shore habitat. Gravel was added to a depth of 60 cm (two ft).

A summary of gravel added is given below (Kris Vyverberg, personal communication):

Habitat Site	Project area dimensions	Amount of Gravel to be Added to the River at Each Project Site
2	200' x 50' = 10,000 ft^2	gravel to a depth of 2' [200'x50'x2' of gravel = 20,000 ft^3 = 1,000 tons of gravel]
3	200' x 50' = 10,000 ft^2	gravel to a depth of 2' [200'x50'x2' of gravel = 20,000 ft^3 = 1,000 tons of gravel]
7	200' x 50' = 10,000 ft^2	gravel to a depth of 1' [200'x50'x1' of gravel = 10,000 ft^3 = 500 tons of gravel]
37/39	450' x 50' = 22,500 ft^2	gravel to a depth of 1' [450'x50'x1' of gravel = 22,500 ft^3 = 1,125 tons of gravel]
42	450' x 50 = 22,500 ft^2	gravel to a depth of 2' [450'x50'x2' of gravel = 45,000 ft^3 = 2,250 tons of gravel]

Table I.1: Habitat sites, project dimensions and volume of gravel added to each site during Phase 2 gravel manipulation experiment.

Gravel size distribution for new gravel was specified to the contractor who performed the restoration work, and used the following guidelines:

100 percent finer than 5-inch
85-90 percent finer than the 4-inch sieve
75-85 percent finer than the 3-inch sieve
30-35 percent finer than the 2-inch sieve
0-5 percent finer than ½ inch sieve

The intended result from these Phase 2 actions was to improve spawning habitat, and to allow later comparison of the effectiveness of different treatment methods on spawning gravels that had a range of pre-project physical limitations.

II.D. Phase 3- Post-treatment Monitoring and Evaluation

Beginning in Fall 1999, post-treatment spawning use, spawning densities and redd distribution were monitored using the aerial photograph survey approach applied to pre-project conditions. Similarly, juvenile salmonid rearing distribution and emigration has continued through the present time, and has been conducted by DFG. These monitoring efforts are combined with re-evaluation of the physical conditions in each gravel bar, conducted from September 2002 to August 2003 by CSUS. The goal of Phase 3 is to assess the effectiveness of each gravel treatment, with respect to spawning use and current substrate conditions. The remainder of this report summarizes results from post-treatment monitoring and evaluation.

III. SPAWNING DENSITY AND HABITAT DESIGNATIONS

Estimates of spawning density are a critical part of this study, because several of the project objectives rely on comparison of physical or geochemical properties between high use and low use spawning areas. Spawning densities were estimated before new monitoring points were installed to ensure appropriate placement of new monitoring points. Spawning densities were estimated using the following formula:

$$\text{Spawning density (redds per m}^2\text{)} = \frac{\text{Number of redds in habitat region}}{\text{Stream bed area in habitat region (m}^2\text{)}}$$

Redd density was estimated using low altitude, high resolution air photographs obtained from BOR. Photographs were scanned, imported into Adobe Photoshop, and expanded to several times their original size. These large photographs were imported into MS Powerpoint, and individual redds were digitally circled in pink or white depending on the certainty of the identification. Redds that seemed definite and distinct were circled in pink, and redds that were indistinct or questionable were circled in white. All circled redds (both distinct and indistinct) were used for redd density calculations. These methods were compared to techniques use by DFG (Rob Titus, Mike Brown and Kris Vyverberg), although advisors from DFG are not responsible for any inaccuracies in our estimates.

Approximations of redd density in this project are based on air photo interpretation only, and spawning data were not field checked. This technique provides reasonable estimates of spawning density when the water is shallow, sun angle is high, turbidity and wind speed are low, and atmospheric conditions are clear (Vyverberg et al., 1997). The air photo set chosen for this interpretation was flown on November 4th, 2002 at a river flow of 1500 cfs, and conditions were nearly ideal.

Habitat designations were taken from a study by Snider et al. (1992), and transferred to the November 2002 digital photos. These habitat designations proved to be very accurate and useful at the scale of river reaches. We occasionally noted smaller habitat designations during our detailed, small-scale field analysis, and these modifications are noted in discussion of results. Habitat designations were combined with redd density estimates as the first step in the new study. Results are shown in Figures III.1, III.2, and III.3. These summaries were then used to select sites for new monitoring point installation.

IV. INSTALLATION OF NEW MINI-PIEZOMETER TIPS

Previous spawning gravel assessment by the CSUS group focused on DFG gravel manipulation sites (Vyverberg et al., 1997; Horner et al., 2003 draft report). Most measurements were confined to the new gravel sites, and manipulated gravels were not compared to nearby areas of the stream in any detail. As the 2002/2003 field season came to an end, the monitoring network was expanded to include areas of the stream bed that are adjacent to gravel manipulation sites. These included heavily used spawning areas, moderately used spawning areas, and sites with little or no natural spawning use by Fall run Chinook salmon and steelhead. The objective was to identify physical or geochemical variables that were distinct or different in the high use spawning areas.

Mini-piezometers are an important part of the expanded monitoring network. Mini-piezometers are miniature monitoring points that provide discrete water sampling capability in the stream gravel, and were hammered to depths of 30 cm and 90 cm below the gravel surface. Some localities also include a 60 cm monitoring point to give more detailed description of the gravel interval used by spawning salmonids.

Sampling tips are approximately 1.5 cm wide by 3 cm high, and the screened interval is less than 1 cm long (Figure IV.1). Tips are made out stainless steel, and connected to the surface using a 3 mm diameter polyethelene tube. This tube projects 20-40 cm above the gravel surface, and is plugged by a golf tee to prevent exchange between stream water and subsurface gravel pore water between sampling events (Figure IV.2). The result is a miniature well (piezometer) installation that allows sampling from a discrete depth interval in the gravel.

Mini-piezometers have advantages and disadvantages. The American River Parkway is used by almost five million people per year, so there are advantages to low-profile, “hidden” installations that do not attract attention from the recreational parkway users. Mini-piezometer tubes are clear, wave gently in the current, and become coated with algae in a matter of weeks. This makes them very difficult to see, and the general public usually leaves them alone. They do not provide navigational hazards to boaters, swimmers and fishermen, and we have been able to justify this as a low impact approach that does not significantly alter the streambed.

The largest disadvantage to mini-piezometers is that most field instruments can’t be inserted into the 3 mm. diameter tube. Temperature and pressure are measured directly from the tube (see section VI below), but all other measurements are made by pumping water out of the tube, and making readings at the surface. Larger well installations with filter pack and clay seals would be preferred for many methods of analysis, but mini-piezometers offer an acceptable compromise on the heavily-used American River Parkway.

IV.A. Sailor Bar

Sailor Bar posed the most problems for new mini-piezometer installations. Our installation method used a steel drive rod to hammer the monitoring points to a particular depth, and monitoring points were then pumped with a hand pump to remove excess silt and clay. Both of these operations proved to be very difficult at Sailor Bar. Boulders up to 30 cm diameter were present in the subsurface, and the drive rod did not slide easily past grains of this size. Repeated attempts often allowed us to drive the points to depths of 30 or 60 cm, but subsurface layers with low permeability created additional problems. These low permeability layers clogged the sampling tips, and we were not able to withdraw water from the majority of the mini-piezometers. Additional details about the underlying geology and comments about habitat suitability at Sailor Bar are given in section IX.A. (Site-specific observations). The result was that we spent several days trying to install monitoring points near Sailor Bar, but were only successful in a few places. Taken from upstream to downstream, the following conditions were encountered:

The riffle upstream from Sailor Bar has a consistent clay layer in the shallow subsurface that is very impermeable, and we were not able to install shallow or deep monitoring points directly upstream from Sailor Bar (see Figure IV.1). This clay layer is probably an ash-rich interval in the underlying Mehrten Formation, and it may occur in combination with the shallow infiltrated fines that clog the pore spaces of coarse river gravels. River gravel is thin at this upstream extent of our study area, and the general environment in the narrow, high-velocity channel is erosional rather than depositional.

Stream gravels located directly off-shore from Sailor Bar (flat water pool 4) contained many small boulders, and piezometer installations met with limited success in this area (Figure III.3a and III.B). Shallow (30 cm) installations near the north shore encountered frequent impermeable layers that are probably a result of organic material and clay infiltrating from the surface (see section IX.A.1. for more detail). Deeper (60 cm) installations were sometimes successful, indicating that cleaner, better sorted gravel layers exist in the subsurface.

Mini-piezometer installations were more successful downstream from Sailor Bar (see Figure IV.1). Sailor Bar has a downstream tail of finer sediment (sand, granules, pebbles, and cobbles), with abundant material in the size range used by spawning salmonids. Visual inspection shows that surface armoring is absent, and large boulders are much less common when compared to upstream locations. Appropriate-sized spawning gravel accumulates in the velocity shadow caused by Sailor Bar, and it is likely that the river gravels are several meters thick in this area. This area was more conducive to monitoring point installation, and 3 nested sets of piezometers were placed on the shallow gravel ridge that extends downstream from Sailor Bar (bar complex riffle 8, from habitat designations of Snider et al., 1992).

The result was that we placed several new monitoring points in a high-use spawning area downstream from Sailor Bar. It would have been preferable to include moderate or low use spawning areas or other habitat areas near Sailor Bar, but underlying geologic conditions did not permit mini-piezometer installation in several target areas.

III.B. Lower Sunrise Access

Fourteen nested monitoring points were added at the Lower Sunrise Access site to expand the project beyond the boundaries of the DFG gravel manipulation area (Figure IV.4). New monitoring points were installed in an upstream glide (flat water glide 29), upstream riffle (bar complex riffle 30), the run, pool and glide just offshore (north) from the manipulated gravels (bar complex run 31, bar complex pool 32 and bar complex glide 33), and the narrow downstream riffle where the channel constricts (bar complex riffle 34). These habitat designations are taken from Snider et al, 1992 (see Figure III.2).

Spawning use varied between these sites. The upstream glide and riffle are areas with high spawning use, and the downstream riffle has moderate to low spawning use. The intervening run, pool and glide to the north of the gravel manipulation site have low spawning use (Figure III.2). One of the major objectives at these sites was to examine the differences between upstream and downstream riffles, and determine whether measurable physical or geochemical parameters are responsible for the differences in spawning density. In general, piezometer installation was successful at the upstream, high-use spawning riffle and glide, indicating that permeability is high in these gravels. Piezometer installation was more difficult at the downstream sites including the downstream riffle, and may indicate the presence of fine material in pore spaces, or an impermeable layer in the subsurface (see section IX.A.2 below).

IV.C. Sacramento Bar

Nine new piezometer clusters were added to Sacramento Bar to expand the existing monitoring network and improve our understanding of nearby high use and moderate use spawning areas. Piezometers installed easily and we were able to pump large volumes of clear water across most of Sacramento Bar, indicating that the gravel has high permeability. This entire area was named flat water glide 42 by Snider et al., (1992), but we have subdivided it into two additional riffles. These are labeled “upstream riffle 42” and “downstream riffle 42” on Figure III.5, and are identified on the basis of increased slope of the water surface, shallow, high velocity flow, turbulent surface, and the presence of coarser, highly permeable gravel.

An upstream pool leads into Sacramento Bar, and in this pool the channel is approximately 100 m wide. Channel width decreases to approximately 55 m through Sacramento Bar, stream gradient increases slightly, and the reduced water depth and higher gradient are responsible for an increase in velocity through flatwater glide 42 the and upstream and downstream riffles. Grain size is coarser through the riffles and glides, although sandy material is still common. Sand content increases offshore from the point bar (see below), and the river bottom in flat water glide 42 is composed of sandy gravel.

The interior of the meander bend at Sacramento Bar is a large, attached point bar that is probably several meters thick. Cobbles 10 – 20 cm diameter are the most common grain size, and from a surface view only, the bar appears to be massive (structureless). Clean, well-rounded andesite and metamorphic cobbles make up at least 95% of the clasts. Fine sediment content is limited to small amounts of infiltrated material, and the gravel bar appears to be winnowed and current-sorted. This may be an older, established bar form in a system that has seen many anthropogenic changes. Many of the cobbles may have been contributed by mining, but this area still has many characteristics of a natural gravel bar.

Upstream riffle 42 and downstream riffle 42 lie along the interior edge of the meander, in an area where current velocity is high during high flow events. Surface water is shallow and moves significantly faster in these riffles, and spawning density is high. Grain size in these riffles ranges from pebbles to cobbles, and the coarse, clean gravel is highly permeable.

V. PERMEABILITY MEASUREMENTS

Note: The following section on permeability measurements is adapted from a M.S. thesis in preparation by Tim Bishop, CSUS Geology Department.

River gravel was sampled and analyzed at several new localities to give a more complete view of variations in grain size distribution and stream bed permeability. Initial results (Horner et al., 2003 draft report) show that permeability measurements do not agree between our three standard methods of analysis (Terhune standpipe, sieve analysis, slug tests). The reasons for lack of agreement between methods are only partially clear, and we are continuing to evaluate permeability testing in gravel bed streams during the 2004/2005 field season. Preliminary results of the gravel permeability study will be given in this section, although in some cases the discrepancies raise questions that don't have immediate answers.

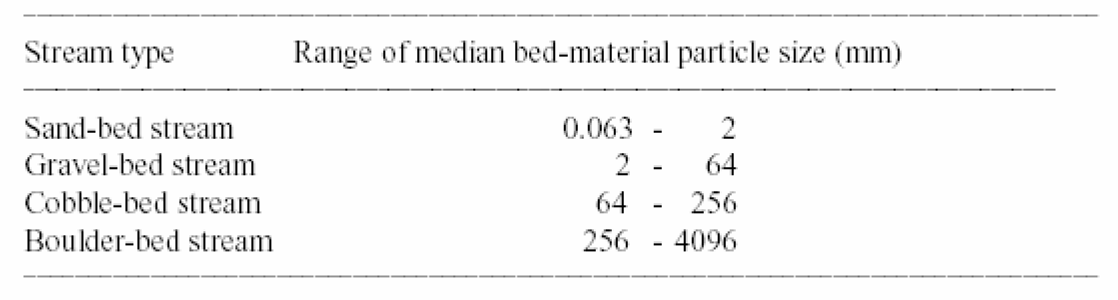
New sampling sites were added in or near each of the DFG gravel manipulation sites. At Sailor Bar, site 1003 was added for bulk grain size analysis inside a manipulated area, and site 1001 was determined to be just outside of the manipulated area. Sites 1701 and 1702 were selected for permeability analysis using the Terhune standpipe and slug test methods. (Fig. V.1). At Lower Sunrise access, sites 3003 and 3004 were added for additional bulk grain size analysis, and sites 3701 and 3702 were used for permeability tests (Fig. V.2). At Sacramento Bar, sites 5003 and 5004 were chosen for new bulk grain size measurements, and sites 5701, 5702 and 5703 were used for permeability tests (Fig. V.3).

V.A. Grain Size Analysis

Grain size analysis is a fundamental part of habitat suitability studies, and is also used in this project to provide indirect information about permeability and porosity of river gravels. Grain size can be a primary limiting factor for salmon habitat spawning, and several aspects of grain size are potentially harmful. Spawning salmonids prefer material in the range of small cobbles, and are unable to move material past a certain size during redd construction (Crisp and

Carling, 1989). Excess fine material is also detrimental (Lisle, 1989; Milan et al., 2000; Wu, 2000; Soulsby et al., 2001), and conventional thinking limits sand content to less than 20% of the bed material (Cederholm et al., 1980; Barnard and McBain, 1994). Another potential habitat problem that is related to grain size is excess coarse material that interlocks and forms a barrier at the surface. This phenomenon is called armoring, and occurs where strong surface currents winnow away the finer material, leaving behind coarse lag deposits that cover the bed of the stream (Bunte and Abt, 2001).

Rivers and streams can be characterized by the mean grain size of their channel sediments (Bunte and Abt, 2001). Channel sediments with a mean particle size ranging between 0.063 and 2mm are considered sand-bed streams. Gravel-bed streams range between 2 and 64mm, and cobble-bed streams between 64 and 256mm. Boulder-bed streams are the largest, ranging between 256 and 4096mm. The American River is dominantly a cobble bed stream in Reach IV, although coarser areas at Sailor Bar are classified as boulder bed stream deposits (based on information from Snider et al, 1992).



Stream type	Range of median bed-material particle size (mm)
Sand-bed stream	0.063 - 2
Gravel-bed stream	2 - 64
Cobble-bed stream	64 - 256
Boulder-bed stream	256 - 4096

Table V.1. Stream Classification based on the median bed-material particle size (from Bunte and Abt, 2001).

V.A.1. Grain size analysis- site selection and surface vs. subsurface samples

Sites were selected for additional bulk grain size analysis at each gravel bar. These new measurements were necessary because several samples are required to properly characterize a heterogeneous gravel bar. Each gravel bar was first canvassed on foot, and a representative surface area was identified. Sites were then selected by randomly tossing a marker to indicate the center of the sample area. Sample size was determined by weighing the largest surface grain, and using this as 1% of the total sample weight (Church et al., 1987). This ensured reasonable reproducibility, but resulted in sample sizes that weighed more than 2000 kg in coarser areas.

Surface samples and subsurface samples were measured separately to identify armoring. Surface depth was defined by measuring the d_{max} of the largest surface grain in the sample plot (Ettema, 1984). This number was used as the depth of the surface sample, and varied from 10-30 cm at all sites. All material below this depth was considered the subsurface sample, and was sieved and weighed separately. Results were compiled into cumulative frequency curves, and used to evaluate the size distribution of spawning gravels.

V.A.2. Field sampling and sieve analysis method

Grain size samples were collected in-stream or at the water's edge, and sampling was usually done in the late summer or early fall months when river discharge was low. Samples collected above the water line were either chosen to represent grain size conditions on a particular bar feature, or were collected at unusually low flows. Cobbles and boulders found on the Lower American River are too coarse to permit the use of McNeal samplers or grab samplers, so shovels were used to collect bulk samples. In-stream sampling with shovels is a reasonably accurate method if the finest fraction can be contained (Hames et al., 1996), but in practice it may be very difficult to prevent the finest material from escaping in the current. In sample locations where current was a concern, a plywood shield was staked out upstream from the site, and 5 gallon buckets were used to collect the samples and move them to the shore, where they were drained and weighed to obtain the total sample weight (Bunte and Abt, 2001). Published references advise caution when using this method, because the current can wash fines out of the sample.

Grains larger than 256 mm diameter were measured by hand in the field using a template or caliper, and the weight of each size fraction was recorded. Ten progressively smaller rocker sieves were set up to collect grain size distribution data for size fractions between 256 mm and 8 mm. Each rocker sieve was a 35 cm by 35 cm steel box, with a pan to collect the individual size fraction. Sieves openings were 256mm, 180mm, 128mm, 90mm, 64mm, 45mm, 32mm, 22mm, 16mm, and 8mm. Samples were split by size class using the rocker sieves, and each size class was weighed and recorded in the field using a digital balance accurate to 0.01 kg. When all measurements were complete, the material was scattered back into the sample pit.

In regions where wet samples were excavated, samples were dried on tarps to prevent the smaller grains from sticking together. If the presence of excess fines hindered the drying process, material was washed though the sieves using a dunk tank. This washed the fines through the sieve, and fines were collected from the dunk tank and weighed separately. The largest problem with wet sieving was excess water sticking on samples, but it was not a significant factor for any of the larger size fractions. Smaller size fractions were allowed to drain before weighing.

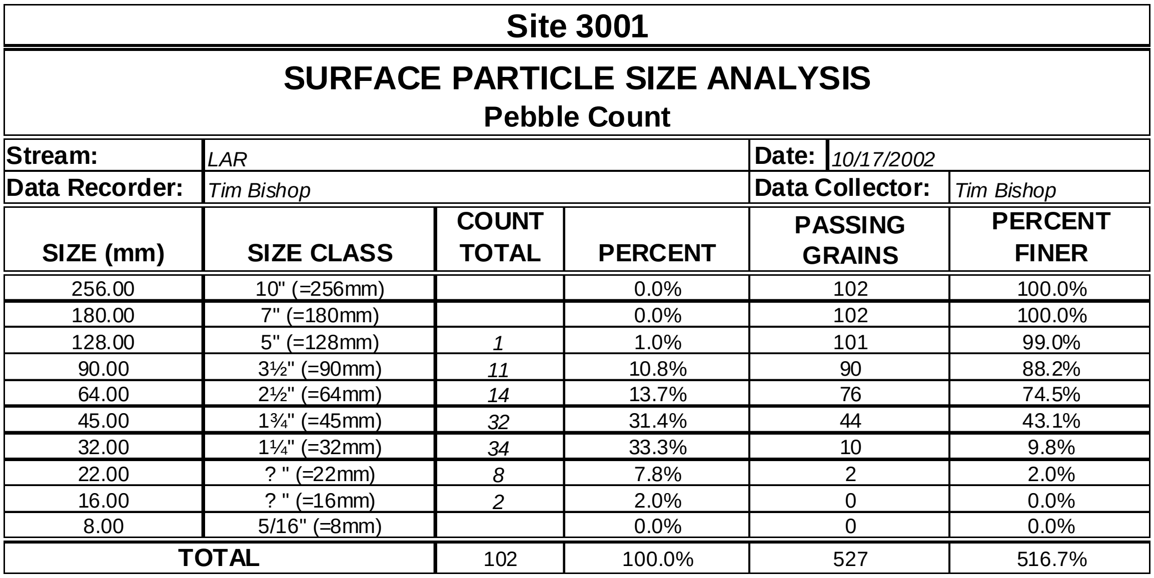
Many samples had significant proportions of fine material (grains less than 8 mm), and these fine samples were taken to the lab for further analysis. Fine fractions that weighed less than 1-2 kg were collected in steel cans, sealed, and processed in the lab. Larger fine fractions were weighed, then split in the field using the pie separation technique. A fraction of the fine sample was transported to the lab for analysis, and results were extrapolated to include the entire fine sample.

In the lab, fine samples were dried for 24 hours at 60° C, weighed, and split using a riffle splitter to obtain a sample fraction that weighed less than 25 gm. This fraction was sieved for 20 minutes with a rotap machine. Sieves in the rotap stack had openings equal to 7mm, 4mm, 2.83mm, 2mm, 1.41mm, 1mm, 0.71mm, 0.5mm, 0.35mm, 0.25mm, 0.177mm, 0.125mm, 0.088mm, and 0.0625mm. Weights from each fine size class were added to the field tally of coarser material weights, converted to weight percent, and plotted on cumulative frequency curves.

V.A.3. Wolman Pebble Count method

The Wolman pebble count is a method of analyzing grain size distribution based on surface coverage of a specific area (Wolman, 1954). Using this method, a grid or systematic method of sampling was established, and at least 100 grain diameter measurements were collected (see example, table V.2). Measurements were made using a ruler or template, and the intermediate axis was taken as a representative measure of grain size. These data were then plotted as “percent finer” on log grain size distribution graphs.

Wolman pebble counts can be advantageous in situations where high current velocity impedes in-channel sampling. The Wolman pebble count method also analyzes a larger area of the stream bed than a bulk sample collected from a single pit. In areas dominated by large grains, Wolman pebble counts may be preferred because of the physical labor required to collect a representative bulk sample. However, this method is not suitable for areas where fine material dominates. It may also be difficult to avoid human error introduced by preferred grain selection. Wolman describes how the sampler should practice only selecting grains from beneath the tip of the toe of his or her boot. “Randomness in the selection of each pebble can only be obtained if the sampler tries not to look at the bed as he picks up each pebble” (Wolman, 1954).



Site 3001

SURFACE PARTICLE SIZE ANALYSIS

Pebble Count

Stream:	*LAR*			**Date:**	*10/17/2002*
Data Recorder:	*Tim Bishop*			**Data Collector:**	*Tim Bishop*

SIZE (mm)	SIZE CLASS	COUNT TOTAL	PERCENT	PASSING GRAINS	PERCENT FINER
256.00	10" (=256mm)		0.0%	102	100.0%
180.00	7" (=180mm)		0.0%	102	100.0%
128.00	5" (=128mm)	*1*	1.0%	101	99.0%
90.00	3½" (=90mm)	*11*	10.8%	90	88.2%
64.00	2½" (=64mm)	*14*	13.7%	76	74.5%
45.00	1¾" (=45mm)	*32*	31.4%	44	43.1%
32.00	1¼" (=32mm)	*34*	33.3%	10	9.8%
22.00	? " (=22mm)	*8*	7.8%	2	2.0%
16.00	? " (=16mm)	*2*	2.0%	0	0.0%
8.00	5/16" (=8mm)		0.0%	0	0.0%
TOTAL		102	100.0%	527	516.7%

Table V.2 – Example of Wolman pebble Count data set.

V.A.4. Results of grain size analysis

8 pebble counts and 13 bulk samples were collected over a two year period, and results of the two methods were compared. A comparison of Wolman pebble counts to the bulk sampling method showed that pebble counts underestimated the amount of fine material, overestimated the amount of coarse material, and overestimated sorting (as shown by the slope of the frequency distribution curve) (see Fig. V.4). This observation was consistent for all eight sample sites where the two methods were compared. Because of this finding, Wolman pebble

counts were discontinued in year two of the project. This brings up several issues that range from philosophical to practical, and each future study will need to judge whether the additional accuracy of bulk sampling is worth the extra time and effort.

There were minor differences in bulk sampling methods between year one and year two of the project, and these differences are summarized in Table V.3. In year one we did not initially collect separate surface and subsurface samples, and this did not allow direct identification of armoring. In an effort to correct this mistake, surface samples were collected at these sites several months later. Early bulk sample results (see Horner et al., 2003 draft report) showed bulk and surface sample results, but do not have a separate subsurface sample. These comparisons may give an indication of armoring, but the bulk sample also included the surface component. Plots from year one under-estimate armoring because of this problem.

	Type of raw data collected (this report, and Horner et al draft report, 2003)				**Pre-project assessment: Summary of findings by Vyverberg et al., 1997, from closest location**			**Post-project assessment: Fndings- this report**		
Site I.D. (see Fig. V.1, V.2, V.3)	**Bulk Sample**	**Surface Sample**	**Subsurface Sample**	**Pebble Count**	**Armored**	**Excess fine material**	**Excess coarse material**	**Armored**	**Excess fine material**	**Excess coarse material**
Sailor Bar: gravel sites in habitat zones 3, 4										
1001**	X	X		X	Excessive coarse sediment, low permeability, excessive fine sediment in (downstream) habitat zone 7			X		X
1002**	X	X		X						X
1003		X	X					X		X

Lower Sunrise Access: gravel sites in habitat zones 32, 33								
3001**	X	X		X		X		
3002**	X	X		X	Single sample from (upstream) habitat zone 30: was armored, had minor excess coarse material	X		X
3003		X	X			X		
3004		X	X			x	X	
Sacramento Bar: gravel sites in habitat zone 42								
5001**	X	X		X		X		X
5002**	X	X		X	Minor excess fine material, no armor from single sample site in habitat zone 42.			x
5003		X	X			x		x
5004		X	X			X		X

** Graphs and raw data from 2002/2003 gravel analysis are available in Horner et al draft report, 2003.

Table V.3: Summary of current gravel conditions, and comparison of pre- and post- project gravel conditions. Closest available sites are used for comparison, but pre- and post- project gravel assessments are frequently from different habitat zones.

Samples from year two have discrete surface and subsurface fractions, allowing more accurate identification of armoring (Table V.3). Results of bulk grain size analyses from the current project (2003/2004 study) are shown in Figures V.5, V.6, V.7, V.8, and V.9. A grain size window that brackets suitable salmonid spawning habitat was added to each graph, based on work by Vyverberg et al., 1997.

A comparison of pre- project and post- project grain size analyses is also included in Table V.3. Conditions reported by Vyverberg et al (1997) are reported, but pre-project work conducted in the mid-1990's is frequently from different habitat zones than the sites that were later selected for gravel manipulation experiments. This lowers the value of the comparison, although several observations can be made. Armoring and excess coarse material were common problems at Sailor Bar, before the gravel manipulation experiment, and these problems persist today in the experiment areas. Lower Sunrise Access has a problem with excess fine sediment, and Sacramento Bar has excess coarse material that was not reported in the initial pre-project study. It is likely that the new grain size problems reported from Lower Sunrise Access and Sailor Bar are related to heterogeneity in the natural environment, and we have no way to evaluate whether they are recent problems that developed after the gravel was emplaced in 1999.

A thorough study of gravel mobility and grain size distribution should include several points that we were not able to address properly: 1) pre-project assessment *in the area that will be manipulated* 2) post-project assessment at the same locations, immediately following the gravel emplacement and 3) post-project assessment after high flows or after a certain time has elapsed. This would give a much better understanding of gravel mobility and expected project duration.

High flows in February 2000 may have contributed to the rapid mobilization and re-armoring of several sites (Figure V.10). Clean, unseasoned gravels were subjected to flows of up to 23,000 cfs less than six months after emplacement. Post-construction air photos taken in November 2002 show a slight downstream tail of sediment at each site, and imply that some gravel was mobile at these flow levels (see Horner et al., 2003 draft report, Fig. 2, 3, 4). We can speculate that the gravel would have been less mobile if a year or two had elapsed before encountering flows of this magnitude, but this highlights one of the risks of any stream restoration project. High flows soon after project completion can mobilize material that might have become more stable with time.

V.B. Hazen method

The Hazen method (Hazen, 1911) was explored briefly as a method of estimating spawning gravel permeability. This method uses the d_{10} value from cumulative frequency plots to estimate hydraulic conductivity, and is one of a large group of mathematical solutions based on grain size distribution curves (Bunte and Abt, 2001). The Hazen method was not acceptable for most spawning gravels on the Lower American River, because the Hazen method is only appropriate when the effective grain size (read from the cumulative frequency plot as the d_{10} value) is between 0.01 and 0.3 cm (Hazen, 1911). Other methods including Shephard (1989) were also explored, but none of these approaches are valid for the coarse cobble-sized material found in our study area.

Site 3004 (Lower Sunrise Access) was the only locality that had a d_{10} value less than 0.3 cm. A Hazen coefficient of 120 was used to calculate hydraulic conductivity for this sample, based on the assumption that the sample was composed of coarse, poorly sorted sand. Field observations verified this assumption, although there was a significant pebble component to the sample. Calculations are shown below:

$$K = C\ (d_{10})^2$$

$$K = 120(0.14\ cm)^2$$

$$\boxed{K = 850\ cm/hr}$$

The Hazen method provides a reasonable estimate of hydraulic conductivity in this finer interval, although it cannot be compared directly to other nearby sites. Hydraulic conductivity in coarser intervals is expected to be significantly higher.

V.C. Terhune standpipe

Terhune (1958) and Pollard (1955) gave detailed descriptions of methods of estimating hydraulic conductivity in salmon spawning gravels. Both of these early approaches were based on dye dilution in a standpipe (piezometer) that was hammered into the gravel. These methods used calibration curves or empirical calibration in lab settings, and have recently been modified to use hand pumps or portable electronic pumps that create a constant 2.54 cm (one inch) drawdown in the piezometer (Barnard and McBain, 1994). We used the modified method described by Barnard and McBain to make a series of permeability measurements in American River spawning gravels, with the goal of comparing results to permeability estimates based on grain size distribution (section V.B., above), and slug test estimates (section V.D., below).

Sample sites for Terhune standpipe permeability tests are shown in Figures V.1, V.2, and V.3. These sites were selected because of proximity to gravel manipulation sites, and all sites except the Lower Sunrise site are within the manipulated areas. Lower Sunrise permeability tests were conducted in a shallow riffle that consistently receives heavy spawning use, and are intended for comparison to the modified gravels.

Permeability tests were conducted at 30 cm (one ft) and 60 cm (two ft) depths in the stream gravel. These depths include the depths that spawning salmonids use for redd construction (Montgomery et al., 1995), and were intended to measure background permeability levels in areas near spawning sites. Permeability values were standardized to 10° C and corrected for viscosity differences before final permeability values were reported. No actual redds were measured during permeability tests.

Results from the Terhune standpipe analysis are shown in the last column of table V.3. A complete table of field measurements for Terhune standpipe analyses is given in Appendix B.

Results varied by an order of magnitude between sites and depths, and there were no obvious trends. Sailor Bar had the coarsest surficial deposits, but yielded low permeability values. We suspect that there was an impermeable layer in the shallow subsurface at Sailor Bar. This was supported by permeability tests where pore water did not flow into the standpipe, or flowed very slowly. Lower Sunrise showed the highest variability, although the two permeability locations were 10 m apart. This indicates a high degree of heterogeneity in the subsurface. Measurements taken at Sacramento Bar had consistently high permeability measurements that would be expected from the clean, well-sorted, cobble-sized material observed at this site.

Permeability (cm/hr)				
Location	**Depth in gravel**	**Hvorslev slug test method**	**Bouwer & Rice slug test method**	**Terhune Standpipe estimate**
Sailor Bar				
1701-1	30 cm	2040.71	645.03	8,000
1701-2	60 cm	187.8	47.66	850*
1702-1	30 cm	19.85	2.84	No Flow
Lower Sunrise				
3701-1	30 cm	690.26	166.16	3600
3701-2	60 cm	1427.16	395.83	15000
3702-1	30 cm	1493.48	282.66	20000
3702-2	60 cm	2950.55	911.03	100000+
Sacramento Bar				
5701-1	30 cm	779.65	256.1	8,000
5702-1	30 cm	1345.26	358.67	11,000
5702-2	60 cm	928.13	292.27	15,000
5703-1	30 cm	8994.86	2378.98	40,000**
5703-2	60 cm	1353.48	502.84	20,000
*Not pumping at 1" drawdown. -- Measured at 2" drawdown.				
**.5" drawdown				

Table V.4: Comparison of results from standpipe (piezometer) permeability tests. Bouwer and Rice and Hvorslev methods used identical raw data sets, and Terhune tests were conducted in the same piezometer installation.

V.D. Slug tests

Slug tests are a standard method that hydrogeologists use to estimate hydraulic conductivity in rock or sediment. Slug tests are usually conducted in engineered water wells, but the technique was easily adapted to the Terhune-style piezometers used in this project. To simplify the comparison, slug tests and Terhune-style tests were conducted in the same piezometer installation at each test site (same piezometer installation, same depth). This minimized variability, and allowed direct comparison of results from the two test methods.

A slug test stresses the aquifer by inserting or removing a physical object (slug) from the piezometer. The aquifer is stressed when the slug is quickly inserted or removed from the piezometer, and the response of the aquifer is recorded. An aquifer that takes a longer time to return to equilibrium has a lower hydraulic conductivity, and an aquifer that returns quickly to equilibrium has a higher hydraulic conductivity. We used a 2 m by 2.54 cm wooden dowel to stress the aquifer, and recorded aquifer response (changes in water level) using an electronic pressure transducer and data logger. The data logger and pressure transducer recorded water levels twice per second, allowing very rapid and precise measurements of changes in water level inside the piezometer.

Two methods of analysis were used to process the raw data from each slug test. The Hvorslev (1951) method makes assumptions about the shape of the zone of influence when the aquifer is stressed, and uses a linear plot of change in water level vs. time to estimate hydraulic conductivity. Bouwer and Rice (1976) started with a different set of assumptions that relate more to the size of the zone of influence and details of well construction, and used these parameters to estimate hydraulic conductivity based on aquifer response. Differences in results produced by the two methods of analysis are shown in table V.4.

V.E. Comparison of permeability estimates

Estimates of hydraulic conductivity from the two methods of slug test analysis differ by a factor of three, with higher values reported by the Hvorslev method. Hydrogeologists usually expect better agreement between these two methods, and the discrepancy may indicate a problem with assumptions about the form factor of Hvorslev, or assumptions about well geometry used in Bouwer and Rice. We will continue to evaluate this problem, but in the meantime these values give a broad indication about permeability in Lower American River spawning gravels.

Values obtained by the Terhune method have greater variability, are much higher than results from either slug test method, and do not always vary directly with slug test results. There may be a fundamental problem with one or more of our methods of permeability analysis, and we plan to explore these problems in year three of the project.

