NATURAL WATER CHEMISTRY AND VERTICAL HYDRAULIC GRADIENT IN THE HYPORHEIC ZONE OF THE COSUMNES RIVER NEAR SACRAMENTO, CALIFORNIA

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A Thesis

by

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Abstract

of

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This project was developed to determine if a relationship exists between natural water chemistry and vertical hydraulic gradient within the hyporheic zone of the Cosumnes River near Sacramento, California. In addition, chemistry and gradient results will be compared to areas of suitable spawning habitat to determine if any relationships exist.

Water samples were collected from the hyporheic zone of the streambed. Sampling events occurred in the spring and summer of 2002, and in the winter of 2003. Eighteen monitoring points were installed in the streambed. Each monitoring point consisted of three mini-piezometers installed to depths of one-foot, two-feet, and nine-feet below the surface of the streambed. Water samples were analyzed for dissolved oxygen, pH, and electrical conductivity in the field. Water samples were also preserved for laboratory analysis of major ion chemistry including dissolved sodium, potassium, magnesium, calcium, chloride, sulfate, and dissolved organic carbon. At each monitoring point, vertical hydraulic gradient was measured at the one- and two-foot sampling intervals.

Results indicate areas that are upwelling are more likely to have chemistry similar to water samples collected at depth and areas that are downwelling are more likely to have chemistry similar to the surface water of the stream. In addition, results show that a relationship may exist between major ion chemistry and suitable habitat for salmon spawning.

________________________________, Committee Chair
Dr. Timothy C. Horner

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1.0 Introduction

1.1 Salmon Spawning Habitat

Pacific Coast Salmonids are considered a depressed species due to over-fishing and increasing urbanization throughout the Pacific Northwest. Many research and restoration projects are currently ongoing in order to help salmon recover a portion of former population numbers. The environment of the hyporheic zone is crucial to spawning habitat. Hyporheic zones increase "solute residence times, and more specifically solute contact with substrates, in environments with spatial gradients in dissolved oxygen and pH" (Bencala, 2000). Water within the hyporheic zone is a mixture of stream and subsurface water that is continuously changing (Bencala, 2000).

Spawning grounds are typically visited by the same species year after year (Powers, 1941) and previous research projects have established the ideal habitat for salmon spawning. Chapman et al., (1986) stated that salmon select spawning sites solely on the basis of velocity, depth and substrate. As part of the same research, Chapman studied the Columbia River, and found that salmon spawned in facing velocities of 0.67 meters per second (m/s) to more than 1 m/s and at depths greater than 8.5 meters (m). In smaller streams, it has been found that salmon will spawn in average velocities as low as 20-100 centimeters per second (cm/s) and in only 15-35 centimeters (cm) of water, enough to cover the fish (Bjornn and Reiser, 1991).

Particle size is also a crucial factor in salmonid spawning habitat. Through sieve analysis of spawning gravels, it has been determined that suitable gravels consist of 4.3-5.8% by weight of substrate smaller than 0.85 millimeters (mm) and particles smaller that 6.0 mm made up 15.2-19.2%, by weight of the substrate (Chapman et al., 1986). More generally, substrate particles should be between 1.3 and 10.2 cm, although salmon have been observed moving particles as large as 30 cm (Bjornn and Reiser, 1991). If a redd site contains more fine sediment than average, then seepage velocity in interstitial waters will be reduced. This reduction in velocity creates a problem for developing eggs and alevine by decreasing dissolved oxygen concentrations and inhibiting removal of waste products (Sowden and Power, 1985). A redd that contains too many fines may also hinder the movements of the alevine as they attempt to escape from the subsurface (Sowden and Power, 1985). Although substrate and river velocity preferences have been well documented, it is not clear what is necessary for the survival of developing embryos in the substrate with regard to vertical flow (direction and rate) of water through the gravel or the water chemistry circulating through redds. It has become increasingly important to understand such preferences so that restoration projects can accurately imitate natural conditions.

1.2 Objectives

The objectives of the research are to determine if a relationship exists between the major element chemistry and field parameters and temporal and spatial distribution in the hyporheic zone, where interactions between the surface water and the ground water are significant. In addition, patterns in water chemistry and field parameters are related to vertical hydraulic gradient and streambed morphology in an attempt to determine if natural water chemistry and vertical gradient relate to salmonid spawning habitat quality.

Flows within the hyporheic zone are turbulent and irregular and create areas where interstitial water can flow rapidly, slowly, or not at all. These conditions can create anaerobic environments even in well-oxygenated hyporheic zones (Boulton, 1998). Intergravel water flows vertically and horizontally through the gravel and brings chemical compounds and nutrients to the developing salmon eggs. Intergravel flow also removes waste products from the hyporheic zone. Salmon prefer to spawn in pool-riffle transitions, sites where downwelling currents are common (Bjornn, 1991). However, upwelling zones are also commonly used by spawning salmonids (Geist and Dauble, 1998). Although vertical flow helps to keep the dissolved oxygen levels high, remove waste, supply nutrients, and generally keep the eggs viable, direction may not be as important a factor as the rate of flow of water through nest sites. A portion of this project will involve determining the vertical hydraulic gradient that moves the water flowing through the gravel.

Relationships have been established which relate gravel permeability, or hydraulic conductivity, to salmonid embryo survival. Barnard and McBain (1994) determined that streambed gravels with permeabilities greater than 10,000 centimeters per hour (cm/hr), or approximately 7,900 feet/day ensured an embryo survival rate greater than 85%. Below 7,900 ft/day, considerable scatter existed in the data and a relationship between survival rates and permeability could not be determined (Barnard and McBain, 1994). Therefore, hydraulic conductivity was also measured, using Barnard and McBain's 1994 method, at several locations within the study area to determine if a relationship exists between the hydraulic conductivity of the hyporheic zone and the upstream or downstream portions of the study area, differences in depth within the gravel, changes in the streambed morphology, and the direction of the vertical hydraulic gradient. These relationships will then be analyzed to determine if likely salmonid spawning habitat has suitable rates of hydraulic conductivity.

The final factor to be considered in this study is the relationship between surface and pore water chemistry. A site that is found to be upwelling will have water chemistry similar to that of the local groundwater while a site which is downwelling will have water chemistry similar to the surface water. Certain chemical parameters such as temperature, dissolved oxygen content, or major ion concentrations, may also affect where salmon are likely to spawn and how likely eggs are to survive. Salmon spawn in temperatures ranging from 10-17 degrees Celsius (^{o}C), but incubation of the embryos occurs at temperatures ranging from 4-12^{o}C (Bjornn, 1991). Dissolved oxygen concentrations are perhaps the most important factor in survival of the eggs and alevine. Sowden (1985) found that when dissolved oxygen (DO) was below 4.3 milligrams per liter (mg/l) within the substrate, no eggs survived. He also found that eggs were more likely to survive when DO concentrations rose above 5.2 mg/l. Several chemical analyses have been performed on the interstitial waters to determine if sites are more desirable for spawning due to the chemistry of the interstitial water.

Since olfaction is key to the homing of salmon during their upstream migration (Bjornn, 1991) statistical analyses have been used to determine the water type of each sample with regard to the major ion chemistry. Water type is then related to areas of likely spawning habitat to determine if any relationships exist between the sites of appropriate spawning habitat and natural water chemistry.

1.3 Development of Project

A gravel bar and the immediate downstream course of the Cosumnes River were carefully studied over the course of a year. A system of nested mini-piezometers was installed throughout the study area. These mini-piezometers were used to sample subsurface pore water from the streambed. At each of the nested sites measurements were made that included the vertical gradient of the water. These measurements were made using a bubble manometer board. Permeability data of the upper gravels (1- and 2-foot depths) was also gathered by conducting modified pump tests during the summer of 2002. Chemical measurements that were made in the field included pH, temperature, dissolved oxygen, and electrical conductivity. Samples were also collected for analysis in the lab. These lab samples were analyzed for dissolved organic carbon (DOC), dissolved sodium, potassium, calcium, magnesium, chloride, sulfate, and nitrate.

After all fieldwork and lab analyses were complete, the data were examined to determine whether a relationship exists between the water chemistry, vertical hydraulic gradient, permeability, and salmon spawning locations.

1.4 Site Description

The project was located on the Cosumnes River southeast of Sacramento, California near Highway 16. Figure 1 is a location map of the site (USGS, Carbondale Quadrangle, 1993).

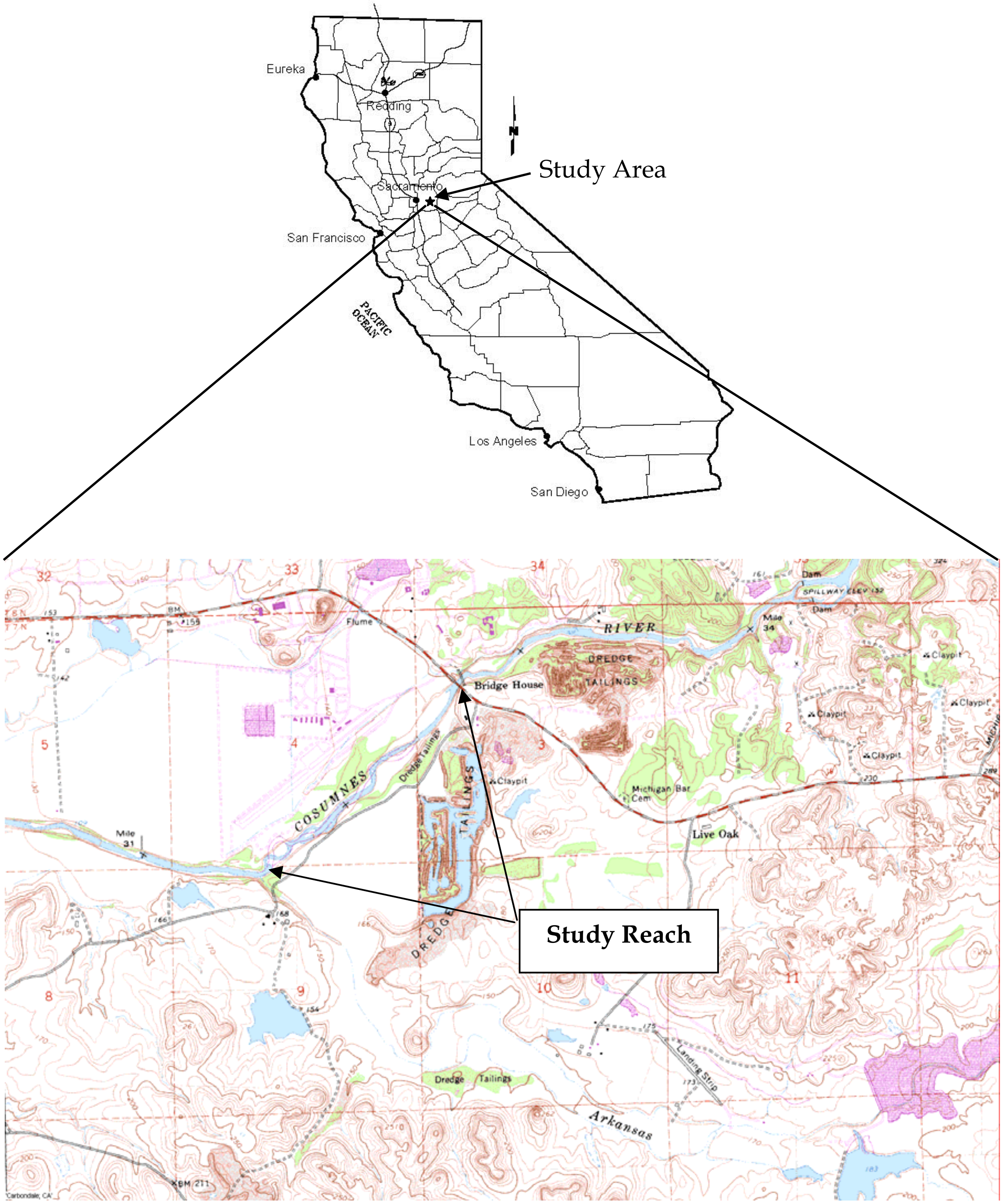

FIGURE 1: Site location map, from the USGS Carbondale Quadrangle, 7.5 minute topographic series, 1993.

At this location the Cosumnes River flows through farmlands on the edge of the Central Valley and the Sierra Nevada Mountains. The study area was located just downstream from the high gradient areas created by the metamorphic and igneous formations of the Sierra Nevada range. As the Cosumnes River enters the Central Valley, the sediment load settles out of the stream due to the decrease in stream gradient, creating the gravel bars that were the subject of the study. Figure 2 is a geologic map of the area (CDMG, 1981, 1:250,000 Sacramento Sheet).

