Site Assessment at the Lower Sunrise Side Channel:

Surface Water, Pore Water and Intergravel Flow

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Submitted to: The Water Forum
SAFCA

Date: Dec. 14, 2005

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Introduction

This report documents results from preliminary field assessment of the Lower Sunrise side channel area, located at river mile 19 on the Lower American River (Fig. 1). The project was conceived during discussions at an American River Operations Group meeting in spring 2005, and work was conducted between June 24 and October 31, 2005. A partnership between SAFCA and The Water Forum provided funding for the project, and work was conducted by Philip Williams and Associates and the CSUS Geology Department. The CSUS Geology Department received an award not to exceed $15,799 for their part in the project, as detailed below.

The concept of this project was to take advantage of a water year with unusually high spring and summer flows, and make a series of measurements through the Lower Sunrise Side Channel area that document surface flow and intergravel conditions similar to those encountered by spawning steelhead. Water releases for early summer 2005 included flows in the 3,000- 6,000 cfs range, and were sufficient to inundate the side channel area. These flows produced conditions that were similar in many ways to those encountered by steelhead (*Onchorhynchus mykiss*) during their Winter spawning run.

The Lower Sunrise side channel area was the site of steelhead redd dewatering during 2003 and 2004, and flow management decisions for the entire Lower American River have sometimes been based on the presence of a few steelhead redds at this site. *Onchorhynchus mykiss* is a federally listed species, so flows were kept artificially high to allow eggs to develop and alevine to emerge from the gravel in the side channel area.

The management decision to protect these redds by releasing extra water was justified by fisheries biologists, but there are competing demands for American River water. It may be beneficial to store cold water instead of releasing it during the spring runoff period, and delta water demands during a hot, dry summer can deplete reservoir storage. With these competing interests in mind, long-term management goals are to restore the Lower Sunrise Side Channel site so that steelhead redds are not dewatered by spring flow fluctuations, and avoid excess water releases that were previously used to protect these redds. The ultimate solution is envisioned as a wider, deeper channel with continuous flow as low as 1,500 cfs. Currently, the side channel is only inundated when flows exceed 3000 cfs. This new design would give steelhead a place to spawn without danger of dewatering the redds.

A larger proposal to rehabilitate the area will be submitted to appropriate funding agencies in the upcoming months, but in the meantime, high summer flows allowed the project team to do some initial monitoring and site evaluation. Measurements documented in this report (and the complimentary hydrology report submitted by Philip Williams and Associates) will be used during the design-build phase of the restoration project, and will give an accurate indication of existing conditions that attract steelhead to the site. This pre-project monitoring will allow more accurate project design, and will also serve as a reference point for later monitoring and evaluation of the success of the restoration project.

Tasks

The CSUS Geology project focused on evaluation of surface water, inter-gravel pore water, and intergravel flow conditions in the Lower Sunrise side channel area. Six tasks were completed before the October 31 project end, and an additional task will be completed during high winter flows in 2006. These tasks and corresponding results are summarized below.

Task 1: Install mini-piezometers

Ten sets of nested mini-piezometers were installed in the side channel area. These mini-piezometers were used to collect pore water samples and measure vertical gradient (upwelling and downwelling) in the gravel. Mini-piezometers consist of small, stainless steel sampling tips that were connected to the surface with 6 mm diameter plastic tubes (Figure 2). A nested piezometer is a pair of closely spaced shallow and deep monitoring points that allows comparison of physical or geochemical conditions at different depths in the gravel. All sites had a 30 cm deep piezometer, and this was paired with piezometers installed 60 and/or 90 cm deep in the gravel. 30 cm was chosen as a standard piezometer depth because this is a typical depth for redd formation by spawning salmonids, and is consistent with the size (depth) of natural redds on the American River. 60 cm and 90 cm depths were used to compare surface water to deeper water sources, and determine the amount of surface water exchange through the gravel.

Piezometers formed a longitudinal transect through the proposed side channel area, and included upstream and downstream monitoring points that were outside of the proposed restoration project (Figure 3). Mini-piezometer locations were recorded using a high resolution GPS, accurate to within 20 cm. UTM locations of the mini-piezometer nests are summarized in Table 1. With all points counted at all depths, a total of 17 mini-piezometer monitoring points was used to evaluate the side channel gravel conditions. A complete description of piezometer depths in each cluster is included with field parameter summaries (Tables 2 and 3).

Task 2: Measure dissolved oxygen and other field parameters

Field parameters (dissolved oxygen, pH, temperature, electrical conductivity and turbidity) were measured twice during the project to document surface water and intergravel conditions in the side channel area. The first sampling event was conducted on July 7-8, with river flows of 3,500 cfs, and followed late spring flows of 6,000 – 8,000 cfs (Figure 4). The second sampling event was conducted on July 27 at a flow of 3,500 cfs, and followed river conditions that had been warm and stable for several weeks (Figure 4). These sampling events were relatively close in time because river flows were projected to drop below 3,000 cfs in August, at which time the side channel would be dry. Summer monitoring and evaluation was designed to use higher flow conditions whenever possible.

Surface water dissolved oxygen (DO) values were measured using a YSI model 50 field meter, geotech peristaltic pump and geotech flow-through chamber. This technique minimized contamination from atmospheric oxygen, and maintained appropriate flow velocity past the DO probe tip. Electrical conductivity (EC) and pH were measured with Orion field meters, and intergravel temperature was measured with a Fluke thermocouple meter and type "K" thermocouple wire, inserted into the mini-piezometers. Turbidity was measured with a DRT model 15 turbidity meter. All meters were calibrated daily or twice daily in the field (using calibration fluids where appropriate), and standard field methods were used to ensure accuracy and reproducibility of results.

Complete results from field parameter measurements are shown in Tables 2 and 3, and a summary of average (mean) values is given in Table 4. Although this is primarily a data report, several trends and averages from Table 4 are worth noting.