VI. FIELD PARAMETERS

Current velocity, water depth, vertical gradient, and field parameters (dissolved oxygen, electrical conductivity, pH, turbidity and temperature) were measured twice during the 2003/2004 project. This was less than the stated project goal of quarterly field parameter sampling. High runoff in the spring and unusual delta water quality demands in early summer kept American River discharge high for a significant part of the year. This prevented the field team from accessing many in-stream monitoring points.

Physical parameters can be flow dependant, so it is important to consider river discharge during each sampling event. A hydrograph based on water releases from Nimbus Dam is shown in Figure VI.1 for reference. Field parameters were sampled at 2000 cfs in December 2003, and

2500 cfs in August 2004. These differences in flow are relatively insignificant, and are not expected to be the major factor in any observed field parameter trends.

Field parameters were measured in surface water and at each nested mini-piezometer point during field sampling runs. Locations of mini-piezometers are shown in Figures IV.1, IV.2 and IV.3. During sampling runs, an inflatable raft was anchored near each piezometer set. The raft held meters, a flow-through cell, a pump, and a car battery was used to power the pump (see Horner et al. 2003 draft document, Fig. 15). This allowed us to access monitoring points in-stream, withdraw a small volume of pore water, and make accurate measurement of field parameters.

VI.A. Dissolved oxygen

Dissolved oxygen is especially important for spawning salmonids, because low DO in pore waters may be a limiting factor for egg survivability (Sowden and Power, 1985). In addition to direct survival, DO levels affect the rate of development (Silver et al. 1963; Brannon 1965; Wells and McNeil 1970), growth rate of embryos (Silver et al. 1963), and the size at emergence of alevins or fry (Silver et al. 1963; Shumway et al. 1964; Mason 1969).

A YSI model 52 or model 58 dissolved oxygen meter was used to measure dissolved oxygen levels in surface water and intergravel pore water. These meters were calibrated daily in the field, and surface water values were recorded daily to provide a reference point for intergravel conditions. Surface water is essentially saturated with dissolved oxygen, and dissolved oxygen decreases along short flow paths in the subsurface as a result of interaction with organic matter and mineral constituents (Horner et al., 2003 draft report; Horner and Bush, 2000; Head and Horner, 2004). A low volume Geotech flow-through cell and peristaltic pump were used for all intergravel dissolved oxygen measurements. Water was pumped to the surface from previously installed mini piezometer tips located at 30 cm (1 ft) , 60 cm (2 ft) and sometimes 90 cm (3 ft) depths in the gravel. Pore water passed through the connecting tubing and flow-through cell without exposure to the atmosphere, and dissolved oxygen was measured inside the flow-through cell. This technique minimized contamination from atmospheric oxygen, and maintained appropriate flow velocity past the DO probe tip.

VI.B. pH, electrical conductivity, turbidity, field temperature

Field parameters are an excellent indicator of mixing between surface water and shallow ground water. Field parameters were measured using research-grade field meters, and standard field protocols (USGS, 1980; Koterba et al., 1995; Wilde and Radtke, 1999; Weight and Sonderegger, 2001). pH was measured with a temperature-corrected Orion model 210 or model 250 pH meter, calibrated daily in the field using a two point calibration method that bracketed the pH of sample waters. Electrical conductivity (E.C.) was measured with a temperature-corrected Orion model 128 conductivity meter, calibrated daily in the field using a one point calibration check. pH and E.C. probes were inserted into the flow-through cell, although these measurements are not sensitive to atmospheric contamination.

Temperature was measured with a Fluke thermocouple meter and type “K” thermocouple wire, threaded into the mini-piezometers. This gave accurate inter-gravel temperature during field sampling events, and was also used as a quick check to confirm that sample tubes were open (unclogged) and still inserted to the proper depth in the gravel. Turbidity was measured by collecting a water sample from the outlet tube on the flow-through cell. A DRT model 15 turbidity meter was used for this measurement, and was calibrated daily in the field using a 0.002 NTU reference standard.

VI.C. Surface water depth and velocity

Surface water depth and velocity were measured at each mini-piezometer station using a Price AA or Pygmy current meter mounted on a topset wading rod (Wilde and Radtke, 1999). The Price AA meter was used for most measurements, but the Pygmy current meter was used when water depth was shallower than 15 cm (1.5 ft). Velocity measurements were taken at 0.2, 0.6 and 0.8 of total water depth. The 0.6 water depth measurement was used as an indicator of average water velocity at a station, and the 0.2 and 0.8 measurements were averaged to provide a second indicator of average water depth. Raw data were reported in the results section rather than simply reporting the averages, because the 0.8 water depth reading is also a good indicator of the "nose velocity" experienced by spawning salmonids.

VI.D. Upwelling and downwelling conditions

Vertical head gradients were measured using a bubble manometer board, and these measurements were used to infer upwelling and downwelling conditions (Horner and Bush, 2000). The bubble manometer board compares hydraulic head (pressure differences) between the river and shallow depths in the gravel bar. Higher pressure at depth in the gravel was used to indicate upwelling, and higher pressure in the river indicated downwelling conditions. Where there was a pressure difference on the manometer board, the potential for vertical flow was recorded as a direction and magnitude (Hubbert 1940). The term "potential" is used because vertical subsurface flow can be inhibited by confining layers. Upwelling and downwelling have been identified as a key factor in spawning site selection (Barnard and McBain, 1998; Geist and Dauble, 1998), so these measurements are an important part of site characterization. Our bubble manometer board was built by the CSUS machine shop, and we also used a custom “baffle box” on the stream side to damp pressure fluctuations caused by moving water.

VI.E. Results from field parameter measurements

Complete results from December 2003 and August 2004 field parameter sampling are given in Appendix C. Trends shown by field parameters are included in the more detailed discussion of pore water geochemistry (section VII, this report).

VII. PORE WATER GEOCHEMISTRY

The following section on pore water geochemistry is modified from a M.S. thesis chapter in preparation by Eric Morita, CSUS Geology Department.

VII.A. Background and importance of geochemical studies

River water chemistry fluctuates seasonally due to changes in source, volume of flow, biological activity, and interactions with rock and sediment. Spatial characteristics (e.g., gravel bars, channel morphology, gradient, bedrock, water depth) can also alter the flow of surface water through the gravel bed, and may exert a strong influence on pore water chemistry (Savant et. al. 1987; Thibodeaux and Boyle, 1987; Harvey and Bencala 1993; Wroblicky et al. 1999; Storey 2002). Water chemistry was examined on the Lower American River to establish baseline conditions, and identify possible relationships to salmon spawning habitat.

The purposes of this phase of the project are to 1) identify trends in pore water chemistry that are related to seasonal or spatial variability on the Lower American River and 2) examine relationships between differential spawning use and geochemical trends. Specific attention was given to geochemical sampling in the hyporheic zone (the zone of significant interaction between surface water and groundwater) and comparison of surface water to hyporheic water. Water fluxing through the hyporheic zone has been shown to accelerate biogeochemical reactions due to the increased delivery of oxygenated water to riverbed sediments (McMahon et. al. 1995, Findlay 1995, Grimm and Fisher 1984, Triska et al. 1993, Harvey and Bencala 1993). Better understanding of the variables that control hyporheic water chemistry may ultimately lead to better understanding of spawning site selection by salmonids.

VII.B. Analytes and sampling strategy

The most common, naturally occurring geochemical constituents that are found in surface waters (Drever, 1997) were analyzed during this phase of the project; these included chloride, nitrate, sulfate, sodium, potassium, calcium, and magnesium. Successful field sampling runs were conducted in December 2002, April 2003, and December 2003. An additional sampling run was attempted in August 2003, but flow was too variable to call this a contiguous sampling event. Water chemistry was not analyzed from this protracted sampling event, although field parameters were collected and reported (see section VI above).

VII.C. Sample collection and preservation

Water was pumped from nested drive-tip piezometers installed at 30 cm (1 ft) , 60 cm (2 ft) and sometimes 90 cm (3 ft) in the stream gravel, passed through a 0.045 μm filter to remove suspended material and transferred into 250 milliliter pre-cleaned, non-reactive plastic bottles.

Two samples were collected at each site; samples for trace metals, nutrients (with the exception of nitrate) and major element analysis were preserved with ultrapure nitric acid to a pH of less than 2.0. Nitrate samples were collected in a separate bottle and were not preserved. Bottles were sealed, labeled, and placed in a cooler filled with ice, then stored at 4 degrees Celsius until they were analyzed in the laboratory. Surface water samples were collected two times per day to establish the relationship between surface water and hyporheic pore water, and replicate samples were collected at every tenth site to evaluate reproducibility of results. Trip blanks and equipment blanks were collected daily as part of the QA/QC process.

VII.D. Methods of data analysis

Standard statistical methods were used to assign probabilities to geochemical trends. The properties of each data set (normality and variance) were used to determine the proper statistical method to use when evaluating the significance of trends.

VII.D.1. Box and whisker plots

Box and whisker plots were used as an initial method to identify chemical trends that were sensitive to seasonal or spatial variables. Each plot is a graphical representation of a frequency distribution, and displays the symmetry and variability associated with a single data set. The box portion of the plot outlines the two middle quartiles, while the whiskers are connected to the minimum and maximum value. When multiple variables were compared, greater vertical separation between box and whisker plots was interpreted as uniqueness for the variables.

VII.D.2. Hypothesis testing and assigning probabilities to trends

Trends identified with the box and whisker plots were further analyzed using the Wilcoxon Rank Sum Test to determine the significance of each event. Preliminary tests for normality indicated that non-parametric methods were most appropriate for the data sets under investigation. The Wilcoxon Rank Sum Test is a non-parametric statistical method that can be used for non-normal distributions of large or small data sets. The statistical significance of trends was reported in parentheses on graphs of results (α = probability of a Type I error). Methods of non-parametric statistics are detailed in Dietrich et al. (1991).

VII.E. Results: Major elements, nutrients and field parameters

Data were first analyzed *between* sampling runs to examine the influence of seasonal variability on hyporheic water chemistry. The influences of geomorphic and geologic features were then compared *within* each sampling run (Figure VII.2). Results from comparison of major elements, nutrients and field parameters are shown in this section.

VII.E.1. Median and variability for nutrients, major elements and field parameters (all samples)

Median values and variability of nutrients, major elements and field parameters are shown in Figure VII.3. This plot included all sampling runs, so compounds with high variability may have underlying trends or patterns (see section VII.E. below). Nitrate, sodium, temperature, electrical conductivity, and dissolved oxygen showed the greatest variability on this plot, although many other compounds were relatively invariant. This general comparison demonstrates that water quality on the American River is excellent. Surface water and gravel pore waters in the Lower American River are low in dissolved constituents. Because of this, the

American River is a highly sought-after for municipal water supply, agricultural uses, delta water quality demands, and water exports.

VII.E.2. Seasonal variability in hyporheic water chemistry

Seasonal variability of chemical constituents was compared between sampling events. Many major elements or nutrients did not show significant temporal variability, but chloride, sulfate, sodium, and potassium concentrations were found to be significantly different between sampling runs. This explains some of the variability observed over the entire year as shown in Figure VII.3.

The winter events defined by December 2002 and December 2003 samples revealed significantly lower concentrations of chloride, sulfate, and sodium compared to the April 2003 (spring) event ($\alpha<0.001$). Conversely, potassium concentrations were higher in the winter ($\alpha<0.001$). Median concentrations for the spring and winter events are displayed as box and whisker plots in Figure VII.4. None of the other major elements or nutrients revealed statistically significant seasonal trends during the sampling period.

Water temperature and dissolved oxygen content also showed the expected seasonal trends. Water temperatures in the hyporheic zone were colder in the winter (December '02 and '03) and warmer in the summer (August 2003). Dissolved oxygen content, which is inversely related to temperature, was generally higher during the winter events and lower in the summer (Figure 6). Other field parameters (i.e., electrical conductivity and pH) showed no significant trends with time.

Interpretations of the seasonal variability in sodium, chloride, sulfate and potassium are speculative, but it is possible that increases in sodium and chloride are related to spring meltwater contributions (runoff) from the high Sierra. Road salt is used on high mountain roads, and it is possible that we are seeing a two- to four- month lag in solute transport due to transport through upstream storage systems. Our infrequent sampling did not allow us to identify a peak for this increase.

The winter increase in sulfate and spring increase in potassium are harder to explain. Sulfate is relatively soluble, and may be a component of winter and early spring runoff. Potassium showed less variability than the other compounds mentioned, although it appears to be significant. Potassium is soluble, and is commonly used as a fertilizer. There may a muted seasonal potassium contribution (with lag?) that is related to upstream addition of potassium.

VII.E.3. Spatial variability in hyporheic water chemistry

The influence that spatial features (river mile, channel feature, gravel depth, and vertical flow potential) have on hyporheic water chemistry was determined using comparisons of variability associated with these features. To avoid the variability associated with seasonal changes, hyporheic water chemistry was compared within each sampling run. A summary of significant spatial, geomorphic, and geologic trends is given below. Compounds that showed no significant variability using this approach are not discussed.

VII.E.3.a. Variability in geochemical measurements by gravel bar

Although Lower Sunrise Access and Sacramento Bar are located within two kilometers of each other, they had significant differences in pore water chemistry for magnesium, calcium, and electrical conductivity. These components were lower at Sacramento Bar during April and December of 2003. Median concentrations for these components are listed in table VII.1.

	April 2003			December 2003		
	Lower Sunrise Access	Sacramento Bar	Difference	Lower Sunrise Access	Sacramento Bar	Difference
Mg ++ (mg/L)	2.24	1.98	-0.26	1.76	1.72	-0.04
Ca++ (mg/L)	4.50	4.01	-0.49	4.48	4.33	-0.15
EC (μS/cm)	68.1	63.0	-5.1	66.0	60.8	-5.2

Table VII.1: Median values of calcium, magnesium, and electrical conductivity are higher at Lower Sunrise Access than at Sacramento Bar.

In April 2003, the difference in the median magnesium concentration between Lower Sunrise Access and Sacramento Bar was 0.26 mg/L. In December of 2003, the difference in the median magnesium concentration between Lower Sunrise Access to Sacramento Bar was 0.04 mg/L. Although this change is numerically small, the differences were both shown to be statistically significant ($\alpha<0.002$). Calcium concentrations and electrical conductivity measurements from Lower Sunrise Access were also found to be significantly higher than those collected at Sacramento Bar (all $\alpha<0.005$).

Differences in dissolved constituents between the two gravel bars may be related to grain size. Lower Sunrise Access has excess fine material (organic material, silt and clay) at the gravel manipulation sites (see section V.A.4. above), and field observations show heavy algal growth and fine sediment accumulation near many in-stream sampling points. Hyporheic water would tend to move more slowly in these finer-grained intervals, allowing more time for geochemical reactions in the subsurface. This could explain the higher dissolved constituent concentrations at Lower Sunrise Access when compared to the clean, coarse gravels generally found at Sacramento Bar.

VII.E.3.b. Variability in geochemical measurements by geomorphic feature (habitat zone)

This section investigates whether unique chemical properties exist between glides, riffles, and pools. Additionally, this section investigates the chemical uniqueness between similar channel features that have distinctly different spawning preferences.

When all values were averaged by feature, riffles were slightly more basic (α=0.07, Figure VII.6), had higher dissolved oxygen content (α=0.02) and less variable dissolved oxygen content (α=0.036, Figure VII.7) than glides and pools during April, August and December of 2003. Higher dissolved oxygen content in riffles is a result of interaction with oxygenated stream water, implying that riffles have higher permeability or greater inter-gravel flow. Higher pH in riffles has a similar source, because river water in the Lower American River is more basic than intergravel pore water (see section VII.3.c. below). Higher pH in riffles implies more mixing with surface water.

VII.E.3.c. Variability in geochemical measurements by depth in gravel

Field parameters (i.e., pH and dissolved oxygen) showed significant changes between the stream and subsurface, and notable trends with depth. Stream water was consistently more basic, and had higher concentrations of dissolved oxygen than water from the subsurface (Figures VII.8 and VII.9, respectively). Within the subsurface, water became more acidic and dissolved oxygen decreased with depth. No notable trends with depth were observed for the other major elements and nutrients under investigation.

Decreases in dissolved oxygen with depth are caused by oxidizing reactions in the shallow subsurface. Decomposition of organic matter and oxidation of mineral constituents consumes free oxygen, so stream gravels that are isolated from the surface become gradually depleted in dissolved oxygen. Decreases in pH in the subsurface are probably related to release of humic and fulvic acids during the decay of organic matter. A significant amount of organic matter is contributed by decaying algae that infiltrate into the coarse interstices of the gravel bed.

VII.E.3.d: Correlation with spawning

Most field parameters did not show direct relationships to spawning density, possibly because several variables work together to define areas with high spawning use. The exception was surface water velocity, which showed a strong relationship to spawning density and habitat type (Fig. VII.8). Pools had the lowest spawning density and current velocity, glides had intermediate current velocity and spawning density, and riffle BC 30 had high current velocity and high spawning use. BC riffle 34 has much lower spawning density, possibly because a velocity threshold has been exceeded. If this interpretation is correct, it implies that the threshold current velocity for fall run Chinook Salmon on the Lower American River is slightly greater than 3 ft/s..

VII.F: Trace metals

A suite of trace metals was selected for additional geochemical analysis, with the objective of identifying significant differences in salmonid spawning gravels that relate to trace metal concentrations. Arsenic, copper, iron, manganese, nickel and lead were chosen as representative trace metals in this pilot study. Sampling strategy, results, and interpretations of trace metal distribution are given below.

VII.F.1. Trace metal sampling and analysis

River water and pore water samples were collected using the protocols, sampling strategy and monitoring points described in section VII.B (above). Trace metal analyses were only performed for a single sampling run using samples collected in late June/ early July 2004, so seasonal variability in trace metals was not examined. All samples were analyzed in the CSUS chemistry department using Perkins Elmer flame and graphite furnace Atomic Absorption Spectrophotometers.

QA/QC data (replicates, trip blanks, calibration samples and lab spikes) were used to establish lower instrument detection limits, instrument precision and reporting limits (Table VII.2). Instrument detection limits were constrained by the concentration of the most dilute standard used in the calibration process, but working detection limits are frequently one-tenth of these values (Professor Roy Dixon, personal communication).

Detection Limits- trace metals					
As	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**
10 ppb	0.010 ppb	10 ppb	0.10 ppb	1 ppb	0.2 ppb

Table VII.2: Instrument detection limits for trace metals analyzed in this project.

Errors introduced during sample collection and handling were also considered, and were examined by comparing results from replicate samples. The difference between measured values for ten pairs of replicate samples was calculated, and the mean of this difference was used as a reporting limit for each trace metal (Table VII.2.) These reporting limits are less than the instrument detection limits reported in Table VII.2, but are more conservative than the working detection limits based on instrument precision that a chemist might use.

Reporting Limits- based on replicate analyses						
Sample ID	**As**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**
	ppb	ppb	ppb	ppb	ppb	ppb
1104-3	n.d.	0.021	24	n.d.	1	0.5
1104-3 Rep	n.d.	0.020	24	n.d.	n.d.	0.4
Difference	0 / 10	0.001	0	0.00 / 0.10	0 / 1	0.1
3104-1	n.d.	0.023	25	0.10	1	0.3
3104-1 Rep	n.d.	0.022	23	n.d.	2	0.3
Difference	0 / 10	0.001	2	0.00 / 0.10	1	0.0
3104-2	27	0.022	22	n.d.	2	0.4
3104-2 Rep	24	0.022	21	n.d.	n.d.	0.3
Difference	3	0.00	1	0.00 / 0.10	1 / 2	0.1
3111-1	n.d.	0.020	32	0.20	1	0.4
3111-1 Rep	n.d.	0.019	37	0.20	1	0.3
Difference	0 / 10	0.001	5	0.00	0	0.1
3111-3	n.d.	0.024	25	0.18	1	0.4
3111-3 Rep	n.d.	0.052	23	0.15	2	0.4
Difference	0 / 10	0.028	2	0.03	1	0.0
Average Difference	**1 / 9**	**0.006**	**2**	**0.01 / 0.07**	**1 / 1**	**0.1**

Table VII.3: Reporting limits for trace metals are based on reproducibility of replicate samples. Samples that were below instrument detection limits were reported as a range from zero ppb to the instrument detection limit.

VII.F.2. Trace metal results

Complete results from trace metal analysis are shown in Appendix D. Lead and nickel were invariant or near the reporting limit, given the reproducibility shown in Table VII.3. More than half of the arsenic samples were below the reporting range of 1-9 ppb, although several arsenic samples showed elevated (measureable) levels in pore water or surface water. Copper, iron, lead, and more than half of the manganese levels showed significant variability that will be discussed below.

It is important to remember that trace metals are relatively insoluble, and a quick check of equilibrium constants will show that saturated levels for arsenic, lead, copper, manganese and nickel are at the ppb level or lower. Iron is more soluble, and this is reflected in the higher iron values measured in surface water and pore water.

Trace metal results were averaged by depth and channel feature. Averaging results by depth did not show significant trends with the possible exception of a decrease in iron with increasing depth in the gravel (Table VII.4). Where non-detects were present in the data, averages were reported as a range, in the format minimum / maximum. Changes in iron content do not appear to be related to input from surface water, because surface water (0 cm depth) has relatively low dissolved iron levels. Individual iron measurements have high variability, so the significance of this trend is low. It is possible that high organic or clay content in the shallow subsurface produces the elevated iron levels, but this is speculative.

Depth	As ppb	Cu ppb	Fe ppb	Mn ppb	Ni ppb	Pb ppb	n
0 cm	9 / 16	0.020	36	0.35 / 0.35	1 / 1	0.5	3
30 cm	7 / 14	0.024	46	0.43 / 0.44	1 / 1	0.4	18
60 cm	11 / 17	0.022	41	0.34 / 0.38	1 / 2	0.4	12
90 cm	16 / 22	0.020	36	0.22 / 0.25	1 / 1	0.4	18

Table VII.4: Trace metal results, averaged by depth. The only trend is a decrease in iron content with depth, and this has low significance due to high variability in iron measurements. n equals the number of samples in each average.

Trace metal contents were also averaged by geomorphic feature (Table VII.5). Riffles and glides had similar trace element values, but pools had elevated manganese and possibly iron levels. This would be consistent with an increase in fine sediment volume in pool environments, where organic material and clay are more likely to accumulate.

Channel Feature	As ppb	Cu ppb	Fe ppb	Mn ppb	Ni ppb	Pb ppb	n
Riffle	16 / 21	0.022	40	0.30 / 0.33	1 / 1	0.5	14
Glide	9 / 16	0.024	40	0.30 / 0.31	1 / 1	0.4	26
Pool	11 / 18	0.026	47	0.53 / 0.53	1 / 2	0.4	8

Table VII.5: Trace metal results, averaged by geomorphic feature. Riffles and glides have similar trace metal content, but values for iron and manganese were slightly elevated in pools. This may be caused by increased organic and fine sediment (clay) content in pools. n equals the number of samples in each average.

VII.G: Summary of pore water geochemistry

Major elements, nutrients, field parameters and trace metals were analyzed in an effort to identify geochemical characteristics that were unique to spawning gravels. American river water is generally low in dissolved constituents, but there are identifiable trends in surface water and pore water chemistry:

- Chloride, sodium and sulfate levels are elevated in April (vs. December).
- Dissolved oxygen content is lower in the summer and higher in the winter.
- pH and dissolved oxygen are higher and less variable in riffles than in pools and glides.
- pH and dissolved oxygen decrease with increasing depth in the gravel.
- Current velocity may be limiting at greater then 3 ft/s

- Trace metals are present at or near reporting limits, and are relatively invariant.
- Iron and manganese concentrations may be slightly elevated in the near-surface environment and in pools.

The measured variables with the stongest relationship to spawning site selection were dissolved oxygen content and velocity. Riffles tended to have lower variability in pore water D.O., moderate to high surface water velocity, and higher D.O. content than other nearby habitats. This may be a powerful signal for spawning site selection by salmonids.

VIII. GRAVEL TEMPERATURES

Surface water temperatures were evaluated in an effort to characterize habitat quality for juvenile steelhead. Juvenile steelhead may stay in their natal river for a year or more, and surface water temperature can be a limiting factor for young- of- the- year. Surface water temperatures were measured in a variety of off-channel areas to evaluate temperature in rearing habitats on the Lower American River. These temperatures were collected at the gravel/water interface.

VIII.A. Background and importance of surface temperatures (rearing habitat)

Temperature is one of the most important limiting factors on the Lower American River, and excessively high temperatures have several harmful ecological effects. Mean daily temperatures higher than 18.3° C (65° F) may prevent the onset of spawning by fall run Chinook salmon, resulting in large fish die-offs before reproduction has occurred. Temperature is also a factor for juvenile steelhead that remain in the system after emerging from spawning gravels in early spring. High summer temperatures can limit their growth and development, and have recently been blamed for the occurrence of "rosy anus disease", a common ailment in young- of- the-year. A daily mean temperature of 18.3° C (65° F) is a common management target for summer water temperatures, and cooler water minimizes these harmful effects in developing steelhead.

Four established temperature monitoring points allow modelers and managers to predict surface water temperatures in the Lower American River. This is very effective for mid-channel water parcels that tend to be well-mixed, with predictable travel times and warming rates as the water travels downstream from Nimbus Dam. Skilled engineers at the U.S. Bureau of Reclamation are able to control mid-channel temperatures using a combination of atmospheric data, in-stream monitoring points, flow information, and variable release points from Folsom Dam.

Surface water temperature distribution is less well constrained in side channels, backwater areas, shallow pools, and shallow riverine habitat. This phase of the project was designed to examine temperature distribution and temperature variability in off-channel areas that juvenile steelhead use for rearing and refuge. A total of 23 temperature loggers was installed at the gravel/ river interface to document surface water temperatures and habitat issues, and sixteen of these loggers produced useable results (Figure VIII.1). Vandalism and high flows were responsible for the high attrition rate of temperature loggers..

VIII.B. Temperature methods

Temperature loggers were checked in the lab before deployment, then set to log at 15 or 30 minute intervals, depending on available internal memory. This gave each logger a three- to six- month window where it would record temperature data. Temperature loggers were attached to 30 cm long rebar (steel) posts using plastic zip ties, and staked to the river bed in each area of interest. Locations were marked with a high-resolution GPS unit, and temperatures were downloaded periodically using a hand-held PDA with an infrared port.

VIII.C. Temperature results and comparison

Results show high variability between main channel temperatures and side channels, shaded banks, pools, and other microhabitats that could potentially be used for rearing. Examples of this variability are shown in Figures VIII.2 – VIII.8. Additional temperature plots are shown in Appendix E, Figures VIII.9 – VIII.17.

Temperature loggers located in mid-channel areas were most likely to meet the 18.3 °C (65° F) temperature target. This generalization applies to Figure VIII.2 (logger 009), Figure VIII.9 (logger 0011), Figure VIII.10 (logger 0014), Figure VIII.12 (logger 0019), Figure VIII.13 (logger 001) and Figure VIII.16 (logger 0005). These loggers were all located at river mile 19.5 or higher, and were in deeper channel areas that received well-mixed water.

Several off-channel areas located upstream from mile 20 did not meet the 18.3°C (65°F) temperature target. Figure VIII.3 (logger 13) was located in the channel margin, and had a temperature profile similar to Watt Ave., despite being several river miles upstream from Watt Ave. This location was analyzed because it is probably rearing habitat. Figure VIII.4 (logger 0016) was located near Upper Sunrise island at river mile 21, and exceeded the 18.3°C (65°F) target temperature for part of its record in mid- to late- October. Figure VIII.11 (logger 0018) was located in a shallow marginal area near river mile 20, and typically exceeded the Watt Ave. reported temperature by 5 or more degrees. This would be a likely refuge or rearing habitat if temperatures were lower.

Moving downstream, several temperature loggers were placed in shallow side channel areas near the Lower Sunrise bar complex. Figure VIII.6 (logger 20a) was located on the downstream end of the side channel, and this rearing habitat had large diurnal temperature fluctuations, temperatures that usually exceeded Watt Ave. values, and daily temperatures in August that peaked at 23° C (73° F). Other temperature loggers are located further upstream in the side channel had even higher daily maximum temperatures, and dried out for parts of the summer (Figure VIII.14- logger 20c; Figure VIII.15- logger 20b).

Farther downstream, temperature loggers were placed near the waterline at Sacramento Bar and in the shallow riffle at Sacramento Bar. Figure VIII.8 (logger 0007) is from the channel margin, and is warmer than reported temperatures for Watt Ave. The logger from the mid-channel riffle at Sacramento Bar (Figure VIII.17- logger 0022) has values similar to Watt Ave. temperatures.

In summary mid-channel locations upstream from river mile 19.5 were most likely to meet the 18.3°C (65°F) temperature target, and were most likely to be cooler than reported values from the Watt Avenue gaging station. Temperature loggers located at channel margins, near large bar forms or islands, in shaded riverine habitat, and in shallow pools or side channels were likely to exceed the 18.3°C (65°F) temperature target, and were often warmer than reported values from the Watt Avenue gaging station, even though Watt Ave. is still several miles downstream..

IX) SITE-SPECIFIC OBSERVATIONS

Salmon spawning habitat should have a supply of permeable gravel of appropriate size. This allows surface water to percolate freely through the hyporheic zone, delivering oxygenated surface water to developing eggs and alevine. In specific situations, any or all of the following factors can degrade spawning habitat quality:

- Presence of impermeable units
- Insufficient gravel thickness
- Excess coarse material
- Excess fine material
- Grain size distribution (sorting and armoring)
- Grain fabric (packing and particle orientation)

Field observations over the past two years have identified several of these limiting factors at study sites on the Lower American River.

IX.A.) Sailor Bar

Spawning habitat and gravel quality at Sailor Bar is limited by an underlying clay layer from the Mehrten Formation, the presence of shallow infiltrated fine material in pore spaces, excess coarse material in the surface and subsurface, and armoring. Each has a different origin and distribution.

Low permeability intervals were encountered upstream and offshore from Sailor Bar. Modern river gravels in this area are underlain by the Miocene Mehrten Formation, which contains fine, ash-rich intervals up to 2 m. thick. These sandy, ash-rich clays are frequently called “hardpan layers”, but are really primary depositional features in the Mehrten Formation, and are a result of volcanic activity in the ancestral Sierra Nevada. Ash-rich beds of the Mehrten Formation appear as tan- to cream-colored intervals along the south bank near Sailor

Bar, and also outcrop on the river bottom about 200 m. downstream from the Nimbus Fish Hatchery.

Ash-rich intervals from the Mehrten Formation may explain our inability to install shallow or deep monitoring points and pump subsurface pore water at the upstream end of Sailor Bar. A relatively thin layer of stream gravels lies on thick, impermeable clays in this area. Gravel and clay thicknesses are variable, because the Mehrten Formation dips gently to the west, and individual beds are not exposed for long distances.

A different low-permeability zone was frequently encountered 20-30 cm below the gravel surface. This low permeability layer may be formed by a combination of decayed organic matter and fine sediment. Fine sediment infiltrates from the surface during low flow, and accumulates in the pore spaces of the coarse gravel. Heavy algal buildup is visible on the gravel during warm summer months, and this is an obvious source of organic material. Deeper (60 cm) piezometer installations were sometimes successful, so the organic-rich impermeable layer seems to be a near-surface feature.

Sailor Bar has a downstream tail of appropriate-sized spawning gravel (sand, granules, pebbles, and cobbles) that is much better quality than upstream material. Surface armoring is absent downstream from the bar, and large boulders are much less common when compared to upstream locations. This spawning gravel accumulates in the velocity shadow caused by Sailor Bar, and it is likely that river gravels are several meters thick in this area.

IX.B. Lower Sunrise Access

The Lower Sunrise Access site is underlain by the Fair Oaks Formation, a Pliocene alluvial unit that contains 1-3 m thick beds of fine-grained silt and clay. This unit is a potential permeability barrier, but it does not appear to outcrop or limit spawning habitat quality across most of the Lower Sunrise Access site. Modern river gravel is a minimum of two meters thick (based on field observations during piezometer point installation), and may be much thicker.

The upstream end of Lower Sunrise Access has an abundance of loose, permeable gravel that is optimal for spawning. Fine sediment becomes a problem at the head of the low-gradient bar, because small, flucutating flows repeatedly inundate the bar surface, then recede. This inundation occurs when flow varies between 1500 and 4000 cfs. Near-shore areas have lower current velocity that is suboptimal for spawning, and this leads to subaqueous sediment deposition from suspension. Young willows and grasses have colonized the exposed surface since the 1997 flood and 1999 gravel manipulation experiment. This creates a self-feedback mechanism, and as each flow inundates a portion of the bar, the current is baffled by vegetation, and even more fine sediment is deposited. The bar surface is rapidly stabilizing, soil is forming, and fine sediment is accumulating along the southern margins of habitat zones 29-34.

A low permeability, shallow, subsurface layer may be present along the south bank of bar complex riffle 30, bar complex riffle 34, and bar complex glide 33 (see Figure III.4). This low permeability layer is hypothesized to result from infiltration of fine suspended sediment into gravel pores. The impermeable layer appears to be a near-surface phenomena, because deeper piezometer points at the same localities often produced clear, low turbidity sample water with no evidence of fine sediment.

From a habitat standpoint, the fine sediment accumulation and bed/bank stabilization along the southern bank of Lower Sunrise Access do not produce good spawning habitat. Large natural flows that mobilized bed material might eventually reverse the process, but these flows are missing in our regulated system. Gravel ripping might be a cheap alternative to gravel augmentation in this area.

IX.C. Sacramento Bar

Sacramento Bar does not appear to have any underlying geologic control or geologic limitations that affect spawning habitat. The surface of the attached cobble-filled point bar is steep and this may limit recruitment of appropriate-sized material, but in general Sacramento Bar and the nearby channel have abundant, loose, highly permeable gravel that is suitable for salmon spawning.

X) MANAGEMENT RECOMMENDATIONS

X.A. Cold water supply

Cold water supply is a limiting factor on the Lower American River. Successful in-stream spawning by Fall Chinook salmon has been impacted by a shortage of cold water, and rearing of juvenile steelhead has been heavily impacted by warm summer conditions in side channels, covered areas and channel margins. These conditions must be addressed to improve habitat on the Lower American River. An obvious solution is to store more cold water earlier in the season, and release warmer runoff water later as Folsom Dam fills. This will require adjustment of the SAFCA and ACOE flood control curves, structural modifications to Folsom Dam to allow access to different levels of the thermally stratified cold water pool, and careful advanced forecasting to protect downstream life and property.

X.B. Grain size and bed mobility

Armoring, presence of excess coarse material, presence of excess fine material, and decreases in dissolved oxygen have important management implications. Some of these trends are natural, but in extreme cases they are also indicators of degraded spawning habitat quality. Trends and suggestions are given below:

- Sailor Bar is too coarse and armored, and there is an impermeable subsurface layer. Upstream areas are not a good candidate for small rehabilitation projects, although downstream areas show some potential.
- Lower Sunrise is armored and too fine. Periodic ripping would be a low-cost method of rehabilitating the Lower Sunrise site.
- Sacramento Bar has a large supply of nearly ideal gravel on the exposed bar surface, but it is rarely inundated. The channel is slightly too deep directly offshore. A low cost solution would be to push the existing gravel out into the river, creating more shallow spawning habitat.

Many of these problems are related to bed mobility. When the gravel bed is mobilized by moderate to high flows, fines are periodically winnowed from the system, inter-gravel flow is enhanced, armoring is reduced, and spawning gravels are naturally rehabilitated. This natural process has been largely eliminated in the Lower American River because of controlled flows from Folsom and Nimbus Dams.

Reduction in decadal-scale flood events is a particular problem. When flows in the 30,000 – 60,000 cfs range are eliminated, spawning gravel mobility is also eliminated (Ayers, 2001). Mats of organic matter combine with silt and clay to form a less permeable layer in the shallow subsurface, and there is probably a trend toward increasing bed stability. If the stream gravels are not periodically disturbed by moderate to large floods or artificial maintenance, these trends will continue. Natural floods are a more important part of the process, and we should be working toward reproducing periodic pulse flows and (artificial) flood events, rather than maintaining constant flows. Restoration of salmonid spawning gravels must include restoration of the natural flow regime.