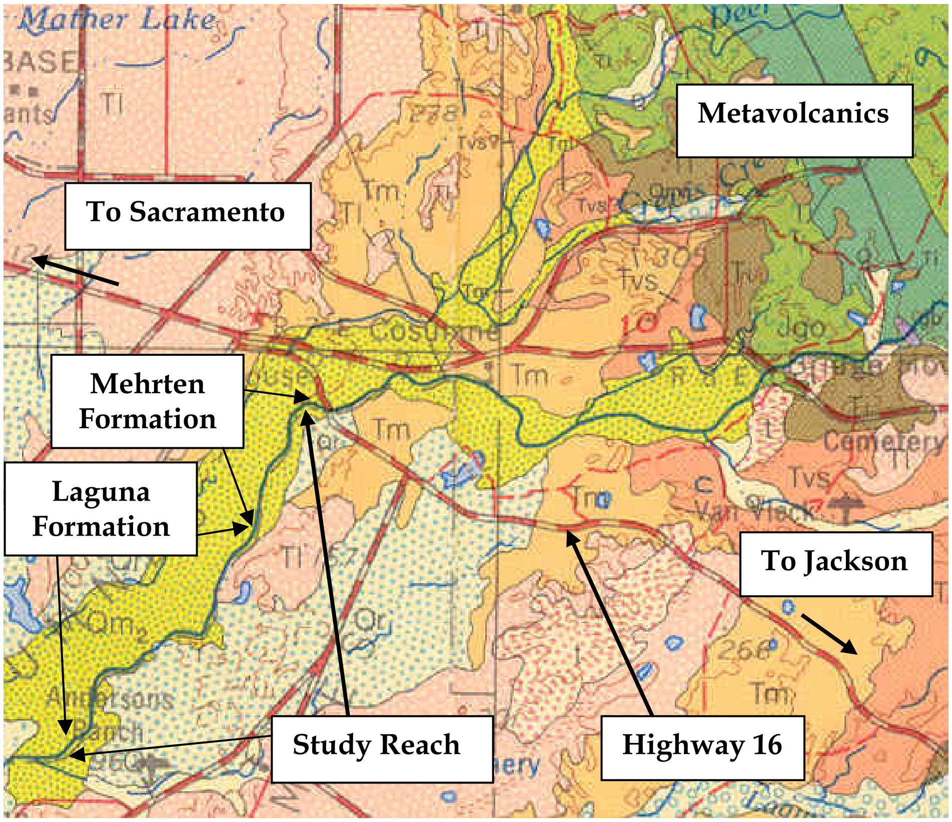

FIGURE 2: Geologic map of the study area, from the CDMG 1:250:000 Sacramento Sheet, 1981. Qm_2: Lower member of the Modesto Formation (alluvium); Qr: Riverbank Formation (alluvium); t: Mine and dredge tailings; Tm: Mehrten Formation; Tl: Laguna Formation.

Field observations indicated that the subsurface geology changes twice within the study area. Just upstream from the study area, under the Highway 16 Bridge, metavolcanic bedrock outcrops forming the stream channel. The upstream third of the study area consisted primarily of steep banks with sandy, gravelly streambed deposits derived from the Miocene Mehrten Formation and upstream metavolcanic sources. In the downstream two thirds of the study area, finer-grained bedrock outcrops. The bedrock in this area was the Tertiary Laguna Formation (CDMG, 1981).

Gravel deposits in the study area were extensively dredged in the middle of the 20th century, and tailings piles are still visible. These anthropogenic modifications shape significant portions of the river topography.

2.0 Methods

2.1 Field Methods

Fieldwork was conducted between May 2001 and January 2003. Installation of the mini-piezometers took place from June 2001 to August 2001. Sampling events occurred in April 2002, July 2002, and January 2003.

2.1.1 Mini-Piezometer Installation

Mini-piezometers were installed at twenty-nine sites along a one-mile stretch of the Cosumnes River near Sacramento, California. However, destruction by beavers ultimately limited the project to eighteen sites. Figure 3 is an aerial photograph with each site plotted.

A primary focus of the study was the gravel bar located at the far northeast (upstream) edge of the study area. Nine of the eighteen monitoring points were installed on this bar. This bar was chosen as the focus of the study because it represented several different stream morphologies (runs and riffles) and was deemed to be likely salmon spawning habitat (Kris Vyverberg, Department of Fish and Game, personal communication; Keith Whitener, Nature Conservancy, personal communication). In addition, conservation groups have considered restoring this portion of the Cosumnes River in order to rehabilitate the dredged gravels for salmon.

FIGURE 3: Cosumnes River study area with approximate locations of monitoring points.

In order to determine the variability of permeability and hyporheic chemistry caused by stream morphology, sites were installed in runs, riffles, and on the mid-channel longitudinal gravel bar (or island). Each site consisted of three nested mini-piezometers at depths of one-foot, two-feet, and nine-feet below ground surface (bgs).

The mini-piezometers consisted of a stainless steel drive point tip attached to a section of polyethylene tubing. The drive point tips were approximately two inches in length with a wire mesh-filtering screen. The tip was then connected to the surface with polyethylene tubing (Figure 4).

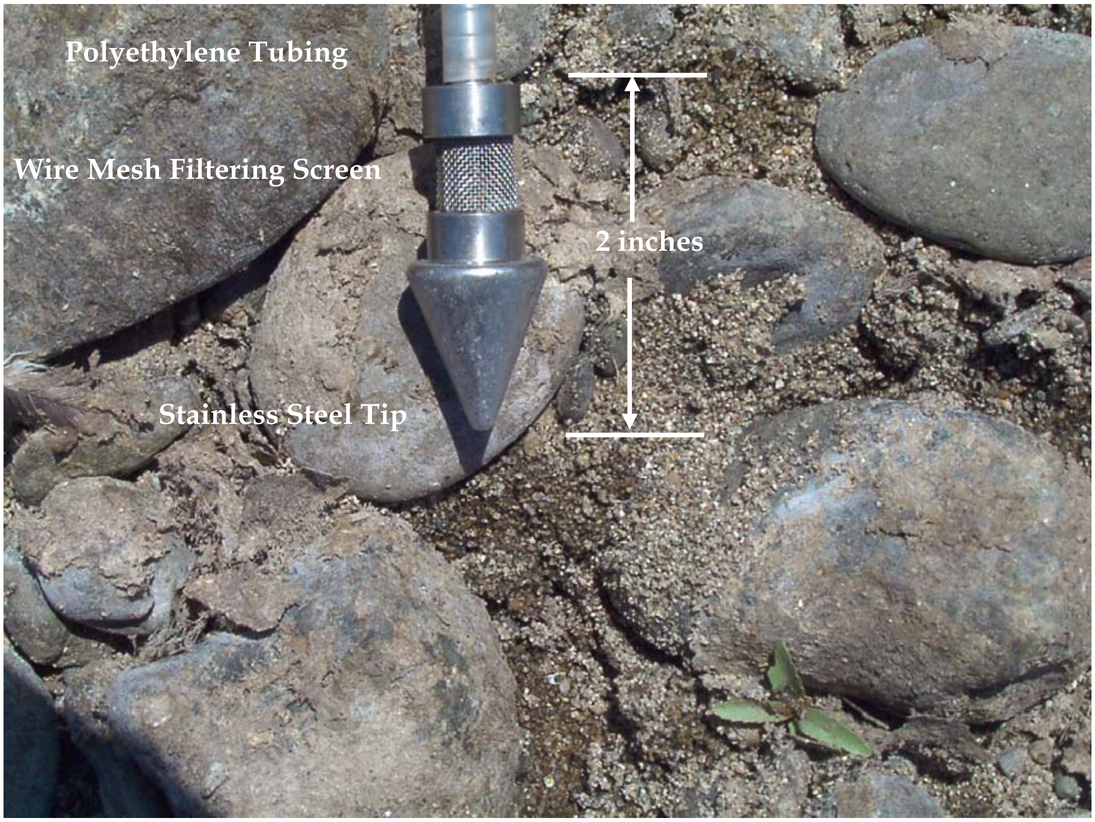

FIGURE 4: Drive point tip with filtering screen and polyethylene tubing, which together make up a mini-piezometer.

The tips were pushed into place by hammering an outer casing to the desired depth (1 ft, 2 ft, or 9 ft bgs) with a slide hammer. The casing consisted of a one-inch diameter, hollow steel rod. The casing was then removed, allowing the drive point tip and tubing to remain in place as the mini-piezometer. This piezometer design and installation method is similar to that of the Lee and

Cherry studies of 1978. Because the streambed is a mixture of fine and coarse-grained material, it is possible that an improper seal between the piezometer and the surrounding materials was created by removing of the outer casing and therefore creating a preferential flow path along the annulus (Geist and Dauble, 1998). However, it is likely that minimal interactions or "leakage" from the stream surface to the subsurface occurred due to the small diameter of the outer casing. In addition, samples or measurements were not made for several months following the installation of the mini-piezometers, thus allowing the stream materials to naturally recover and form a seal following the disturbance caused by the piezometer installation.

After installation, each piezometer was developed using a hand vacuum pump until the purge water was clear. Each piezometer was then "capped" with a wood or plastic golf tee and color coded with plastic ties to note the depth (Figure 5).

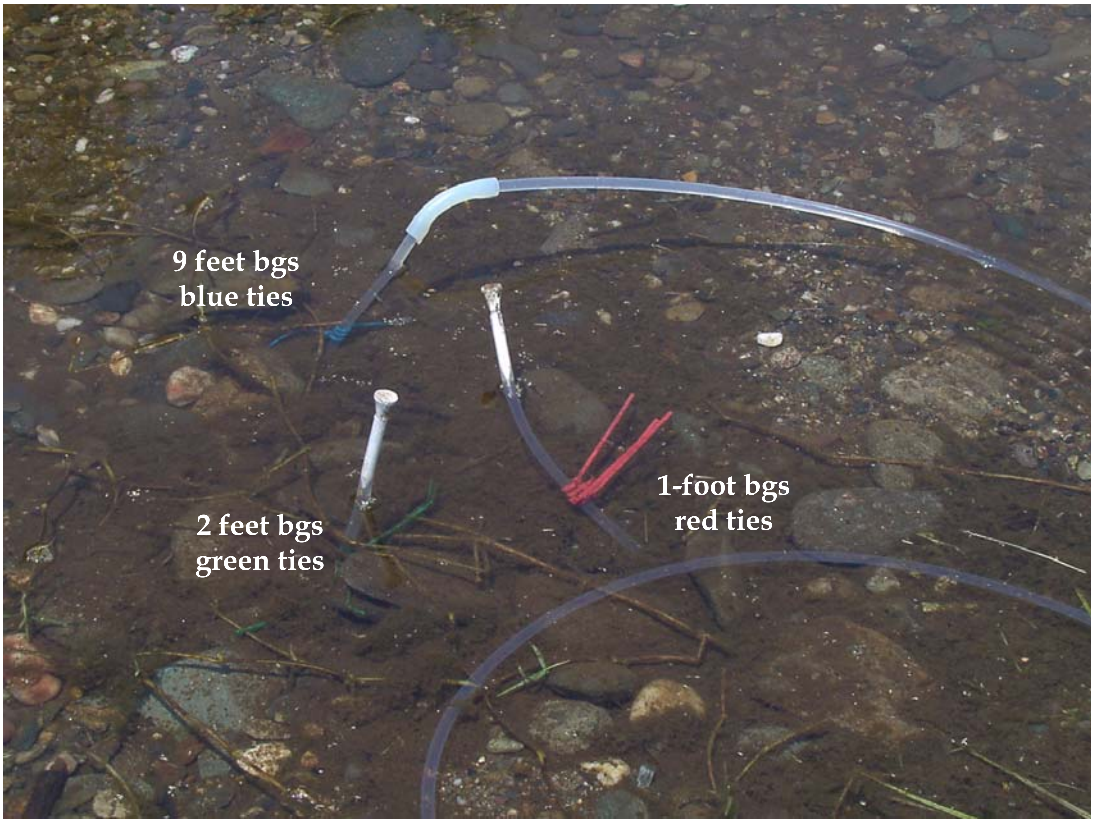

FIGURE 5: A typical monitoring point with three nested mini-piezometers. In a typical installation colored ties mark depth of the drive point tip.

Sites were numbered from east to west, starting with Monitoring Point 1 (MP1) on the northeast point of the gravel bar and ending with Monitoring Point 18 (MP18), approximately one mile downstream (see Figure 3). Individual mini-piezometers were then assigned a number according the depth of installation (i.e. MP18-2 for a mini-piezometer installed to two feet bgs at Monitoring Point 18). Mini-piezometers that were installed at nine feet bgs at MP17 and MP18 produced no water. Both of these mini-piezometers were very difficult to install due to the consolidated nature of the Laguna Formation in this area of the study reach. This area is different than the upstream Mehrten Formation in which the other 9-foot mini-piezometers were placed; the Laguna Formation was impermeable and not conducive to removing water. These mini-piezometers were therefore abandoned at the time of installation.

2.1.2 Field Equipment and Measurements

2.1.2.1 Manometer Board

A manometer board was constructed to measure the difference in pressure head between the piezometers at various depths in the gravel and the bottom of the streambed. These measurements were then converted to vertical hydraulic gradient (VHG). The manometer board consisted of a graduated board with a glass tube in the shape of an inverted "U". The glass tube was then attached to the piezometer of interest on one side and a baffle box on the streambed bottom on the other side. The baffle box consisted of two one-inch thick aluminum squares with weather stripping on one side of each square. The two pieces of aluminum were then screwed together with the weather stripping on the inside. The tubing from the manometer board was then inserted into the box through the weather stripping. This created an environment that easily equilibrated to the pressure of the streambed, but removed the issue of stream flow past the manometer tubing, which can greatly affect readings in the manometer board. At the top of the glass tube, a release valve allowed water to be drawn into the manometer board from the bottom of the streambed and the piezometer. Figure 6 shows the details of the manometer board used in this study.