Dissolved oxygen is critical for egg and alevine development, and can be a primary limiting factor for spawning habitat quality. All dissolved oxygen measurements from the first sampling event were relatively high, indicating rapid exchange of oxygenated surface water with deeper pore water. This may be one of the reasons that steelhead prefer this site. Dissolved oxygen decreased at 90 cm depth in the second sampling event. This is not a concern, since spawning salmonids only interact directly with the top 10-30 cm of gravel, and the juveniles are only present in the gravel during higher flow (winter and spring) conditions that produce cold, oxygenated water.

The overall decrease in D.O. between the first and second sampling events is probably related to summer trends, changes in residence time in the hyporheic zone, and changes in D.O. content of the surface water that serves as a source for hyporheic water. The earlier sampling event was influenced by high flows in May and June 2005 that flushed large volumes of cool, oxygenated water through the gravel (Figure 4). The later sampling event was influenced by four weeks of relatively stable (lower flow) summer conditions with surface water that was lower in D.O. Lower flows resulted in less hyporheic exchange, and a general decrease in D.O. in the stream gravel.

pH shows similar trends, with inter-gravel values that mimic surface water during the early sampling event. Extensive flushing of surface water may extend to a depth of 90 cm., as shown by similar pH values at depth. Three weeks later, pH in inter-gravel samples declined slightly, and there was a slight decrease in pH with depth. This was probably caused by decomposition of (algal) organic matter, production of organic acids, and more stagnant conditions (less hyporheic exchange). pH is not a concern for habitat quality in the Lower Sunrise Side channel.

Electrical conductivity (E.C.) shows a slight increase with depth for both sampling events, probably as a result of increased rock-water interaction in the deeper subsurface. Pore water that has been in contact with minerals and organic matter for longer periods of time tends to pick up dissolved ions, increasing the E.C. Dissolution and oxidation are typical reactions that contribute to this trend. Samples from the shallow pore water were identical to surface water in the first sampling event, indicating heavy mixing of surface water to depths of at least 60 cm.

Temperature tends to decrease with depth in the gravel as a result of heating of surface water and surface gravel during the hot July days. This pattern might be reversed during colder winter flow conditions, so no conclusions or habitat significance are associated with this trend. Additional temperature data that are related to upwelling and downwelling conditions are discussed under Task 7 (below).

Turbidity values have little or no significance. High variability skewed several averages, so trends are obscured. It is possible that some of our less experienced field crew stepped near some sites during sampling. This releases a pulse of muddy water, and increases turbidity. In general, surface water is clear, with low turbidity. There may be an increase in turbidity with depth in the gravel, but this would need further analysis.

Task 3: Measure surface water depth and velocity

Surface water depth and velocity were measured at each mini-piezometer site using a topset wading rod and Price AA or Pygmy current meter. Water velocity was measured at 60% and 80% of total water depth, and raw counts from field measurements were converted to velocity in m/s. The 80% velocity value may be of special interest to fisheries biologists, because this is often taken as the "snout velocity" for anadromous fish.

Complete results from surface water depth and velocity measurements are shown in Table 2 and Table 3. All monitoring points were installed in early July, and at that time areas marginal to the channel were inundated (Figure 3). Although reported flow from Nimbus Dam remained constant (Figure 4), some of these sampling locations were above the water line during subsequent sampling events. Pore water sampling was not affected, because the subsurface was still saturated. Surface water velocity was listed as "dry" with a depth of 0.0 when the surface water level dropped below the gravel surface.

Results were rearranged from upstream to downstream and compared between sampling events in Table 5. For this comparison, 60% of water depth was used as the average current velocity. Current velocity was highest in the upstream riffle and downstream channel, and did not vary significantly between sampling events in these habitat zones. Mean surface velocity for the three riffle sites was 0.5 m/s. Current velocity (and water depth) were lower at sampling sites located along the along the channel margin, as would be expected. Average surface water velocities should be a target for the restoration project, since salmonids may use surface water velocity as a primary spawning site selection factor.

Task 4: Measure upwelling and downwelling conditions and vertical head gradients

A bubble manometer board was used to measure vertical head gradient (pressure differences) between the river bed and mini-piezometer tips installed at the ten permanent monitoring points. When pressure was higher in the river than in the gravel, conditions were downwelling and the gradient was reported as a negative number. When pressure was higher in the stream channel than in surface water, conditions were upwelling, and the gradient was reported as a positive number. Gradients were measure for each piezometer tip in the nested pairs: surface-to-30 cm, surface-to-60 cm, and surface-to-90 cm.

Complete upwelling and downwelling results are shown in Tables 2 and 3. In general, gradient was highest in the top 30 cm of stream gravel, and decreased with depth in the gravel. This is a typical pattern in streams, and indicates that the driving force behind surface water exchange is greatest in the top few cm of stream gravel.

Table 5 shows a comparison of vertical gradient between sampling events and habitat zones. Downwelling gradients of 0.1 – 0.7 at the head of the riffle are extremely high, and support the hypothesis that large volumes of water are flushed through the river gravel in the side channel area. Corresponding upwelling was not observed at the downsteam monitoring points, although upwelling tends to be more diffuse and harder to measure. Task 7 (below) uses temperature to locate the upwelling zone, and will be discussed later. The riffle and downwelling zone are an obvious target for spawning salmonids, with oxygenated surface water delivered to the subsurface.

Task 5: Conduct inter-gravel tracer tests

Meter-scale tracer tests were used to provide information about lateral (horizontal) intergravel flow at the Lower Sunrise side channel area. This is different from the upwelling and downwelling measurements described in Task 4; upwelling and downwelling shows the potential for vertical flow, but does not provide a direct estimate of velocity. Lateral (horizontal) flow is dominant in most geologic systems due to grain packing and preferred grain orientations. Lateral flow velocity through the gravel is a proxy indicator of intergravel permeability, and produces meaningful results in coarse gravel deposits where other types of permeability tests are not appropriate.

During each tracer test, two liters of salt water were injected into an upstream monitoring point, and the progress of the salt water plume was tracked using conductivity meters at downstream monitoring points (Figure 5). An array of large diameter piezometers was installed for each tracer test, than removed after completion of the test. Piezometers were spaced 50 cm, 100 cm, 150 cm and sometimes 200 cm downstream from the injection point. Arrival times of the salt water plume were recorded at each piezometer (Figure 6), and results were converted to seepage velocity using the simple relationship $v = d/t$.