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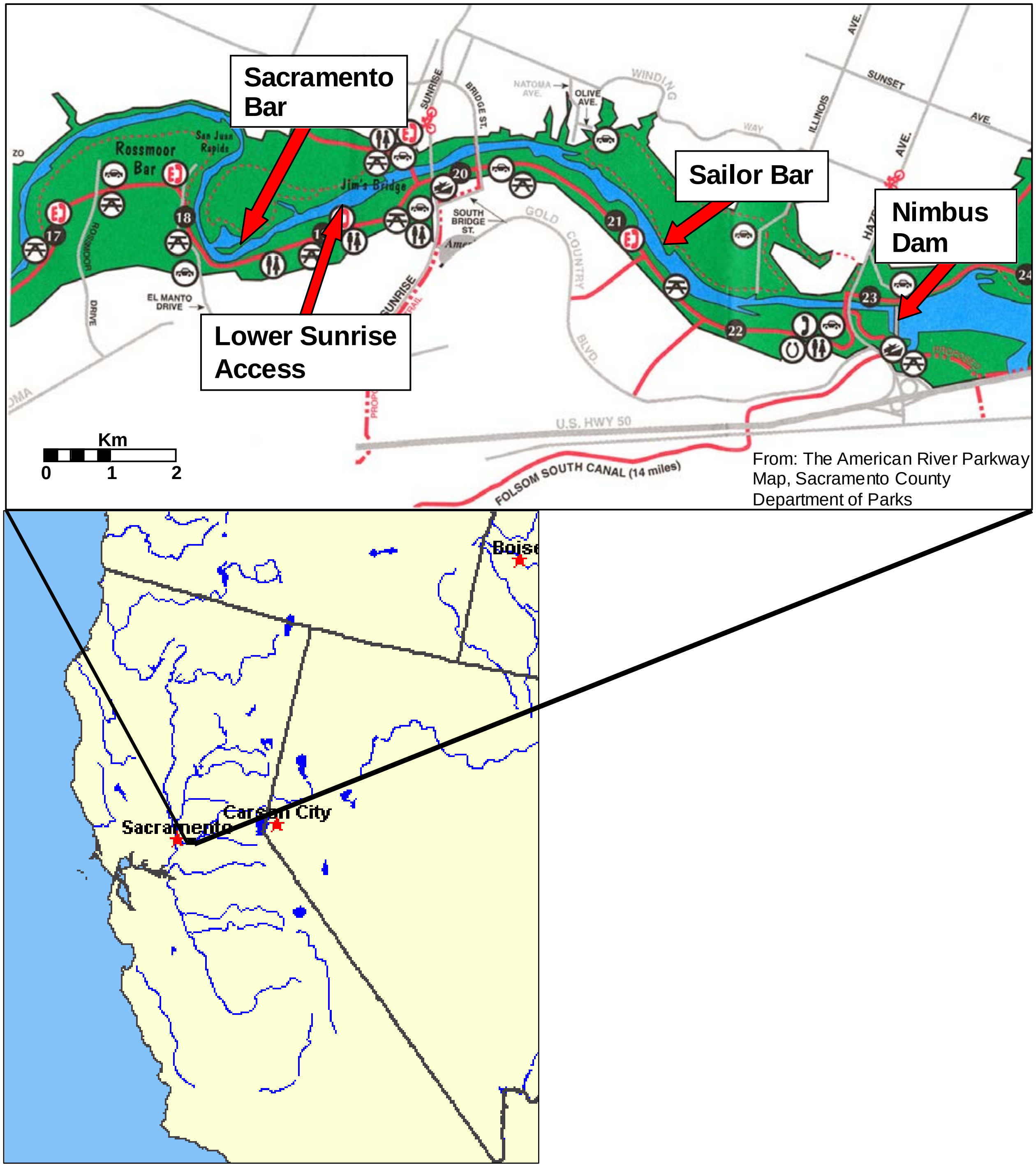


From: The American River Parkway Map, Sacramento County Department of Parks

Figure I.1: Location of gravel manipulation experiments performed by DFG in 1999. These sites were used for comparison to nearby heavily used spawning areas to identify physical and geochemical parameters that may be important to Fall run Chinook Salmon and Steelhead.

Figure III.1: Mini-piezometer tips are installed in spawning gravels to measure pore water chemistry and physical parameters.

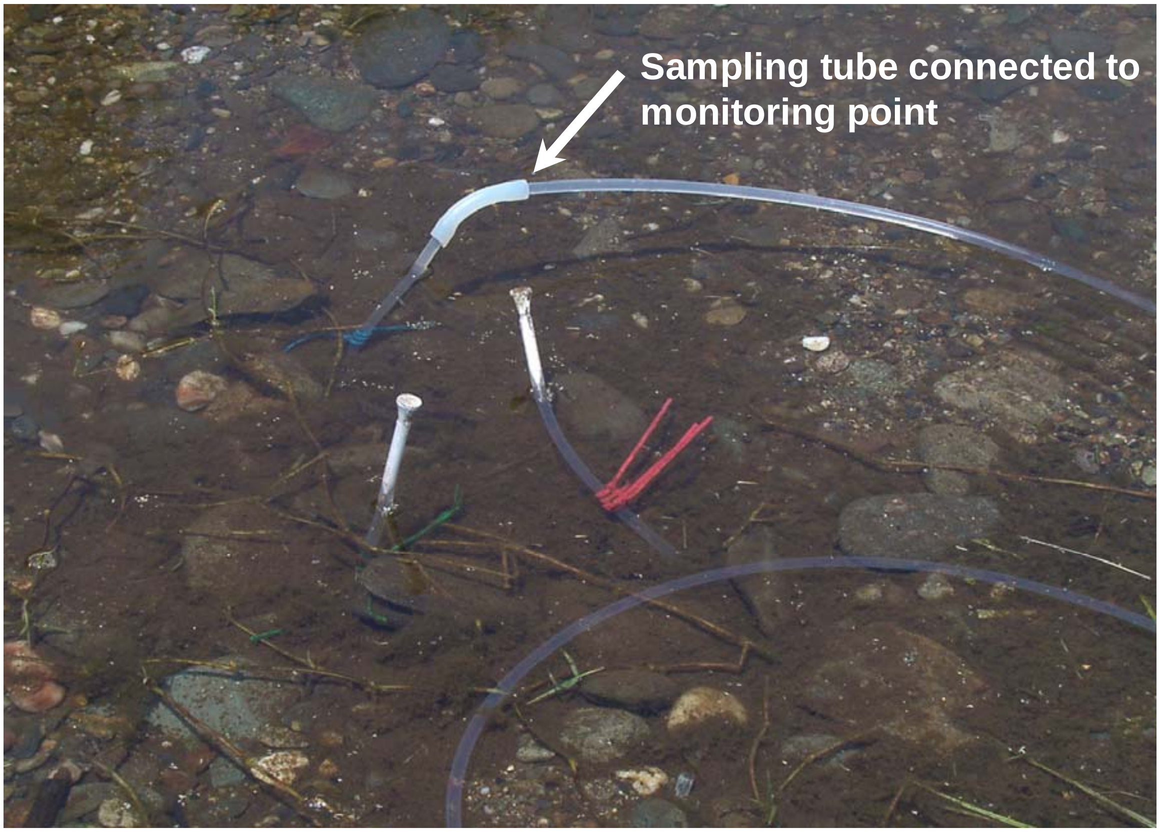


Figure III.2: Clear polyethylene tubing connects mini-piezometer tips to the surface. Tubes are color-coded according to depth in the gravel, and are blocked with golf tees between sampling runs to prevent water circulation between the river and gravel pore waters Water samples are withdrawn by connecting an additional polyethylene sampling tube to the monitoring point, and pumping the sample to appropriate meters or instruments. This allows small volumes of pore water to be extracted from a discrete interval in the stream gravel.

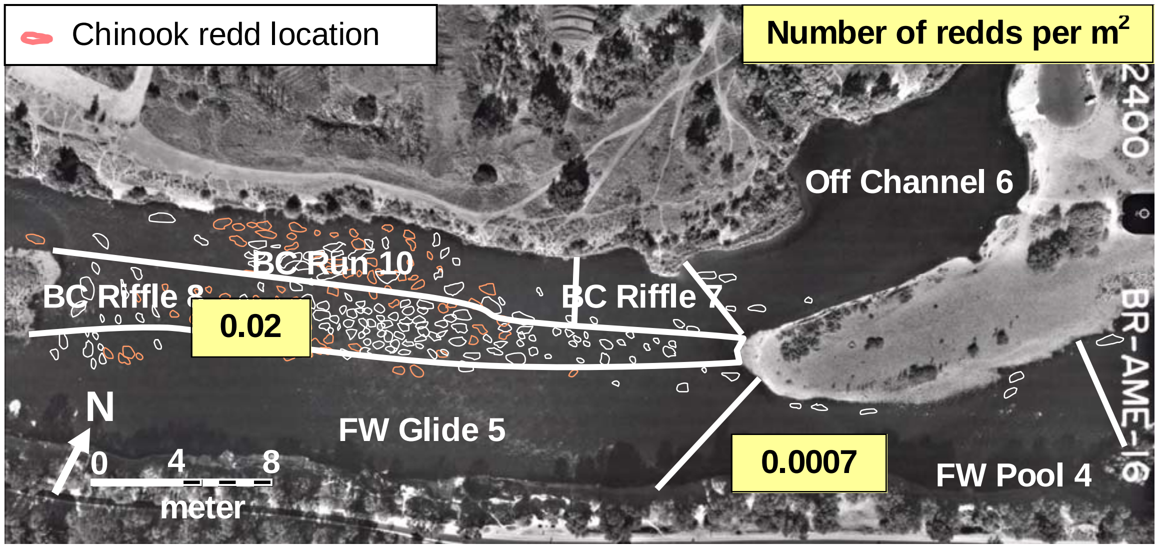


Figure III.3.: Habitat units near Sailor Bar (taken from Snider et al., 1992) and spawning density estimates (this study) were used to select sites for new monitoring point installation. FW pool 4 has low spawning density, and BC riffle 8 has high spawning density. These habitat areas were used for comparison of physical and geochemical conditions that relate to spawning site selection.

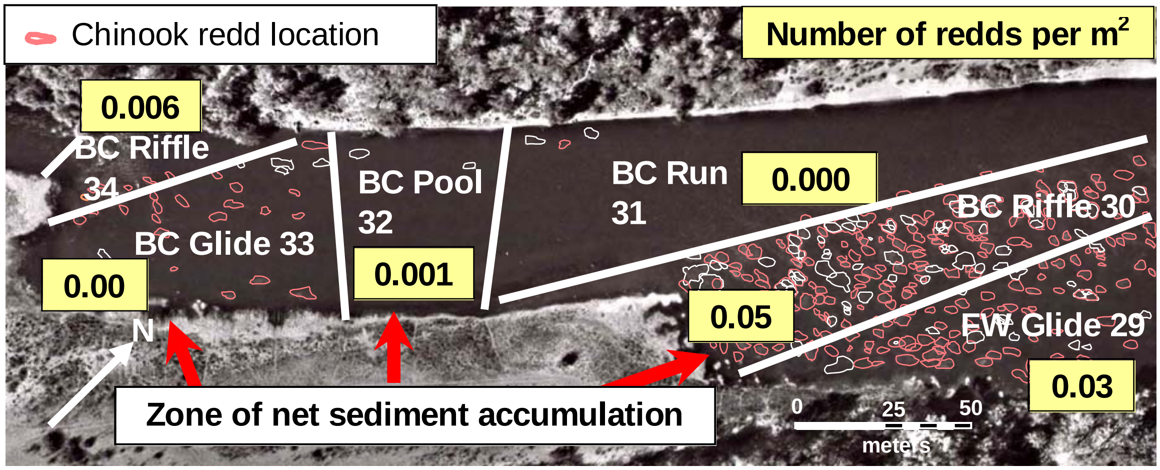


Figure III.4.: Habitat units near Lower Sunrise Access (taken from Snider et al., 1992) and spawning density estimates (this study) were used to select sites for new monitoring point installation. FW glide 29 and BC riffle 30 (right side of map) have high spawning density, BC run31 and BC pool 32 have low spawning density, and BC glide 33 and BC riffle 34 have moderate spawning density. New monitoring sites were installed in these areas.

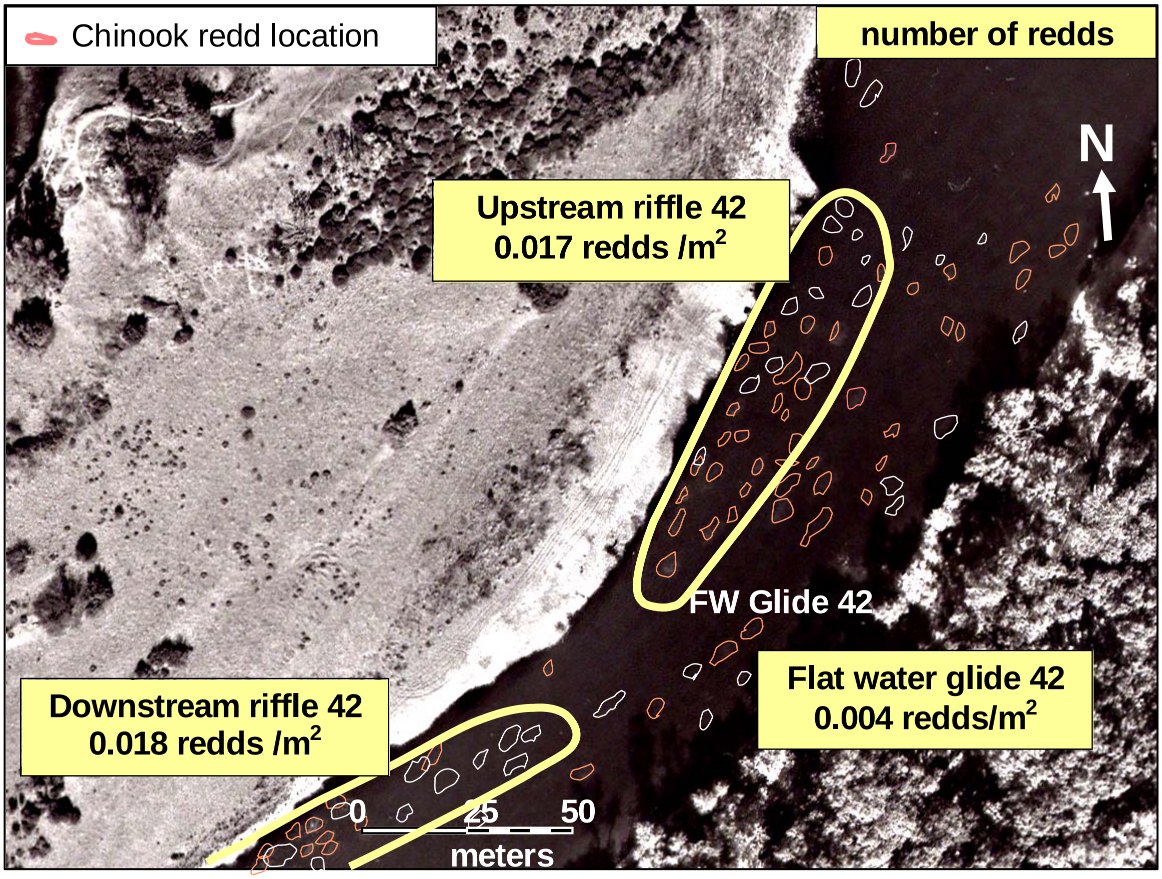


Figure III.5: Sacramento Bar is described by Snider et al., (1992) as a flat water glide. For this study, we identified two additional small riffles near the north bank. These areas have shallow, fast moving water and heavy spawning density.

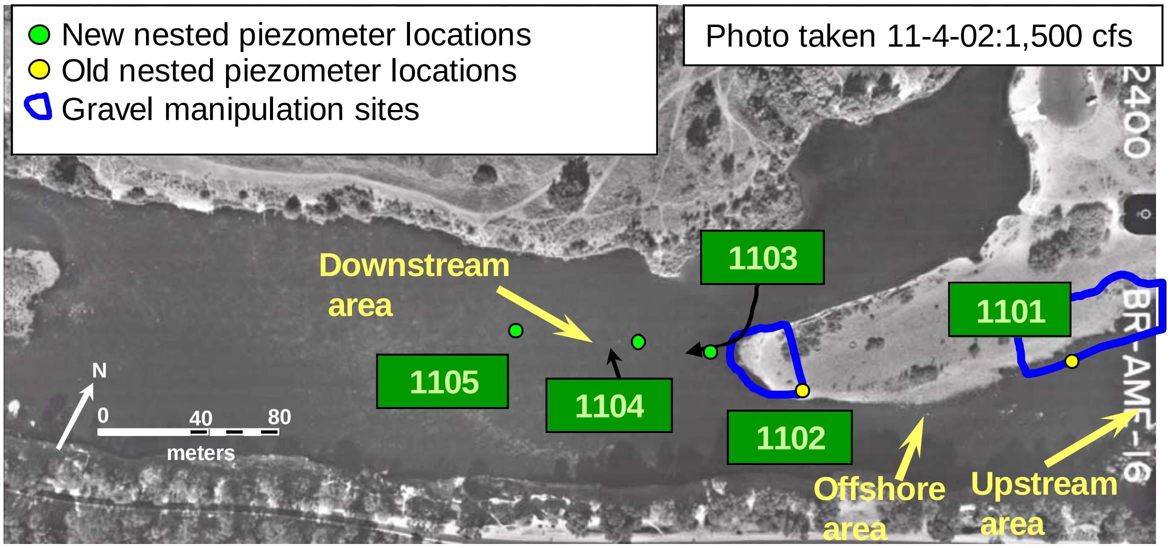


Figure IV.1: New mini-piezometer locations at Sailor Bar. Sites 1103, 1104 and 1105 were added to evaluate spawning gravel conditions near the site used by DFG for a gravel manipulation experiment. Observations recorded during monitoring point installation show that upstream and offshore areas have significant grain size and permeability limitations, and the downstream area has abundant spawning gravel of appropriate size.

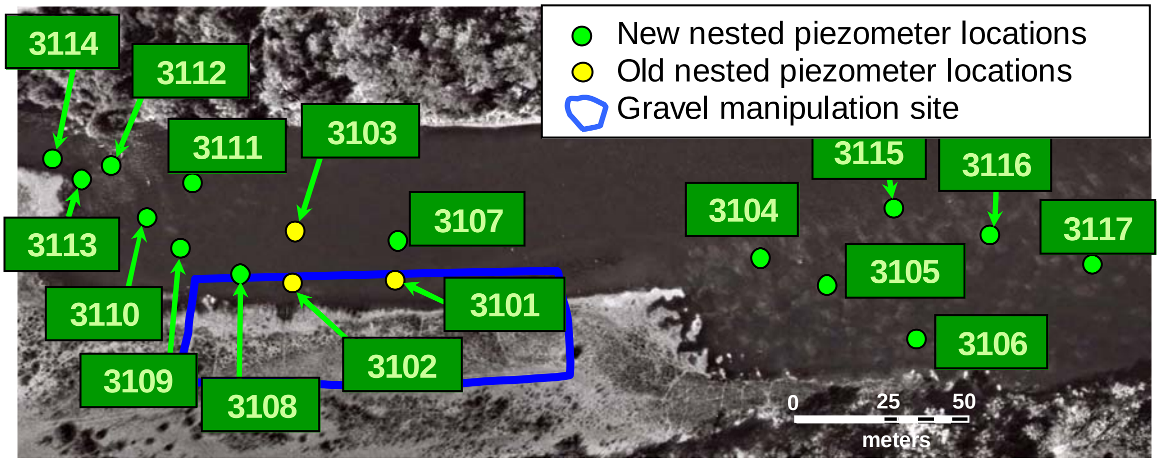


Figure IV.2: Locations of new piezometer nests near the Lower Sunrise Access gravel manipulation project. Sites 3104 – 3117 were added during this year's study to evaluate spawning gravel quality near the DFG gravel manipulation project.

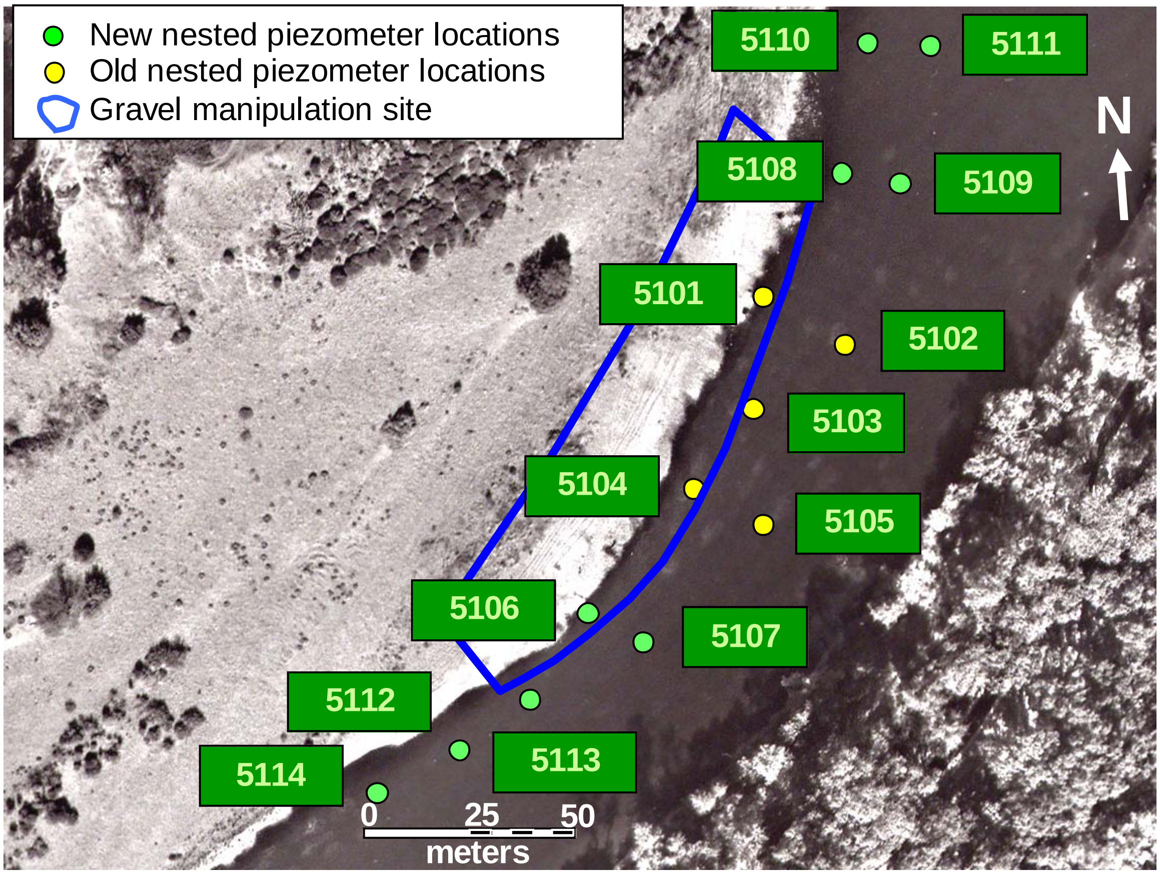


Figure IV.3: Locations of new piezometer nests near the DFG gravel manipulation project at Sacramento Bar. Sites 5106 – 5114 were added during this year's study to evaluate spawning gravel quality in nearby channel areas.

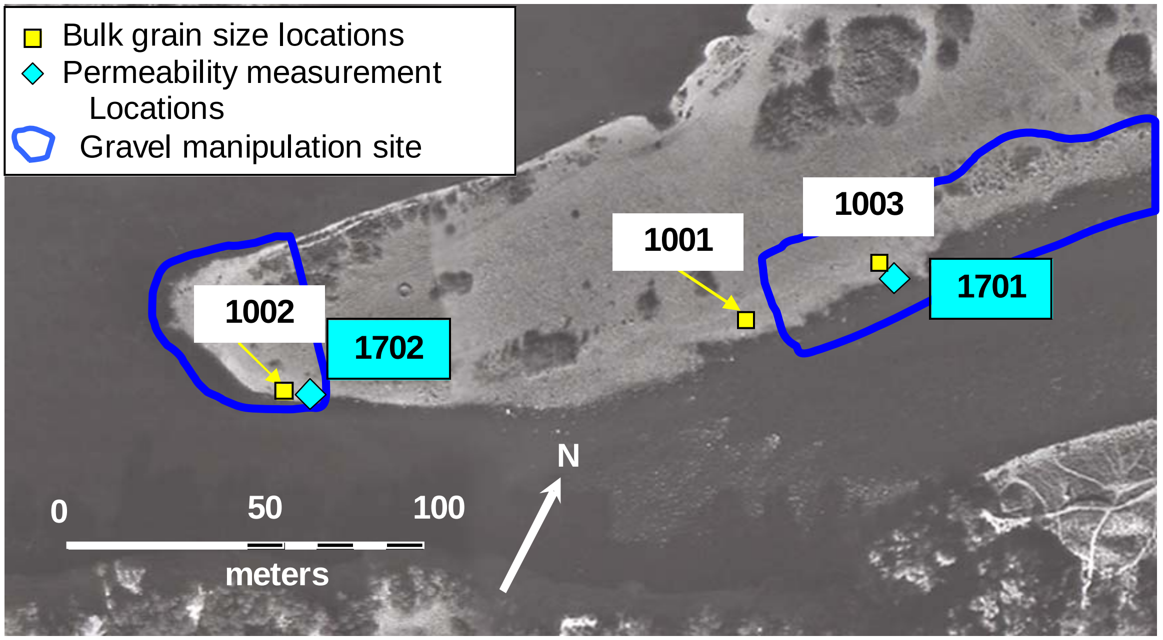


Figure V.1: Location of new bulk gravel sample sites and permeability measurements at Sailor Bar.

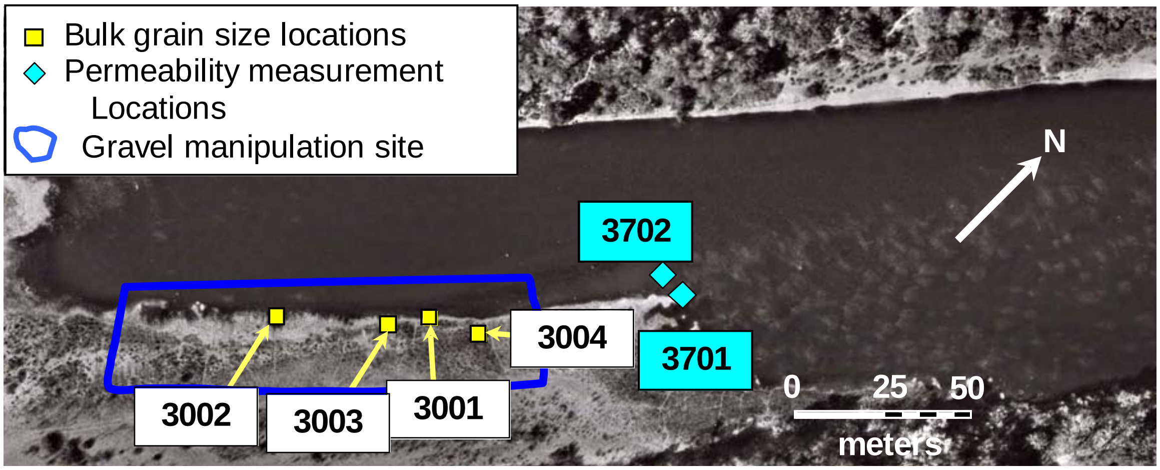


Figure V.2: Location of new bulk gravel sample sites and permeability measurements at Lower Sunrise Access.

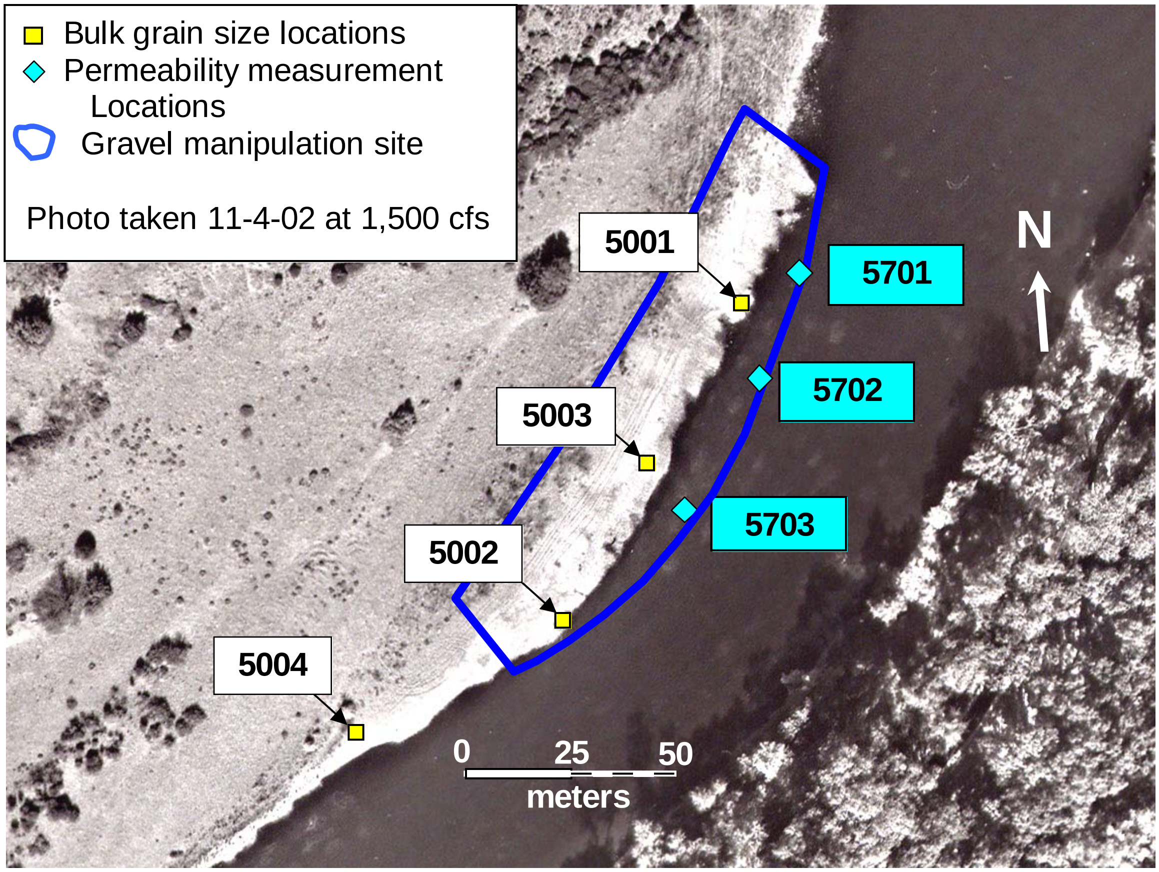


Figure V.3: Location of new bulk gravel samples and permeability measurements at Sacramento Bar.

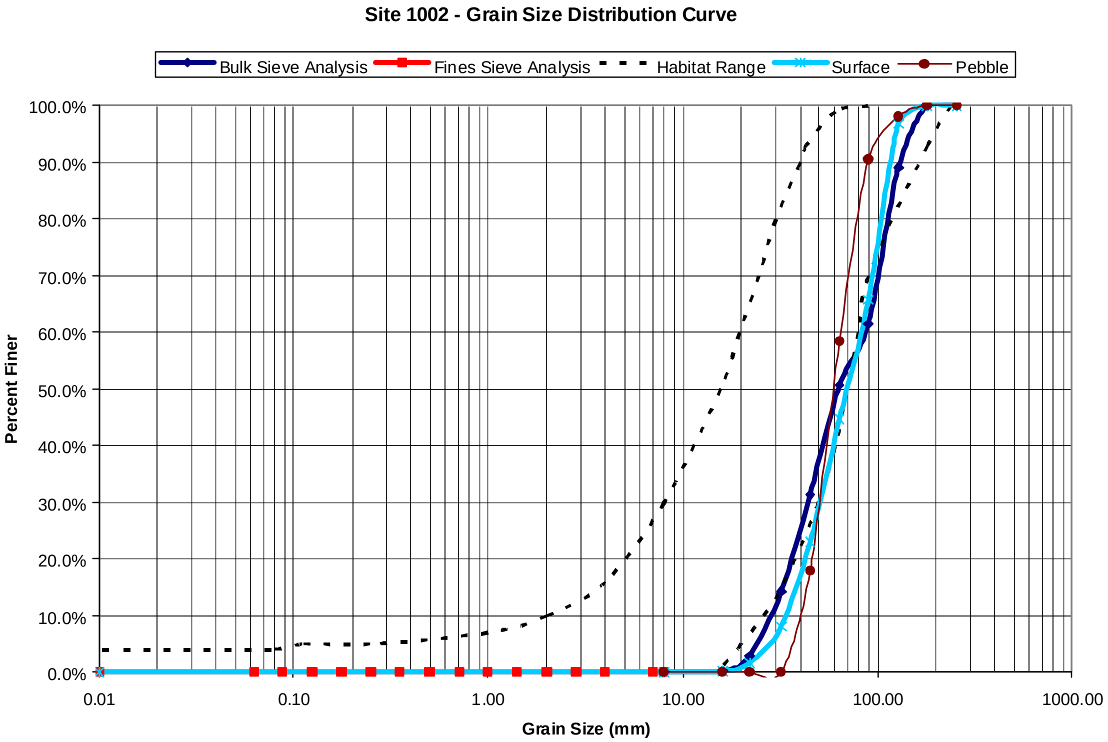


Figure V.4: Comparison of pebble count and bulk grain size analysis (sieve method) shows that pebble count underestimates fine component, overestimates coarse component, and overestimates sorting (slope of line).

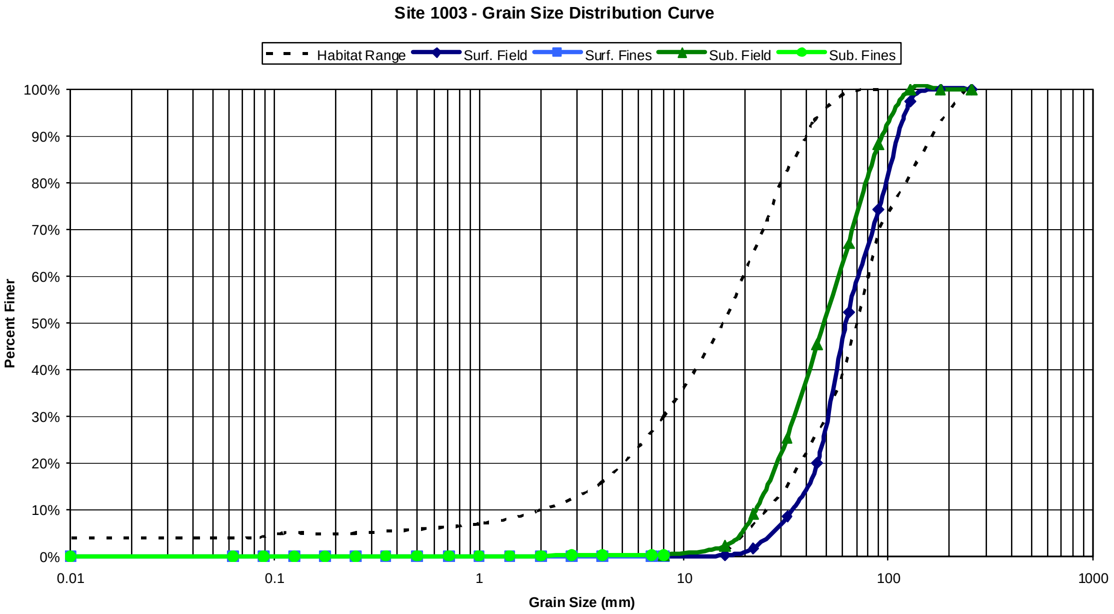


Figure V.5: Cumulative grain size distribution curve for site 1003 (Lower Sunrise Access site) shows coarser surface material (armoring) when compared to subsurface sediment. Coarse material in the surface is also larger than optimal grain size for spawning gravel.