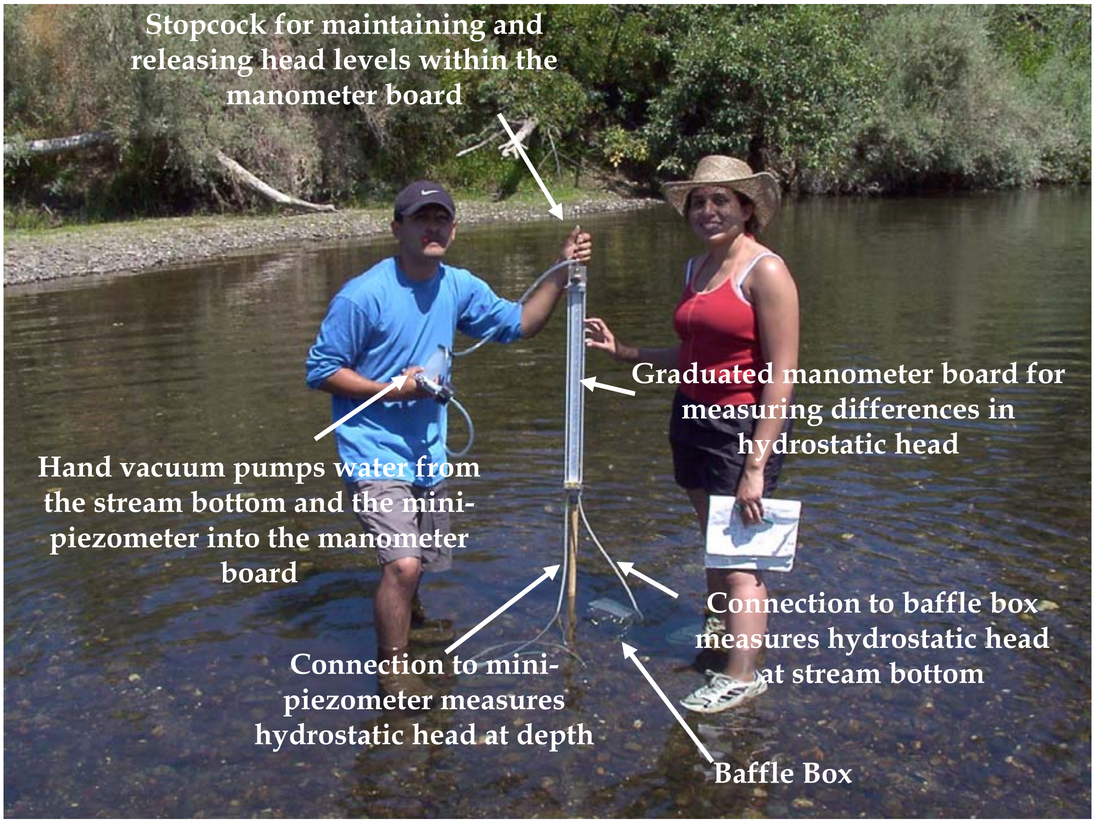

FIGURE 6: Details of manometer board.

After water was drawn into the manometer board, the valve was closed to the atmosphere and pressure within the glass tube was allowed to equilibrate. When the pressure had equilibrated, the difference in pressure head between each side of the tube (dH) was recorded. The vertical gradient in the streambed is equal to the pressure head divided by the vertical depth of the piezometer (dL) in the stream gravel (Equation 1).

Equation 1: $$VHG = \frac{dH}{dL}$$

The manometer board was also used to determine whether the stream was upwelling or downwelling. Positive VHG results indicate that the interstitial waters of the hyporheic zone were upwelling and entering the surface flow of the stream; negative VHG results indicated the stream was losing water (downwelling) to the hyporheic zone (Valett, 1994).

2.1.2.2 Standpipe

A standpipe based on the Terhune mark VI standpipe was used to measure seepage and permeability in gravels (Terhune, 1958). The standpipe consisted of a two-inch inside diameter stainless steel pipe with a three-inch length of perforations at the end. The standpipe was manually inserted to the desired depth in the streambed gravels using a slide hammer. Permeability studies were conducted at depths of 1- and 2-feet bgs. After the standpipe was inserted and water levels were allowed to equilibrate, a ½ inch stainless steel tube was clamped in place inside the standpipe. Water was withdrawn from the standpipe at a constant rate, through the thin tube, via a backpack pump that maintained the water level within the standpipe at one inch below the static water level (Pollard, 1955; Barnard and McBain, 1994). A pumping rate, or discharge, was then measured by collecting the pumped water in a graduated vessel over a measured time interval. Figures 7 and 8 show the details of the standpipe and pump.

FIGURE 7: Standpipe for determining hydraulic conductivity in streambeds.

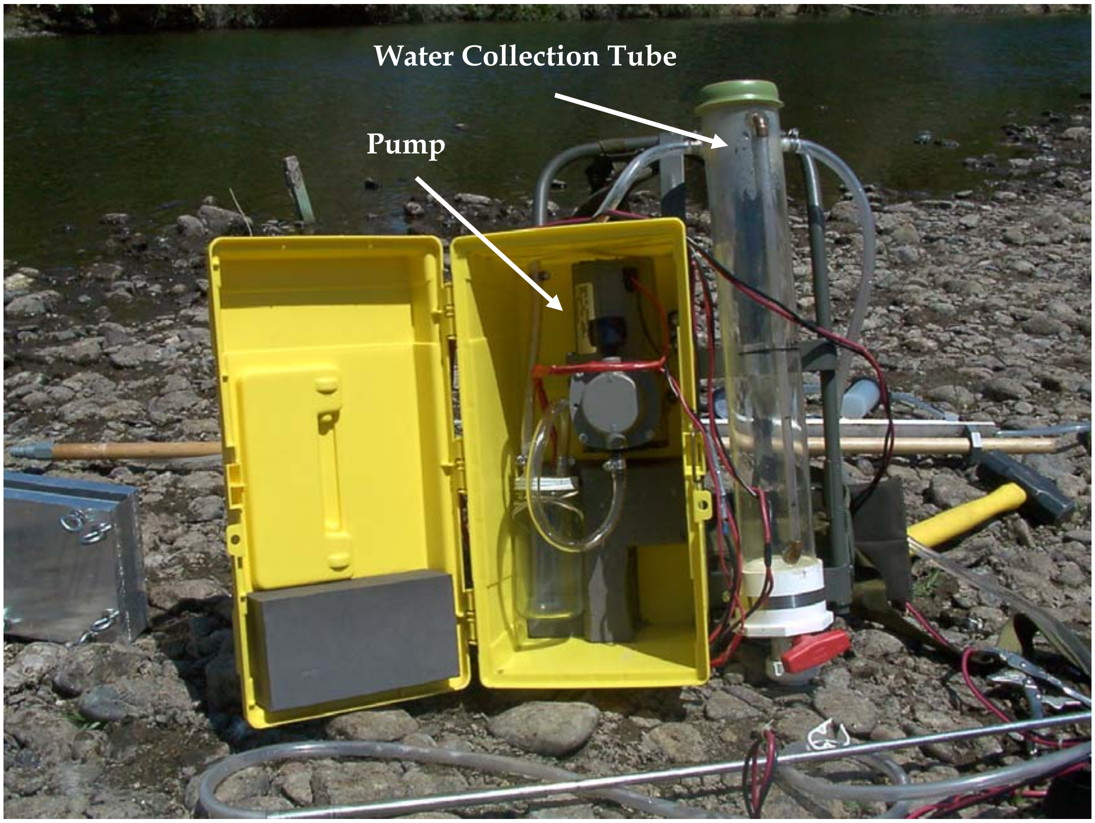

FIGURE 8: Backpack with pump for use with standpipe.

Hydraulic conductivity was then read from a calibration curve of permeability versus standpipe inflow, or discharge, as determined by empirical laboratory studies (Barnard and McBain, 1994). Figure 9 contains the calibration curve used to determine permeability.

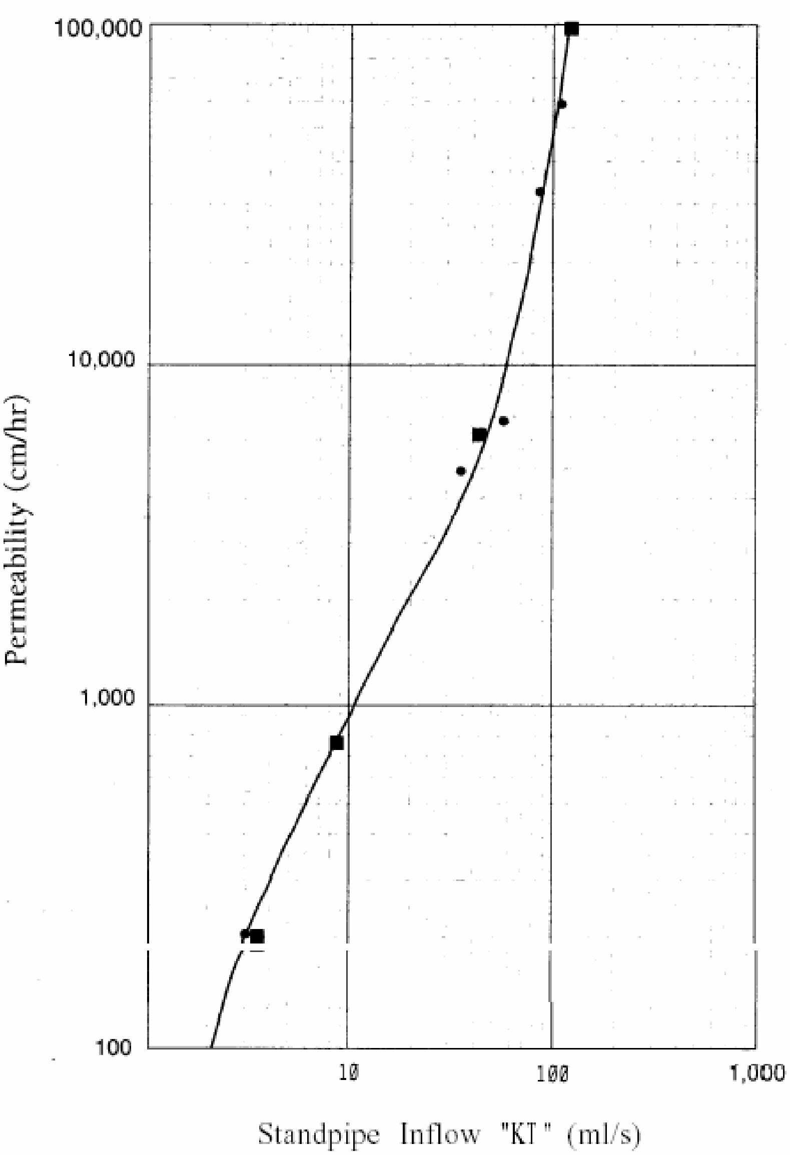

FIGURE 9: Calibration curve that relates rate of groundwater inflow to the standpipe to permeability of gravel. From Barnard and McBain, 1994.

2.1.3 Water Quality Equipment and Measurements

Several water quality parameters were measured in the field. Water was pumped from the piezometers into a sealed flow-through chamber, where dissolved oxygen (DO), pH, electrical conductivity (EC), and temperature were measured. When water was pumped through the flow-through chamber, samples were monitored without any interaction with the atmosphere. DO concentrations are particularly susceptible to equilibration with the atmosphere, and care must be taken to insure that results are as representative of the subsurface as possible.

Two different flow-through cells and instrument types were used throughout the course of the project. The first set of sampling instruments is shown in Figures 10 and 11.

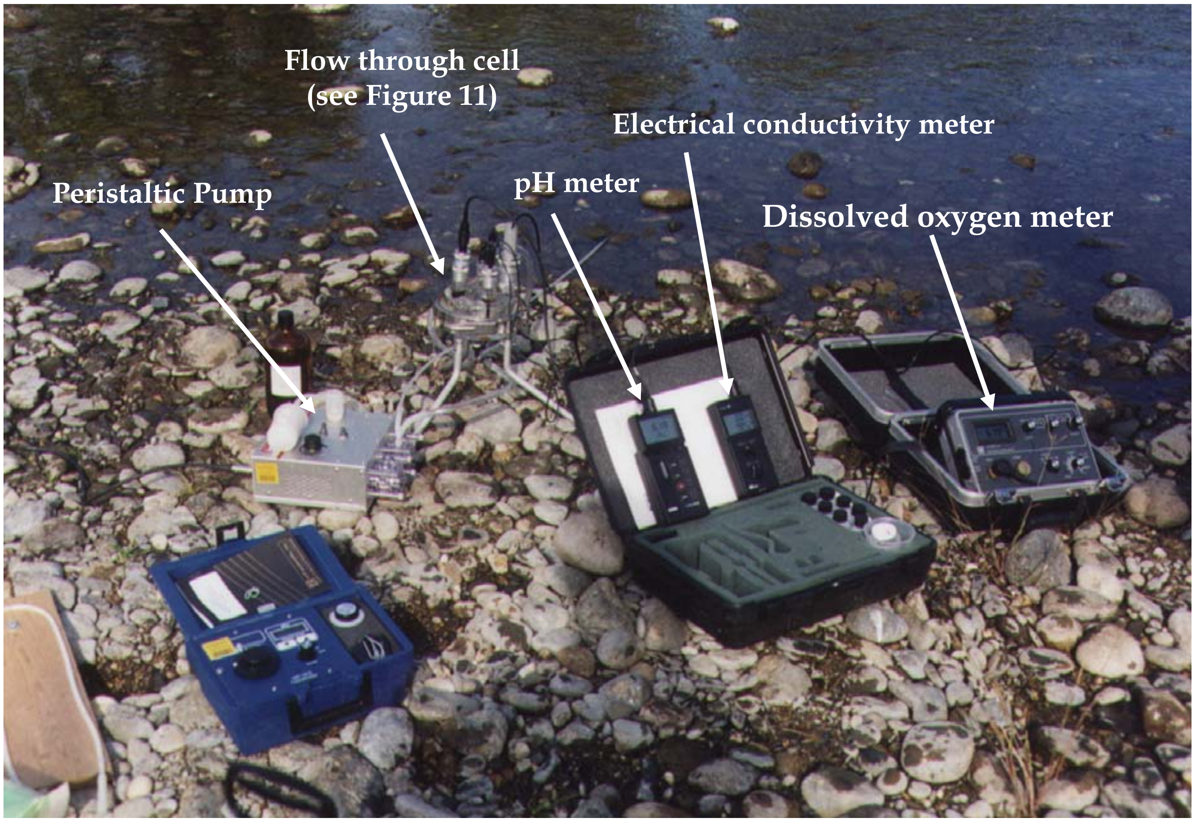

FIGURE 10: Instruments used for measuring field parameters.