Tracer tests were conducted at twelve locations in the proposed study area: upstream from the project, in a longitudinal section through the side channel, and at an additional site downstream from the project (Figure 7). Results from tracer tests are shown in Table 6. Some tracers missed the monitoring piezometers, and these tests did not produce useable results. Table 6 is limited to the eight tracer tests where at least one monitoring piezometer detected the saltwater plume.

Results showed that gravel in the Lower Sunrise side channel is very permeable, especially in areas outlined as “riffle habitat” in Figure 7. Seepage velocity was lowest in the upstream pool, where fine sediment was common. Seepage velocity was also low at the downstream end of the study area, where surface water velocity was lower and fine sediment began to accumulate again. Seepage velocity in these marginal areas ranged from 0.06 - 0.14 cm/s. Seepage velocity was highest at the head of the riffle, through the upstream riffle, and through the center of the downstream riffle. Seepage velocity in riffle areas ranged from 0.27 - 0.67 cm/s. This is the area where steelhead selectively spawn, so it is likely that high gravel permeability is a factor in spawning site selection.

Task 6: Complete fines infiltration study

The fines infiltration study was postponed until January and February 2006 for two reasons. Fine sediment can be mobilized by high spring runoff or by spawning fish, and neither of these conditions was present during the summer evaluation period. There is also a compositional difference in the summer. Fine sediment that is part of the summer bed and suspended load consists mainly of decaying organic material, and has different composition than the sand, silt and clay that is mobilized during winter and spring events. After consulting with other project members, the fines infiltration study will be started in January, and continued through the spring months when the side channel is likely to experience higher flows. Results from this study will be added as an appendix to this report when they are available in Spring, 2006.

Task 7: Collect temperature data for inter-gravel velocity model

Subsurface temperature data will be used to develop a heat flow model that simulates intergravel flow through the side channel area. This is part of an on-going M.S. project in the CSUS Geology Department. The agreement as part of the Lower Sunrise side channel contract was to collect, tabulate and plot temperature data through the side channel area, with the understanding that the modeling will be done at a later time. The data CD included with this report has Microsoft Excel spreadsheets of temperature data, in addition to digital versions of text, tables and figures.

Temperature data were collected by installing vertical strings of data-logging temperature sensors in the gravel. One string was placed at the head of the side channel, in an area know to have downwelling conditions. This site had temperature sensors at the surface, 30 cm (1 ft), 60 cm (2 ft) and 120 cm (4 ft) depths in the gravel. The second temperature string was installed at the base of the side channel area, in a region predicted to have upwelling conditions (Figure 8). The downstream temperature sensors were located at the surface, 60 cm (2 ft) and 120 cm (4 ft) depths in the gravel. All temperature loggers were set to record information at 15 minute intervals, providing a continuous record of heat flow between the surface and subsurface.

Results from the upstream temperature string are shown in Figure 9. The daily temperature signal is propagated to a depth of 120 cm in the gravel with little lag, indicating high permeability and downwelling conditions in this upstream riffle. This is consistent with gradient measurements and downwelling conditions described in Task 4.

Results from the downstream temperature string are shown in Figure 10. At this location, the diurnal temperature signal is strongly damped, and is not visible at 60 cm depth in the gravel. This indicates upwelling conditions. Upwelling in this area would be consistent with a conceptual model that predicts downwelling at the head of the riffle, and diffuse upwelling at the base of the riffle. Our bubble manometer measurements (Task 4) were not able to identify this upwelling region, because point measurements may miss the critical area or lack the sensitivity required to measure a weaker upwelling signal. Temperature modeling averages hyporheic flow over larger distances, and can provide valuable information about upwelling and downwelling conditions. Additional work with temperature modeling will provide estimates of groundwater flow velocities in the shallow gravel, and will be compared to results from tracer studies.

Summary and conclusions

Several approaches were used to evaluate existing spawning gravel conditions at the Lower Sunrise side channel site. This site is slated for restoration, and it is important to document existing conditions so that the project can be designed to compliment and enhance conditions that are preferred by spawning steelhead.

Lower Sunrise side channel gravels have shallow, fast-moving surface water, high inter-gravel permeability, high dissolved oxygen content in the gravel, high vertical gradient, rapid horizontal intergravel flow, and a high volume of exchange with surface water. These conditions are most pronounced in the shallow riffles that form at the head and middle of the side channel. Conditions are slightly less optimal in the pool that leads into the side channel, at the base of the side channel, and along the margins of the channel. Even in these “marginal” areas, the side channel contains gravel that appears to be suitable for spawning. The ideal restoration project would preserve or create a riffle through the side channel area, and maintain high levels of intergravel flow.