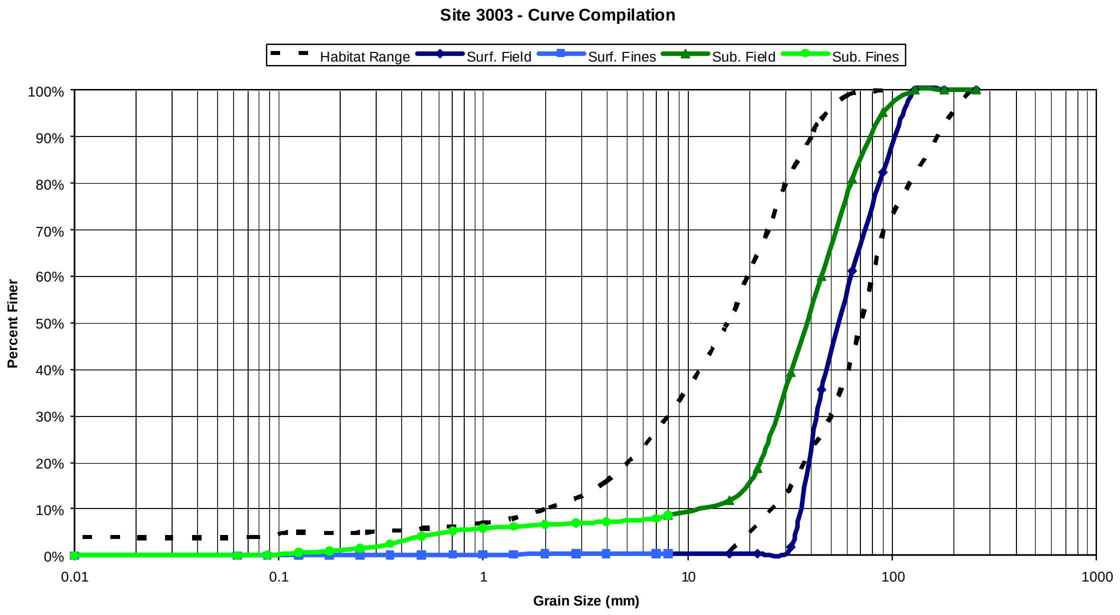


Figure V.6: Cumulative grain size distribution curve for site 3003 (Lower Sunrise Access site) shows coarser surface material (armoring) when compared to subsurface sediment. Surface material is also coarser than optimal for spawning. See Figure V.5 below for comparison.

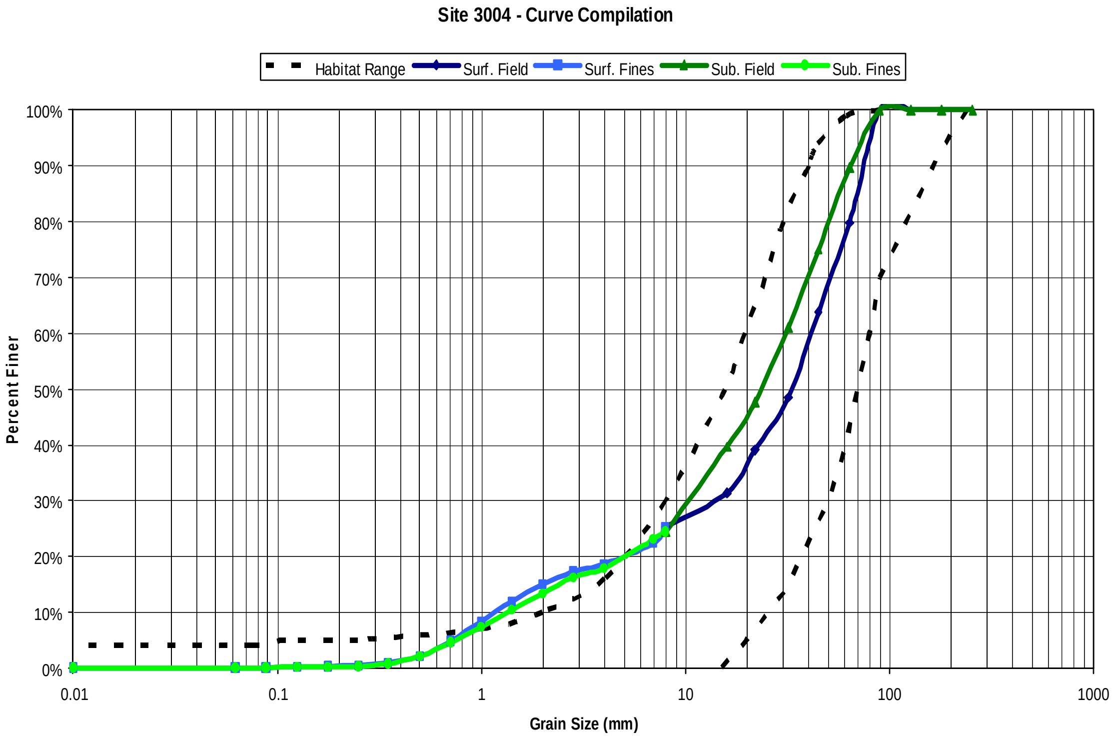


Figure V.7: Cumulative grain size distribution curve for site 3004 (Lower Sunrise Access site) shows excess fine material. This site is approximately 30 m. north of the site shown in figure V.5, and the differences between these sites illustrates small scale heterogeneity in gravel bars.

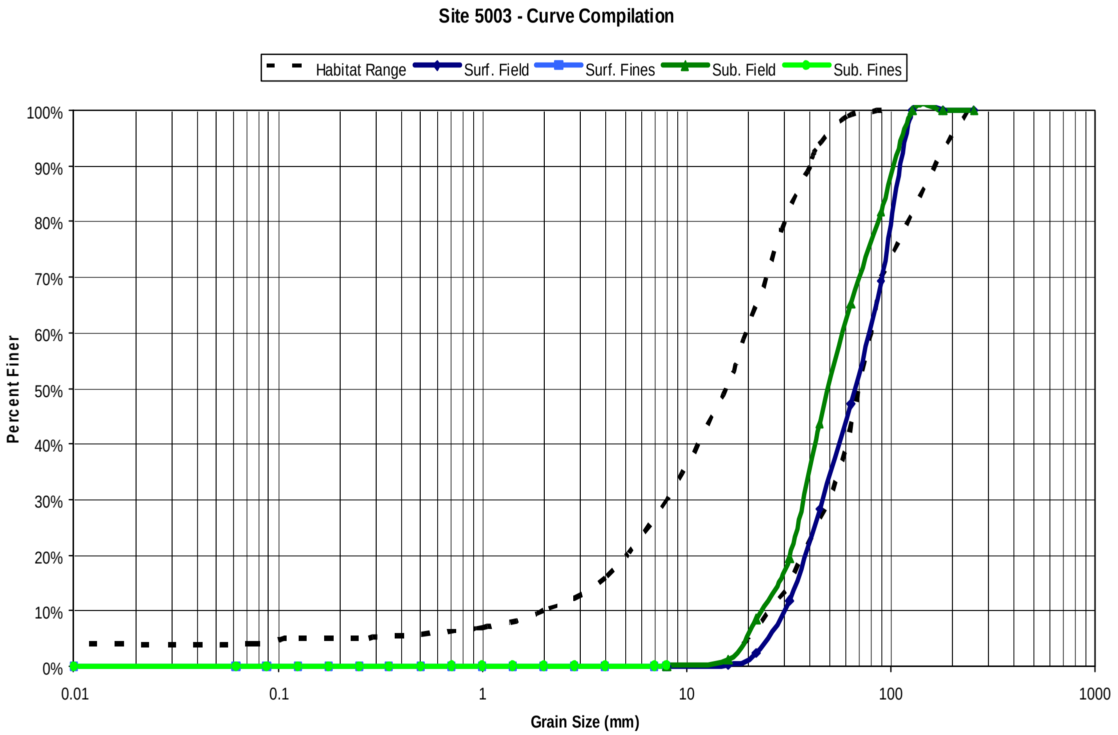


Figure V.8: Cumulative grain size distribution curve for site 3003 (Sacramento Bar site). Armoring is minimal, but grain sizes approach the maximum acceptable for salmonid spawning.

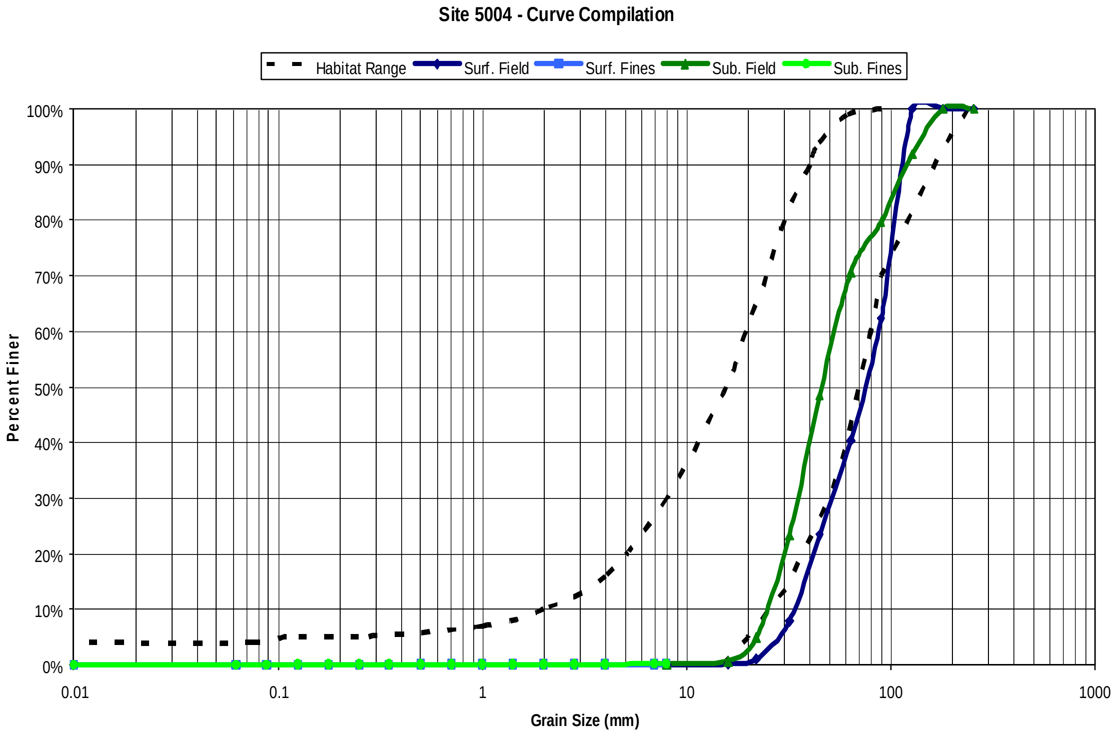


Figure V.9: Cumulative grain size distribution curve for site 3003 (Sacramento Bar site). Armoring is minimal, but grain sizes approach or exceed the maximum acceptable for salmonid spawning.

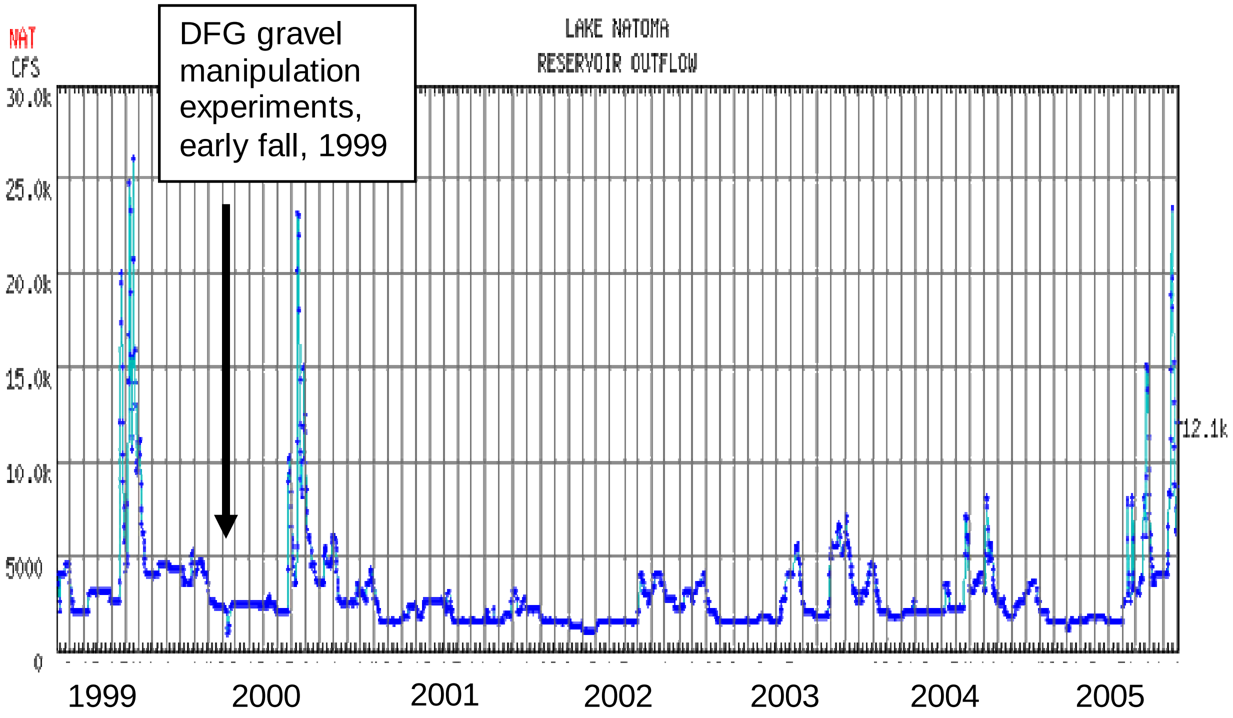


Figure V.10: Outflow from Nimbus Dam, Oct. 1998 to present. Gravel was emplaced in early fall, 1999. Less than six months later, flows of up to 23,000 cfs may have mobilized clean, unseasoned gravel. Flows of this magnitude were not encountered again until spring, 2005.

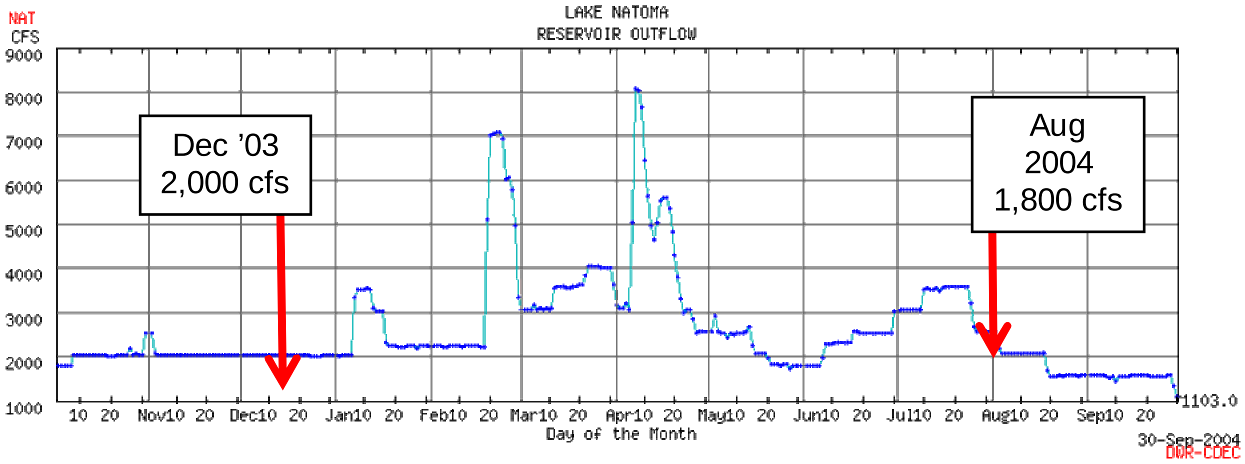


Figure VI.1: Hydrograph showing flows during field sampling events. Two field parameter sampling events were completed during the 2003/2004 season. Field sampling was scheduled during lower flows because some of our sites cannot be accessed by wading at discharge higher than 3000-4000 cfs. The April sampling event follows a spring snowmelt pulse, while December sampling events follow longer periods of low flow that are more typical of baseflow conditions.

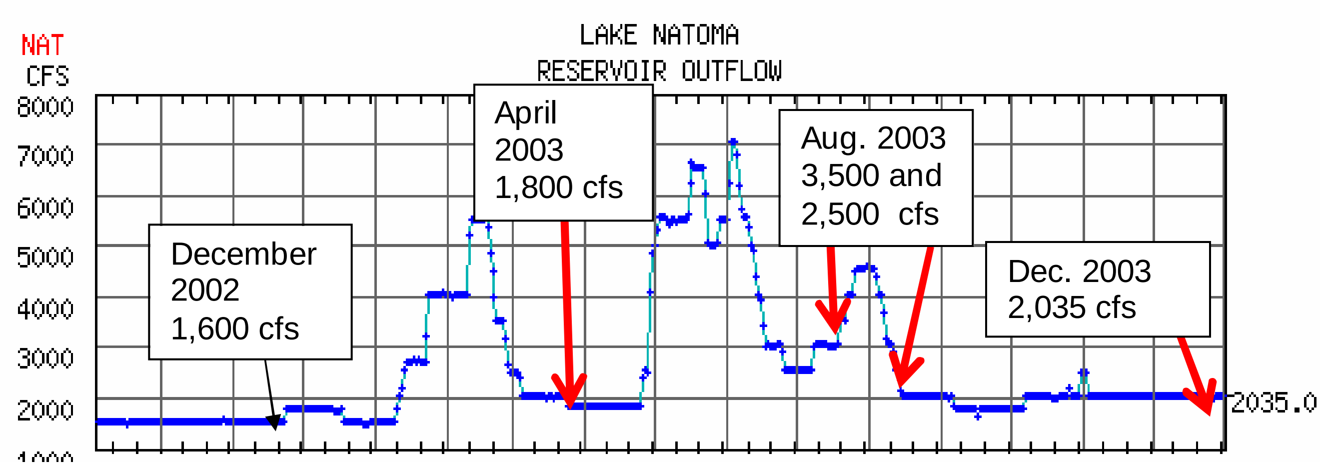


Figure VII.1: Hydrograph showing flows during geochemical sampling events. Additional samples were collected for major element, nutrient and trace metal analysis in pore water and surface water. Chemical constituents were analyzed from December 2002, April 2003, and December 2003 sample runs, and results are discussed in this report. Samples were collected but not analyzed in August 2003 because of flow fluctuations during the sampling event.

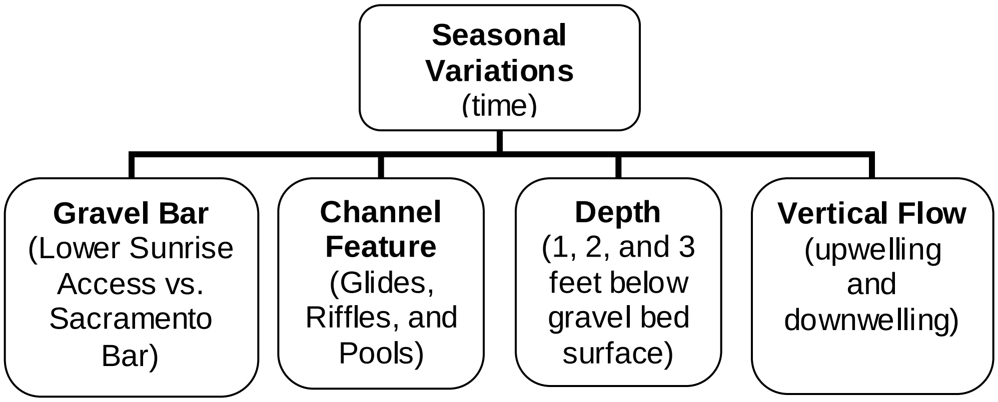
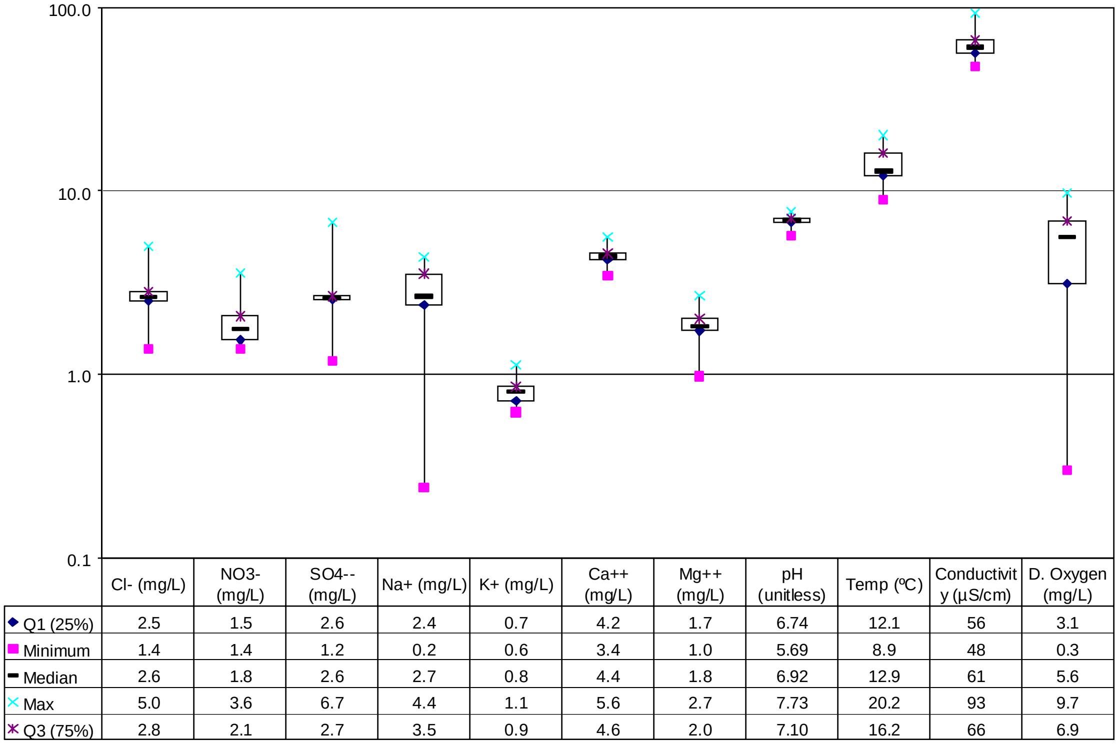


Figure VII.2: Strategy for data analysis to determine the effects of time and space on hyporheic water chemistry. Trends were first identified between the different seasons. Spatial features were then compared within each sampling run.



	Cl- (mg/L)	NO3- (mg/L)	SO4-- (mg/L)	Na+ (mg/L)	K+ (mg/L)	Ca++ (mg/L)	Mg++ (mg/L)	pH (unitless)	Temp (ºC)	Conductivity (µS/cm)	D. Oxygen (mg/L)
◆ Q1 (25%)	2.5	1.5	2.6	2.4	0.7	4.2	1.7	6.74	12.1	56	3.1
■ Minimum	1.4	1.4	1.2	0.2	0.6	3.4	1.0	5.69	8.9	48	0.3
▬ Median	2.6	1.8	2.6	2.7	0.8	4.4	1.8	6.92	12.9	61	5.6
× Max	5.0	3.6	6.7	4.4	1.1	5.6	2.7	7.73	20.2	93	9.7
✳ Q3 (75%)	2.8	2.1	2.7	3.5	0.9	4.6	2.0	7.10	16.2	66	6.9

Figure VII.3: Box and whisker plot shows median values for all major elements, nutrients and field parameters analyzed on the Lower American River during the investigation. This plot averages values from three sampling runs that took place in December 2002, April 2003 and December 2003. Nitrate, sodium, temperature, electrical conductivity, and dissolved oxygen show the greatest variability.

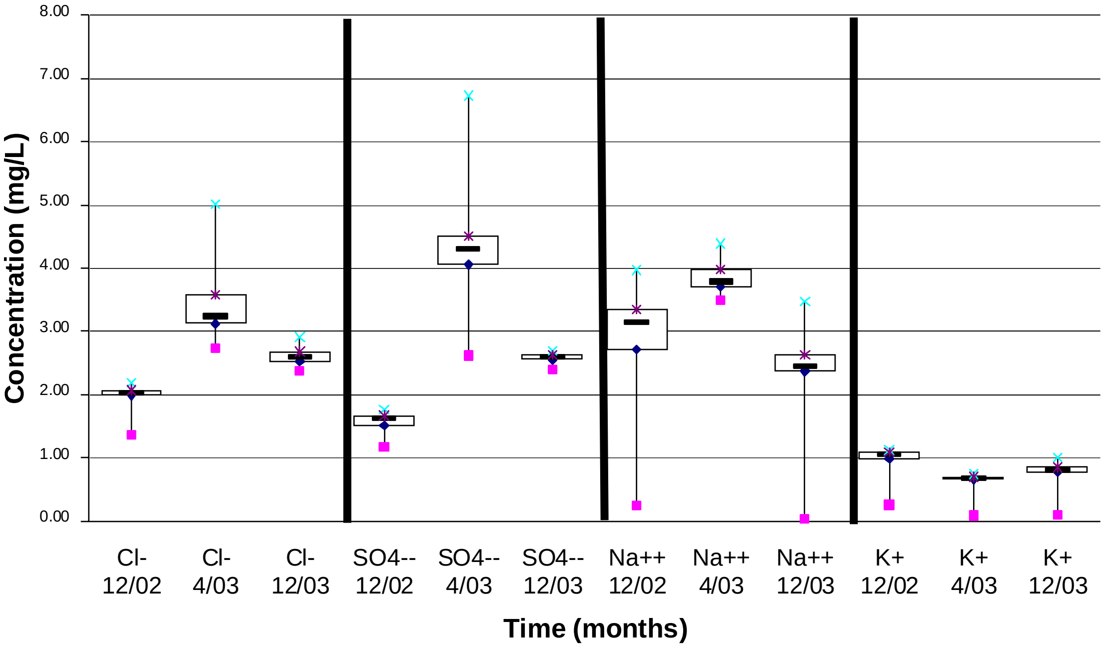


Figure VII.4: Box and whisker plots for chloride (Cl-), sulfate (SO4--), sodium (Na+), and potassium (K+) show significant seasonal variability. Cl-, SO4--, and Na+ concentrations were highest in the spring (4/03) sampling event, and K+ concentrations were higher in the winter. Other major elements and nutrients discussed in this section did not show significant seasonal trends.

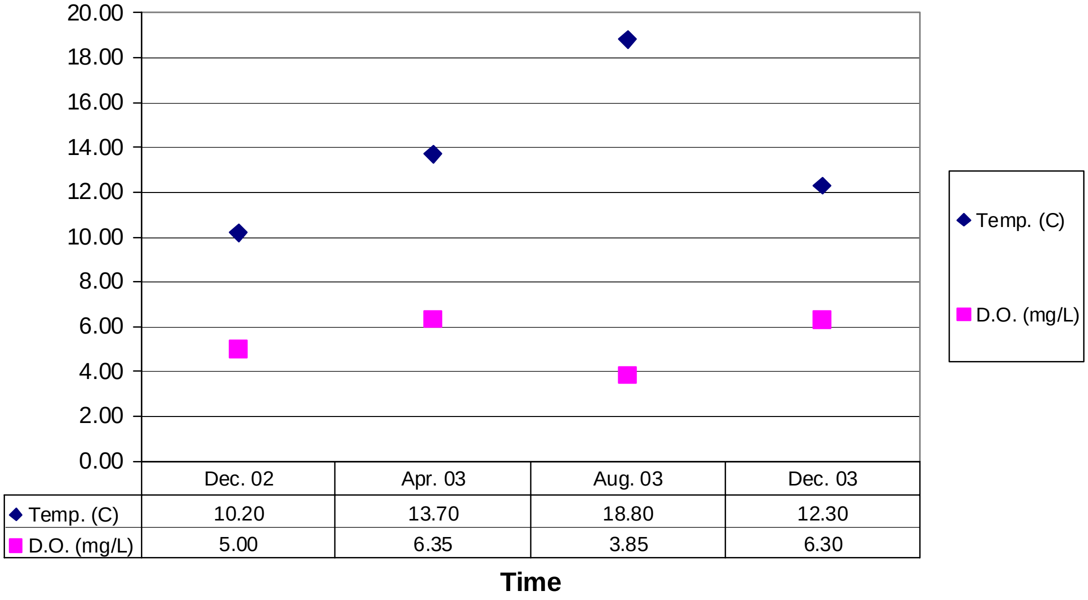


Figure VII.5: Median values of temperature and dissolved oxygen (D.O.) content in stream gravels show seasonal trends. Dissolved oxygen values are lowest in the warm summer months, partly because dissolved oxygen is less soluble in warm water. Colder water leads to higher dissolved oxygen content in the winter months. This chemical pattern may be partially offset by higher biological oxygen production in summer months.

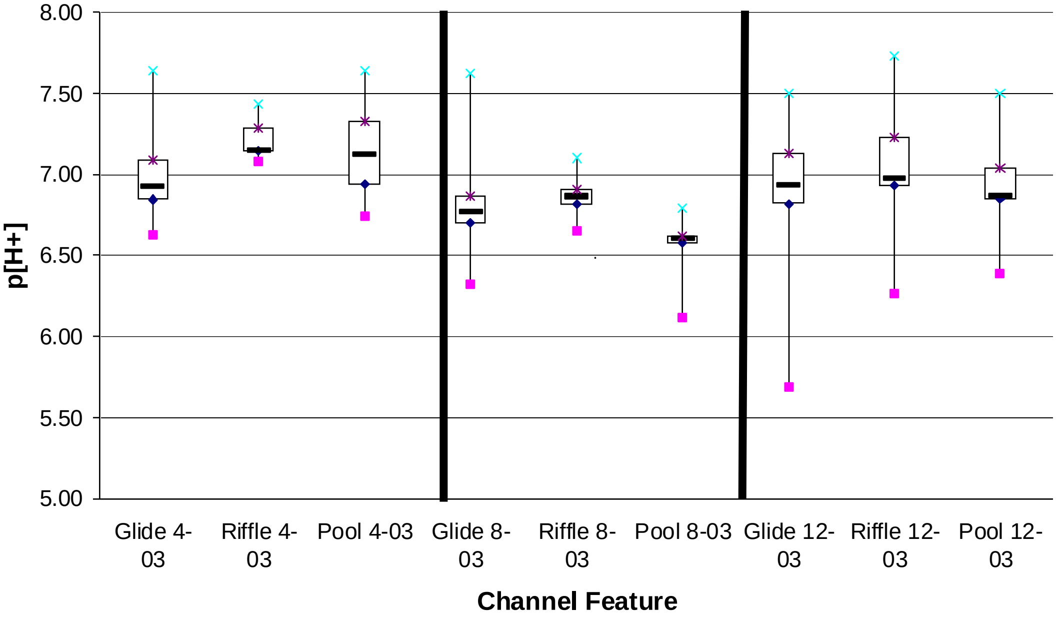


Figure VII.6: Box and whisker plots of pH in geomorphic features show that riffles are more basic than glides and pools during the April, August, and December 2003 sampling runs. Surface water is also more basic than pore water (on average), so this implies a higher degree of mixing between surface water and gravel pore water in riffles.

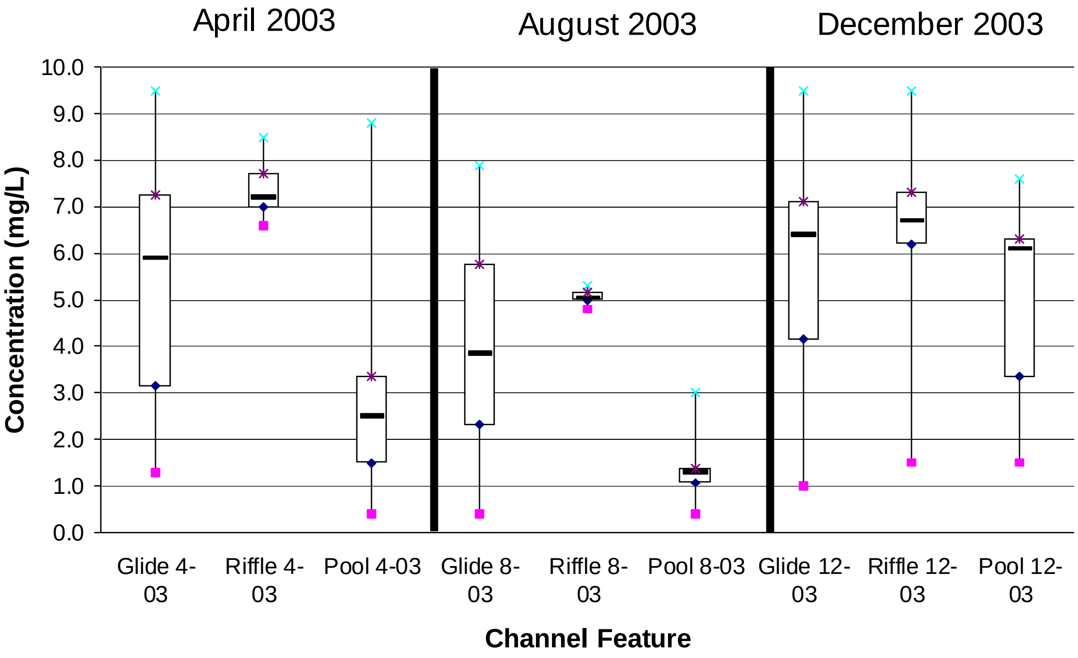


Figure VII.7: Box and whisker plots of channel features vs. dissolved oxygen content show that riffles are less variable and have higher dissolved oxygen content when compared to glides and pools during the April, August, and December 2003 sampling runs.

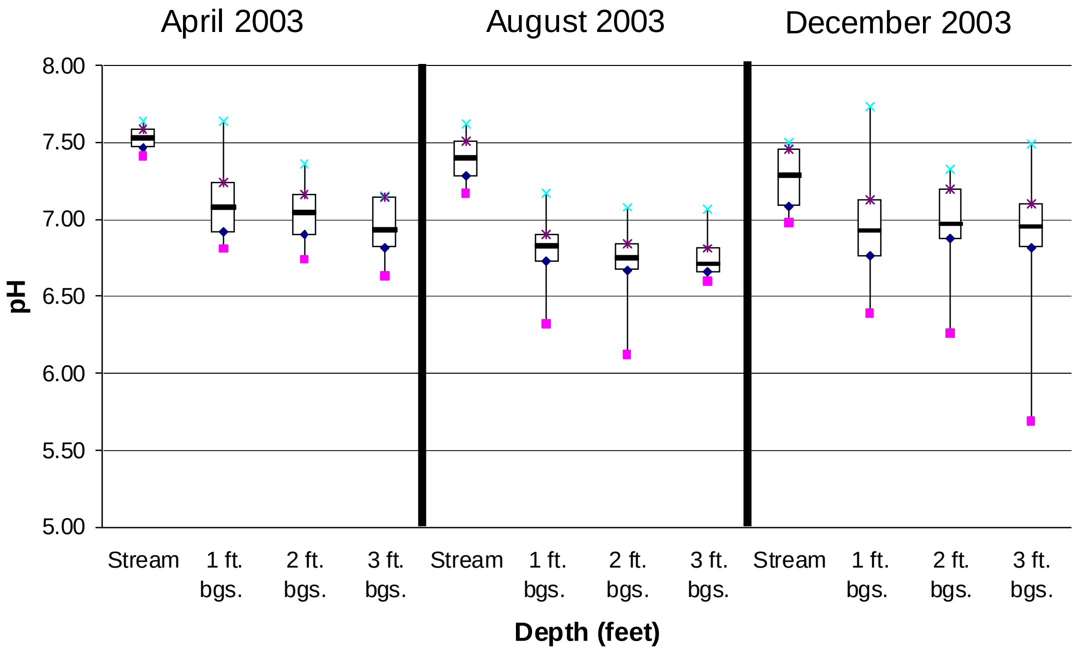


Figure VII.8: Box and whisker plots compare pH in surface water to 30 cm, 60 cm and 90 cm depths in shallow subsurface gravels. April, August and December 2003 sampling events are shown. pH is highest (slightly basic) in surface water, and becomes more acidic with increasing depth in the gravel.