FIGURE 11: Flow-through cell with instrument probes inserted.

The airtight chamber (approximate 2 L capacity) contained five ports for field instruments, of which four were used during this project. Instrument probes were inserted into each port; an airtight seal was obtained by tightening a rubber gasket around the individual probes. A peristaltic pump was then used to pump water through the flow-through chamber from each of the mini-piezometers. Water was allowed to circulate through the chamber until each of the parameters had adequately stabilized, typically 3 to 5 minutes. This method required that several liters of water be removed from the subsurface in order to fill the flow-through chamber and allow the parameters to stabilize. It is possible that water being sampled by this method was not completely representative of the interstitial pore water at the location of the drive point sampling tip. In order to reduce the amount of water being withdrawn from the subsurface and therefore prevent additional water, including surface water from flowing to the piezometer (Eriksen, 1963), a second method was used following the spring 2002 sampling event.

In order to reduce the amount of water being withdrawn from the subsurface, a YSI Multi-Probe with a smaller (approximate 200 mL capacity), attachable flow-through cell and hand vacuum pump were used. This equipment substantially reduced the amount of water required to fill the flow-through cell, and allowed the parameters to stabilize with approximately two liters of pumped water. In addition, the multi-probe and hand vacuum were much less cumbersome for fieldwork. Although a comparison of results between the two different sets of sampling tools was not conducted, all instruments used have been tested throughout the industry and are known to provide reliable results. Therefore, results collected from the different sets of sampling instruments are directly comparable and any differences in results can be considered negligible.

2.1.4 Sample Collection

Water samples were collected in 250 milliliter (mL) amber glass bottles for later laboratory analyses. In addition to samples from each mini-piezometer, trip blanks, equipment blanks, and duplicates were also collected during each sampling event.

During field sampling events, water was pumped from the piezometers through the flow-through cell, where field parameters were monitored and recorded. After field parameters were obtained, water was then pumped through a 0.45-micron (μm) filter and into the sampling bottles. After samples were collected, bottles were labeled with an appropriate site number, piezometer depth, date, and analysis to be performed. Samples were then stored in a cooler with ice, transported back to the laboratory, and refrigerated to a temperature of 4°C.

2.2 Laboratory Methods

Cations, anions, and DOC were analyzed using standard methods and equipment.

2.2.1 Cation Analysis

An Atomic Absorption Spectrophotometer (AA) was used to determine concentrations of dissolved cations found in each sample. The instrument used for analysis was a Perkin-Elmer Model 460 Atomic Absorption

Spectrophotometer. Beer's Law states that a linear relationship exists between the absorbance of an atom and the concentration of the atom in solution (Laidler, 1999). Therefore, a graphical plot, or calibration curve, of standards with known concentrations versus the measured absorbance was used to obtain a linear equation describing the relationship between the two variables (concentration and absorbance). This equation was then used to calculate the unknown concentrations from the measured absorbance of each sample.

Four different cations were analyzed in this experiment: calcium, magnesium, potassium, and sodium. For each cation tested, three to six standard solutions were prepared and then analyzed twice at the beginning of each cation analysis in order to obtain average absorbance values. The average absorbance values of the standards were used to create calibration curves. Calibration curves for each cation and each day of analysis are included in Appendix A. During the analysis, standards were continuously reanalyzed to monitor any possible drift of the instrument.

2.2.2 Anion Analysis

An ion chromatograph was used to determine the concentrations of the anions in water samples. The instrument used for analysis of anions was hand built, but consisted of all the necessary parts and performed well when tested. An eluent mixture of sodium bicarbonate and sodium carbonate was used as the mobile phase. Each sample was analyzed for nitrate, sulfate, and chloride. For each anion, three or four standards were prepared and analyzed at the beginning of each run day. During the analysis, standards were continuously reanalyzed to monitor any possible instrument drift. Standards were then used to create calibration curves (Appendix A) from which sample concentrations were calculated.

2.2.3 Dissolved Organic Carbon Analysis

A Schimadzu TOC-5000A total organic carbon analyzer was used for the analysis of dissolved organic carbon (DOC). The Schimadzu instrument was operated in the nonpurgeable organic carbon mode and samples were analyzed by high temperature catalytic oxidation (Bird et al., 2003). Samples and standards were placed in an auto-sampler. Samples were then acidified and sparged to remove any particulates.

2.3 Quality Control and Assurance

In order to confirm that samples were properly collected and that results were statistically valid, quality control and assurance procedures were implemented throughout the study. These procedures included instrument calibrations, proper preparation of sampling bottles, preservation and storage of samples, and collection of trip blanks, equipment blanks, field duplicates, and laboratory replicates. Approximately 10% of the field samples analyzed were blanks, duplicates, and replicates.

2.3.1 Sample Bottle Preparation

For ease of sampling, all water samples were collected in 125 milliliter (mL) amber glass bottles. Bottles were washed with liquinox soap and water and then rinsed a minimum of three times with deionized water. In order to remove all traces of organic carbon and dissolved ions, the bottles were then baked in a muffle furnace to a temperature of 450°C for a period of twelve hours. Teflon lined caps were used for each of the bottles.

2.3.2 Preservation and Storage

Samples to be analyzed for dissolved cations required acidification to a pH less than 2 upon collection. High purity concentrated nitric acid was used to preserve the necessary sampling bottles prior to a field day; these bottles were labeled as pre-acidified. Samples to be analyzed for dissolved anions and DOC were not acidified. After collection in appropriate bottles, samples were placed in a cooler with ice, and later stored in a refrigerator at temperatures of about 4°C.

Table 1 shows that all samples were properly preserved, stored, and analyzed within the appropriate shelf life of all analytes, with the exception of nitrate. Due to the fact that nitrate was not analyzed within the proper holding time and was not preserved properly, nitrate data will not be included in this report.

Parameter	**Preservation Method**	**Shelf Life**	**Preservation Method Adequate for all Samples**	**Analysis performed for all samples within shelf life**
Dissolved Na	Filter on site; HNO_3 to pH<2	6 months	Yes	Yes
Dissolved K	Filter on site; HNO_3 to pH<2	6 months	Yes	Yes
Dissolved Ca	Filter on site; HNO_3 to pH<2	6 months	Yes	Yes
Dissolved Mg	Filter on site; HNO_3 to pH<2	6 months	Yes	Yes
Dissolved Cl	None	28 days	Yes	Yes
Dissolved SO_4	Cool (4°C)	28 days	Yes	Yes
Dissolved NO_3	Analyze ASAP (<48 hr) or add H_2SO_4 to pH<2; cool (4°C)	28 days	No	No
DOC	Analyze ASAP (<48 hr)	48 hours	Yes	Yes

TABLE 1: Sample preservation and storage requirements.

2.3.3 Field Blanks and Duplicates

Table 2 presents the analytical results for the trip blanks and equipment blanks.

Sample Type	Sample Date	DOC (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)
Trip Blank	4/20/02	0.141	0.52	0.04	nd	nd	nd	nd
Equipment Blank	4/20/02	0.361	0.38	0.08	nd	nd	nd	nd
Equipment Blank	4/21/02	0.682	0.98	0.45	0.62	5.17	0.91	2.07
Trip Blank	4/28/02	0.208	0.76	0.09	nd	nd	nd	nd
Trip Blank	7/29/02	0.046	na	na	na	na	0.46	nd
Equipment Blank	7/29/02	0.362	2.12	0.30	1.31	0.46	0.59	nd
Trip Blank	8/2/02	0.189	1.05	0.13	nd	nd	nd	nd
Equipment Blank	8/2/02	0.26	1.05	0.08	nd	nd	nd	nd
Trip Blank	1/03	NA	0.03	0.08	nd	nd	nd	nd
Mean		0.28	0.86	0.16	0.24	0.70	0.22	0.23
Standard Deviation		0.19	0.62	0.14	0.48	1.8	0.35	0.69

TABLE 2: Analytical results of trip blanks and equipment blanks.

Table 3 presents the analytical results for field duplicates collected throughout the study. Table 3 also contains the calculated percent difference between each duplicate and the original sample. A percent difference that is less than 20% for any given ion was chosen to indicate that samples were collected and analyzed properly and the results are valid. Field duplicates with a percent difference greater than 20% indicate that a possible sampling or analytical error occurred and data for that given ion on that given day may be suspect.

Sample Type	Sample ID	Sample Date	DOC (mg/l)	Na$^+$ (mg/l)	K$^+$ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Cl$^-$ (mg/l)	SO$_4^{2-}$ (mg/l)
Sample	MP3-9	4/20/02	1.3	4.3	1.0	2.4	3.2	1.9	0.9
Field duplicate	MP3-9, fd	4/20/02	2.0	6.2	1.0	2.4	3.2	2.1	2.4
Percent Difference (%)			**39**	**36**	**0**	**0**	**0**	**10**	**90**
Sample	MP5-2	4/21/02	1.0	5.5	2.0	4.7	3.6	1.3	2.3
Field duplicate	MP5-2, fd	4/21/02	0.9	5.3	2.0	4.7	3.4	1.3	2.3
Percent Difference (%)			**7.6**	**3.7**	**0**	**0**	**5.7**	**0**	**0**
Sample	MP15-1	4/28/02	1.0	4.2	1.6	3.4	3.2	1.4	0.2
Field duplicate	MP15-1, fd	4/28/02	0.9	3.7	1.6	3.4	3.2	1.8	4.1
Percent Difference (%)			**2.1**	**13**	**0**	**0**	**0**	**25**	**180**
Sample	MP4-1	7/29/02	1.2	5.8	1.4	4.9	4.1	2.9	3.1
Field duplicate	MP4-1, fd	7/29/02	1.2	5.8	1.2	5.0	4.0	2.0	3.3
Percent Difference (%)			**0.84**	**0**	**15**	**2.0**	**2.5**	**37**	**6.2**
Sample	MP18-1	8/2/02	1.6	6.2	1.5	6.1	4.9	2.3	3.6
Field duplicate	MP18-1, fd	8/2/02	ND	6.0	1.4	5.1	4.7	ND	ND
Percent Difference (%)			**NA**	**3.3**	**6.9**	**18**	**4.2**	**NA**	**NA**
Sample	MP2-1	1/11/03	1.3	4.3	1.1	4.3	4.7	3.9	7.8
Field duplicate	MP2-1, fd	1/11/03	1.4	4.2	1.1	4.4	4.5	3.9	6.9
Percent Difference (%)			**10**	**2.4**	**0**	**2.3**	**4.3**	**0**	**12**
Sample	MP13-2	1/12/03	0.8	4.3	0.9	4.4	4.3	2.5	7.3
Field duplicate	MP13-2, fd	1/12/03	0.9	4.5	0.9	4.4	4.4	5.2	8.0
Percent Difference (%)			**15**	**4.5**	**0**	**0**	**2.3**	**70**	**9.2**
Sample	MP24-1	1/13/03	1.5	4.3	1.0	3.4	3.9	2.7	5.4
Field duplicate	MP24-1, fd	1/13/03	1.5	4.3	0.9	3.4	3.9	2.8	5.4
Percent Difference (%)			**0.67**	**0**	**7.2**	**0**	**0**	**3.6**	**0**
Mean Difference			**0.11**	**0.08**	**0.04**	**0.03**	**0.02**	**0.21**	**0.42**
Standard Deviation of Difference			**0.14**	**0.12**	**0.06**	**0.06**	**0.02**	**0.26**	**0.68**

TABLE 3: Comparison of duplicate field data.

The variability seen in blanks and duplicates indicate that contamination from sampling procedures may be contributing to the final analytical results that will be presented in Section 3.0. Therefore, the average of the mean values of the blanks and the difference in duplicates has been used to limit the precision of the data and to create a range in which the actual results may vary.

2.3.4 Analytical Replicates

Proper laboratory procedures involve the use of replicates. When analysis is being performed on a sample set, at least 10% of the samples should be analyzed a second time to confirm the accuracy of the analytical instruments. Therefore, every tenth sample was re-analyzed to confirm the results of the initial analysis. If replicates were not within approximately 10% of each other, the sampling set was rerun after any necessary adjustments were made to the instruments.