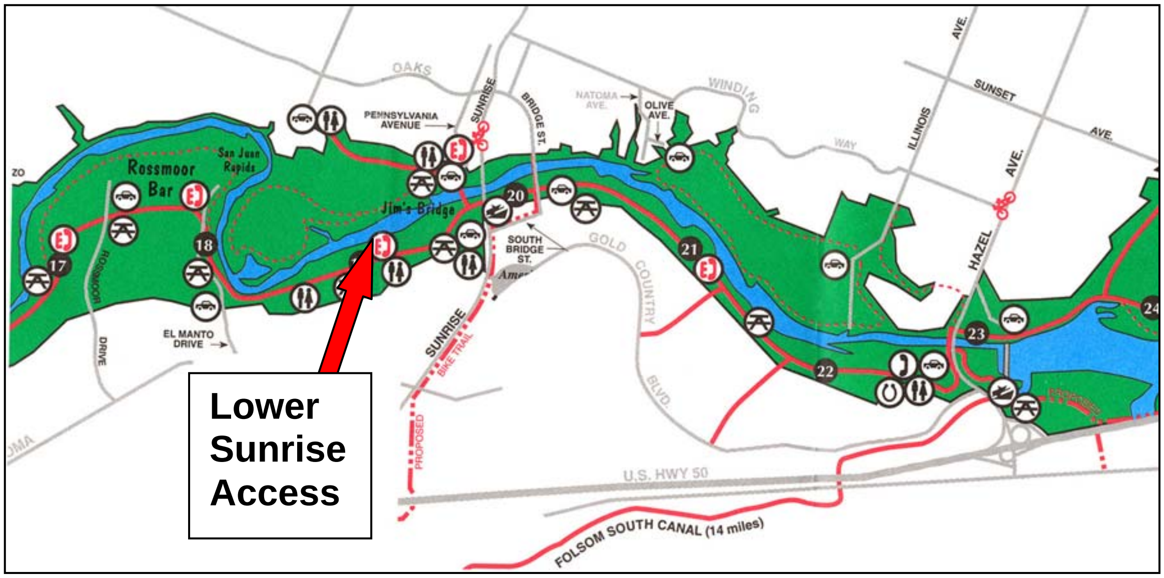

Figure 1: Location of Lower Sunrise side channel project. The Lower Sunrise side channel area is part of a compound, mid-channel bar located at parkway mile 19.2. Modified from Sacramento County Bicycle Trail Map, Department of Recreation, Parks and Open Space.

Figure 2: Photograph of mini-piezometer tip. Mini-piezometer tips were installed to a depth of 30 cm in the gravel using a steel over-drive rod. Piezometer tips were connected to the surface with 6 mm diameter plastic tubing. This allowed pore water samples to be collected from a discrete interval in the gravel. Vertical gradient (upwelling and downwelling) was also measured using these points and a bubble manometer board.

Mini-Piezometer Coordinates

Point ID	UTM Zone 10 Northing (m)	UTM Zone 10 Easting (m)
sc00	4277036.272	650097.562
sc01	4276998.970	650090.191
sc02	4276981.090	650094.785
sc03	4276966.024	650096.210
sc04	4276942.225	650096.906
sc05	4276947.142	650074.488
sc06	4276929.503	650082.459
sc07	4276914.248	650073.658
sc08	4276980.705	650073.374
sc09	4276980.927	650106.997

Table 1: UTM Coordinates are listed for mini-piezometer locations shown in Figure 2. Datum used is North American Datum 1983.

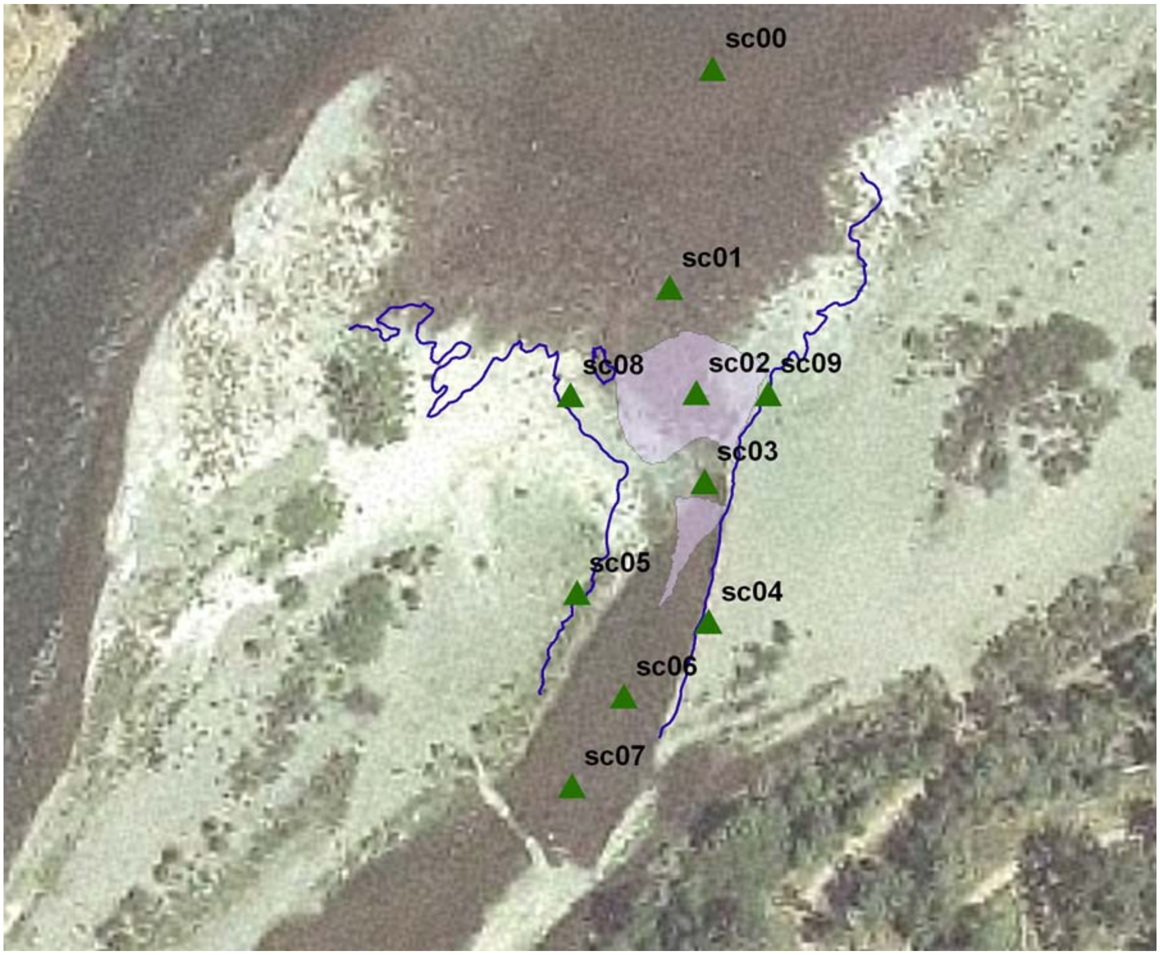

Figure 3: Location map of mini-piezometer installation points in the Lower Sunrise side channel area. Piezometers form a longitudinal transect through the proposed restoration project, and include upstream and downstream monitoring points. Lines at the edge of the channel indicate the position of the shoreline at a flow of 3,500 cfs, and were mapped with high-resolution GPS. Flows of 3,000 cfs or higher create a riffle and side channel that has historically been used for steelhead spawning. The riffle (located in the top third of the side channel) is shaded in purple.