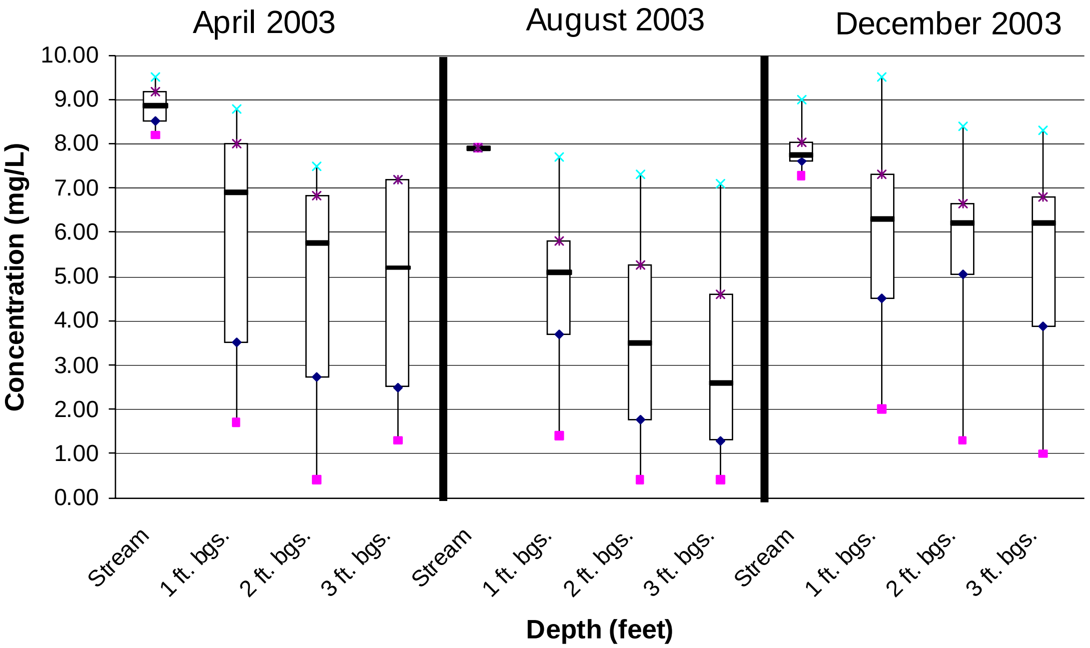


Figure VII.9: Box and whisker plot show depletion of dissolved oxygen with increasing depth in stream gravel for April, August and December 2003 sampling events. There is also a significant decrease in D.O. between the stream and subsurface samples.

Surface Temperature Loggers

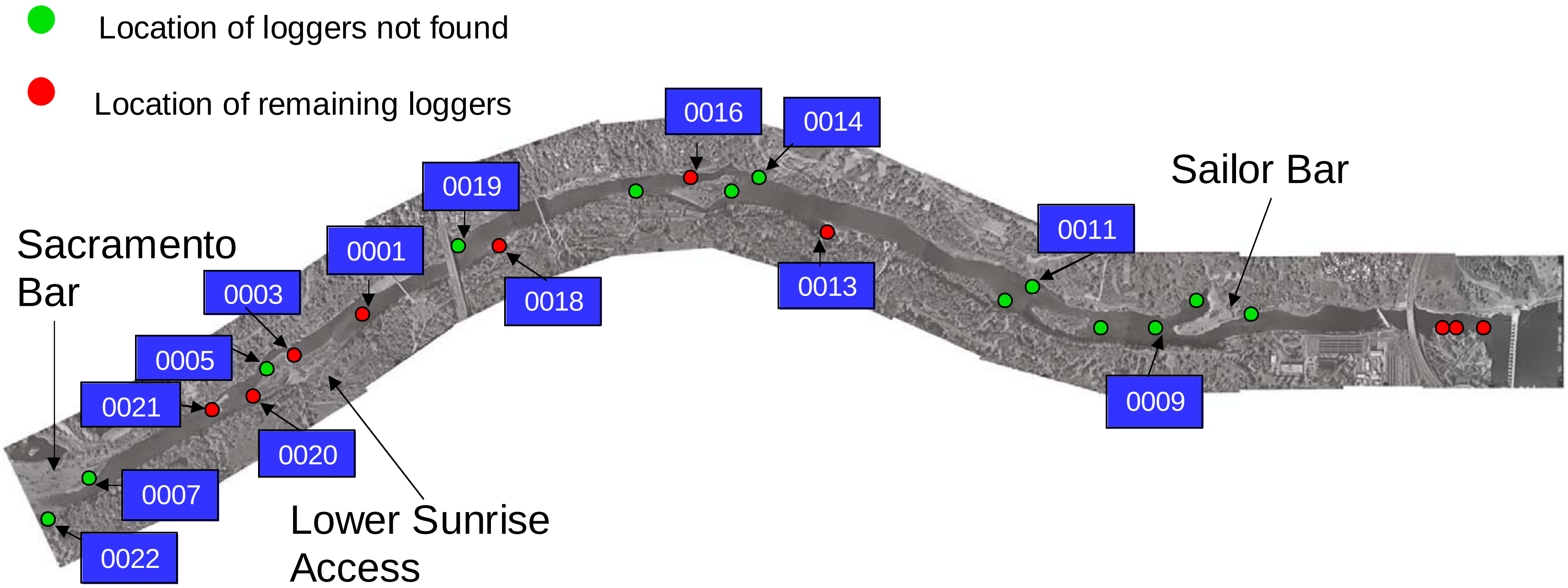


Figure VIII.1: Location of surface temperature loggers used to examine steelhead rearing habitat. Temperature loggers were placed in a variety of mid-channel, side channel, shaded riverine and shallow pool habitats. Fifteen out of the twenty-three temperature loggers initially deployed were functional for some portion of the year. Vandalism and high flows contributed to loss of surface temperature loggers..

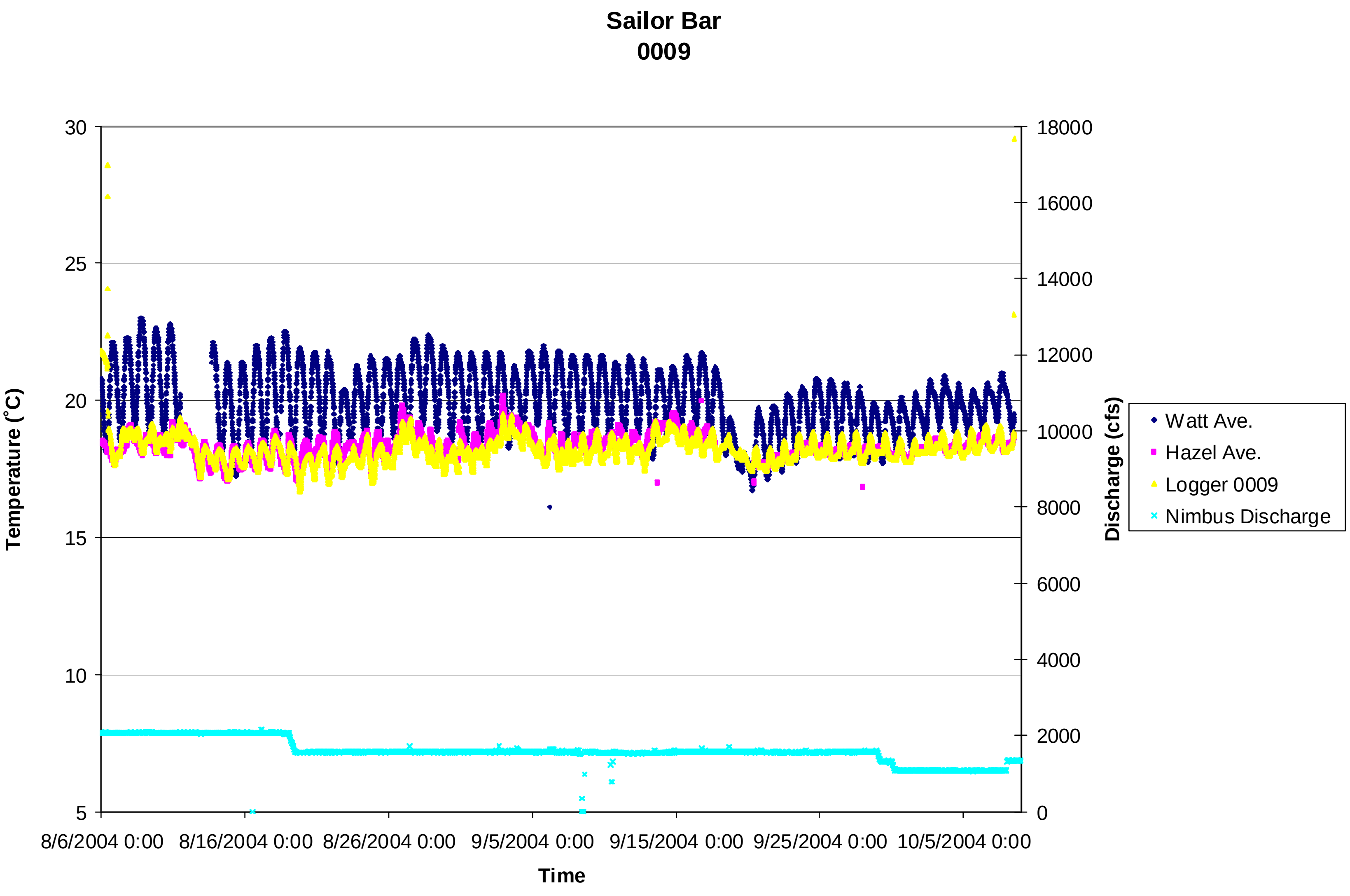


Figure VIII.2: Temperature profile for logger 0009 (Sailor Bar) compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0009 is small and maximum values are well below those at Watt Ave.

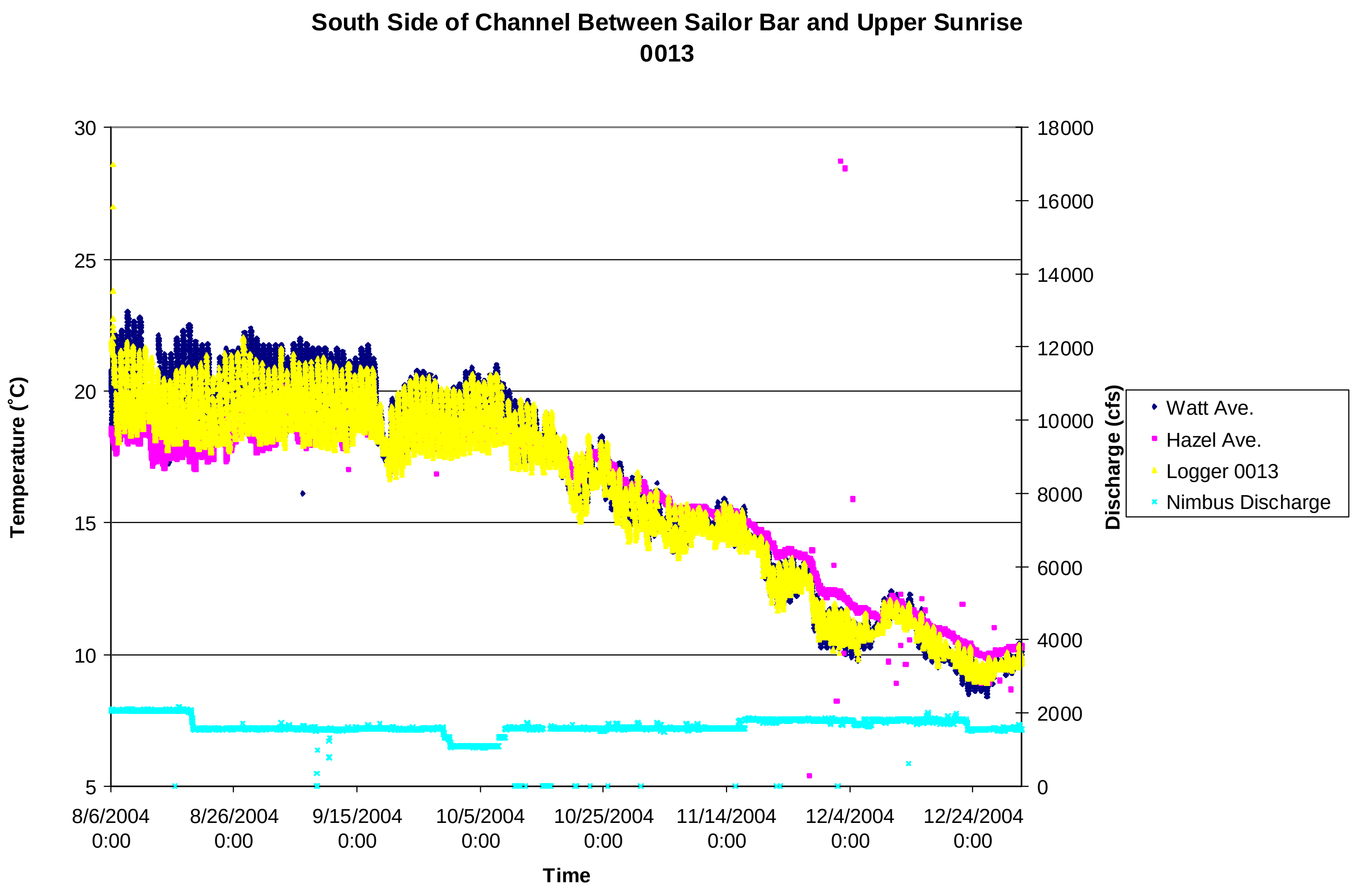


Figure VIII.3: Temperature profile for logger 0013 (Upper Sunrise shaded bank) compared to and Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0011 is similar to the fluctuation at Watt Ave, as are maximum values.

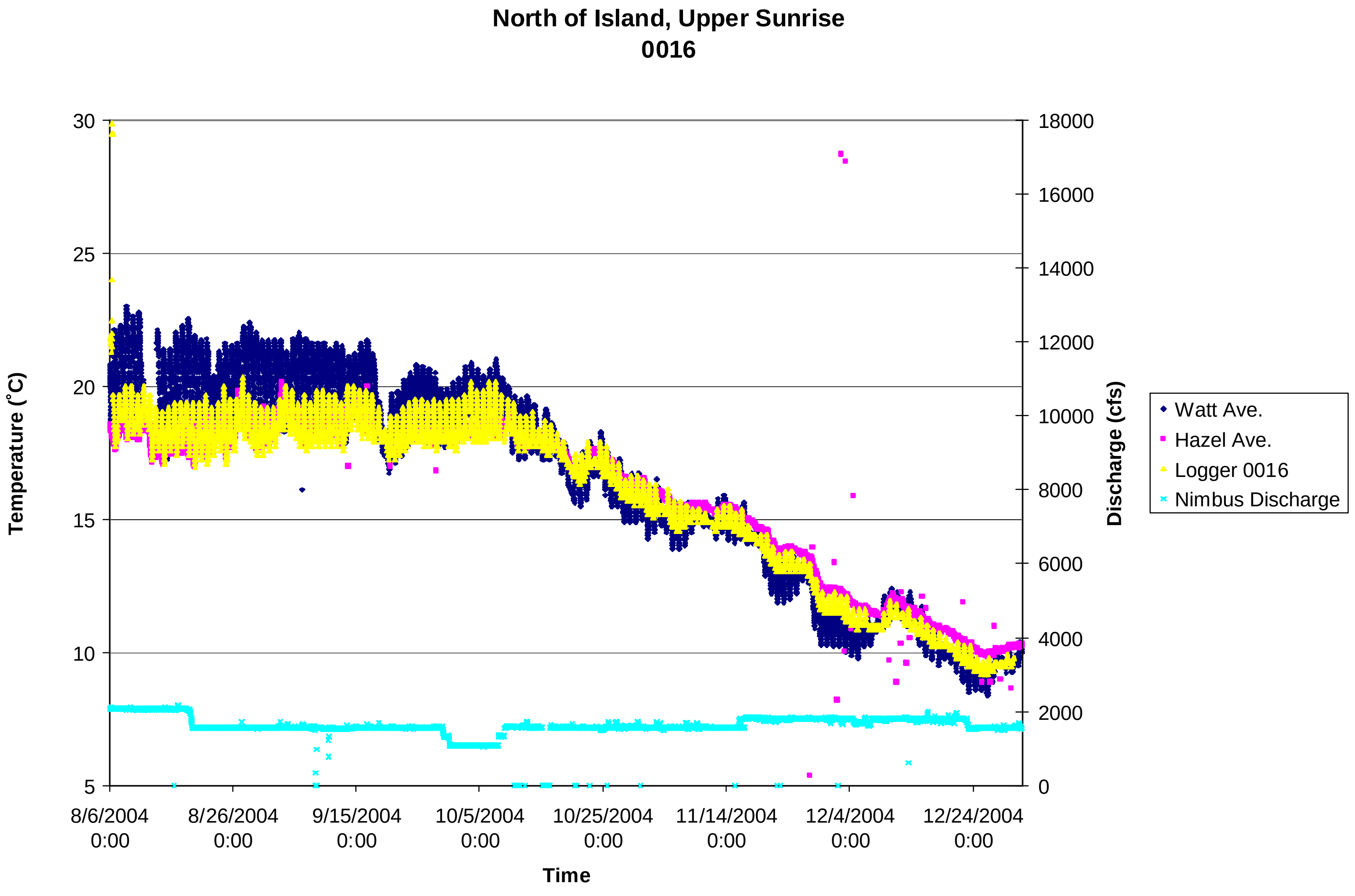


Figure VIII.4: Temperature profile for logger 0016, (Upper Sunrise Island), compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0016 is small. Maximum temperatures approach and exceed those at Watt Ave. in fall.

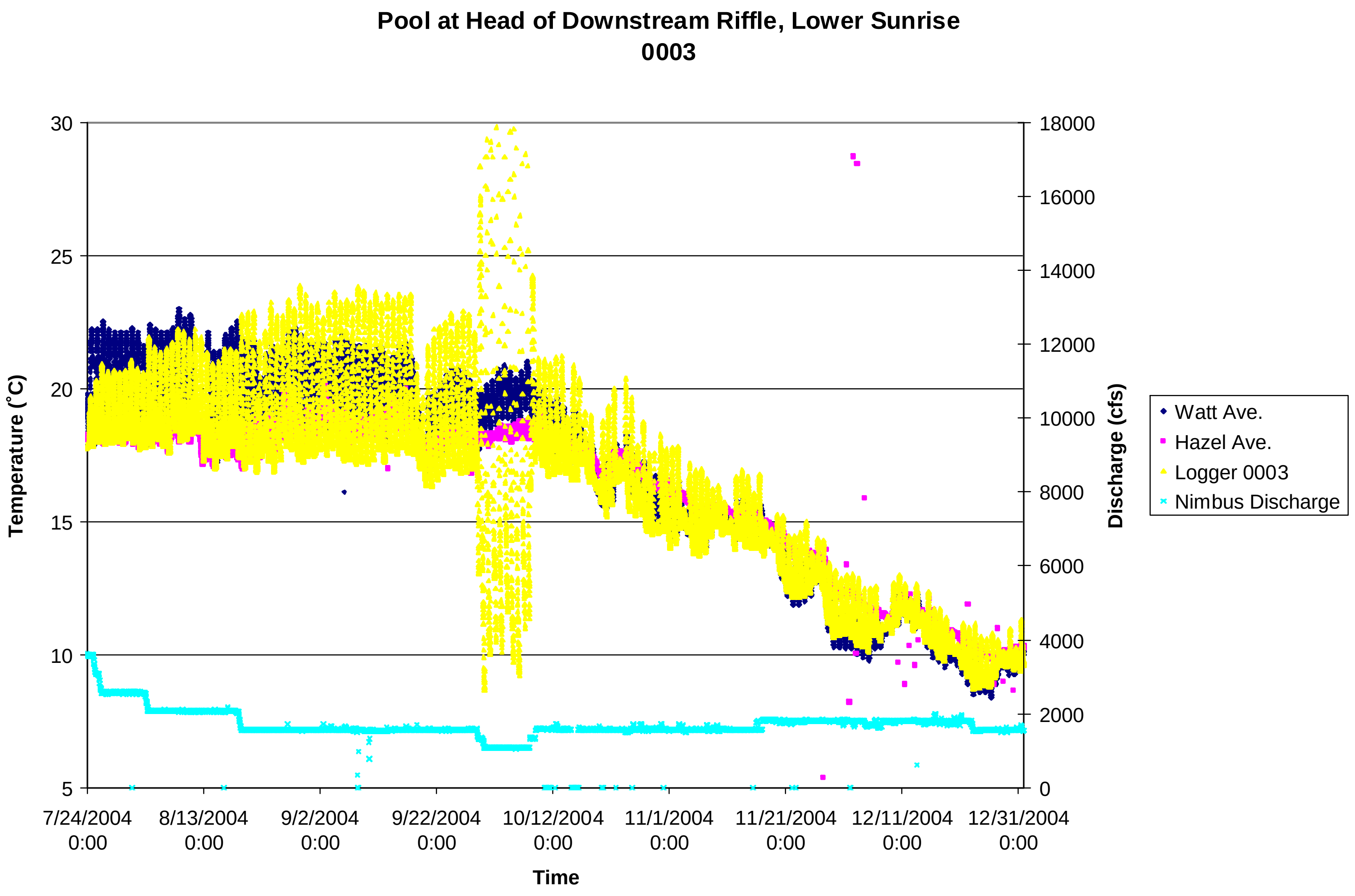


Figure VIII.5: Temperature profile for logger 0003 (Lower Sunrise pool/glide) compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0003 is large, and maximum values exceed those at Watt Ave.

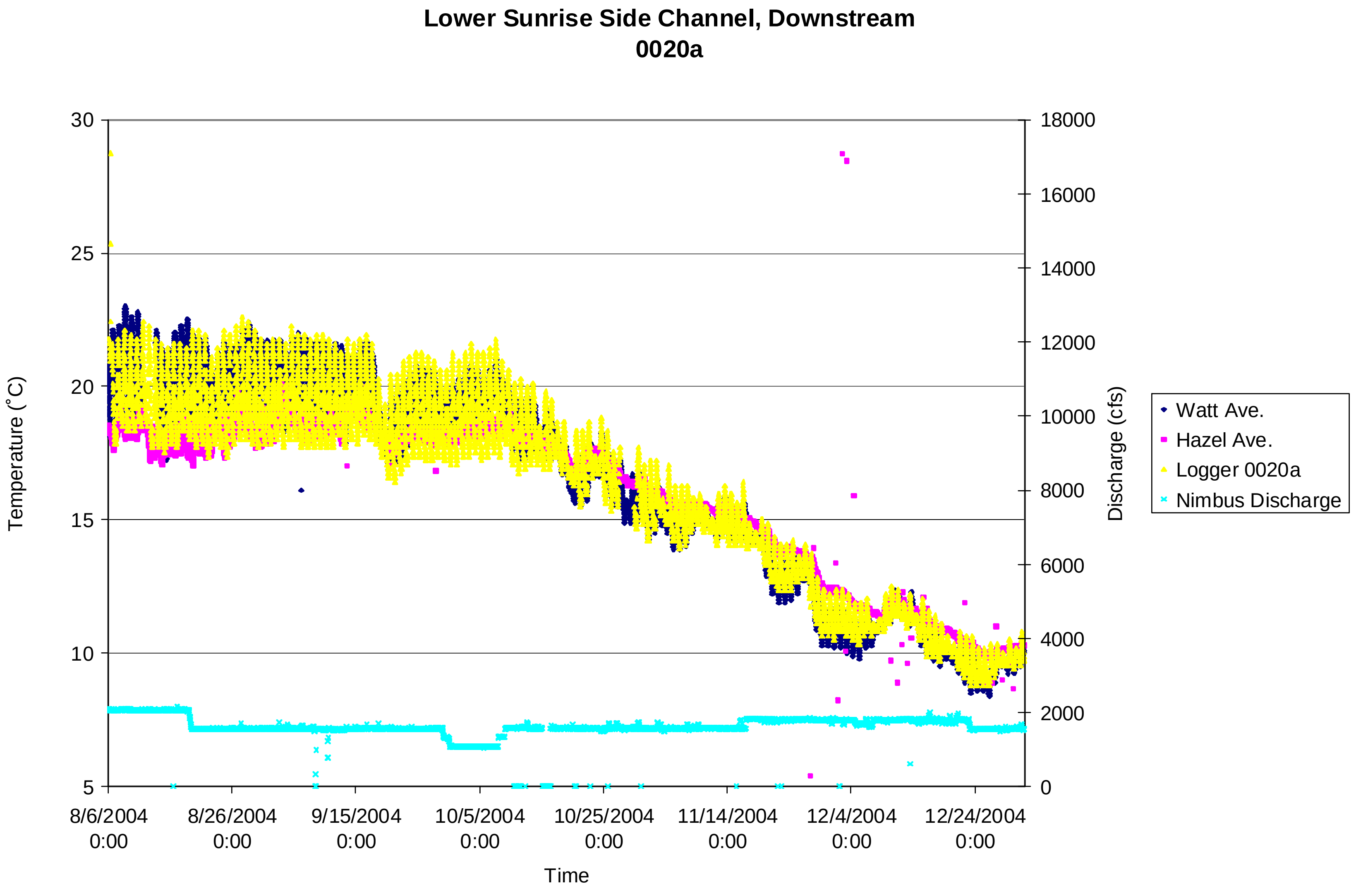


Figure VIII.6: Temperature profile for logger 0020a (downstream tip, Lower Sunrise Bar complex), compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0020a is large, and maximum values exceed those at Watt Ave.

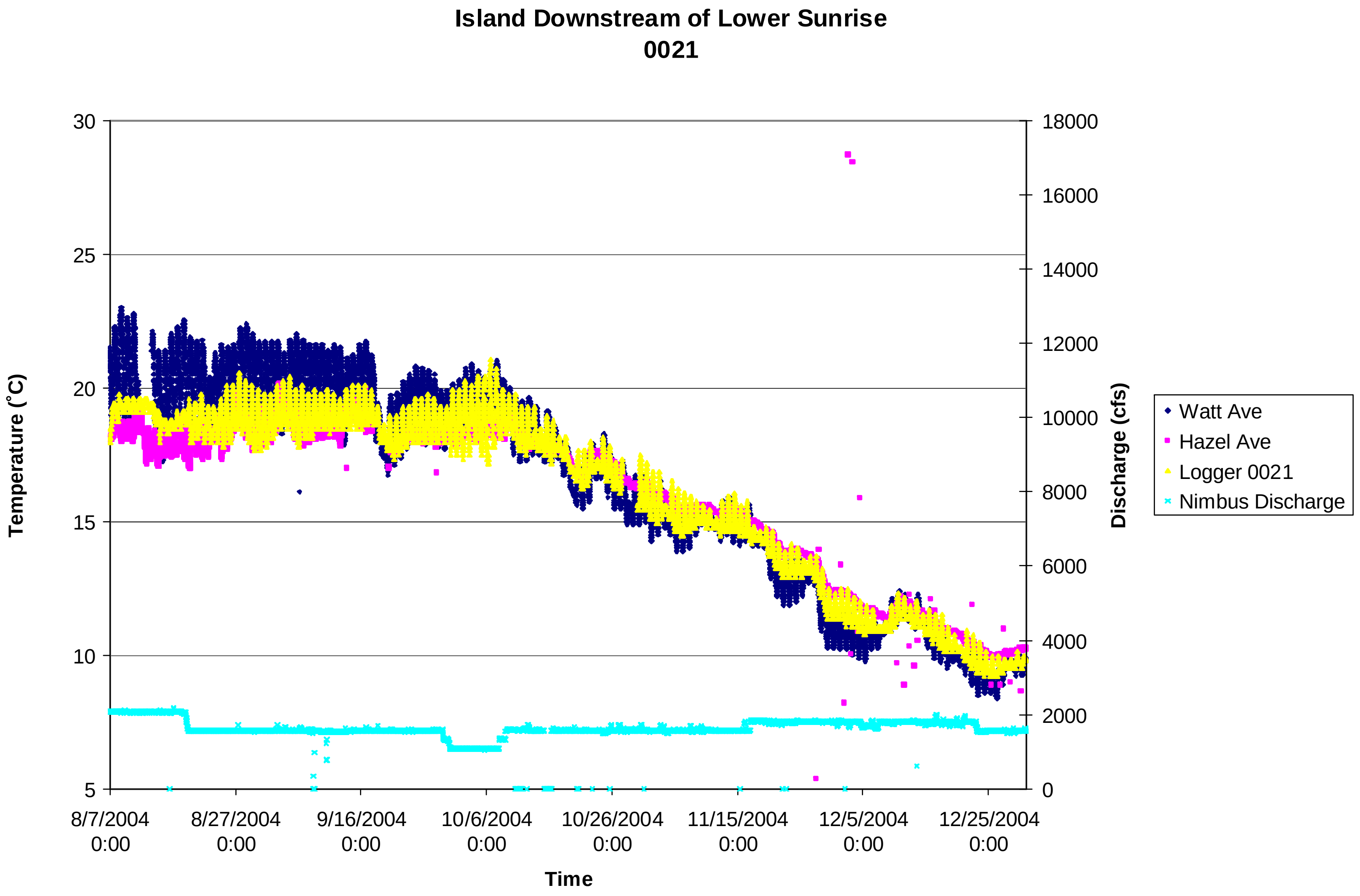


Figure VIII.7: Temperature profile for logger 0021 (mid-channel gravel bar) compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0021 is moderate, and maximum values exceed those at Watt Ave. in the fall.

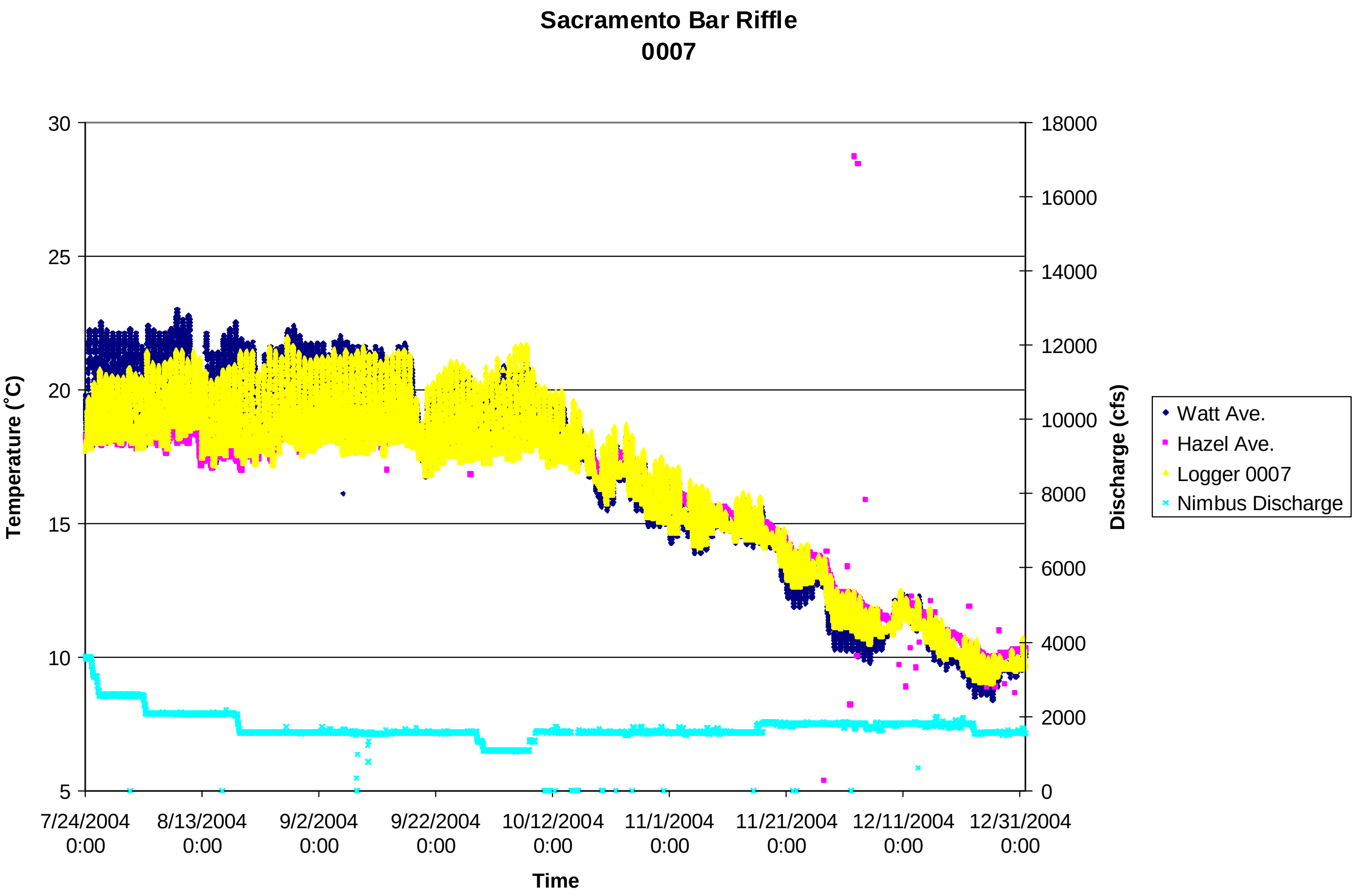


Figure VIII.8: Temperature profile for logger 0007 (Sacramento Bar riffle), compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0007 is large, and maximum values exceed those at Watt Ave in the fall.