3.0 Results and Discussion

3.1 Variables and Data Analysis

In order to determine trends in data, the results were compared with respect to seasonal changes, variability due to longitudinal locations in the study area (i.e. upstream versus downstream monitoring points), variability due to vertical distribution in the gravel, and variability due to streambed morphology (riffle, run, and island features). Details of each of these separate analyses are presented below.

Over the course of a year, sampling events occurred during three seasons: spring 2002, summer 2002, and winter 2003. The fall of 2002 event was not included due to extremely low flows in the Cosumnes River and, after the onset of the rainy season, the possibility of disturbing the few salmon known to spawn in the streambed. The three sampling events occurred during very different stages of flow in the Cosumnes River in order to capture the effects of high, moderate, and low flows on the hyporheic environment. Figure 12 shows the river discharge recorded at the Michigan Bar USGS gauging station, located less than three miles upstream from the study area. Flow data for the figure was downloaded from the California Data Exchange Center at www.cdec.water.ca.gov.

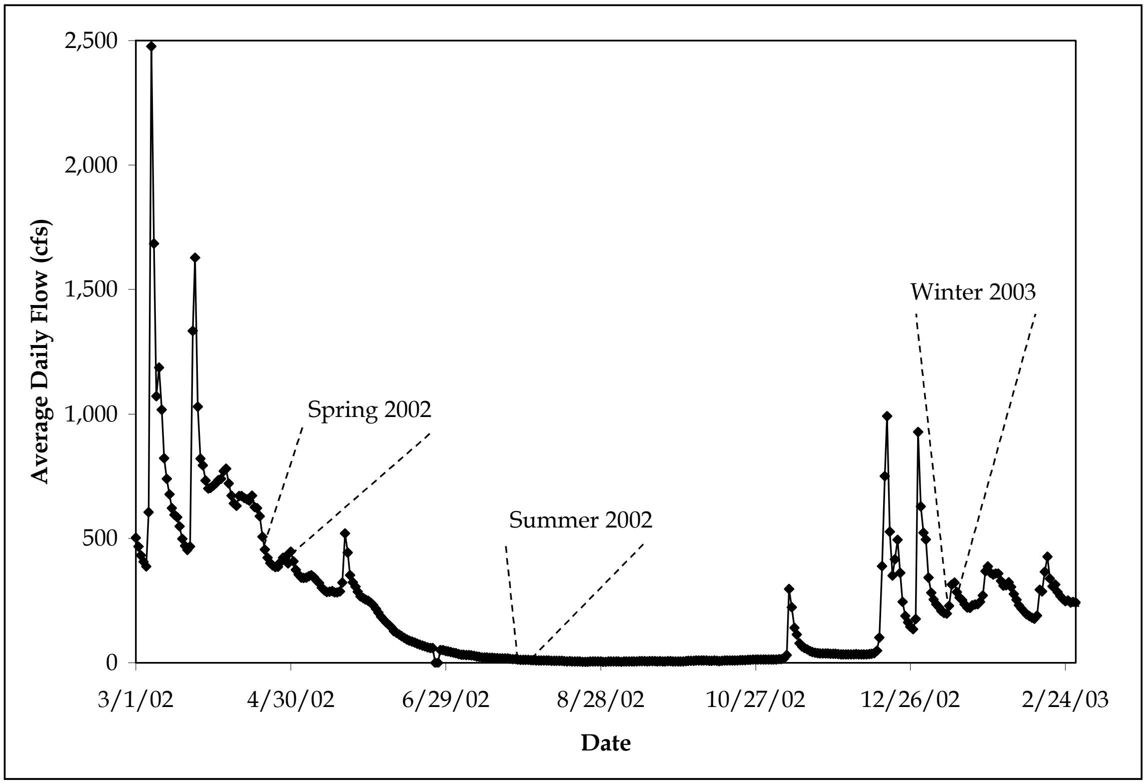

FIGURE 12: Average daily flow in the Cosumnes River during the period of the study, and timing of sampling events.

Field observations and published geologic maps (see Figure 2) indicate that subsurface geology was different between the upper third and lower two thirds of the study area. In the upper portion of the study area the banks of the Cosumnes River were typically steep, sandy, gravel deposits. While installing many of the mini-piezometers, particularly the 9-foot points, sandy units were often encountered (as evidenced by ease of installation or passage of the drive point tip). In addition, in the upper portion of the study area, most of the mini-piezometers, including the 9-foot points, were easy to purge and sample. However, in the lower two thirds of the study area (from MP11 downstream) the geology is quite different. Finer-grained bedrock outcrops along the banks of the river and is aerially exposed during summer and fall low flow conditions. The 9-foot mini-piezometers became difficult (and sometimes impossible) to install. The sandy units of the upstream portion of the study area were no longer encountered. Several of the sampling points could not be purged upon installation of the mini-piezometer, and could not be sampled. Therefore, a significant change in geology occurs in the general area of MP11, and the study area has been divided into an upstream portion (MP1 through MP10) and a downstream portion (MP11 through MP18). Figure 13 shows the division between the upstream and downstream portions of the study area.

FIGURE 13: Longitudinal change in study area (upstream versus downstream).

Samples were collected from different depths in the substrate in order to obtain an understanding of the chemical mixing within the hyporheic zone of the streambed. Samples were primarily collected from mini-piezometers installed to depths of 1-, 2-, and 9-feet below the surface of the streambed. In addition, samples were periodically collected from the surface water of the stream.

Samples were also collected to identify differences between morphological features in the stream. Morphological categories that were analyzed include riffles, runs, a mid-channel longitudinal bar (referred to as the “island”), and surface water. Island samples included sampling sites that were on the island and at the head and toe of the island (MP1, MP3, MP6, and MP9). Figure 14 shows monitoring points that have been designated as riffles, runs, and island samples.

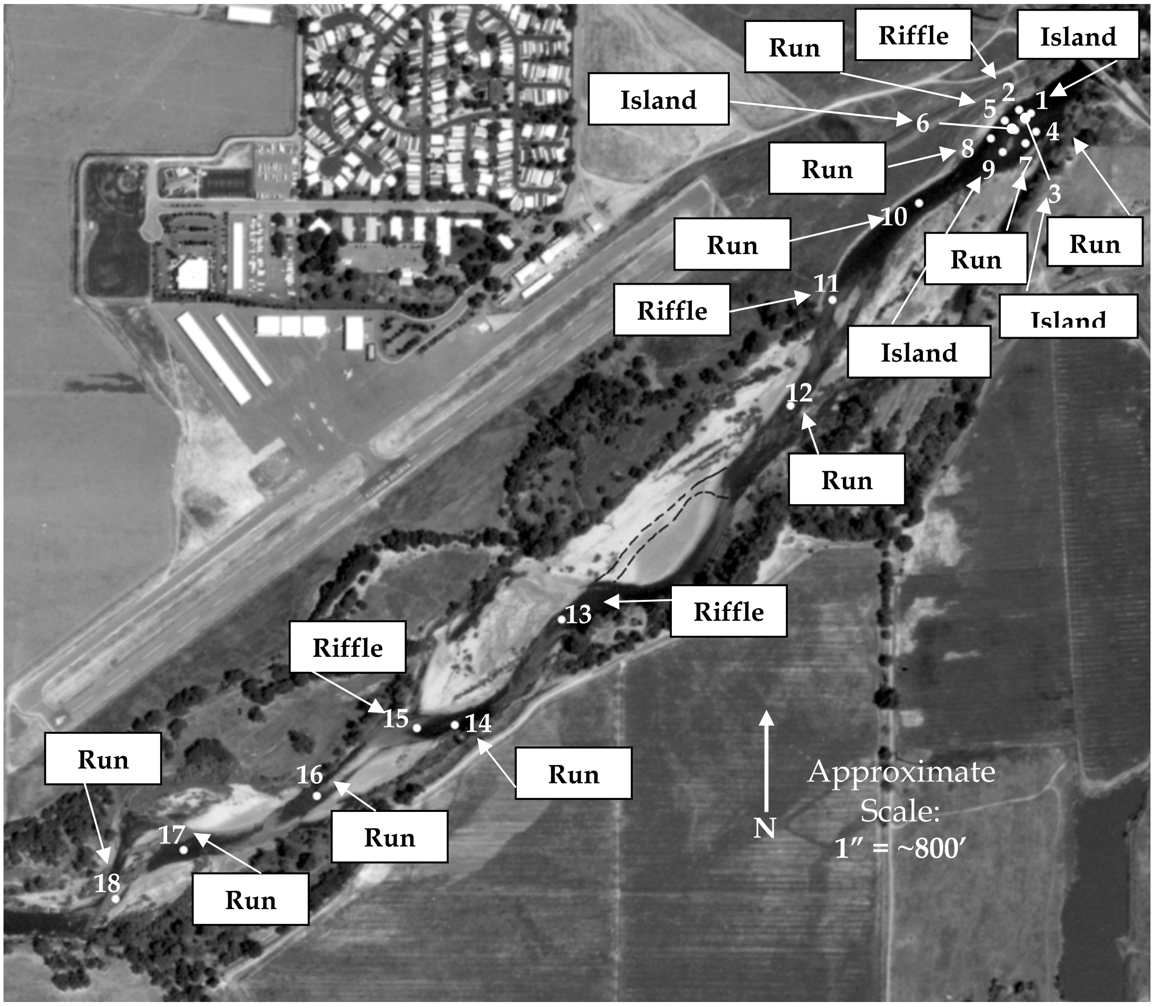

FIGURE 14: Morphological identifiers of each monitoring point.

3.2 Field Parameters

Field parameters including pH, dissolved oxygen (DO), and electrical conductivity (EC) were compared in a variety of ways in order to determine significant trends or variations in the data. Table 4 presents the field parameter results for all samples collected during the study, excluding blanks and duplicates (previously discussed).

Site Number	Depth (ft bgs)	Season Sampled	Dissolved Oxygen (mg/l)	pH	Electrical Conductivity (µS/cm)	Temperature (°C)
1	1	Spring 2002	12.4	5.2	180	No data
		Summer 2002	4.8	7.2	86	30.6
		Winter 2003	Cannot locate monitoring point			
	2	Spring 2002	9.6	6.6	66	14.9
		Summer 2002	1.5	7.1	90	31
		Winter 2003	Cannot locate monitoring point			
	9	Spring 2002	4.6	6.3	85	14.8
		Summer 2002	1.3	6.9	110	26.5
		Winter 2003	Cannot locate monitoring point			
2	Surface Water	Spring 2002	11.0	6.5	67	13.4
	1	Spring 2002	11.8	6.6	67	15.8
		Summer 2002	4.2	7.1	91	27.8
		Winter 2003	10.7*	7.8	99*	8.3
	2	Spring 2002	11.9	6.8	66	15.0
		Summer 2002	3.9	7.1	91	27.9
		Winter 2003	10.2*	7.6	97*	7.9
	9	Spring 2002	8.7	6.5	72	15.5
		Summer 2002	0.4	7.0	92	27.8
		Winter 2003	Insufficient water to collect parameters			
3	1	Spring 2002	11.6	6.8	66	14.8
		Summer 2002	1.8	7.1	91	27.7
		Winter 2003	10.4*	8.0	100*	8.3
	2	Spring 2002	10.7	6.7	66	13.6
		Summer 2002	1.4	7.1	90	27.9
		Winter 2003	9.6*	7.8	99*	8.3
	9	Spring 2002	4.3	6.6	87	14.1
		Summer 2002	0.9	6.7	120	28
		Winter 2003	1.9*	7.4	96*	9.0
4	Surface Water	Winter 2003	11.6*	7.8	96*	8.7
	1	Spring 2002	11.2	6.8	67	15.0
		Summer 2002	6.7	7.3	89	24.2
		Winter 2003	10.6*	7.4	98*	8.7
	2	Spring 2002	11.2	6.8	66	14.1
		Summer 2002	5.9	7.2	90	28
		Winter 2003	11.3*	7.5	97*	8.4
	9	Spring 2002	4.8	6.8	110	14.3
		Summer 2002	0.8	7.1	120	28
		Winter 2003	2.6*	7.1	110*	11.0

TABLE 4: Field parameter results.