Field Parameters, Lower Sunrise Side Channel

Collected July 7-8, 2005; River flow = 3,500 cfs

Monitoring Point	**Stream Depth (m)**	**60% Current Speed (m/s)**	**80% Current Speed (m/s)**	**Sample Depth (cm)**	**D.O. (ppm)**	**pH**	**E.C. (µS/cm)**	**Temp. (°C)**	**Turbidity (NTU)**	**Gradient**
sc00	0.58	0.52	0.23	0	8.8	7.2	52	17.7	1	N/A
				30	8.7	7.6	55	17.4	175	-0.10
				60	8.2	7.8	54	16.7	70	-0.06
				90	7.6	7.4	55	16.6	41	-0.04
sc01	0.21	0.19		30	6.8	7.5	54	19.4	20	-0.33
				60	5.9	7.4	57	18.6	33	-0.17
sc02	0.15	0.47		30	7.2	7.2	58	18.5	28	0.00
				60	6.9	6.4	59	18.2	45	-0.02
				90	6.3	7.1	59	17.8	65	0.02
sc03	0.21	0.81		30	9.1	7.3	58	18.4	37	-0.06
				60	4.5	7.4	61	20.3	334	-0.05
sc04	dry	0.01		30	5.3	7.3	62	22.5	42	0.02
				60	4.1	7.2	65	22.0	39	
sc05	dry	0.01		30	5.6	6.9	65	19.9	14	dry
				60	6.4	7.0	54	18.7	11	dry
sc06	0.46	0.21	0.15	0	9.0	7.2	63	18.6	5	N/A
				30	5.1	7.1	66	20.4	38	dry
				60	4.4	7.1	60	18.3	72	dry
				90	3.3	7.1	73	17.3	51	dry
sc07	0.24	0.16		30	6.8	7.4	55	18.8	38	0.00
				60	3.9	7.1	60	17.5	16	-0.01
sc08	0.04	0.01		30	8.8	7.1	52	20.3	7	dry
				60	7.2	7.2	50	18.9	3	dry
sc09	dry	0.01		30	6.3	6.8	55	20.6	19	dry
				60	5.8	7.0	55	19.6	63	dry

Table 2: Field parameters and field measurements, July 7-8 sampling event. Sample depths designated “0” depth are surface water measurements.

Field Parameters, Lower Sunrise Side Channel
Collected July 27, 2005; river flow = 3,500 cfs

Monitoring Point	**Stream Depth (m)**	**60% Current Speed (m/s)**	**80% Current Speed (m/s)**	**Sample Depth (cm)**	**D.O. (ppm)**	**pH**	**E.C. (μS/cm)**	**Temp. (°C)**	**Turbidity (NTU)**	**Gradient**
SC00	0.6	0.57	0.38	30	6.3	7.0	49	17.2	3	-0.65
				60	5.3	6.9	52	16.5	2	-0.32
SC01	0.2	0.21	0.10	30	6.7	7.0	52	18.2	1	-0.28
				90	4.0	6.7	55	18.0	1	-0.13
SC03				30	7.9	7.2	54	17.6	2	-0.04
SC04	0	Dry	Dry	30	2.7	6.8	60	23.2	2	Dry
SC05	0	Dry	Dry	30	4.0	6.6	53	16.0	1	Dry
				60	4.6	6.7	53	17.2	1	Dry
SC06	0.5	0.42	0.29	30	3.9	6.7	55	17.6	0	0.00
				60	4.1	6.5	55	17.5	0	0.00
				90	2.4	6.6	61	17.3	1	0.00
SC07	0.3	0.26	0.14	30	3.2	6.5	54	18.9	0	-0.01
				90	2.1	6.7	1	17.3	1	0.00
SC08	0.1	0.12		30	6.6	6.9	51	18.1	8	-0.65
				60	6.9	6.9	51	16.9	1	-0.29
SC09	0	Dry	Dry	30	0.5	7.0	54	28.2	50	-0.29
				60	4.9	7.0	54	17.7	13	-0.15

Table 3: Field parameters for July 27, 2005 sampling event. Stream velocity is considered average at 60% of water depth, although measurements were also taken at 80% of water depth to represent snout velocity for spawning salmonids.

Sampling Events vs. River Flow Conditions

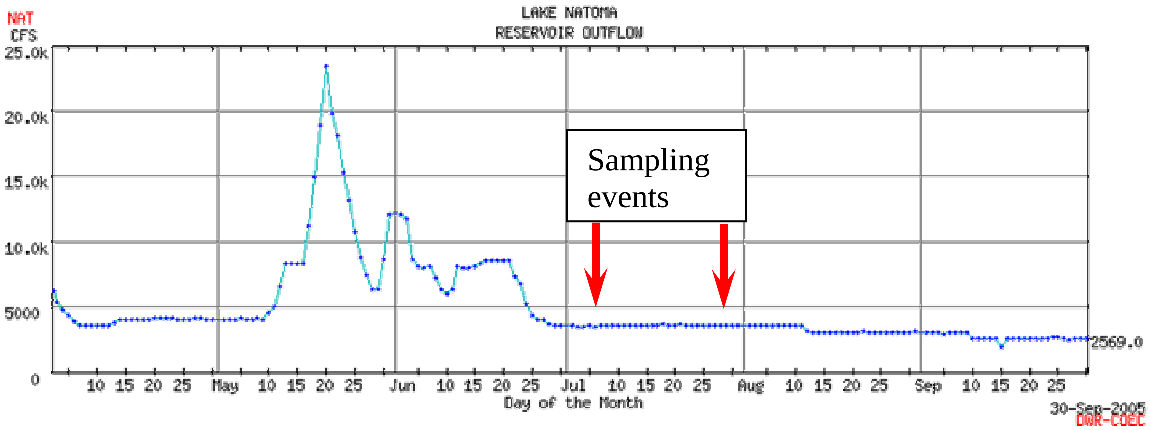

Figure 4: Relationship between river flow and sampling events. Sampling events for surface water and inter-gravel conditions were held on July 7-8, 2005 and July 28, 2005. The earlier sampling event followed a period of high flows. River conditions were stable for four weeks prior to the second sampling event. Modified from California Data Exchange (CDEC) web site (http://cdec.water.ca.gov/).