Appendix A: Sieve analysis results

SITE 1003

SIEVE ANALYSIS (SURFACE)

	Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	*0.00*	*0.0%*	*0.00*	*587.19*	*100.0%*
	180.0000	*0.00*	*0.0%*	*0.00*	*587.19*	*100.0%*
	128.0000	*15.42*	*2.6%*	*15.42*	*571.76*	*97.4%*
	90.0000	*136.53*	*23.3%*	*151.96*	*435.23*	*74.1%*
	64.0000	*127.92*	*21.8%*	*279.87*	*307.31*	*52.3%*
	45.0000	*190.51*	*32.4%*	*470.38*	*116.80*	*19.9%*
	32.0000	*67.13*	*11.4%*	*537.52*	*49.67*	*8.5%*
	22.0000	*39.01*	*6.6%*	*576.53*	*10.66*	*1.8%*
	16.0000	*9.07*	*1.5%*	*585.60*	*1.59*	*0.3%*
	8.0000	*1.36*	*0.2%*	*586.96*	*0.23*	*0.0%*
FINES	7.0000	*0.04*	*0.0%*	*0.04*	*0.19*	*0.0%*
	4.0000	*0.03*	*0.0%*	*0.07*	*0.16*	*0.0%*
	2.8300	*0.01*	*0.0%*	*0.08*	*0.15*	*0.0%*
	2.0000	*0.01*	*0.0%*	*0.09*	*0.14*	*0.0%*
	1.4100	*0.01*	*0.0%*	*0.10*	*0.13*	*0.0%*
	1.0000	*0.01*	*0.0%*	*0.11*	*0.12*	*0.0%*
	0.7100	*0.01*	*0.0%*	*0.11*	*0.11*	*0.0%*
	0.5000	*0.01*	*0.0%*	*0.12*	*0.11*	*0.0%*
	0.3500	*0.01*	*0.0%*	*0.13*	*0.10*	*0.0%*
	0.2500	*0.01*	*0.0%*	*0.14*	*0.09*	*0.0%*
	0.1770	*0.01*	*0.0%*	*0.15*	*0.08*	*0.0%*
	0.1250	*0.01*	*0.0%*	*0.16*	*0.07*	*0.0%*
	0.0880	*0.06*	*0.0%*	*0.22*	*0.01*	*0.0%*
	0.0625	*0.00*	*0.0%*	*0.22*	*0.00*	*0.0%*
	0.0100	*0.00*	*0.0%*	*0.23*	*0.00*	*0.0%*
	Total=	587.19	kilograms			

SITE 1003

SIEVE ANALYSIS (SUBSURFACE)

	Sieve Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	*0.00*	*0.0%*	*0.00*	*451.33*	*100.0%*
	180.0000	*0.00*	*0.0%*	*0.00*	*451.33*	*100.0%*
	128.0000	*0.00*	*0.0%*	*0.00*	*451.33*	*100.0%*
	90.0000	*53.07*	*11.8%*	*53.07*	*398.26*	*88.2%*
	64.0000	*96.16*	*21.3%*	*149.23*	*302.10*	*66.9%*
	45.0000	*97.07*	*21.5%*	*246.30*	*205.03*	*45.4%*
	32.0000	*90.27*	*20.0%*	*336.57*	*114.76*	*25.4%*
	22.0000	*73.94*	*16.4%*	*410.51*	*40.82*	*9.0%*
	16.0000	*30.39*	*6.7%*	*440.90*	*10.43*	*2.3%*
	8.0000	*9.07*	*2.0%*	*449.97*	*1.36*	*0.3%*
FINES	7.0000	*0.25*	*0.1%*	*0.25*	*1.11*	*0.2%*
	4.0000	*0.21*	*0.0%*	*0.46*	*0.91*	*0.2%*
	2.8300	*0.05*	*0.0%*	*0.51*	*0.86*	*0.2%*
	2.0000	*0.07*	*0.0%*	*0.58*	*0.78*	*0.2%*
	1.4100	*0.06*	*0.0%*	*0.64*	*0.72*	*0.2%*
	1.0000	*0.06*	*0.0%*	*0.70*	*0.66*	*0.1%*
	0.7100	*0.06*	*0.0%*	*0.76*	*0.60*	*0.1%*
	0.5000	*0.06*	*0.0%*	*0.82*	*0.54*	*0.1%*
	0.3500	*0.05*	*0.0%*	*0.87*	*0.49*	*0.1%*
	0.2500	*0.07*	*0.0%*	*0.94*	*0.42*	*0.1%*
	0.1770	*0.06*	*0.0%*	*1.00*	*0.36*	*0.1%*
	0.1250	*0.06*	*0.0%*	*1.06*	*0.30*	*0.1%*
	0.0880	*0.19*	*0.0%*	*1.25*	*0.11*	*0.0%*
	0.0625	*0.04*	*0.0%*	*1.29*	*0.07*	*0.0%*
	0.0100	*0.07*	*0.0%*	*1.36*	*0.00*	*0.0%*
	Total=	451.33	kilograms			

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SITE 3003

SIEVE ANALYSIS (SURFACE)

	Sieve Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	0.00	0.0%	0.00	286.46	100.0%
	180.0000	0.00	0.0%	0.00	286.46	100.0%
	128.0000	0.00	0.0%	0.00	286.46	100.0%
	90.0000	50.78	17.7%	50.78	235.68	82.3%
	64.0000	60.73	21.2%	111.51	174.95	61.1%
	45.0000	72.98	25.5%	184.49	101.97	35.6%
	32.0000	97.02	33.9%	281.51	4.95	1.7%
	22.0000	3.62	1.3%	285.12	1.34	0.5%
	16.0000	0.21	0.1%	285.34	1.12	0.4%
	8.0000	0.00	0.0%	285.34	1.12	0.4%
FINES	7.0000	0.06	0.0%	0.06	1.06	0.4%
	4.0000	0.10	0.0%	0.16	0.96	0.3%
	2.8300	0.03	0.0%	0.19	0.93	0.3%
	2.0000	0.06	0.0%	0.25	0.87	0.3%
	1.4100	0.06	0.0%	0.31	0.81	0.3%
	1.0000	0.06	0.0%	0.36	0.76	0.3%
	0.7100	0.08	0.0%	0.44	0.68	0.2%
	0.5000	0.14	0.0%	0.58	0.54	0.2%
	0.3500	0.19	0.1%	0.77	0.36	0.1%
	0.2500	0.15	0.1%	0.92	0.21	0.1%
	0.1770	0.07	0.0%	0.99	0.13	0.0%
	0.1250	0.05	0.0%	1.04	0.08	0.0%
	0.0880	0.04	0.0%	1.08	0.04	0.0%
	0.0625	0.01	0.0%	1.09	0.03	0.0%
	0.0100	0.03	0.0%	1.12	0.00	0.0%

Total= 286.46 kilograms

SITE 3003

SIEVE ANALYSIS (SUBSURFACE)

	Sieve Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	*0.00*	*0.0%*	*0.00*	*354.95*	*100.0%*
	180.0000	*0.00*	*0.0%*	*0.00*	*354.95*	*100.0%*
	128.0000	*0.00*	*0.0%*	*0.00*	*354.95*	*100.0%*
	90.0000	*17.22*	*4.9%*	*17.22*	*337.73*	*95.1%*
	64.0000	*50.32*	*14.2%*	*67.55*	*287.40*	*81.0%*
	45.0000	*74.34*	*20.9%*	*141.89*	*213.06*	*60.0%*
	32.0000	*72.99*	*20.6%*	*214.88*	*140.07*	*39.5%*
	22.0000	*72.99*	*20.6%*	*287.87*	*67.08*	*18.9%*
	16.0000	*24.94*	*7.0%*	*312.80*	*42.15*	*11.9%*
	8.0000	*11.33*	*3.2%*	*324.13*	*30.82*	*8.7%*
FINES	7.0000	*2.68*	*0.8%*	*2.68*	*28.14*	*7.9%*
	4.0000	*2.47*	*0.7%*	*5.15*	*25.67*	*7.2%*
	2.8300	*0.71*	*0.2%*	*5.86*	*24.96*	*7.0%*
	2.0000	*1.32*	*0.4%*	*7.18*	*23.64*	*6.7%*
	1.4100	*1.37*	*0.4%*	*8.55*	*22.27*	*6.3%*
	1.0000	*1.47*	*0.4%*	*10.02*	*20.80*	*5.9%*
	0.7100	*1.97*	*0.6%*	*11.98*	*18.84*	*5.3%*
	0.5000	*4.11*	*1.2%*	*16.09*	*14.73*	*4.1%*
	0.3500	*5.61*	*1.6%*	*21.70*	*9.11*	*2.6%*
	0.2500	*3.78*	*1.1%*	*25.49*	*5.33*	*1.5%*
	0.1770	*2.14*	*0.6%*	*27.63*	*3.19*	*0.9%*
	0.1250	*1.20*	*0.3%*	*28.83*	*1.99*	*0.6%*
	0.0880	*1.70*	*0.5%*	*30.53*	*0.29*	*0.1%*
	0.0625	*0.20*	*0.1%*	*30.73*	*0.09*	*0.0%*
	0.0100	*0.09*	*0.0%*	*30.82*	*0.00*	*0.0%*
	Total=	354.95	kilograms			

SITE 3004

SIEVE ANALYSIS (SURFACE)

	Sieve Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	*0.00*	*0.0%*	*0.00*	*111.50*	*100.1%*
	180.0000	*0.00*	*0.0%*	*0.00*	*111.50*	*100.1%*
	128.0000	*0.00*	*0.0%*	*0.00*	*111.50*	*100.1%*
	90.0000	*0.00*	*0.0%*	*0.00*	*111.50*	*100.1%*
	64.0000	*22.67*	*20.4%*	*22.67*	*88.83*	*79.8%*
	45.0000	*17.68*	*15.9%*	*40.34*	*71.15*	*63.9%*
	32.0000	*17.22*	*15.5%*	*57.57*	*53.93*	*48.4%*
	22.0000	*10.42*	*9.4%*	*67.99*	*43.51*	*39.1%*
	16.0000	*8.61*	*7.7%*	*76.59*	*34.90*	*31.3%*
	8.0000	*6.79*	*6.1%*	*83.39*	*28.11*	*25.2%*
FINES	7.0000	*3.14*	*2.8%*	*3.26*	*24.85*	*22.3%*
	4.0000	*4.20*	*3.8%*	*7.46*	*20.65*	*18.5%*
	2.8300	*1.37*	*1.2%*	*8.82*	*19.29*	*17.3%*
	2.0000	*2.70*	*2.4%*	*11.52*	*16.59*	*14.9%*
	1.4100	*3.37*	*3.0%*	*14.88*	*13.23*	*11.9%*
	1.0000	*3.96*	*3.6%*	*18.84*	*9.27*	*8.3%*
	0.7100	*3.96*	*3.6%*	*22.80*	*5.31*	*4.8%*
	0.5000	*3.09*	*2.8%*	*25.89*	*2.22*	*2.0%*
	0.3500	*1.28*	*1.1%*	*27.16*	*0.95*	*0.9%*
	0.2500	*0.51*	*0.5%*	*27.67*	*0.44*	*0.4%*
	0.1770	*0.18*	*0.2%*	*27.85*	*0.26*	*0.2%*
	0.1250	*0.11*	*0.1%*	*27.95*	*0.16*	*0.1%*
	0.0880	*0.11*	*0.1%*	*28.07*	*0.04*	*0.0%*
	0.0625	*0.01*	*0.0%*	*28.08*	*0.03*	*0.0%*
	0.0100	*0.03*	*0.0%*	*28.11*	*0.00*	*0.0%*
	Total=	111.37	kilograms			

SITE 3004

SIEVE ANALYSIS (SUBSURFACE)

	Sieve Opening (mm)	**Mass of Soil Retained**	**Percent**	**Cumulative Mass of Soil Retained**	**Mass of Soil Passing**	**Percent Finer**
BULK`	256.0000	0.00	0.0%	0.00	74.30	100.0%
	180.0000	0.00	0.0%	0.00	74.30	100.0%
	128.0000	0.00	0.0%	0.00	74.30	100.0%
	90.0000	0.00	0.0%	0.00	74.30	100.0%
	64.0000	7.70	10.4%	7.70	66.60	89.6%
	45.0000	10.87	14.6%	18.57	55.73	75.0%
	32.0000	10.42	14.0%	28.99	45.31	61.0%
	22.0000	9.97	13.4%	38.96	35.34	47.6%
	16.0000	5.88	7.9%	44.84	29.46	39.6%
	8.0000	11.33	15.2%	56.17	18.13	24.4%
FINES	7.0000	1.00	1.3%	1.00	17.13	23.1%
	4.0000	3.87	5.2%	4.87	13.26	17.8%
	2.8300	1.23	1.7%	6.11	12.02	16.2%
	2.0000	2.17	2.9%	8.28	9.85	13.3%
	1.4100	2.19	2.9%	10.46	7.67	10.3%
	1.0000	2.22	3.0%	12.68	5.45	7.3%
	0.7100	2.05	2.8%	14.73	3.40	4.6%
	0.5000	1.90	2.6%	16.63	1.50	2.0%
	0.3500	1.00	1.3%	17.63	0.50	0.7%
	0.2500	0.35	0.5%	17.97	0.16	0.2%
	0.1770	0.09	0.1%	18.06	0.07	0.1%
	0.1250	0.03	0.0%	18.09	0.04	0.1%
	0.0880	0.03	0.0%	18.12	0.01	0.0%
	0.0625	0.00	0.0%	18.13	0.01	0.0%
	0.0100	0.01	0.0%	18.13	0.00	0.0%
	Total=	74.30	kilograms			

SITE 5003

SIEVE ANALYSIS (SURFACE)

	Sieve Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	*0.00*	*0.0%*	*0.00*	*384.47*	*100.0%*
	180.0000	*0.00*	*0.0%*	*0.00*	*384.47*	*100.0%*
	128.0000	*0.00*	*0.0%*	*0.00*	*384.47*	*100.0%*
	90.0000	*118.30*	*30.8%*	*118.30*	*266.17*	*69.2%*
	64.0000	*84.77*	*22.1%*	*203.07*	*181.40*	*47.2%*
	45.0000	*72.52*	*18.9%*	*275.60*	*108.88*	*28.3%*
	32.0000	*63.47*	*16.5%*	*339.06*	*45.41*	*11.8%*
	22.0000	*36.26*	*9.4%*	*375.32*	*9.15*	*2.4%*
	16.0000	*8.15*	*2.1%*	*383.48*	*1.00*	*0.3%*
	8.0000	*0.89*	*0.2%*	*384.37*	*0.10*	*0.0%*
FINES	7.0000	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	4.0000	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	2.8300	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	2.0000	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	1.4100	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	1.0000	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.7100	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.5000	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.3500	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.2500	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.1770	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.1250	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.0880	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.0625	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	0.0100	*0.00*	*0.0%*	*0.00*	*0.00*	*0.0%*
	Total=	384.37	kilograms			

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SITE 5003

SIEVE ANALYSIS (SUBSURFACE)

	Sieve Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	0.00	0.0%	0.00	430.87	100.0%
	180.0000	0.00	0.0%	0.00	430.87	100.0%
	128.0000	0.00	0.0%	0.00	430.87	100.0%
	90.0000	78.42	18.2%	78.42	352.44	81.8%
	64.0000	71.18	16.5%	149.60	281.27	65.3%
	45.0000	92.48	21.5%	242.08	188.78	43.8%
	32.0000	104.28	24.2%	346.36	84.51	19.6%
	22.0000	48.04	11.2%	394.40	36.46	8.5%
	16.0000	31.27	7.3%	425.67	5.19	1.2%
	8.0000	4.52	1.0%	430.20	0.67	0.2%
FINES	7.0000	0.19	0.0%	0.19	0.48	0.1%
	4.0000	0.14	0.0%	0.33	0.34	0.1%
	2.8300	0.03	0.0%	0.36	0.31	0.1%
	2.0000	0.04	0.0%	0.40	0.27	0.1%
	1.4100	0.03	0.0%	0.43	0.24	0.1%
	1.0000	0.03	0.0%	0.45	0.21	0.0%
	0.7100	0.02	0.0%	0.48	0.19	0.0%
	0.5000	0.02	0.0%	0.50	0.17	0.0%
	0.3500	0.03	0.0%	0.53	0.14	0.0%
	0.2500	0.03	0.0%	0.56	0.10	0.0%
	0.1770	0.03	0.0%	0.59	0.07	0.0%
	0.1250	0.02	0.0%	0.62	0.05	0.0%
	0.0880	0.03	0.0%	0.65	0.02	0.0%
	0.0625	0.01	0.0%	0.66	0.01	0.0%
	0.0100	0.01	0.0%	0.67	0.00	0.0%
	Total=	430.87	kilograms			

SITE 5004

SIEVE ANALYSIS (SURFACE)

	Sieve Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	*0.00*	*0.0%*	*0.00*	*418.61*	*100.0%*
	180.0000	*0.00*	*0.0%*	*0.00*	*418.61*	*100.0%*
	128.0000	*0.00*	*0.0%*	*0.00*	*418.61*	*100.0%*
	90.0000	*157.76*	*37.7%*	*157.76*	*260.84*	*62.3%*
	64.0000	*92.02*	*22.0%*	*249.78*	*168.83*	*40.3%*
	45.0000	*70.72*	*16.9%*	*320.50*	*98.10*	*23.4%*
	32.0000	*65.28*	*15.6%*	*385.78*	*32.82*	*7.8%*
	22.0000	*28.55*	*6.8%*	*414.33*	*4.27*	*1.0%*
	16.0000	*3.62*	*0.9%*	*417.95*	*0.65*	*0.2%*
	8.0000	*0.21*	*0.1%*	*418.16*	*0.44*	*0.1%*
FINES	7.0000	*0.06*	*0.0%*	*0.06*	*0.38*	*0.1%*
	4.0000	*0.04*	*0.0%*	*0.10*	*0.34*	*0.1%*
	2.8300	*0.01*	*0.0%*	*0.11*	*0.33*	*0.1%*
	2.0000	*0.02*	*0.0%*	*0.13*	*0.31*	*0.1%*
	1.4100	*0.02*	*0.0%*	*0.15*	*0.29*	*0.1%*
	1.0000	*0.02*	*0.0%*	*0.18*	*0.26*	*0.1%*
	0.7100	*0.03*	*0.0%*	*0.21*	*0.23*	*0.1%*
	0.5000	*0.05*	*0.0%*	*0.25*	*0.19*	*0.0%*
	0.3500	*0.04*	*0.0%*	*0.29*	*0.15*	*0.0%*
	0.2500	*0.03*	*0.0%*	*0.32*	*0.12*	*0.0%*
	0.1770	*0.02*	*0.0%*	*0.35*	*0.09*	*0.0%*
	0.1250	*0.02*	*0.0%*	*0.36*	*0.08*	*0.0%*
	0.0880	*0.07*	*0.0%*	*0.43*	*0.01*	*0.0%*
	0.0625	*0.00*	*0.0%*	*0.43*	*0.01*	*0.0%*
	0.0100	*0.01*	*0.0%*	*0.44*	*0.00*	*0.0%*
	Total=	418.61	kilograms			

SITE 5004

SIEVE ANALYSIS (SUBSURFACE)

	Sieve Opening (mm)	Mass of Soil Retained	Percent	Cumulative Mass of Soil Retained	Mass of Soil Passing	Percent Finer
BULK	256.0000	*0.00*	*0.0%*	*0.00*	*290.10*	*100.0%*
	180.0000	*0.00*	*0.0%*	*0.00*	*290.10*	*100.0%*
	128.0000	*23.57*	*8.1%*	*23.57*	*266.52*	*91.9%*
	90.0000	*35.36*	*12.2%*	*58.93*	*231.17*	*79.7%*
	64.0000	*26.30*	*9.1%*	*85.23*	*204.87*	*70.6%*
	45.0000	*63.92*	*22.0%*	*149.14*	*140.95*	*48.6%*
	32.0000	*73.43*	*25.3%*	*222.58*	*67.52*	*23.3%*
	22.0000	*53.50*	*18.4%*	*276.08*	*14.02*	*4.8%*
	16.0000	*12.23*	*4.2%*	*288.31*	*1.79*	*0.6%*
	8.0000	*1.35*	*0.5%*	*289.66*	*0.44*	*0.2%*
FINES	7.0000	*0.07*	*0.0%*	*0.07*	*0.37*	*0.1%*
	4.0000	*0.03*	*0.0%*	*0.10*	*0.34*	*0.1%*
	2.8300	*0.01*	*0.0%*	*0.11*	*0.33*	*0.1%*
	2.0000	*0.01*	*0.0%*	*0.12*	*0.32*	*0.1%*
	1.4100	*0.01*	*0.0%*	*0.14*	*0.30*	*0.1%*
	1.0000	*0.01*	*0.0%*	*0.15*	*0.29*	*0.1%*
	0.7100	*0.02*	*0.0%*	*0.17*	*0.27*	*0.1%*
	0.5000	*0.02*	*0.0%*	*0.19*	*0.25*	*0.1%*
	0.3500	*0.03*	*0.0%*	*0.22*	*0.22*	*0.1%*
	0.2500	*0.03*	*0.0%*	*0.25*	*0.19*	*0.1%*
	0.1770	*0.04*	*0.0%*	*0.29*	*0.16*	*0.1%*
	0.1250	*0.03*	*0.0%*	*0.32*	*0.12*	*0.0%*
	0.0880	*0.09*	*0.0%*	*0.40*	*0.04*	*0.0%*
	0.0625	*0.02*	*0.0%*	*0.43*	*0.02*	*0.0%*
	0.0100	*0.02*	*0.0%*	*0.44*	*0.00*	*0.0%*
	Total=	290.10	kilograms			

Appendix B: Permeability data

Terhune Standpipe- field data summary

Location	Test Number	Depth in gravel (ft)	Inside Depth to Water (ft)	Outside Depth to Water (ft)	Time to Pump 1 Liter	Time to Pump 2 Liters	Time to Pump 3 Liters	Time to Pump 4 Liters	Average Time to Pump 1 Liter	Average Seconds to Pump 1 Liter	mL/ sec	Terhune Permea-bility (cm/hr)
Sailor Bar	1701-1	1	1.69	1.65	00:17.	00:36.9	00:58.7	01:19.6	00:19.9	19.9	50.25	**8,000**
					00:17.2	00:19.7	00:21.8	00:20.9				
Sailor Bar	1701-2	1			00:20.7	00:42.5	01:03.4	01:26.2	00:21.5	21.5	46.51	**8,000**
					00:20.7	00:21.8	00:20.9	00:22.7				
Sailor Bar	1702-1	1							00:00.0			**No Flow**
					00:00.0	00:00.0	00:00.0	00:00.0				
Sunrise Access	3701-1	1	2.31	2.36	00:32.2	01:08.5	01:43.2	02:19.6	00:34.9	34.9	28.65	**3,500**
					00:32.2	00:36.3	00:34.7	00:36.4				
Sunrise Access	3701-2	1			00:34.8	01:11.8	01:49.5	02:26.4	00:36.6	36.6	27.32	**3,500**
					00:34.8	00:37.0	00:37.7	00:36.9				
Sunrise Access	3701-1	2	1.36	1.43	00:13.9	00:28.5	00:42.6	00:54.3	00:13.6	13.6	73.53	**15,000**
					00:13.9	00:14.6	00:14.1	00:11.7				
Sunrise Access	3701-2	2			00:12.3	00:25.5	00:39.1	00:51.7	00:12.9	12.9	77.52	**19,000**
					00:12.3	00:13.2	00:13.6	00:12.6				
Sunrise Access	3702-1	1	2.01	1.97	00:12.5	00:25.5	00:37.7	00:51.2	00:12.8	12.8	78.13	**20,000**
					00:12.5	00:13.0	00:12.2	00:13.5				
Sunrise Access	3702-2	1			00:11.9	00:24.3	00:36.5	00:48.7	00:12.2	12.2	81.97	**20,000**
					00:11.9	00:12.4	00:12.2	00:12.2				
Sunrise Access	3702-1	2	0.93	0.90	00:07.3	00:15.1	00:23.0	00:30.8	00:07.7	7.7	129.87	**+100000**
					00:07.3	00:07.7	00:08.0	00:07.7				
Sunrise Access	3702-2	2			00:06.8	00:14.3	00:21.8	00:29.1	00:07.3	7.3	136.99	**+100000**
					00:06.8	00:07.5	00:07.5	00:07.4				
Sunrise Access	3703-1	1			00:15.2	00:28.9	00:42.9		00:14.3	14.3	69.93	**15,000**
					00:15.2	00:13.7	00:14.1	00:00.0				

Sunrise Access	3704-1	1			01:00.6				01:00.6	60.6	16.50	**1,600**
					01:00.6	00:00.0	00:00.0	00:00.0				
Sunrise Access	3705-1	1	1.62	1.61	00:11.2	00:21.9	00:32.9	00:43.9	00:11.0	11.0	90.91	**30,000**
					00:11.2	00:10.7	00:11.0	00:11.0				
Sunrise Access	3706-1	2	1.40	1.30	00:39.7	01:22.2	02:07.9	02:51.1	00:42.8	42.8	23.36	**2,300**
					00:39.7	00:42.5	00:45.7	00:43.2				
Sacramento Bar	5701-1	1	1.26	1.17	00:19.2	00:39.9	01:01.8	01:22.3	00:20.6	20.6	48.54	**8,000**
					00:19.2	00:20.7	00:21.8	00:20.6				
Sacramento Bar	5701-2	1			00:19.3	00:39.1	00:59.2	01:18.9	00:19.7	19.7	50.76	**8,000**
					00:19.3	00:19.8	00:20.2	00:19.7				
Sacramento Bar	5702-1	1	1.59	1.40	00:19.7	00:36.4	00:52.9	01:11.0	00:17.8	17.8	56.18	**10,000**
					00:19.7	00:16.7	00:16.5	00:18.2				
Sacramento Bar	5702-2	1			00:15.4	00:31.5	00:47.5	01:04.7	00:16.2	16.2	61.73	**11,000**
					00:15.4	00:16.0	00:16.0	00:17.2				
Sacramento Bar	5702-1	2	0.58	0.47	00:13.9	00:29.1	00:44.2	00:59.2	00:14.8	14.8	67.57	**13,000**
					00:13.9	00:15.1	00:15.1	00:15.0				
Sacramento Bar	5703-1	1	2.32	2.23	00:10.6	00:19.3	00:29.1	00:38.4	00:09.6	9.6	104.17	**70,000**
					00:10.6	00:08.7	00:09.8	00:09.3				
Sacramento Bar	5703-2	2	1.30	1.38	00:13.3	00:25.8	00:38.1	00:50.7	00:12.7	12.7	78.74	**20,000**
					00:13.3	00:12.5	00:12.2	00:12.6				
Sacramento Bar	5705-1	1			00:53.6				00:13.4	13.4	74.63	**19,000**
					00:53.6	00:00.0	00:00.0	00:00.0				
Sacramento Bar	5705-2	1			00:17.5				00:08.8	8.8	113.64	**+100000**
					00:17.5	00:00.0	00:00.0	00:00.0				
Sacramento Bar	5705-3	1			00:56.9				00:14.2	14.2	70.42	**15,000**
					00:56.9	00:00.0	00:00.0	00:00.0				
Sacramento Bar	5706-1	1			00:09.1	00:18.2	00:28.0	00:37.9	00:09.5	9.5	105.26	**70,000**
					00:09.1	00:09.1	00:09.8	00:09.9				
Sacramento Bar	5707-1	1	2.04	2.00	00:07.6	00:15.6	00:23.7	00:31.8	00:08.0	8.0	125.00	**+100000**
					00:07.6	00:08.0	00:08.1	00:08.2				

Sacramento Bar	5708-1	2	1.29	1.28	00:13.3	00:25.8	00:39.0	00:52.2	00:13.0	13.0	76.92	**20,000**
					00:13.3	00:12.5	00:13.2	00:13.2				
Sacramento Bar	5709-1	1	2.51	2.50	00:09.9	00:22.7	00:34.7	00:47.0	00:11.7	11.7	85.47	**24,000**
					00:09.9	00:12.8	00:11.9	00:12.3				
Sacramento Bar	5710-1	2	1.74	1.72	00:28.1	00:58.1	01:29.4	01:59.5	00:29.9	29.9	33.44	**4,300**
					00:28.1	00:30.0	00:31.3	00:30.1				

Terhune standpipe field data, cont’d

Appendix C: Field parameter data

Monitoring Point	Stream Depth (m)	Stream Velocity (m/s)	Sample Depth (cm)	D.O. (mg/L)	pH	E.C. (uS/cm)	Cell Temp. (°C)	Gradient
Sailor Bar								
1100			0	7.3	7.0	59	11.6	N/A
1102	1.0	0.6	30	4.5	6.4	61	12.1	-0.04
			90	5.2	6.7	61	11.9	-0.01
1103	0.6	0.1	30	2.6	7.7	63	12.4	0.00
			90	1.5	7.3	61	12.3	
1104	1.1	0.7	30	6.7	7.0	59	11.6	0.00
			90	6.8	7.0	59	11.5	-0.01
1105	0.9	0.8	30	6.1	7.0	59	11.6	-0.03
			90	6.9	7.1	59	11.6	-0.02
Lower Sunrise								
3101	0.4	0.3	30	2.2	6.9	67	12.2	-0.04
			60	1.8	6.9	66	12.3	-0.04
			90	1.5	6.9	66	12.5	
3102	0.1	0.4	0	8.1	7.0	70	13.0	N/A
			30	2.0	6.9	73	12.9	-0.02
			60	7.1	7.2	68	12.7	-0.01
			90	8.3	7.5	68	13.2	-0.01
3103	0.6	0.8	0	7.6	7.5	61	12.4	N/A
3104	0.6	0.6	0	7.9	7.2	62	12.4	N/A
			30	7.9	7.2	62	12.5	0.05
			60	6.5	7.0	63	12.3	0.03
			90	6.3	6.9	63	12.2	0.02
3105	0.5	0.6	30	7.0	7.4	67	11.9	-0.03
			60	6.7	7.3	66	12.3	-0.02
3106	0.3	0.3	30	3.5	6.5	58	12.8	-0.01
			60	3.6	6.6	58	12.7	-0.02
			90	1.0	5.7	60	13.0	-0.01
3107	1.0	0.4	0	7.6	7.5	61	12.4	N/A
			30	6.3	6.9	61	12.5	-0.05
			60	6.2	7.2	61	12.3	-0.03
			90	6.1	7.1	62	12.5	-0.02
3108	0.5	0.2	30	6.0	7.1	69	12.1	-0.03
			60	5.8	6.9	69	12.3	-0.01
			90	5.5	7.1	71	12.5	-0.01
3109	0.4	0.3	30	7.9	7.1	67	12.8	-0.04
			60	8.4	7.0	67	12.2	-0.07
			90	6.8	6.9	68	12.3	-0.05
3110	0.3	0.3	30	9.5	6.7	68	13.3	-0.25
			60	8.0	6.3	67	12.7	-0.13
			180	6.7	6.9	69	14.9	-0.04

Monitoring	Stream	Stream	Sample	D.O.	pH	E.C.	Cell	Gradient
Point	Depth	Velocity	Depth				Temp.	
	(m)	(m/s)	(cm)	(mg/L)		(uS/cm)	(°C)	
Lower Sunrise, continued								
3111	0.7	0.7	90	6.2	7.3	65	13.9	-0.07
3113	0.2	0.5	30	9.5	6.7	68	13.3	0.01
			90	8.0	6.3	67	12.7	0.01
3114	0.3	0.3	30	4.7	7.0	67	12.9	0.03
			90	6.2	7.3	67	13.6	0.01
3115	0.3	1.0	30	8.0	7.2	65	12.4	0.03
			90	6.8	6.9	63	12.0	0.02
3116	0.7	0.7	30	7.3	6.6	58	12.3	-0.02
			90	6.2	6.7	55	12.5	-0.01
3117	0.5	0.8	30		7.1	59		
			90	6.5	7.1	57	12.4	
Sacramento Bar								
5101	0.3	0.1	30	4.1	6.7	61	12.1	-0.05
			60	1.3	6.6	64	12.1	-0.03
5102	1.0	0.9	30	7.5	6.9	61	12.1	0.00
			60	6.6	7.2	61	12.0	-0.04
5104	0.5	1.2	30					
			60	5.8	6.9	59	12.1	0.02
			90					
5108	1.6	0.2	30	7.1	6.9	58	11.9	-0.08
			90	4.2	6.7	61	12.3	-0.03
5109	2.7	0.6	0	9.0	7.3	58	11.9	N/A
			30	6.8	6.9	58	11.9	-0.05
			60	6.0	6.9	59	11.9	-0.02
			90	6.9	7.0	58	11.9	-0.01
5110	0.5	0.3	30	5.0	7.2	63	11.9	-0.04
			60	4.3	7.2	63	12.1	-0.02
			90	2.2	7.1	65	12.3	-0.01
5112	0.9	0.6	30	6.7	6.6	61	11.7	-0.01
			90	6.4	7.1	61	11.9	-0.01
5113	0.9	0.6	30	4.0	6.9	58	12.4	-0.02
			90	2.9	6.8	58	12.5	-0.01

December 2003 field parameters, cont'd.

Monitoring Point	Stream Depth (m)	20% Depth Velocity (m/s)	80% Depth Velocity (m/s)	60% Depth Velocity (m/s)	Sample Depth (cm)	D.O. (mg/L)	pH	E.C. (uS/cm)	Cell Temp. (°C)	Gravel Temp. (°C)	Turbidity (NTU)	Gradient
Sailor Bar												
1102	1.0	0.5	0.7		30	2.8	6.6	57.9				-0.03
					60							-0.01
					90	3.3	6.8	57.2				
1104	1.1	0.8	0.9		30	4.9	6.9	54.0				0.02
					90	4.6	6.9	54.4				0.01
1105	0.9	0.6	1.0		30	4.0	6.8	52.9				0.00
Lower Sunrise												
3101					30	1.9	6.9	70.4	19.2			
3101					60	1.3	6.8	68.3	18.1			
3101					90	1.1	6.8	70.6	21.2			
3102	0.3			0.3	30	1.3	6.3	72.2	20.3			-0.01
3102					60	4.0	6.4	60.6	19.8			-0.02
3102					90	6.9	7.0	57.4	20.4			-0.002
3103	0.7	0.9	0.9		30	5.8	6.8	58.2	19.8			0.03
3103					60							
3103					90	6.2	6.9	58.1	20.0			0.01
3104	0.6			0.6	30	3.8	6.9	50.0	19.6		8	-0.01
3104					60	4.7	7.0	50.0	19.6		9	0.00
3104					90	4.7	7.0		18.8		7	0.00
3105	0.6			0.9	30	5.8	7.1	48.0	19.2		20	-0.06
3105					60	6.1	7.2	61.2	18.0			
3105					90	5.6	7.1	49.0	20.3		10	-0.02

Monitoring	Stream	20% Depth	80% Depth	60% Depth	Sample	D.O.	pH	E.C.	Cell	Gravel	Turbidity	Gradient
Point	**Depth**	**Velocity**	**Velocity**	**Velocity**	**Depth**				**Temp.**	**Temp.**		
	(m)	**(m/s)**	**(m/s)**	**(m/s)**	**(cm)**	**(mg/L)**		**(uS/cm)**	**(°C)**	**(°C)**	**(NTU)**	
Lower Sunrise, continued												
3106	0.6			0.5	30	2.9	6.5	57.0	19.0		4	-0.02
3106					60	2.2	6.9	67.2	17.9			
3106					90	2.5	6.6	56.0	18.6		21	0.00
3107	1.0	0.6	0.5		30	0.9	6.7	64.0	19.5	19.5	4	-0.07
3107					60	1.0	6.8	62.0	19.7	19.5	7	-0.03
3107					90	1.9	6.8	58.0	19.5	19.9	92	-0.02
3108	0.6			0.5	30	4.2	6.6	61.4	20.1	19.1		-0.03
3108					60	3.6	6.7	65.0	20.2	18.5		-0.02
3108					90					18.5		-0.01
3109	0.5			0.4	30	6.3	6.7	56.9	21.8	20.3	0	-0.13
3109					60	6.1	6.7	51.0	21.5	20.9	1	-0.10
3109					90	4.9	6.7	54.5	21.1	20.6	0	-0.08
3110					30							-0.49
3110	0.5			0.4	60	6.2	6.5	51.1	21.2	21.3	5	
3111	0.8	1.0	0.9		30	6.6	7.1	51.5	22.0	20.3	32	-0.17
3111					60							-0.08
3111					90	4.3	6.9	51.7	24.3	20.6	6	
3112	0.5			1.8	0	7.0	7.4	51.7	21.8		21	N/A
3112					30	6.6	6.8	52.8	22.0	19.1	15	0.11
3113	0.2			0.7	30	6.7	6.9	51.3	21.7	20.4	5	0.00
3113					60	3.4	6.7	60.7	21.2	19.4	17	0.10
3114	0.4			0.5	60							0.01
3114					90	2.89	6.9	66.5	19.7			0.02
3115					30	4.4	7.0	50.0	18.9		2	0.14
3115					90	4.4	7.0	49.0	18.5			0.05
3116	0.9			0.3	0	6.4	7.4	50.0	19.2		2	N/A
3116					30				19.8		1	
3116					90	5.2	6.9	49.5	19.7			-0.01
3117					30	4.3	6.8	55.8	18.7			-0.01
3117	0.6			0.9	90	3.0	6.8	51.0	18.9		3	-0.003

Monitoring	Stream	20% Depth	80% Depth	60% Depth	Sample	D.O.	pH	E.C.	Cell	Gravel	Turbidity	Gradient
Point	Depth	Velocity	Velocity	Velocity	Depth				Temp.	Temp.		
	(m)	(m/s)	(m/s)	(m/s)	(cm)	(mg/L)		(uS/cm)	(°C)	(°C)	(NTU)	
Sacramento Bar												
5101					60	2.1	6.8	59.1	19.4			
5101					90	3.0	6.3	57.8	19.3			
5104					30	4.2	7.0	54.7	20.7			
5104					90	3.6	6.6	56.2	19.7			
5108	0.5			0.4	30	5.4	6.7	56.3	18.8			
5108					90	2.6	6.8	60.9	18.5			
5109	0.9	0.5	0.8		60	4.7	6.8	57.6	18.2			-0.02
5110	0.6			0.5	30	2.6	6.4	60.6	18.4			-0.05
5110					90	1.2	6.6	65.0	18.3			-0.01

August 2004 field parameters, cont’d.