Site Number	Depth (ft bgs)	Season Sampled	Dissolved Oxygen (mg/l)	pH	Electrical Conductivity (μS/cm)	Temperature (°C)
5	1	Spring 2002	7.5	6.9	72	No data
		Summer 2002	0.8	6.8	90	27.3
		Winter 2003	7.3*	7.4	99*	8.4
	2	Spring 2002	7.2	6.8	74	14.5
		Summer 2002	1.1	6.8	90	27.3
		Winter 2003	Piezometer missing			
	9	Spring 2002	3.4	6.6	99	13.9
		Summer 2002	0.4	7.0	100	26.1
		Winter 2003	1.4*	7.2	100*	9.2
6	1	Spring 2002	9.6	6.9	66	13.7
		Summer 2002	Cannot locate monitoring point			
		Winter 2003				
	2	Spring 2002	9.4	6.8	66	13.5
		Summer 2002	Cannot locate monitoring point			
		Winter 2003				
	9	Spring 2002	10.2	6.9	66	12.7
		Summer 2002	Cannot locate monitoring point			
		Winter 2003				
7	Surface Water	Summer 2002	7.2	7.6	93	29.6
	1	Spring 2002	4.4	6.0	74	16.0
		Summer 2002	1.5	7.1	88	27
		Winter 2003	8.2*	7.1	99*	8.4
	2	Spring 2002	3.4	6.7	77	15.5
		Summer 2002	Piezometer missing			
		Winter 2003				
	9	Spring 2002	3.0	6.4	110	14.9
		Summer 2002	0.6	7.0	100	27.9
		Winter 2003	1.6*	7.1	100*	10.0
8	1	Spring 2002	Water too deep to sample			
		Summer 2002	1.4	6.7	94	22.9
		Winter 2003	Water too deep to sample			
	2	Spring 2002	Water too deep to sample			
		Summer 2002	1.5	6.7	94	22.9
		Winter 2003	Water too deep to sample			
	9	Spring 2002	Water too deep to sample			
		Summer 2002	1.4	6.7	110	22.3
		Winter 2003	Water too deep to sample			

TABLE 4 (continued)

Site Number	Depth (ft bgs)	Season Sampled	Dissolved Oxygen (mg/l)	pH	Electrical Conductivity (µS/cm)	Temperature (°C)
9	1	Spring 2002	4.8	6.9	120	17.8
		Summer 2002	2.4	7.0	91	29.4
		Winter 2003	7.1	7.8	110	8.9
	2	Spring 2002	5.7	6.7	97	No data
		Summer 2002	2.4	7.1	91	29.8
		Winter 2003	7.3	7.4	100	8.6
	9	Spring 2002	4.2	6.5	120	14.1
		Summer 2002	1.2	6.9	89	No data
		Winter 2003	6.2	7.2	110	8.8
10	1	Spring 2002	12.9	6.9	63	13.7
		Summer 2002	3.1	6.7	100	28.6
		Winter 2003	8.8	7.1	93	8.9
	2	Spring 2002	11.8	6.8	67	14.4
		Summer 2002	2.7	6.9	100	28.6
		Winter 2003	8.9	7.1	96	8.6
	9	Spring 2002	8.1	6.7	70	13.8
		Summer 2002	1.3	6.7	95	No data
		Winter 2003	7.1	7.0	100	8.8
11	1	Spring 2002	Cannot locate monitoring point, water too fast			
		Summer 2002	Insufficient water to collect parameters			
		Winter 2003	Cannot locate monitoring point, water too fast			
	2	Spring 2002	Cannot locate site, water too fast			
		Summer 2002	2.7	6.7	92	28.1
		Winter 2003	Cannot locate monitoring point, water too fast			
	9	Spring 2002	Cannot locate monitoring point, water too fast			
		Summer 2002	Insufficient water to collect parameters			
		Winter 2003	Cannot locate monitoring point, water too fast			
12	Surface Water	Spring 2002	10.9	6.5	61	13.0
	1	Spring 2002	7.6	Broken probe	89	14.3
		Summer 2002	2.6	6.4	260	25.4
		Winter 2003	6.6	7.1	100	9.8
	2	Spring 2002	9.5	7.4	67	14.7
		Summer 2002	1.4	6.4	260	23.6
		Winter 2003	4.7	6.7	100	9.8
	9	Spring 2002	1.7	Broken probe	240	14.2
		Summer 2002	Insufficient water to collect parameters			
		Winter 2003	Insufficient water to collect parameters			

TABLE 4 (continued)

Site Number	Depth (ft bgs)	Season Sampled	Dissolved Oxygen (mg/l)	pH	Electrical Conductivity (µS/cm)	Temperature (^{o}C)
13	1	Spring 2002	15.2	Broken probe	60	14.4
		Summer 2002	1.8	7.3	110	27.3
		Winter 2003	10.2	8.8	123	10.0
	2	Spring 2002	14.2	Broken probe	66	No data
		Summer 2002	1.6	7.1	110	26.8
		Winter 2003	9.4	8.1	89	9.5
	9	Spring 2002	1.8	Broken probe	110	14.6
		Summer 2002	Insufficient water to collect parameters			
		Winter 2003	Insufficient water to collect parameters			
14	1	Spring 2002	10.2	Broken probe	61	14.5
		Summer 2002	1.9	6.7	130	25.6
		Winter 2003	9.6	7.8	86	10.6
	2	Spring 2002	7.2	Broken probe	76	15.0
		Summer 2002	1.7	6.6	220	25.9
		Winter 2003	No data			
	9	Spring 2002	Insufficient water to collect parameters			
		Summer 2002				
		Winter 2003				
15	1	Spring 2002	7.2	Broken probe	72	14.5
		Summer 2002	3.0	6.5	110	28.2
		Winter 2003	6.7	7.0	100	10.3
	2	Spring 2002	Piezometer missing			
		Summer 2002				
		Winter 2003				
	9	Spring 2002	No field data			
		Summer 2002	1.6	6.5	94	30.5
		Winter 2003	1.8↓	7.2	140	14.5

TABLE 4 (continued)

Site Number	Depth (ft bgs)	Season Sampled	Dissolved Oxygen (mg/l)	pH	Electrical Conductivity (µS/cm)	Temperature (°C)
16	1	Spring 2002	Did not sample during this event			
		Summer 2002	Piezometer missing			
		Winter 2003	Cannot locate monitoring point			
	2	Spring 2002	Did not sample during this event			
		Summer 2002	1.6	6.6	220	24.6
		Winter 2003	Cannot locate monitoring point			
	9	Spring 2002	Did not sample during this event			
		Summer 2002	1.4	6.4	230	26.7
		Winter 2003	Cannot locate monitoring point			
17	1	Spring 2002	Did not sample during this event			
		Summer 2002	Cannot locate monitoring point			
		Winter 2003	9.1	7.7	83	9.9
	2	Spring 2002	Did not sample during this event			
		Summer 2002	Cannot locate monitoring point			
		Winter 2003	1.8↓	7.1	97	10.3
	9	Spring 2002	No piezometer installed			
		Summer 2002				
		Winter 2003				
18	Surface Water	Summer 2002	7.2	7.6	110	No data
		Winter 2003	11.4	8.1	80	10.2
	1	Spring 2002	Did not sample during this event			
		Summer 2002	1.9	6.4	450	25.7
		Winter 2003	7.1	7.0	130	10.4
	2	Spring 2002	Did not sample during this event			
		Summer 2002	1.7	6.4	470	25.7
		Winter 2003	2.0	7.0	170	11.1
	9	Spring 2002	No piezometer installed			
		Summer 2002				
		Winter 2003				

ft bgs – feet below ground surface
mg/l – milligrams/liter
µS/cm – microseimens/centimeter
°C – degrees Celsius
* - These data corrected for errors in calibration

TABLE 4 (continued)

Temperature data were collected in the flow-through cell, but this is not an accurate method to measure subsurface temperatures; while pumping water from each sampling point, the temperature of each sample quickly equilibrated with ambient surface water and air temperatures. For these reasons trends in temperature data (Table 4) are not discussed. The data in Table 4 were analyzed to determine if significant variations existed seasonally, longitudinally (upstream versus downstream samples), vertically (changes with depth of samples), and morphologically (island versus runs versus riffles).

The data were compared using box and whisker plots. A box plot shows the median of the data set, which is the number that is in the middle of the data set (half the results are above the median, and half the results are below the median). In addition, a box and whisker plot displays the interquartile range which is represented by the box in each plot. The interquartile range is the difference between the first and third quartiles. The first quartile is the 25th percentile of the ranked data set, and the third quartile is the 75th percentile of the ranked the data set. Half of the data set falls in the interquartile range (Wikipedia, 2005). The whiskers in a box and whisker plot show the range of the data set. The box and whisker plots presented here include possible outliers. Typically, an outlier is present if a whisker is longer than three times the interquartile range (the length of the box) (Hunt, 2004). The following sections present the field parameter results for each type of comparison. Complete statistical results are contained in Appendix B. Box and whisker plots for all field parameters analyzed are included in Appendix C.

3.2.1 Seasonal Variability in Field Parameters

Statistical analysis of the samples collected during each season was performed to identify seasonal patterns in DO, pH, and EC in pore water. Figures 15 to 17 present summaries of the statistical results of this analysis in the form of box and whisker plots. Table B-1 of Appendix B presents the complete results of the statistical analysis for each season.

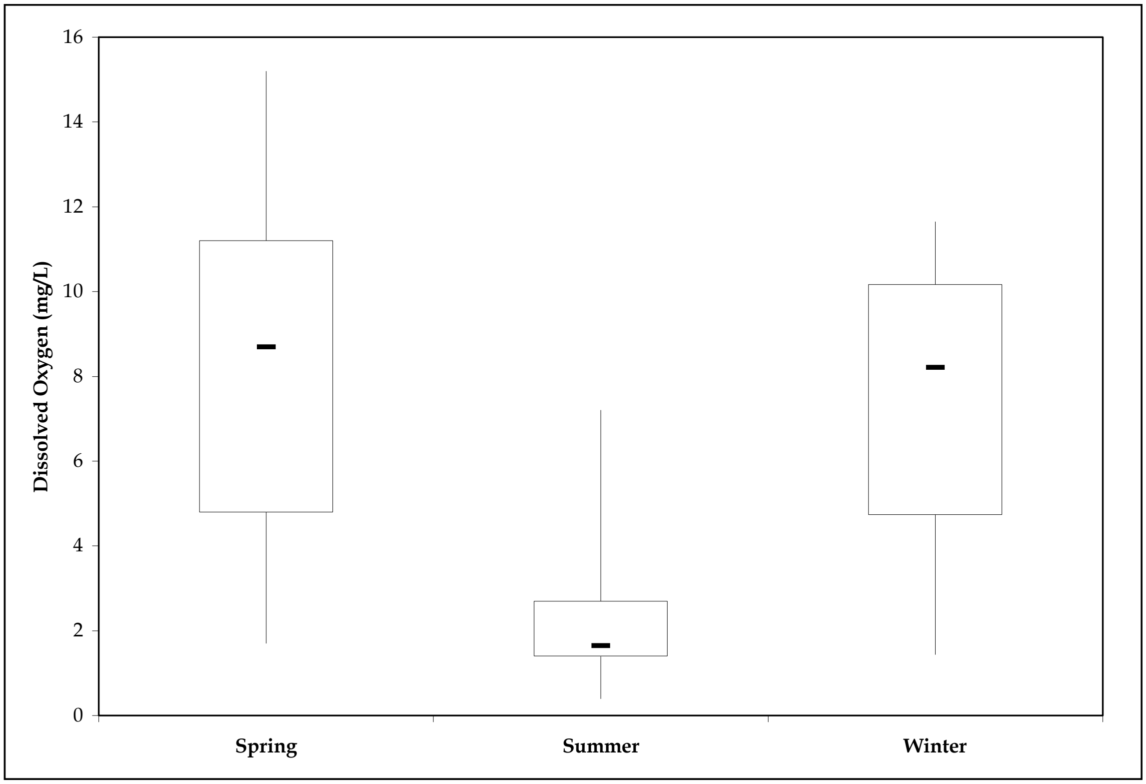

FIGURE 15: Box and whisker plot of seasonal variability in DO. Average DO concentrations in surface water during the spring = 11.0 mg/l; summer = 7.2 mg/l; winter = 11.5 mg/l.

Figure 15 shows that a significant decrease in DO occurs during the summer months in the Cosumnes River. During the spring and winter the median DO concentrations in the subsurface of the streambed are only slightly less than saturated. However, in the summer, the median DO concentration in the subsurface is only 1.65 mg/l. This low concentration is probably due to the significant decrease in flow in the Cosumnes River during the late summer and early fall (see Figure 12); in some areas the water was stagnate and on rare occasions dried up completely. With little surface water seeping through the streambed gravels, the hyporheic DO was depleted by biological activity. In the spring and winter, surface water flow was much greater, and exchange of oxygenated surface water replenished the hyporheic zone with oxygen, therefore keeping the DO concentrations relatively high. It should be noted that DO is highly temperature dependent and that average DO concentrations in the surface water should be taken into consideration on a seasonal basis. It can be assumed that the surface water is saturated with oxygen and that the average concentrations of the surface water vary due to the difference in temperature. This provides a baseline for comparison and discussions of DO levels in the subsurface. In addition, the variability in the data collected during the summer is significantly less than in the spring and winter, as seen by the interquartile range, where the middle 50% of the results can be found. Thus, variability in DO is greater during the spring and winter.