Summary and Average Values of Field Parameters

July 7-8 vs. July 21 Sampling Events

Parameter, depth, units	July 7-8 sampling event		July 21 sampling event	
	Mean	number of samples	Mean	number of samples
Surface water D.O. (mg/l)	8.9	n=2	N.A.	0
Average DO @ 30 cm	7.0	n=10	4.6	n=9
Average DO @ 60 cm	5.7	n=10	5.2	n=5
Average DO @ 90 cm	5.7	n=3	2.8	n=3
Surface water pH	7.2	n=2	N.A.	0
Average pH @ 30 cm	7.2	n=10	6.8	n=9
Average pH @ 60 cm	7.2	n=10	6.8	n=5
Average pH @ 90 cm	7.2	n=3	6.6	n=3
Surface water E.C. (µS/cm)	58	n=2	N.A.	0
Average E.C. @ 30 cm	58	n=10	54	n=9
Average E.C. @ 60 cm	58	n=10	53	n=5
Average E.C. @ 90 cm	62	n=3	58	n=2
Surface water temp. (° C)	18.2	n=2	N.A.	0
Average temp. @ 30 cm	19.6	n=10	19.4	n=9
Average temp. @ 60 cm	18.9	n=10	17.2	n=5
Average temp. @ 90 cm	17.2	n=3	17.5	n=2
Surface water turbidity (NTU)	3	n=2	N.A.	0
Average turbidity @ 30 cm	42	n=10	7.3	n=9
Average turbidity @ 60 cm	19	n=10	3.3	n=5
Average turbidity @ 90 cm	52	n=3	17.5	n=2

Table 4: Summary and comparison of field parameter measurements. A decrease in dissolved oxygen and increase in pH between sampling events is probably related to lower summer flow conditions.

Upstream-downstream comparison of depth, velocity and gradient between sampling events

		July 7-8 sampling event			July 27 sampling event		
Sample location	**Habitat zone**	**Depth (m)**	**Velocity (m/s)**	**Gradient**	**Depth (m)**	**Velocity (m/s)**	**Gradient**
sc00	upstream pool	0.58	0.52	-0.1	0.60	0.57	-0.7
sc01	head of riffle	0.21	0.19	-0.3	0.20	0.10	-0.3
sc02	riffle	0.15	0.47	0.0	n.a.	n.a.	n.a.
sc08	channel margin	0.04	0.01	dry	0.10	0.12	-0.7
sc09	channel margin	dry	0.00	dry	0.00	dry	-0.3
sc03	riffle	0.21	0.81	-0.1	n.a.	n.a.	0.0
sc05	channel margin	dry	0.00	dry	0.00	dry	dry
sc04	channel margin	dry	0.00	0.0	0.00	dry	dry
sc06	downstream channel	0.46	0.21	n.a.	0.50	0.42	0.0
sc07	downstream channel	0.24	0.16	0.0	0.30	0.26	0.0

Table 5: Comparison of surface water depth and velocity and vertical gradient between sampling events. Samples are oriented from upstream to downstream, and habitat designations are listed in the second column. Riffles tend to have higher surface water velocity and higher vertical gradient.

Figure 5: Piezometer array with dedicated electrical conductivity meters was used to track progress of the salt water plume during tracer tests. Piezometers were spaced 50 cm apart, and salt water was injected in the upstream piezometer (barely visible to the right of this photo).

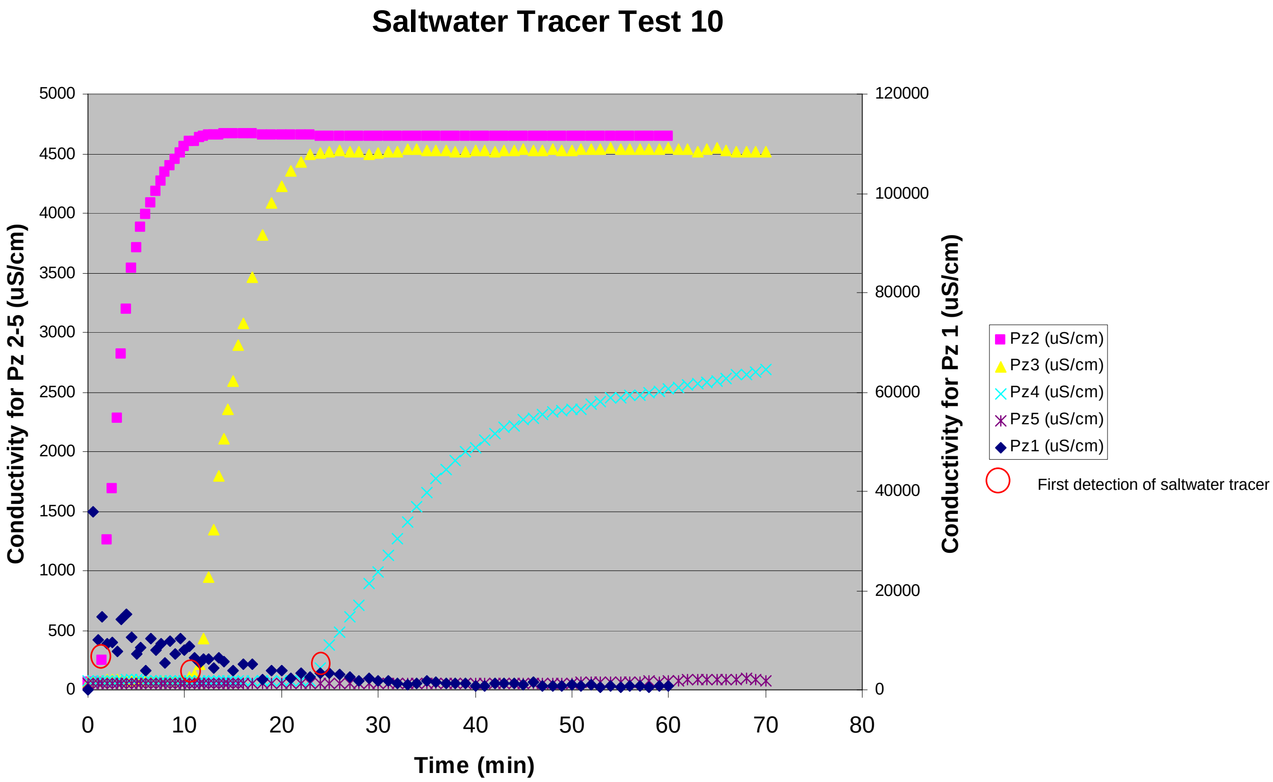

Figure 6: Arrival times for the saltwater plume were used to calculate intergravel flow velocity.