Appendix D: Trace element concentrations

Sample ID	Depth	As	Cu	Fe	Mn	Ni	Pb
	cm	ppb	ppb	ppb	ppb	ppb	ppb
1102-1	30	n.d.	0.024	29	0.33	n.d.	0.4
1102-2	60	n.d.	0.025	31	0.17	1	0.4
1104-1	30	n.d.	0.023	29	0.21	1	0.3
1104-3	90	n.d.	0.021	24	n.d.	1	0.5
1104-3 Rep	90	n.d.	0.020	24	n.d.	n.d.	0.4
1105-1	30	n.d.	0.018	163	1.9	2	0.4
3110-2	60	n.d.	0.019	37	0.44	n.d.	0.5
3112-1	30	n.d.	0.024	33	0.28	n.d.	0.6
3113-1	30	n.d.	0.021	48	0.18	2	0.5
3114-3	90	n.d.	0.021	25	1.1	1	0.5
Stream 06/28/04	0	n.d.	0.022	31	0.34	1	0.6
Trip Blank 06/28/04	-	n.d.	0.009	13	n.d.	1	0.5
3101-1	30	n.d.	0.019	29	1.5	n.d.	0.3
3101-2	60	n.d.	0.028	22	0.83	1	0.4
3101-3	90	n.d.	0.026	18	0.86	2	0.4
3104-1	30	n.d.	0.023	25	0.10	1	0.3
3104-1 Rep	30	n.d.	0.022	23	n.d.	2	0.3
3104-2	60	27	0.022	22	n.d.	2	0.4
3104-2 Rep	60	24	0.022	21	n.d.	n.d.	0.3
3104-3	90	45	0.021	26	n.d.	1	0.3
3105-2	60	42	0.019	20	n.d.	1	0.5
3105-3	90	32	0.019	23	n.d.	2	0.6
3106-1	30	37	0.028	37	0.17	5	0.3
3106-2	60	n.d.	0.023	15	n.d.	1	0.3
3106-3	90	47	0.020	13	n.d.	n.d.	0.3
3107-1	30	n.d.	0.022	147	0.22	1	0.4
3107-2	60	27	0.042	15	0.17	5	0.5
3107-3	90	57	0.024	84	0.12	1	0.3
3115-1	30	24	0.027	49	0.10	1	0.5
3115-3	90	32	0.022	32	0.10	1	0.4
3116-3	90	27	0.021	43	0.12	2	0.5
3117-1	30	24	0.024	24	0.40	2	0.4
3117-3	90	n.d.	0.022	24	0.26	3	0.4
Stream 06/29/04	0	27	0.018	41	0.35	2	0.4
3102-1	30	22	0.023	29	1.4	1	0.3
3102-2	60	19	0.020	29	0.34	n.d.	0.4
3102-3	90	50	0.021	40	0.40	n.d.	0.4

Sample ID	**Depth**	**As**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**
	cm	ppb	ppb	ppb	ppb	ppb	ppb
3108-1	30	19	0.025	29	0.16	1	0.3
3108-2	60	14	0.024	32	0.22	1	0.3
3108-3	90	n.d.	0.023	162	0.11	2	0.3
3109-1	30	n.d.	0.021	39	0.13	n.d.	0.4
3109-2	60	n.d.	0.020	27	0.13	1	0.3
3109-3	90	n.d.	0.020	21	0.20	1	0.3
3111-1	30	n.d.	0.020	32	0.20	1	0.4
3111-1 Rep	30	n.d.	0.019	37	0.20	1	0.3
3111-3	90	n.d.	0.024	25	0.18	1	0.4
3111-3 Rep	90	n.d.	0.052	23	0.15	2	0.4
Stream 06/30/04	0	n.d.	0.019	35	0.36	1	0.4
Trip Blank 06/30/04	-	n.d.	0.011	16	n.d.	n.d.	0.3
5108-1	30	n.d.	0.025	29	0.22	1	0.6
5108-3	90	n.d.	0.025	19	0.13	1	0.5
5110-1	30	n.d.	0.056	33	0.22	2	0.7
5110-3	90	n.d.	0.029	18	0.12	n.d.	0.5
5109-2	60	n.d.	0.026	18	n.d.	1	0.6
Equiptment Blank 07/01/04	-	n.d.	0.14	16	n.d.	n.d.	2.8
Trip Blank 07/01/04	-	n.d.	0.011	15	n.d.	n.d.	0.6
5101-2	60	n.d.		228	1.8	2	0.5
5101-3	90	n.d.		30	0.25	1	0.5
5104-1	30	n.d.		26	0.21	1	0.5
5104-3	90	n.d.		26	0.16	1	0.5
Equipment Blank 07/07/04	-	n.d.		20	0.10	1	0.5

Trace element concentrations, cont’d

Appendix E: Surface temperature plots

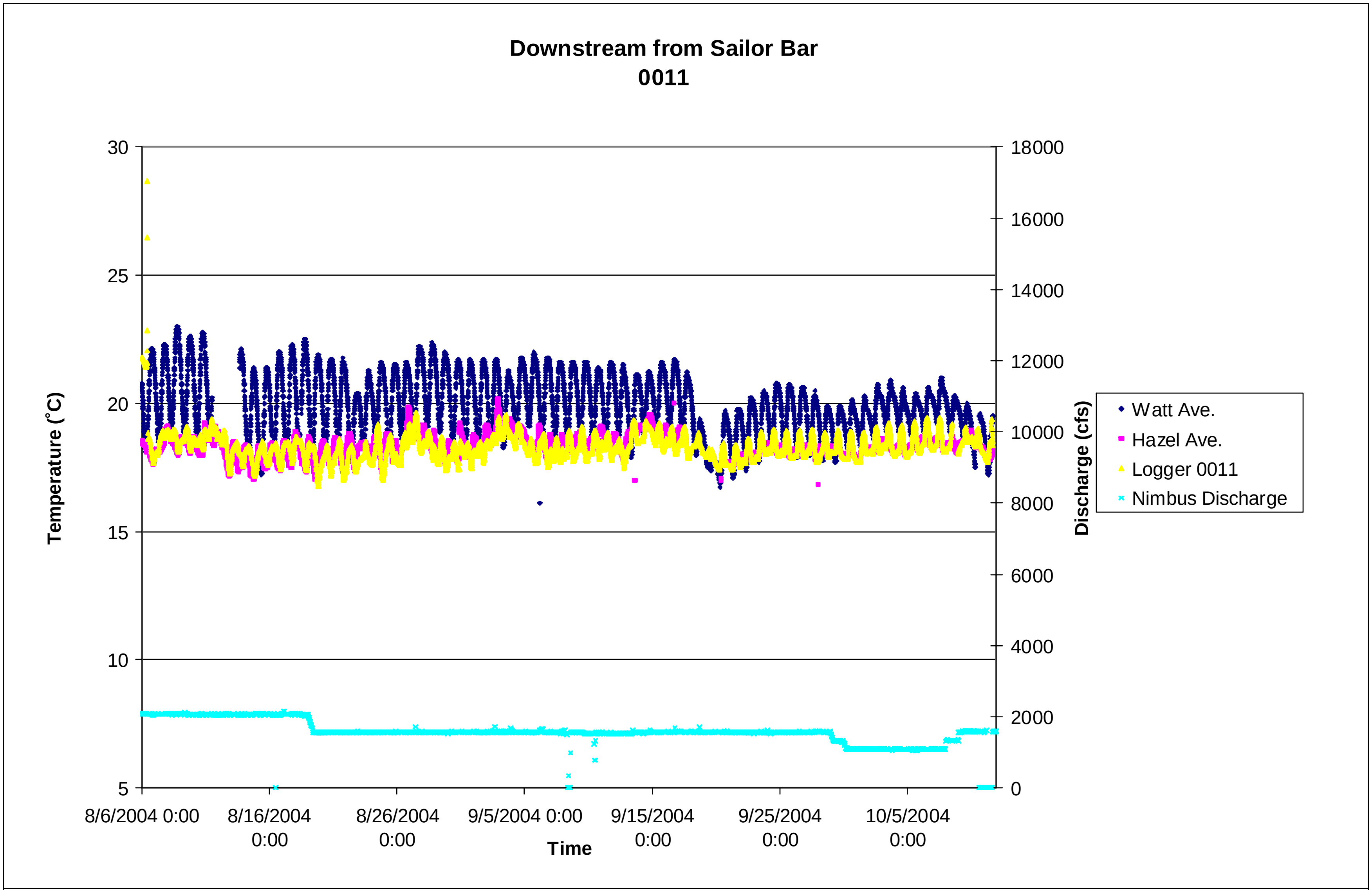


Figure VIII.9. Temperature profile for logger 0011 (Sailor Bar) compared to Hazel and Watt Avenues. The temperature fluctuation recorded by logger 0011 is small, and maximum values are well below those at Watt Ave.

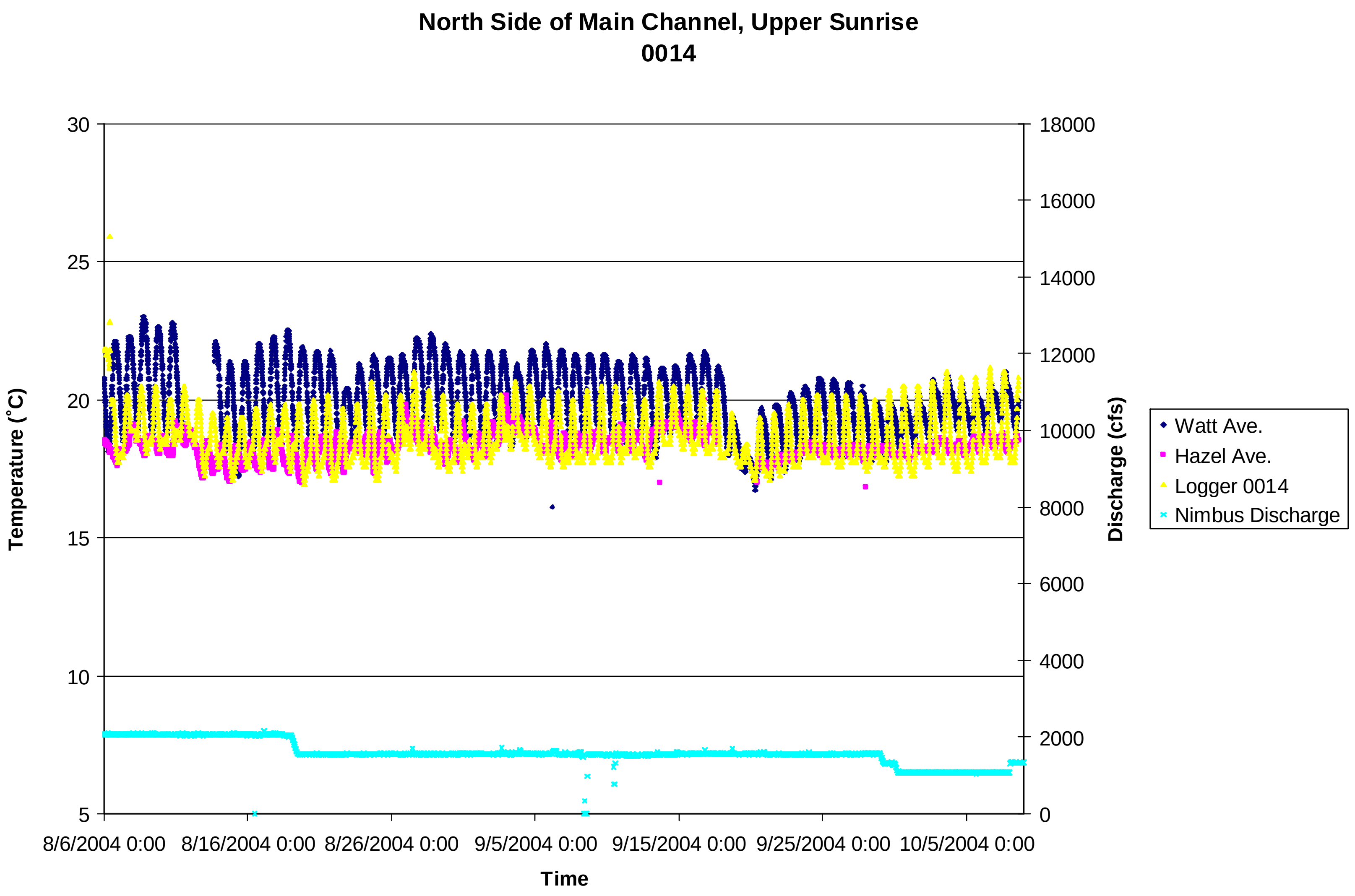
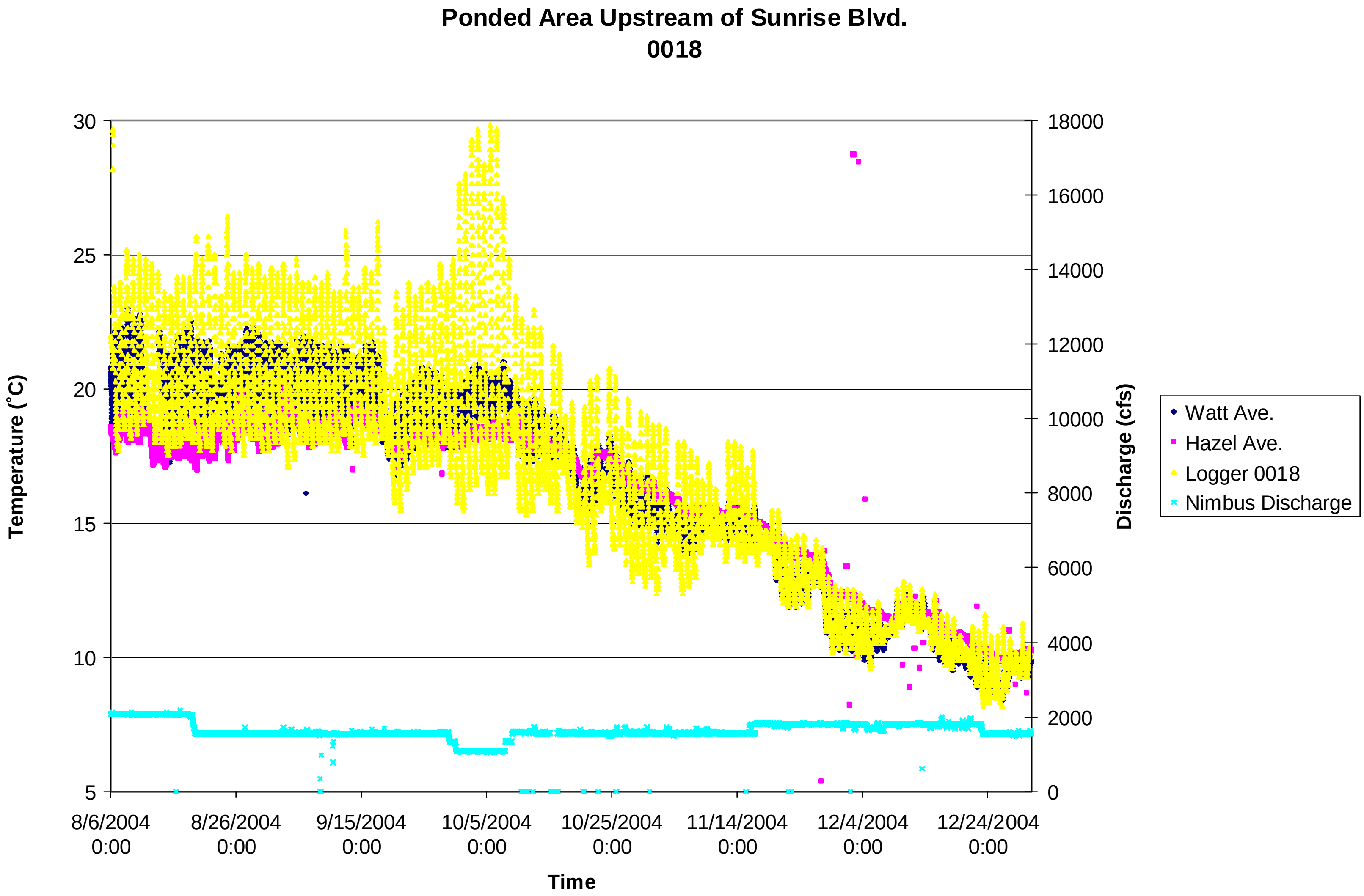


Figure VIII.10: Temperature profile for logger 0014 (Upper Sunrise main channel), compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0014 is moderate to large, and maximum values mostly fall below those at Watt Ave.



Ponded Area Upstream of Sunrise Blvd.
0018

Figure VIII.11: Temperature profiles for logger 0018 (Upper Sunrise shaded cover), compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0018 is large, and maximum values commonly exceed those at Watt Ave.

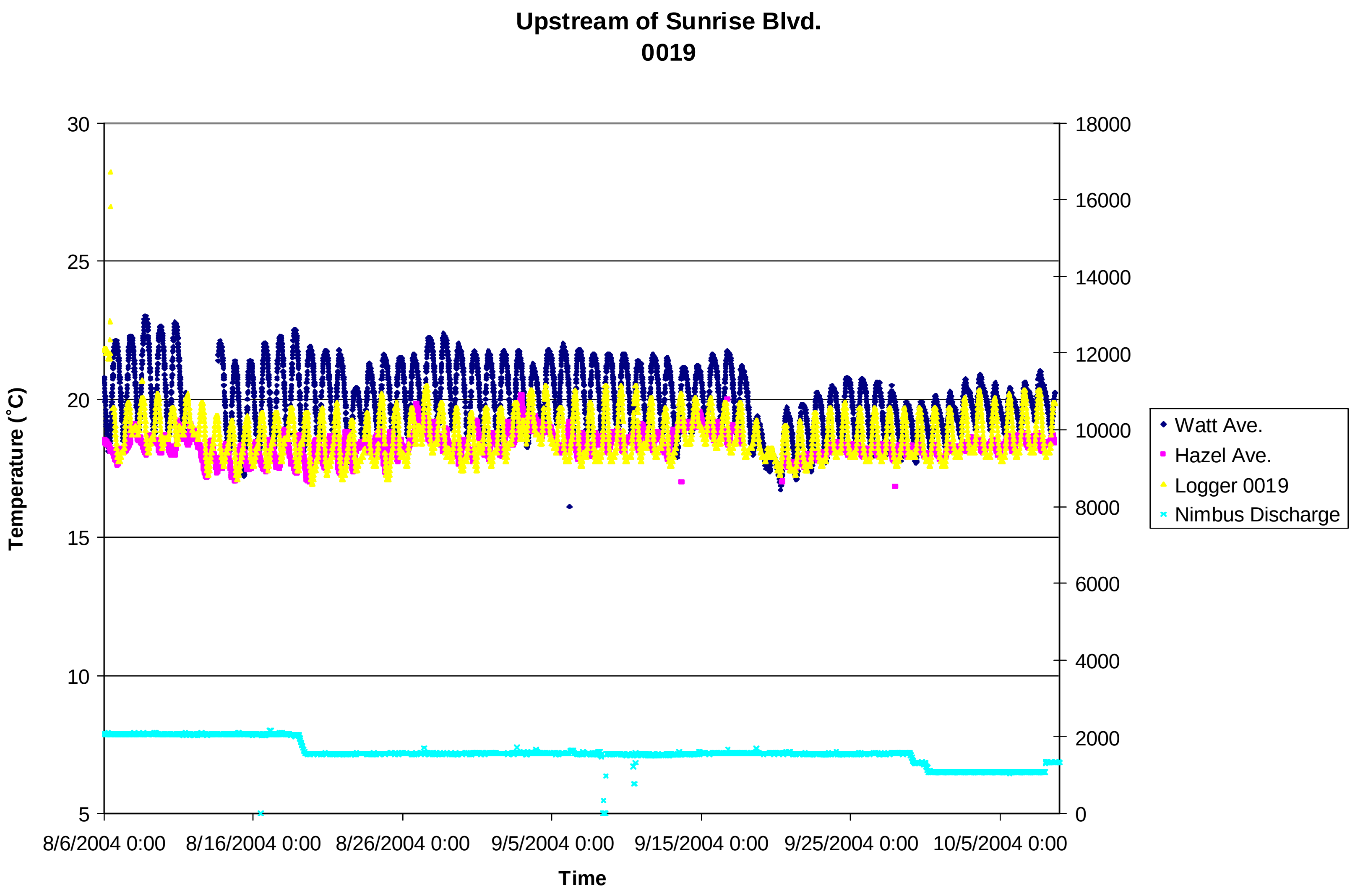


Figure VIII.12: Temperature profile for logger 0019 (in-channel, north of Sunrise Bridge), compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0019 is small, and maximum values are below those at Watt Ave.

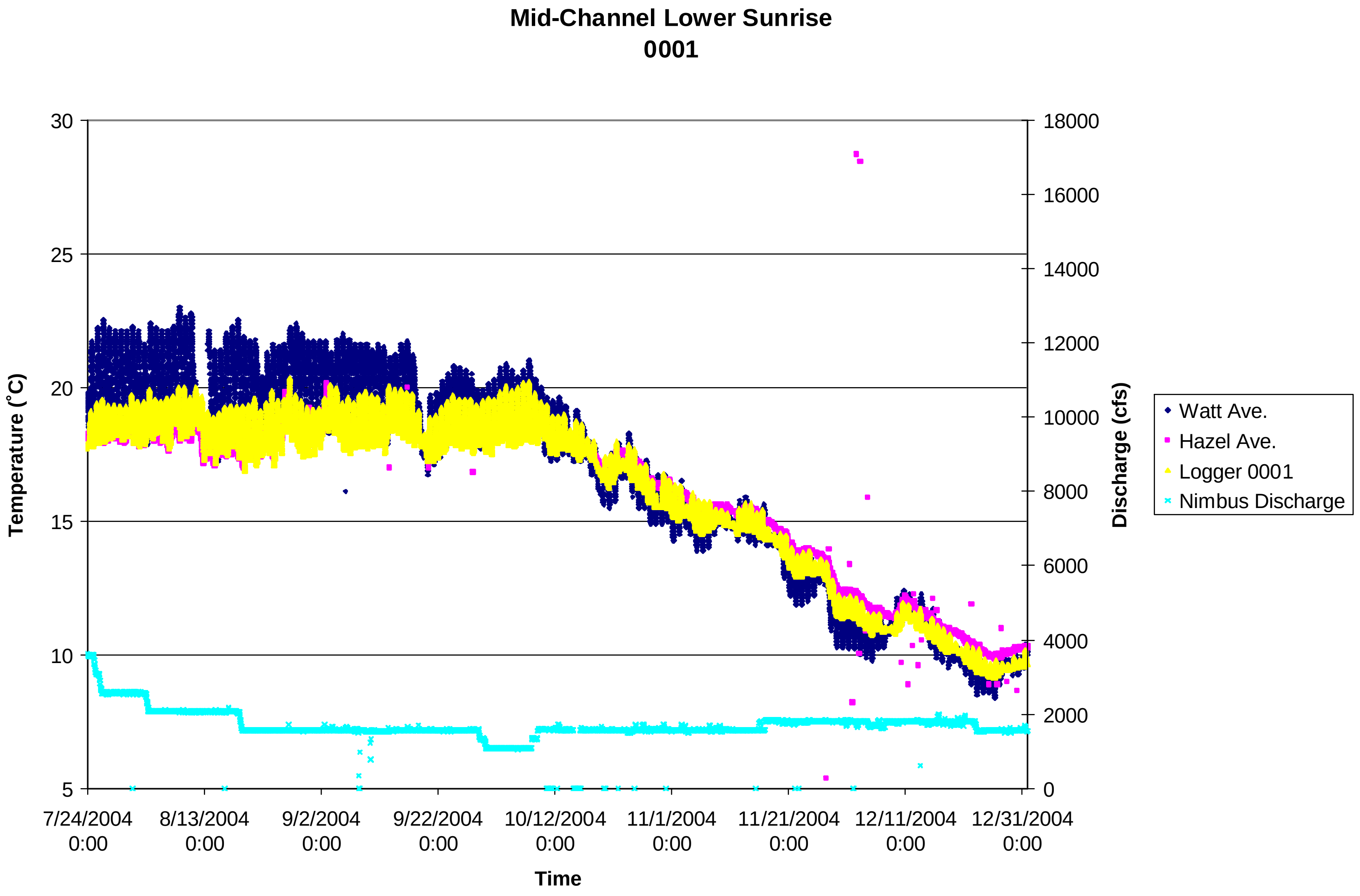


Figure VIII.13: Temperature profile for logger 0001 (Lower Sunrise mid-channel), compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0001 is small, and maximum values are below those at Watt Ave., except in the fall.

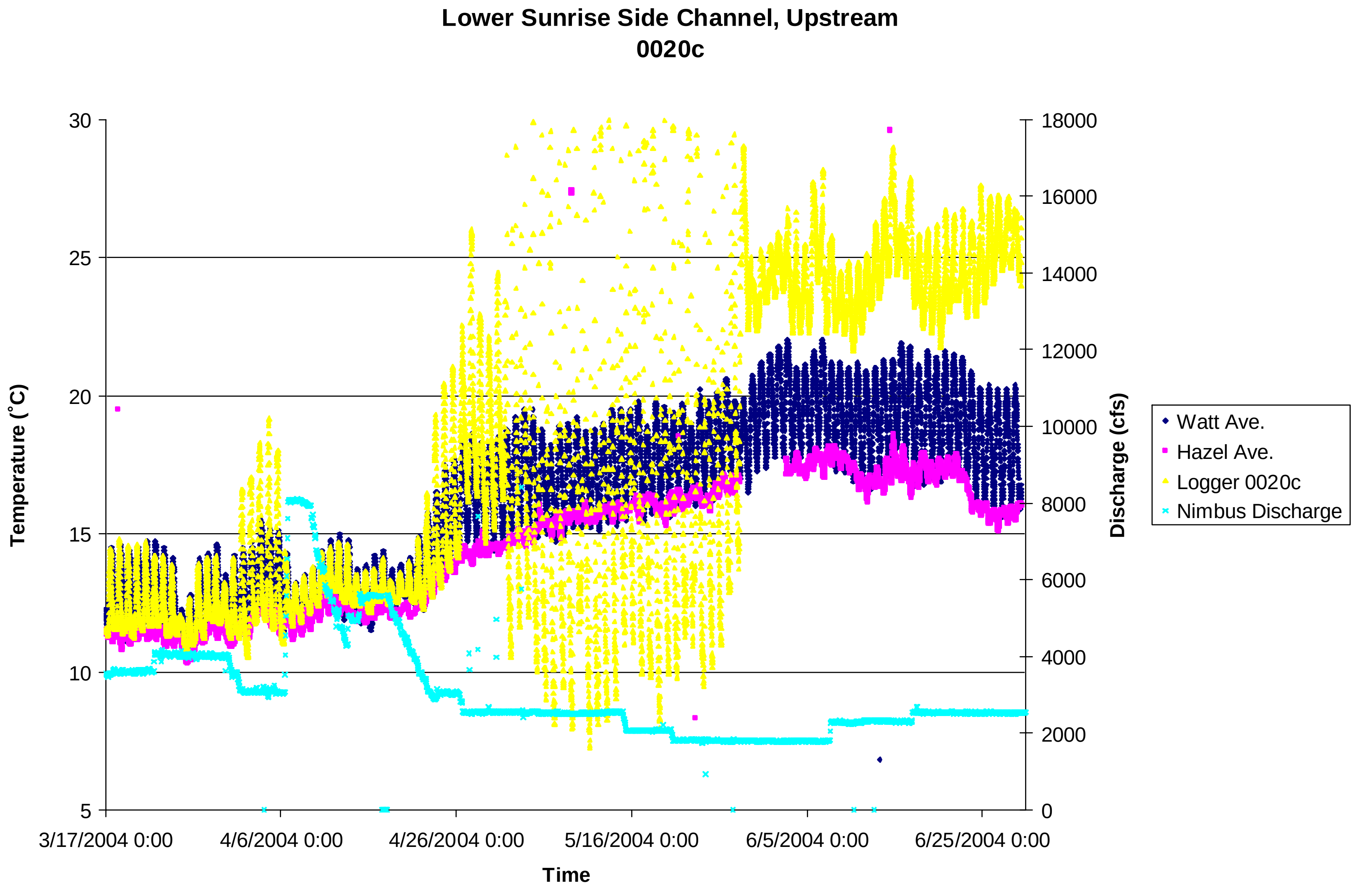


Figure VIII.14: Temperature profile for logger 0020c, (Lower Sunrise side channel) compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0020c is large, and even minimum temperatures exceed maximum Watt Ave. temperatures in late Spring. The extremely large fluctuation in mid-May indicates that the channel went dry.

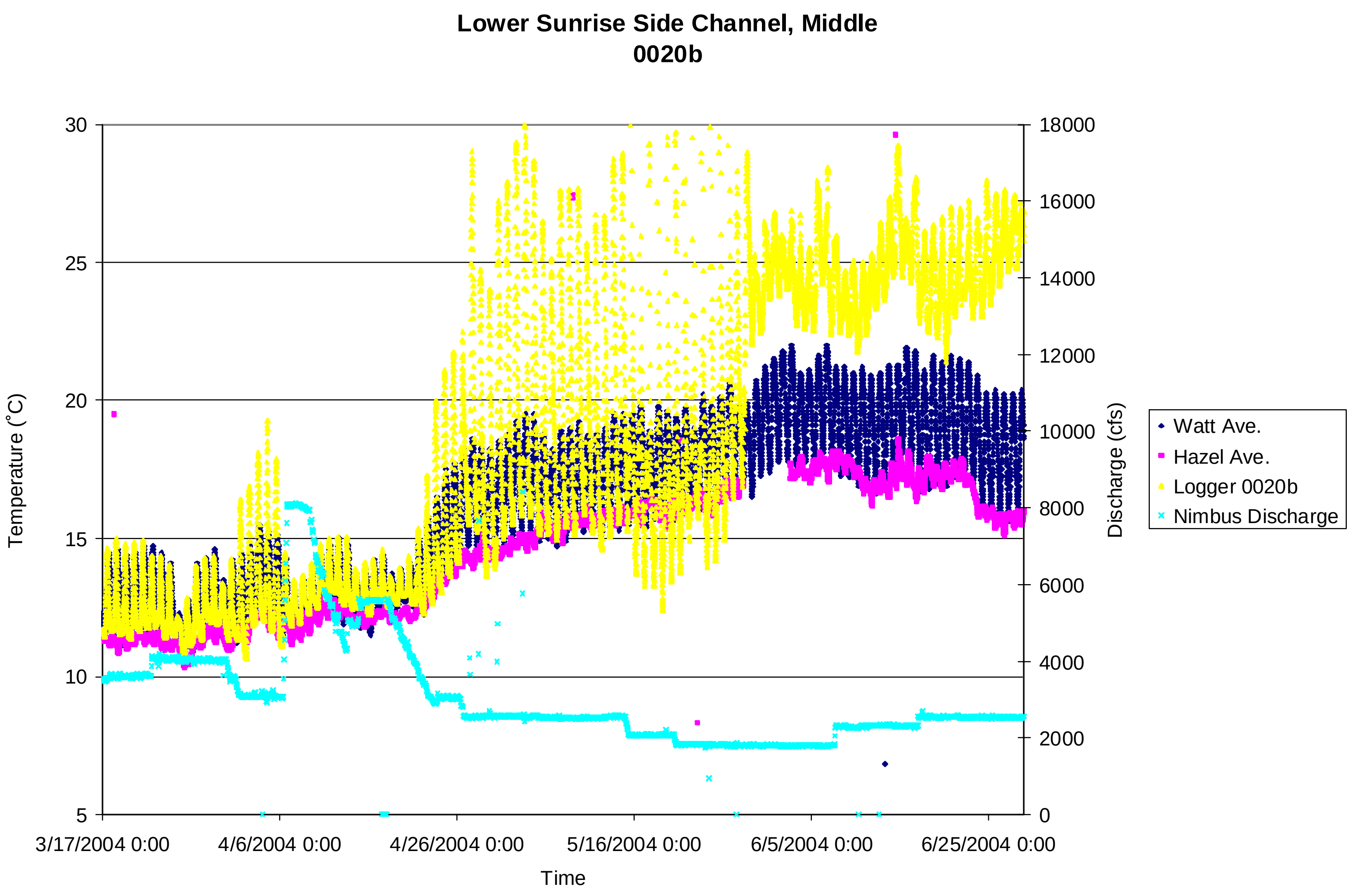


Figure VIII.15: Temperature profile for logger 0020b (Lower Sunrise side channel) compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0020b is large, and even minimum temperatures exceed maximum Watt Ave. temperatures in late Spring. The extremely large fluctuation in mid-May indicate that the channel went dry.

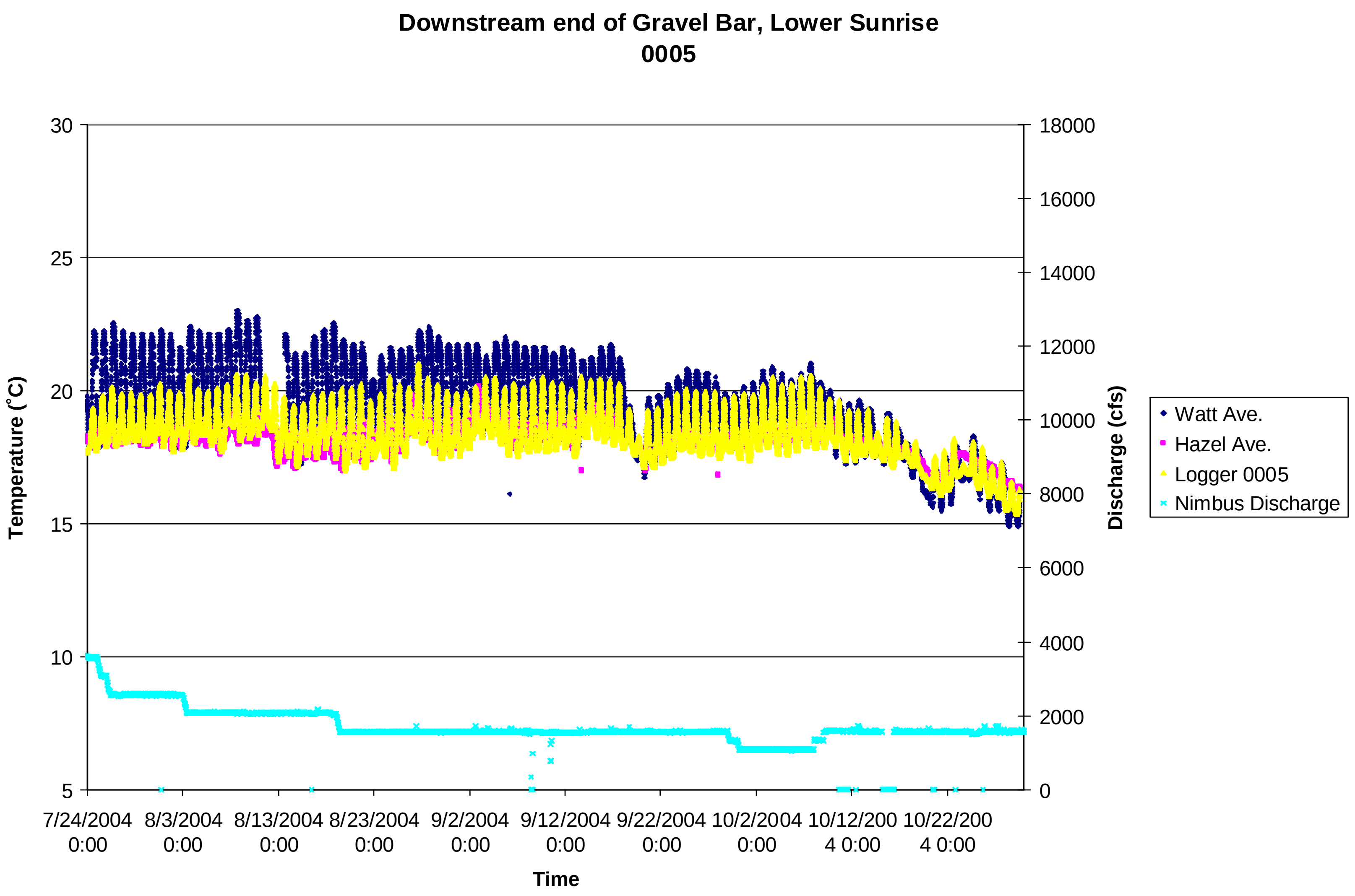


Figure VIII.16: Temperature profile for logger 0005 (Lower Sunrise) compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0005 is moderate, and maximum values are mostly below those at Watt Ave.