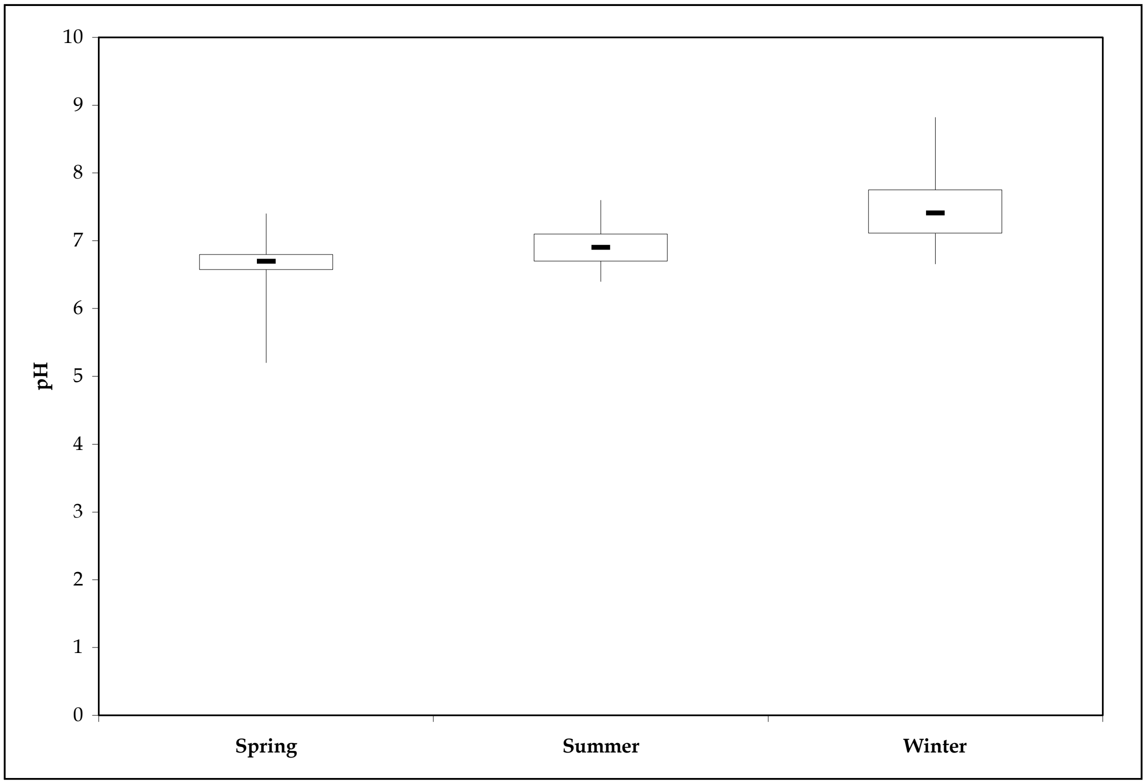

FIGURE 16: Box and whisker plot of seasonal variability in pH. The mean pH in surface water during the spring = 6.5; summer = 7.6; winter = 8.0.

Seasonal differences in pH are not as pronounced. There is a slight increase in pH in the winter, summer pore water is more acidic, and variability is lower in summer. Average surface water pH follows the same trend as the subsurface samples. The lower pH in the summer and spring may be due to increased production of organic acids that form when organic matter decomposes. This is probably related to increased organic production in spring and summer months.

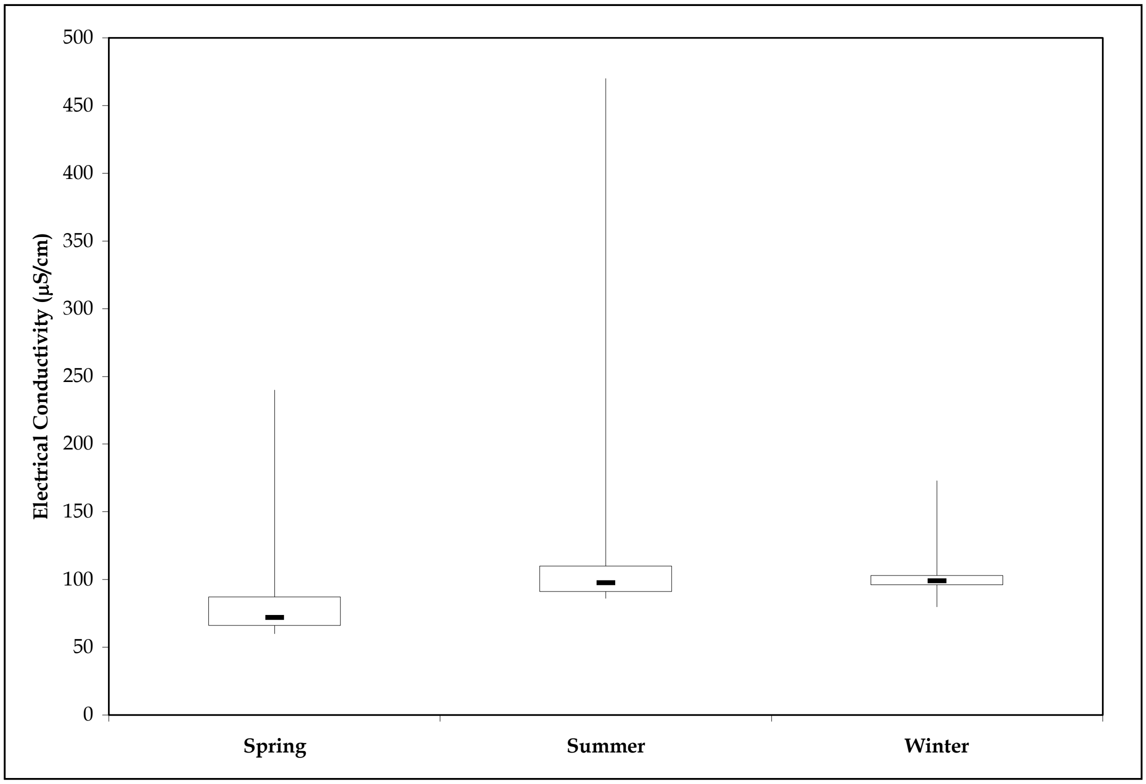

FIGURE 17: Box and whisker plot of the seasonal variability in EC.

The median EC for spring (72 µS/cm) is much less than the median EC results in the summer (97.5 µS/cm) and winter (99 µS/cm). This difference indicates that ions are more concentrated in the summer and winter, as opposed to the spring. In the summer this is likely due to the low flow conditions in the Cosumnes River (see Figure 12); lower flows create higher concentrations of the naturally occurring ionic constituents. In the winter, it is possible that the higher EC results are due to an influx of sediment that would accompany initial high flows. The additional sediment in the stream system would also increase the naturally occurring ions. By spring, the influx of sediment due to increased winter flows has been flushed out of the stream and the higher flows have equilibrated with the typical sediment load of the stream. The skewness of the spring and summer data is also statistically significant. The upper whiskers are significantly longer in spring and even greater in summer indicating that the EC measurements are skewed toward higher values. However, it is likely that the data creating the lengthy whiskers can be considered outliers. The maximum values of EC for the spring and summer are 240 and 470 µS/cm and are likely outliers causing the skewness of the data set.

3.2.2 Longitudinal Variability in Field Parameters

65% of the total samples were collected in a cluster of mini-piezometers surrounding the island in the upstream portion of the sampling area (MP1 through MP10). Only 35% of the samples collected were from the downstream locations of MP11 through MP18. Figures 18 to 20 present a comparison of the longitudinal (upstream vs. downstream) variability in the data set. Table B-2 of Appendix B presents the statistical results of the upstream versus the downstream samples collected throughout the entire project, and at all depths.

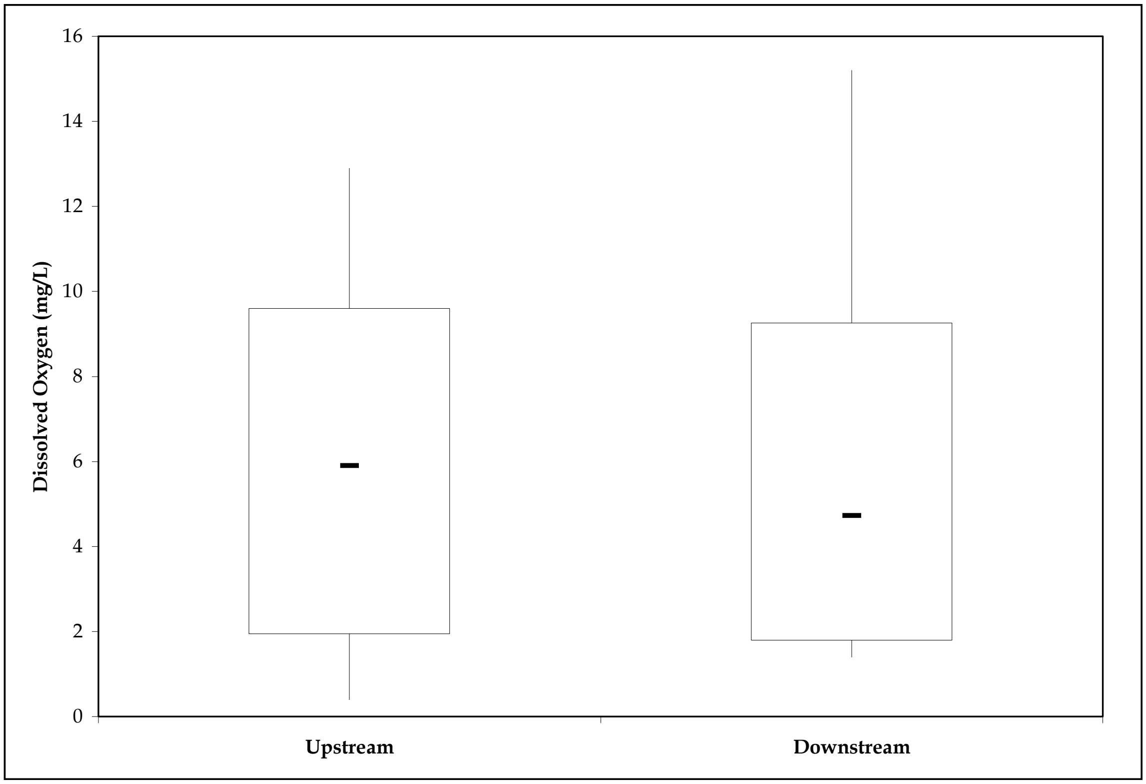

FIGURE 18: Box and whisker plot of longitudinal variability in DO.

Despite other observed field differences between the designated upstream and downstream sampling points, no significant variations in DO exist. Although the median DO concentration in the downstream samples is slightly less than the median in the upstream samples (4.7 and 5.9 mg/l, respectively), the variability in the two data sets encompasses the median values.

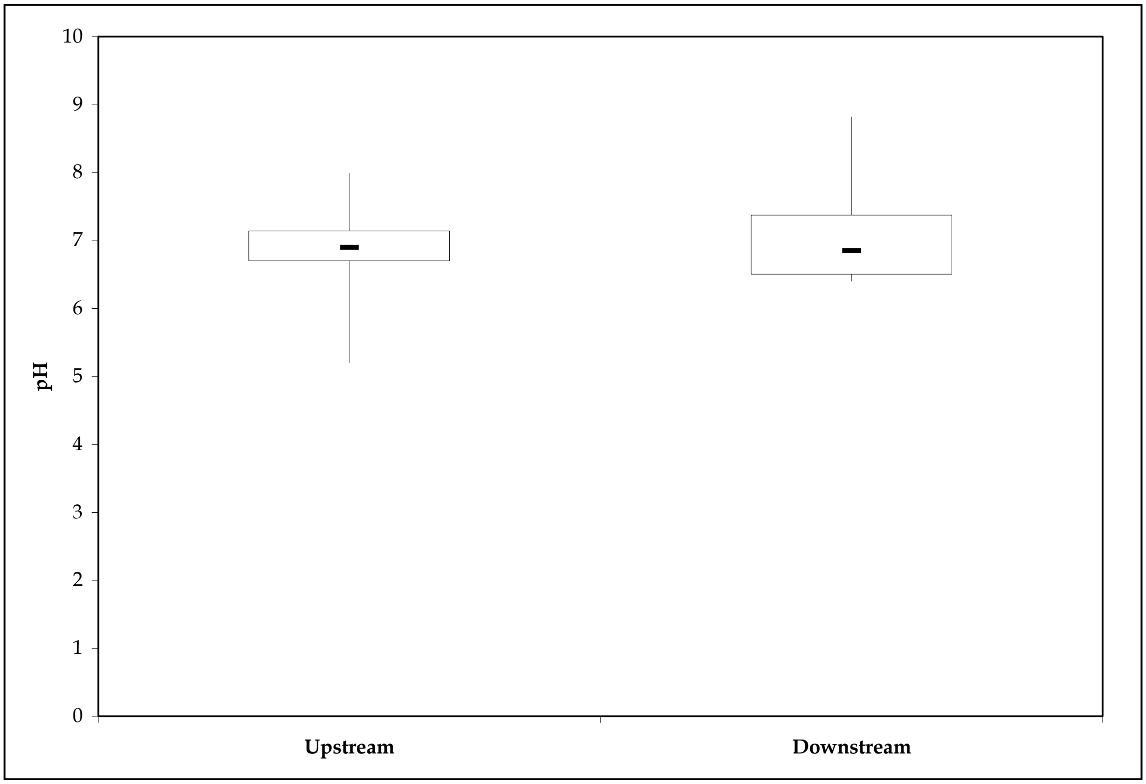

FIGURE 19: Box and whisker plot of longitudinal variability in pH.

Few statistical differences in pH exist between pore waters of the upstream and downstream samples. The medians of each are approximately the same, although the variability in pH in the downstream samples is slightly greater than that of the pH in the upstream samples.