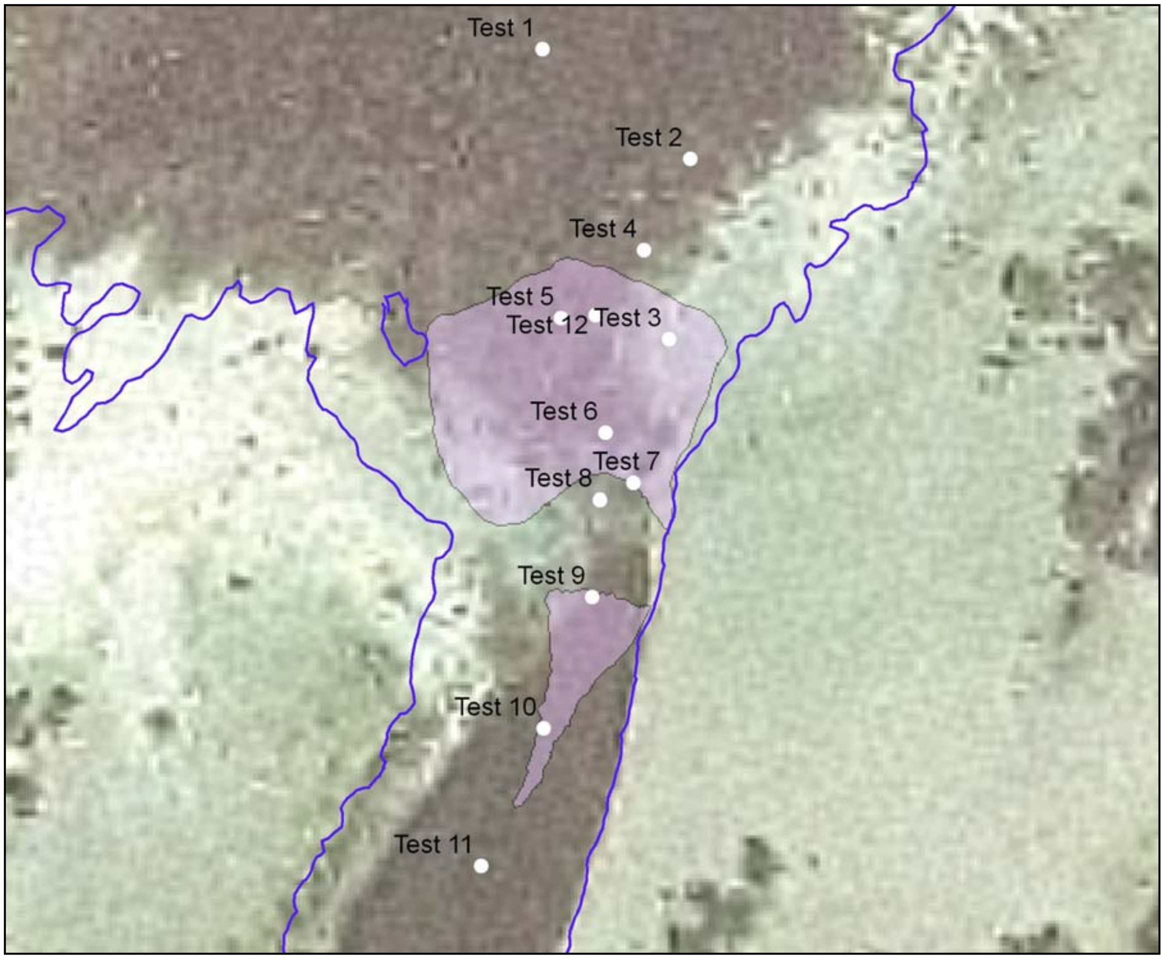

Figure 7: Location of saltwater tracer tests through the Lower Sunrise side channel area. Tracer tests were used to estimate (horizontal) intergravel seepage velocity. The riffle area is shaded in purple.

Test Site	**1**	**3**	**6**	**7**	**9**	**9a**	**10**	**11b**
Distance to first piezometer (cm)	58	50	100	150	50	58	50	50
First piezometer seepage velocity (cm/s)	0.06	0.83	1.11	0.42	0.14	0.39	0.56	0.08
Distance to second piezometer (cm)		100	50				100	
Second piezometer seepage velocity (cm/s)		0.56	0.28				0.16	
Distance to third piezometer (cm)		150	150				150	
Third piezometer seepage velocity (cm/s)		0.63	0.13				0.10	
Average seepage velocity (cm/s)	**0.06**	**0.67**	**0.50**	**0.42**	**0.14**	**0.39**	**0.27**	**0.08**

Table 6: Results from salt water tracer tests. See Figure 7 for location of test sites. Average seepage velocity is reported in cm/s for all tests where the saltwater plume was detected at downstream monitoring points. Seepage velocity was calculated using the relationship v = d/t.

Figure 8: Location of vertical temperature strings. Data collected from 30, 60, 90 and 120 cm in the gravel will be used to model flow through the gravel, and will be compared to results from salt water tracer tests.