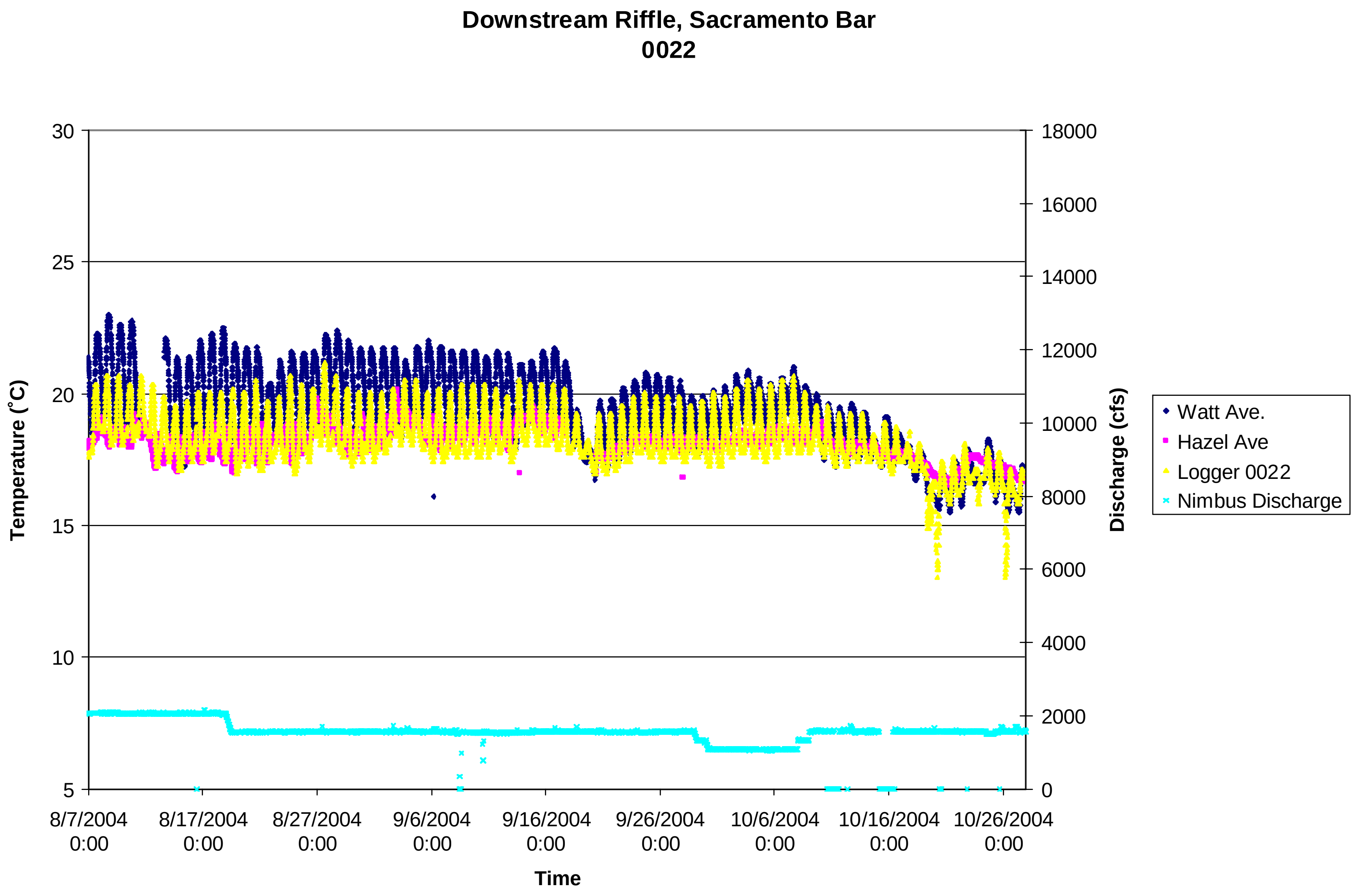


Figure VIII.17: Temperature profile for logger 0022 (Sacramento Bar downstream riffle) compared to Hazel and Watt Avenue records. The temperature fluctuation recorded by logger 0022 is moderate, and maximum values are below those at Watt Ave., except in the fall.

Appendix F: Andrew Head Senior thesis- Modification of intergravel dissolved oxygen content by spawning steelhead

Modification of intergravel dissolved oxygen content by spawning steelhead

Andrew Head
Unpublished Senior Thesis
CSUS Geology Department
Submitted to Dr. Tim Horner
May 20, 2005

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Abstract

Dissolved oxygen (D.O.) levels were monitored in steelhead redds in the Lower American River, CA during the Spring 2004 spawning run. The American river is a regulated river controlled by Folsom and Nimbus dams. Spawning habitat is limited, and previous studies have shown that spawning steelhead often construct redds in areas with marginal inter-gravel D.O. The hypothesis of this study is that steelhead and other salmonids modify the stream bed and improve D.O. levels during spawning. The project began after observing salmonids spawning in areas where inter-gravel D.O. is known to be low.

Miniature drive point tips were installed in four steelhead redds. All sampling tips were placed at the depth of the egg pocket, and each redd was instrumented with four tips that formed a longitudinal transect from the upstream side to the tail spill of the redd. Field parameters including p.H., D.O., water level, and surface water velocity were measured at each site. A flow-through cell and micropurging technique minimized impact on the redds.

Results show a higher level of D.O. in the egg pocket than other nearby inter-gravel sites. Average upstream D.O. was 5.5 mg/l, average egg pocket D.O. was 8.2 mg/l, average tail spill D.O. was 6.9 mg/l, and the downstream D.O. averaged 5.3 mg/l. The D.O. spike around the egg pocket is interpreted to show modification and enhancement of gravel permeability by spawning salmonids.

Average D.O levels decreased from 7.2mg/l to 3.0mg/l during the study period. As the spawning season progressed, lower hyphoreic flow, infiltration of fines, and accumulating metabolic waste have all contributed to oxygen consumption. This project explains the importance of modifications that salmonids make to their environment, and helps explain spawning site selection in areas with low inter-gravel D.O. levels.

Background and purpose of study

Steelhead (*Oncorhynchus Mykiss*) are one of the most sought after sport fish in the western United States, but as of March 1998, Central Valley steelhead have been listed as a threatened species. 95% of salmonid habitat in California's Central Valley has been lost, mainly due to mining and water development activities (Reynolds et. 1993). Historically, anadromous salmonids had access to over 125 miles of spawning habitat in the upper reaches of the American River. However, since the early 1900s, access has been impeded by dams constructed for mining debris containment, flood control, and water supply diversions. Construction of Folsom and Nimbus dams in 1955 permanently blocked upstream passage. Anadromous salmonids are now restricted to the lower 23 miles of the American River extending from Nimbus Dam to the Sacramento River (www.waterforum.org). Information from this study will be valuable to steelhead habitat restoration projects on the American river.

Four steelhead redds were monitored during the spring 2004 spawning season in a side channel near the lower sunrise access area on the American river. The American river is located in northern California northeast of Sacramento (figure 1). Standard field parameters including, dissolved oxygen, pH., and conductivity were measured once weekly for a duration of seven weeks, The purpose of this monitoring was to evaluate changes the steelhead make to the substrate during spawning.

Dissolved oxygen levels in natural systems are dependent on many variables such as temperature, salinity, turbulence, and photosynthetic activity, and are one of the most important limiting factors for spawning salmonids. The purpose of this study is to become more familiar with the processes of steelhead spawning as they affect dissolved oxygen levels, and to study how steelhead may manipulate stream substrate to enhance gravel permeability during spawning.

This study was conducted after observing the emergence of steelhead fry in areas known to have inter gravel D.O. levels as low as 1.0 mg/l. This is very puzzling, because steelhead, Chinook salmon, and Coho salmon exhibite avoidance behaviors of water that is low in dissolved oxygen (Warren et al

1973). Laboratory studies suggest that developing salmonid eggs need inter-gravel D.O. levels greater than 5.0 mg/l for normal healthy development (water quality assessment, 1996). Concentrations below 5mg/l may adversely affect function and survival of biological communities and below 2mg/l leads to death in most developing fish embryos (water quality assessment, 1996). Successful incubation of salmonid embryos depends on adequate oxygenation and removal of metabolic waist (Barnard, and McBain, 1994), which in turn depends on adequate inter-gravel flow of water past the eggs.

Previous studies

Many previous studies have been conducted with regard to salmonid spawning habitat, including pebble counts, permeability measurements, and the effects of infiltrating fines (Water quality assessment, 1996). All of these variables affect D.O. levels, but very few studies have been conducted that examine localized D.O. levels with respect to the location in the redd. Although there has been extensive research done on the effects of D.O. on incubating salmonids in the laboratory, there is little information on D.O. levels experienced by salmonid embryos in complex natural systems. It is very important to be familiar with the D.O. levels inside of natural redds, and to conduct more comprehensive regional studies before determining if an area is suitable for spawning.

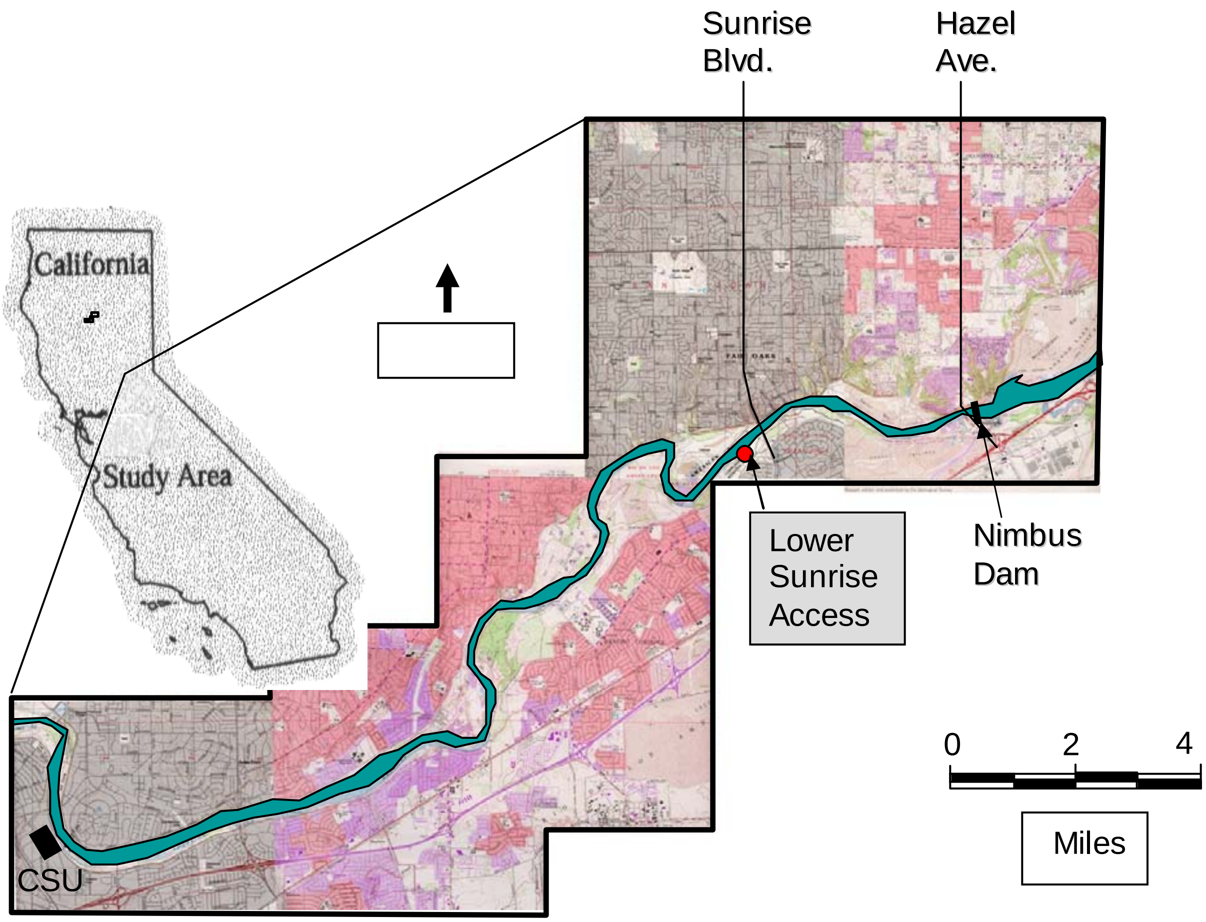

Figure 1: Location of study area.

Equipment and Methods

Four different steelhead redds were examined in this study. Each of the redds was instrumented with four piezometer points at the following locations: upstream from the redd, in the egg pocket, in the tailspill, and downstream from the redd. The four steelhead redds that were selected showed a well developed egg pot, which helped determine the location of the eggs within the redd. Fisheries biologists from the California Department of Fish and Game and the United States Bureau of Reclamation assisted in installation of monitoring points to the depth of the egg pocket. All other monitoring points were installed at this depth throughout the individual redds (figure 2).

Piezometer points

Many authors have utilized piezometers for extracting inter-gravel pore water samples, but most use piezometers made out of polyvinyl chloride pipe (PVC). (Baxter, Hauer, Woessner, 2003). The piezometer points we used are typically used for measuring volatile gasses in soil, but the robust stainless steel construction worked well for penetrating through the stream gravels into the hyporheic zone. The total length of the piezometer tip was 6cm, with a 2cm screened interval containing 8 evenly spaced holes, allowing us to extract a low volume of pore water. ¼ inch outside diameter polypropylene tubing extended to the surface, and allowed us to get water samples from the piezometer points to the flow-through cell.

Installation of piezometer points

Piezometer points were installed using a drive rod and slide hammer. The drive rod is a steel pipe with a machined sleeve that rest over the collar of the piezometer points. After pounding the drive rod into the substrate to a desired depth, the drive rod is carefully removed leaving the piezometer tip in the substrate (Figure 3).

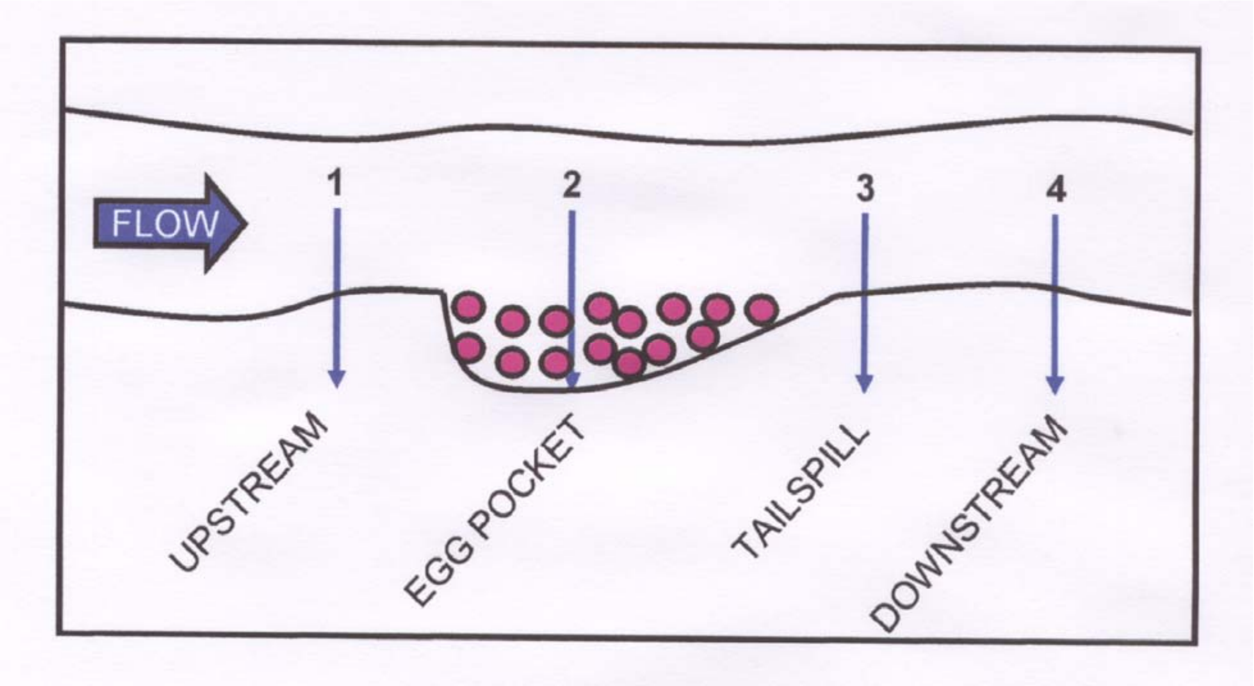

Figure 2: Cross sectional view of redd instrumented with piezometer points. All points are installed to the depth of the egg pocket.

Figure 3: **a)** Piezometer points were used to instrument the steelhead redd, **3b)** A drive rod and slide hammer were used to install piezometer points.

Monitoring meters

An inflatable raft equipped with a car battery, peristaltic pump (Geotech brand), low volume flow-through cell (Geotech), and D.O. (YSI model 58), ph (Orion model 210A), and conductivity meters (Orion model 128) were used to measure standard field parameters (Figure 4).

Monitoring technique

A micro purging technique was used to withdraw small amounts of pore water, and to minimize impact to the steelhead redd. This technique also minimized the effect of outside atmospheric influence on the sample. Using the 600 rpm setting on the peristaltic pump maintained appropriate flow past the probe tips, as required for D.O. measurements. All meters were calibrated on site before each day of sampling.

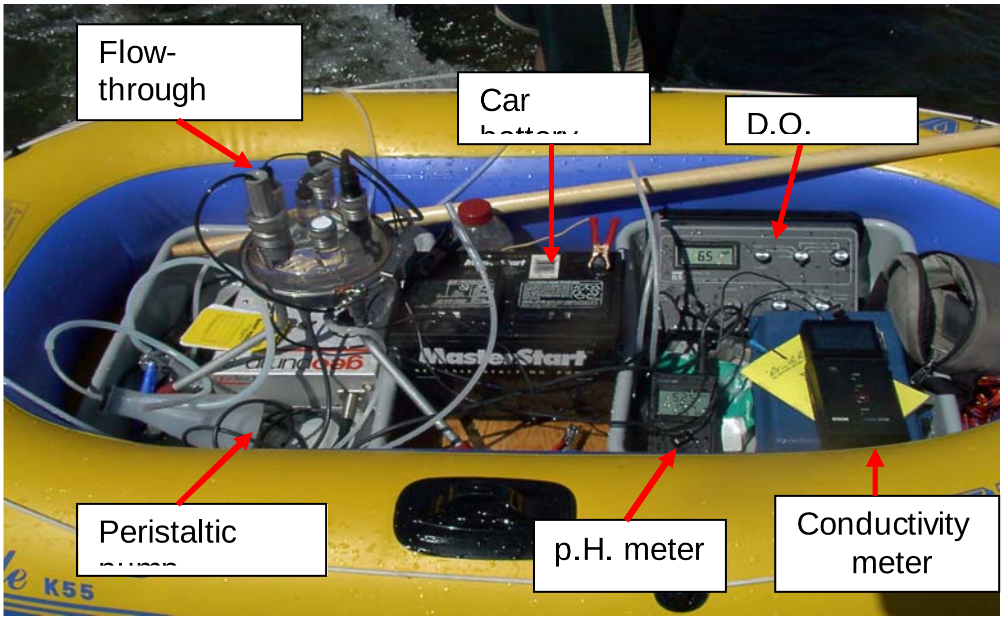

Figure 4: Photograph of inflatable raft equipped with meters used for field measurements.

Results

Results from seven weeks of field measurements are shown in figures 5, 6, 7, and 8, which shows D.O. levels versus location of the redd. In redd number 1, which is the furthest upstream site (figure 5), shows an increase in D.O. levels from the upstream location within the redd, to the egg pocket location and D.O. levels remain high throughout the redd except for a slight decrease at the downstream location on 3/13/2004. Unfortunately data was only obtained on 3/13/2004 and 3/16/2004 due to the removal of monitoring tips from vandals.

Measurements from redd number 2 (figure 6), shows a spike in D.O. over the egg pocket on 3/13/2004, 3/16/2004, and 3/18/2004. A dramatic decrease in D.O. over the egg pocket on 4/23/2004 and 5/1/2004 is a good indication of egg mortality. This could passably explain lower D.O. values directly over the egg pocket and not at any other location within the redd. Data from the upstream and downstream location were unobtainable on 3/26/2004 due to vandalism.

Except for a few outliers D.O levels are usually higher over the egg pocket in redd number 3 (figure 7). Redd number 4 (figure 8), also follows the general trend of higher D.O. levels over the egg pocket very nicely. D.O. levels are consistently higher over the egg pocket during the seven weeks of monitoring.

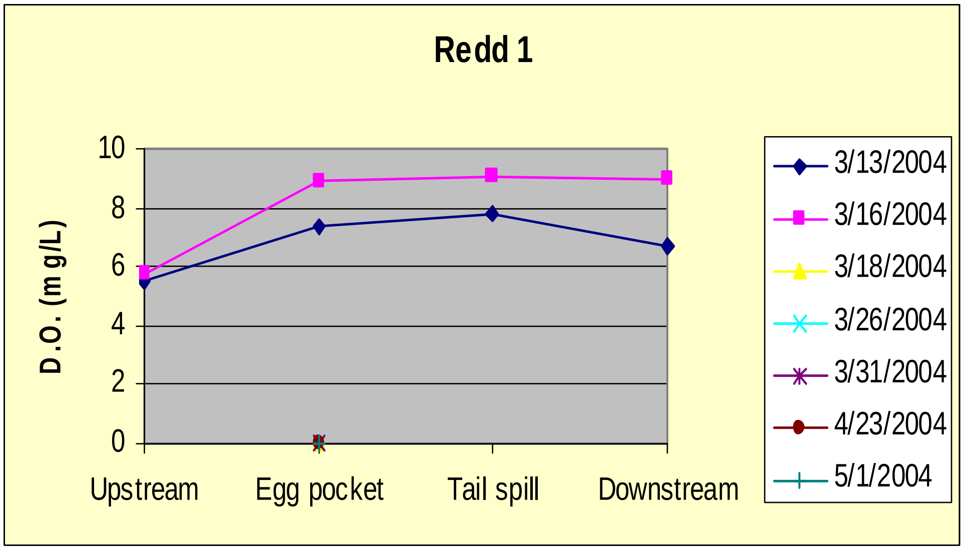

Figure 5: Initial results for redd #1 showed higher D.O. in the egg pocket and downstream from the redd. Spawning steelhead on the site prevented measurements on 3/18/04. Vandals removed the sampling tips prior to 3/26/04.

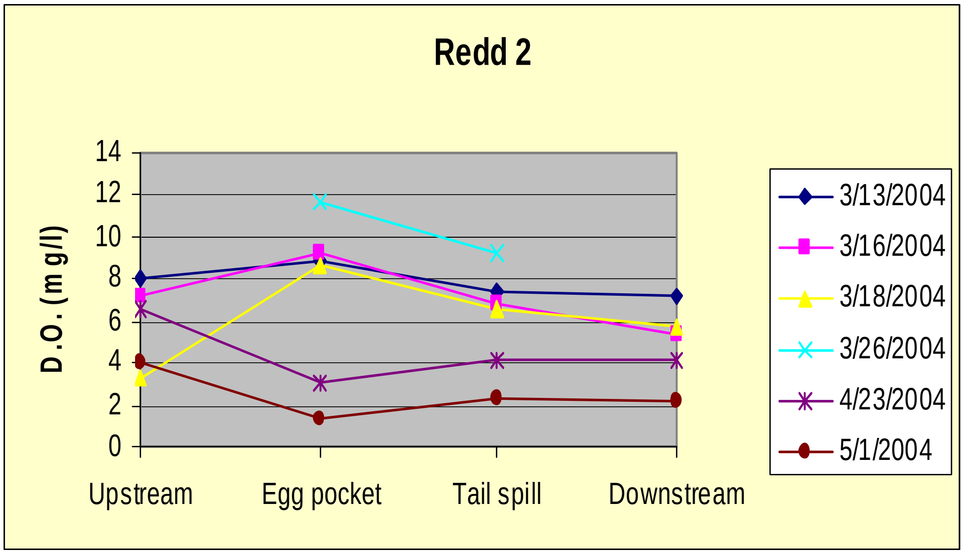

Figure 6: Early measurements show high D.O in the egg pocket. Measurements on 4/23/04 and 5/1/04 are much lower, possibly due to egg mortality.

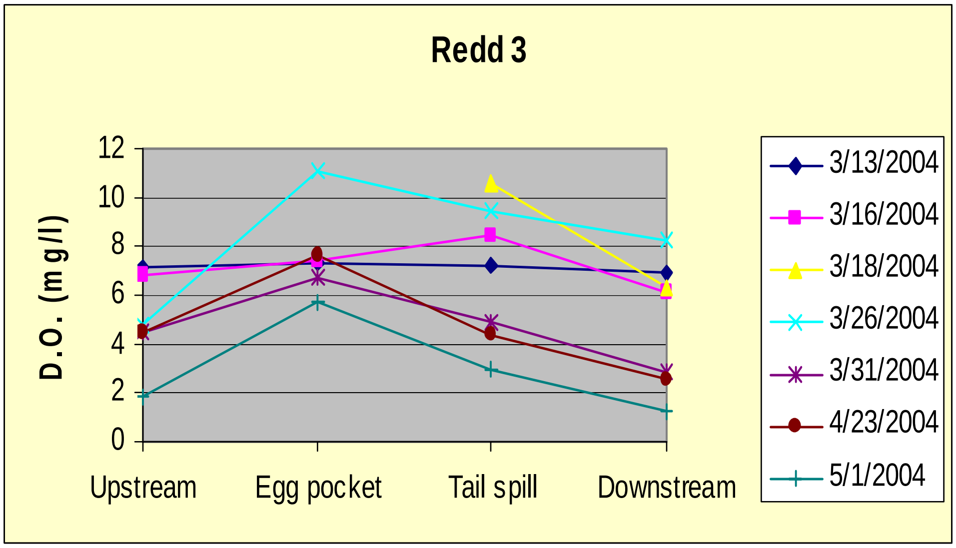

Figure 7: D.O. levels are consistently higher in the egg pocket.

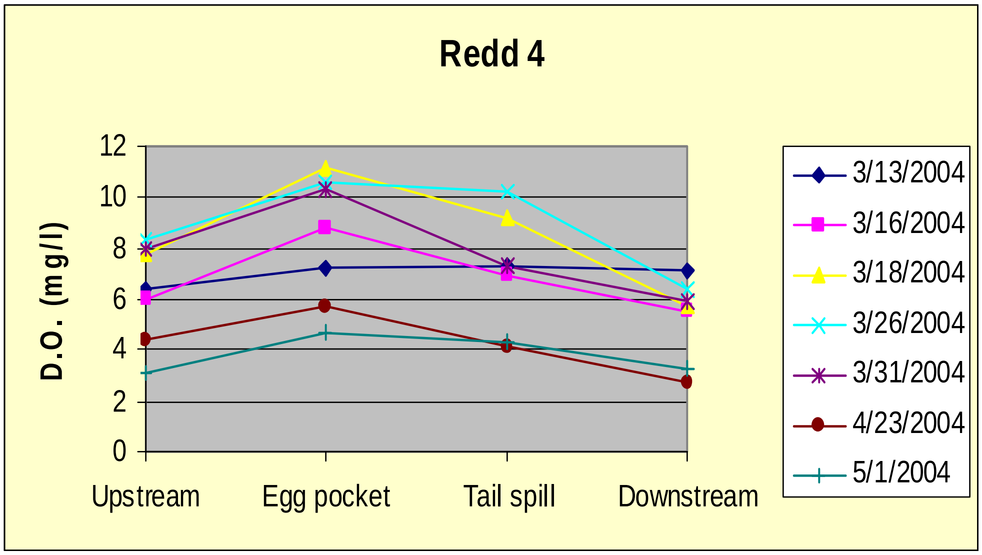

Figure 8: D.O. levels are usually higher in the egg pocket

Conclusions

D.O. levels near the egg pocket are the highest, with an average of 8.2 mg/l (figure 9). The other D.O. levels for other locations within the redd are as follows; upstream D.O. was 5.5 mg/l, tailspill D.O. was 6.9 mg/l, and the average downstream D.O. was 5.3 mg/l during the study period

The D.O. spike around the egg pocket is interpreted to show modification and enhancement of gravel permeability by spawning salmonids, and is not a result of change in stream flow (velocity or depth). A hydrograph of outflow from Nimbus Dam shows that flows during the time of study remained fairly constant (approximately 1800-2000 cfs) (figure 10).

Although average D.O. levels remained the highest over the egg pocket, average D.O. levels decreased with time from 7.2 mg/l to 3.0 mg/l during the seven week study period (figure 11). Lower hyporheic flow due to infiltrating fines, and accumulation of metabolic waste are possible causes for this decrease. Spawning salmonids appear to have increased inter-gravel permeability during the spawning season to make suitable spawning habitat in areas that were previously low in dissolved oxygen.

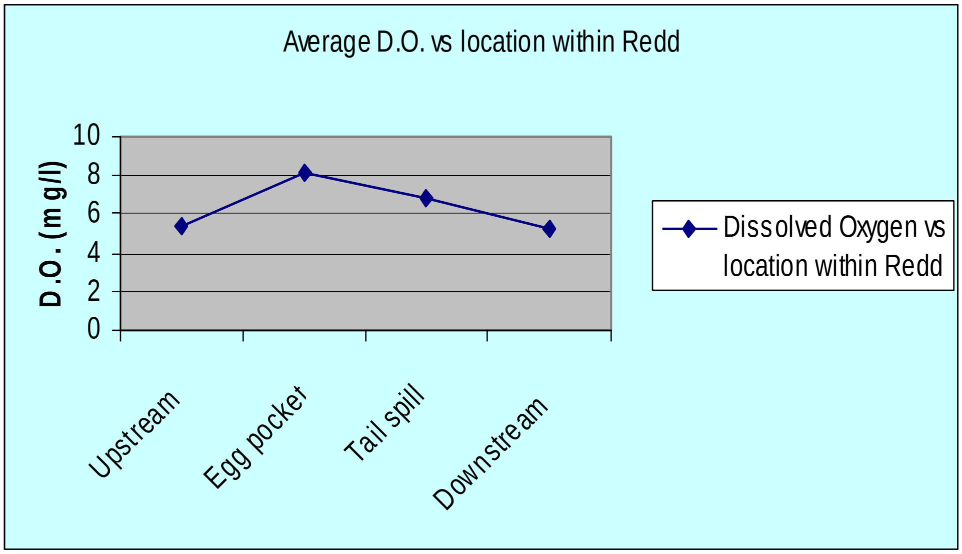

Figure 9: Results indicate that average D.O. levels are highest near the egg pocket.

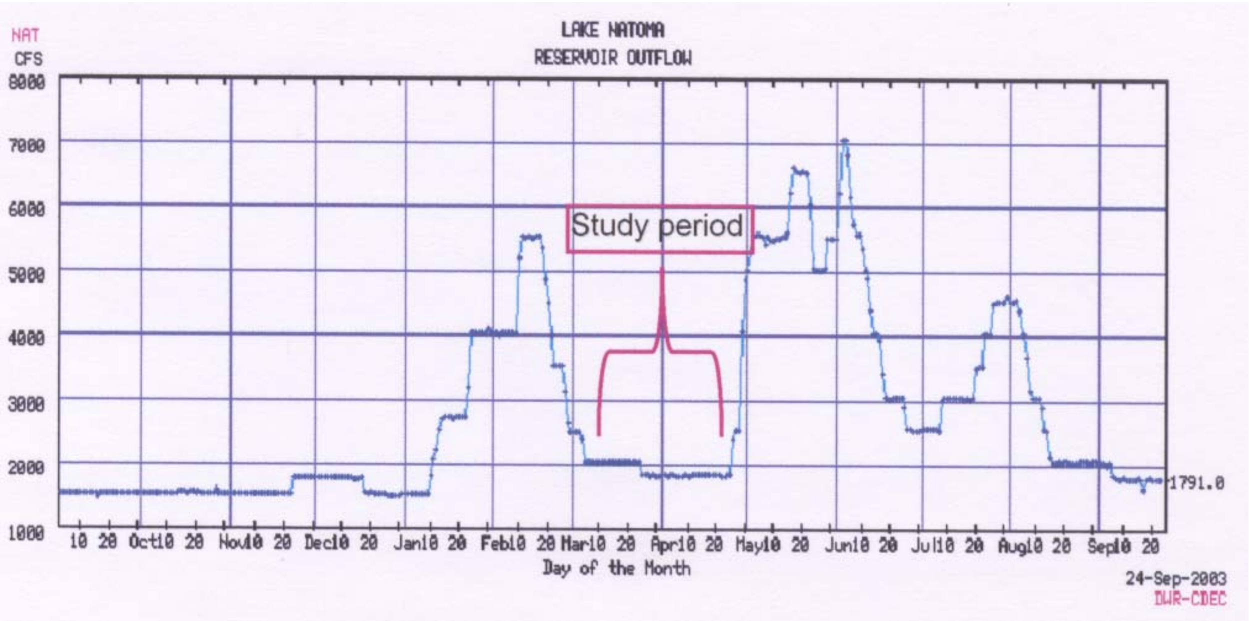

Figure 10: Hydrograph of Lake Natoma outflow, showing constant flows during the seven week study period.

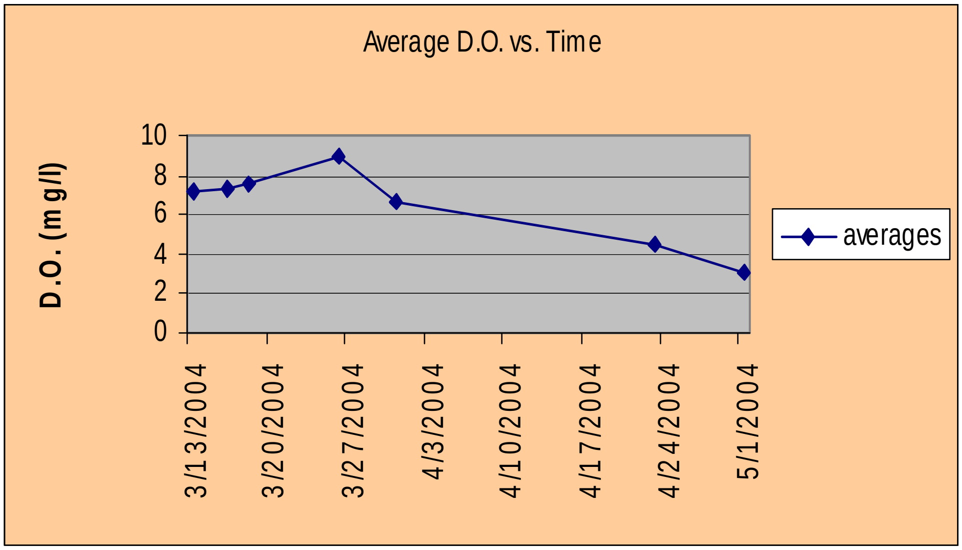

Figure 11: Average D.O. levels decreased with time

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