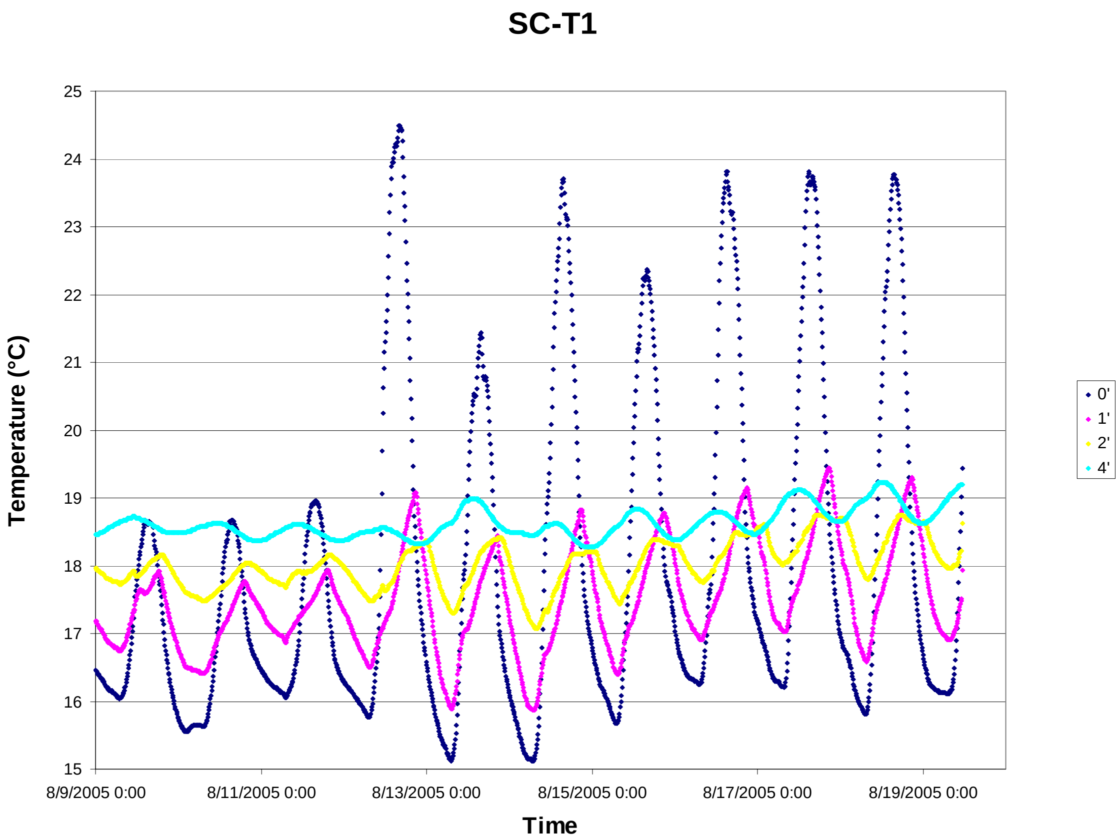

Figure 9: Temperature data collected from the head of the Lower Sunrise side channel (location SC-T1 on Figure 8). This information will be used to model intergravel flow. The diurnal temperature signal is propagated to 120 cm (4 ft) depth in the gravel, indicating downwelling conditions.

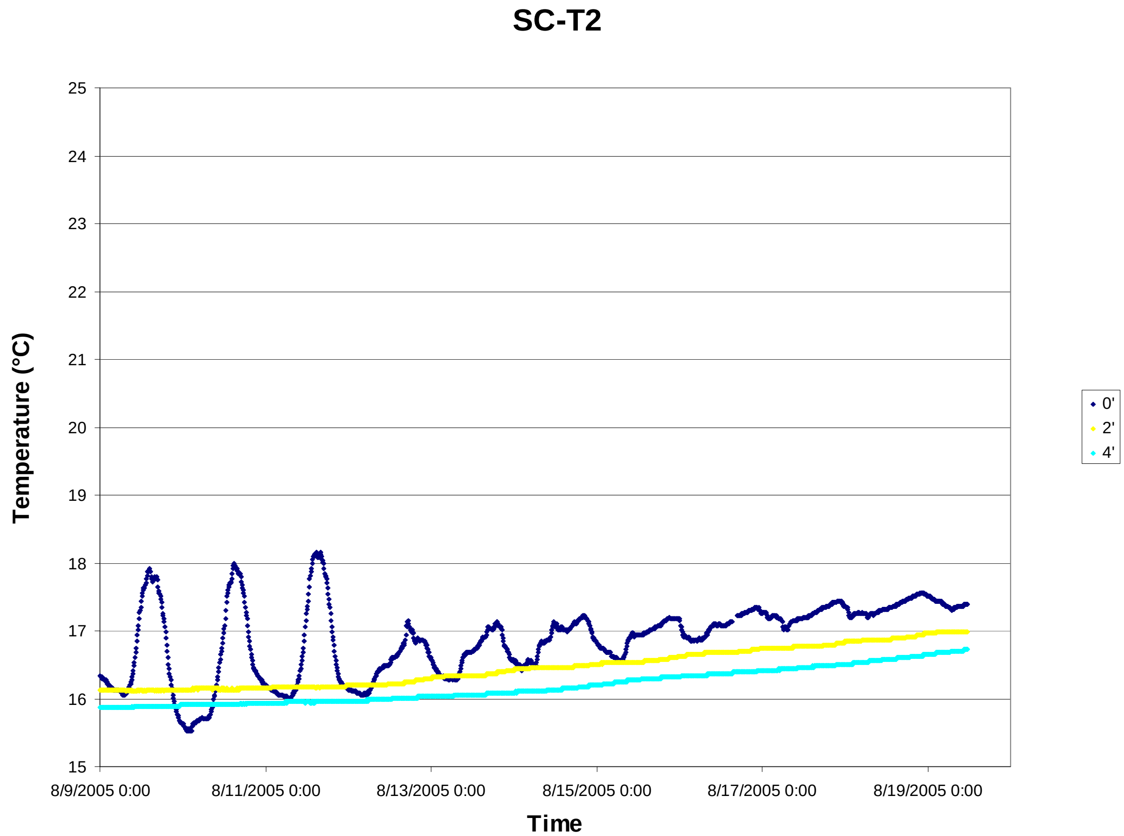

Figure 10: Temperature data collected from the base of the Lower Sunrise side channel (location SC-T2 on Figure 8). This information will be used to model intergravel flow. The diurnal temperature signal is damped, and is not propagated to the temperature logger located at 60 cm (2 ft) depth in the gravel. This indicates upwelling conditions.