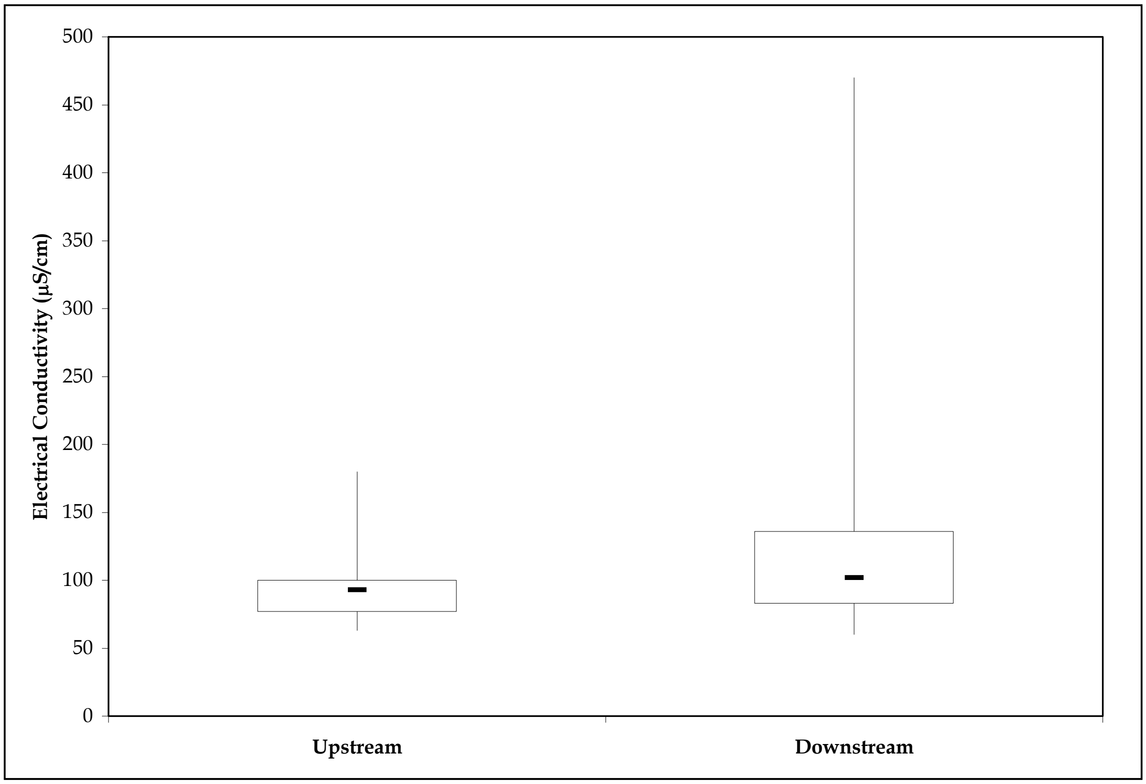

FIGURE 20: Box and whisker plot of longitudinal variability in EC.

EC in the downstream sites is more variable, however this is likely due to the outliers previously discussed. The median EC values for the upstream and downstream data sets are 93 and 102 µS/cm, and are not significantly different if outliers in the downstream data set are considered.

3.2.3 Variability of Field Parameters with Depth in the Gravel

Statistical analysis of the four different (1-, 2-, 9-foot depths and the surface water) data sets was performed in order to compare the results from the different depths. Figures 21 to 23 present a summary of the results of these analyses. Table B-3 in Appendix B contains the complete results of the statistical analyses.

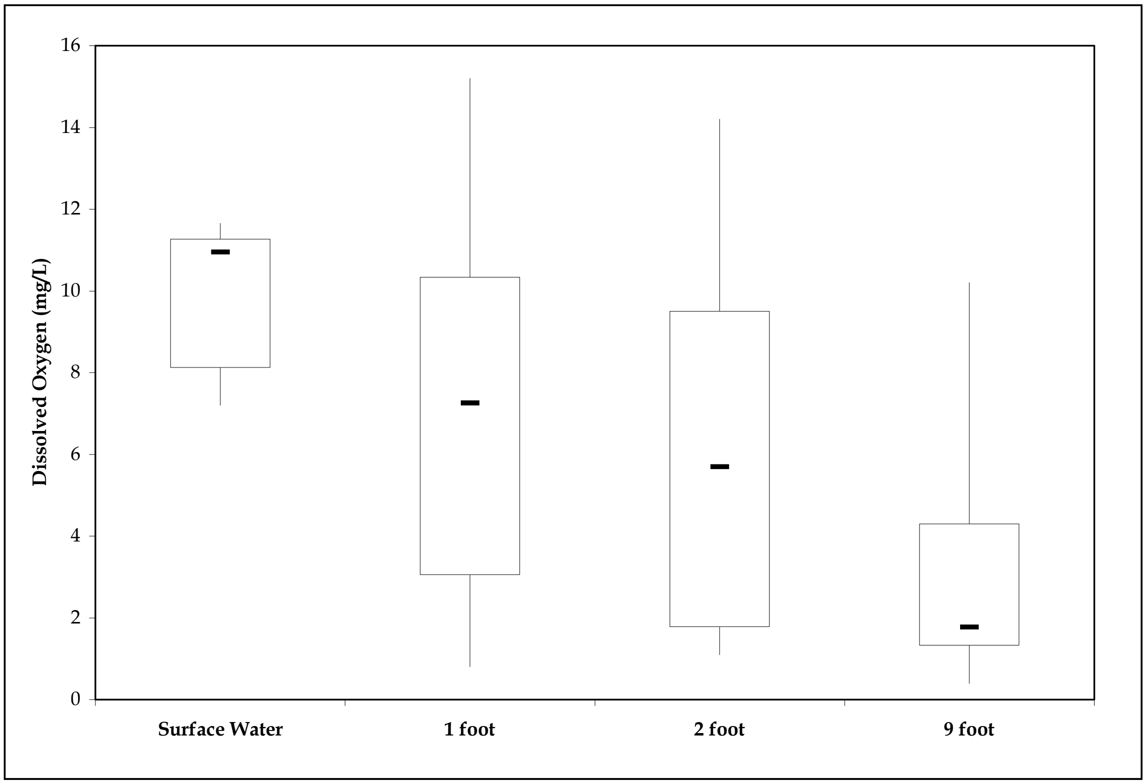

FIGURE 21: Box and whisker plot of DO vs. depth in gravel.

Throughout the year, the surface water has a median DO concentration 11.0 mg/l and a relatively small interquartile range (or small variability). The median DO concentration of the 1-foot sampling interval decreases significantly to 7.3 mg/l and has much more variability in the data. The median DO concentration decreases again to 5.7 mg/l in the 2-foot interval with similar variability to the 1-foot range. In the 9-foot sampling interval the median DO concentration is 1.8 mg/l with less variability in the data as compared to the 1- and 2-foot intervals. This shows that a dissolved oxygen gradient exists from the surface of the streambed to the monitored depths of 9 feet. In other words, DO concentrations are greater in the shallower depths of the streambed gravels, where there is more interaction and mixing with the oxygen-saturated surface water. The DO content decreases with depth because interactions with surface water decrease.

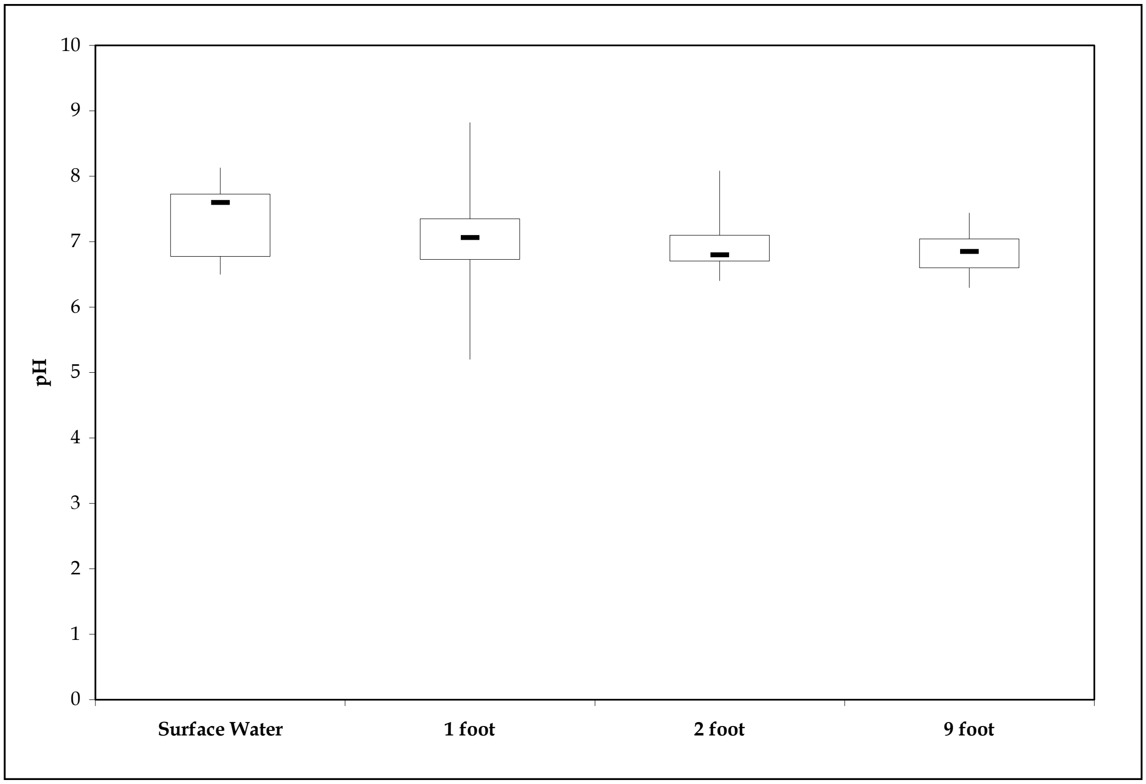

FIGURE 22: Box and whisker plot of pH vs. depth in gravel.

Vertical variations in pH are not as significant as the vertical variations in DO. Although the median pH is slightly higher in the surface water (with a value of 7.6), the subsurface median pH results are similar at each of the monitored depths (7.1, 6.8, and 6.8 for the 1-, 2-, and 9-foot intervals, respectively). Variability is greatest in the surface water samples, but is similar in the subsurface intervals. There may be a slight trend toward decreasing pH with increasing depth, but median values are not distinctly different at each depth.

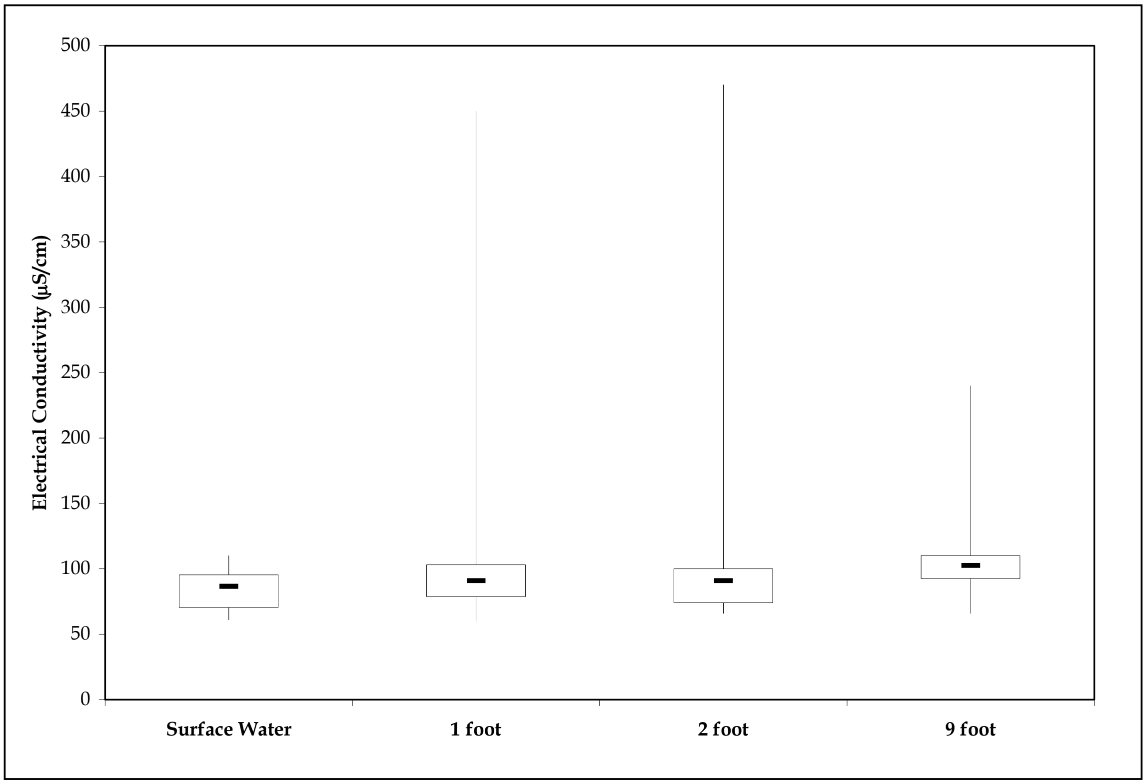

FIGURE 23: Box and whisker plot of EC vs. depth in gravel.

Median results for EC are 86, 91, 91, and 102 µS/cm for the surface water, 1-, 2-, and 9-foot sampling intervals. Little variability exists in each of the data sets, although EC is slightly higher at 9 feet bgs. This is probably due to increased pore water residence time at depth, resulting in increased rock-water interactions (dissolution). This is also in accordance with research that found near-surface interstitial water consistently had lower levels of conductivity than the groundwater (Fraser, 1998). As seen in the previous figures for EC, outliers significantly skew the data for each of the subsurface data sets.

3.2.4 Variability of Field Parameters Due to Streambed Morphology

Figures 24 to 26 present a summary of the results of the statistical analyses of variability due to streambed morphology, and Table B-4 in Appendix B presents the complete results of the analysis.

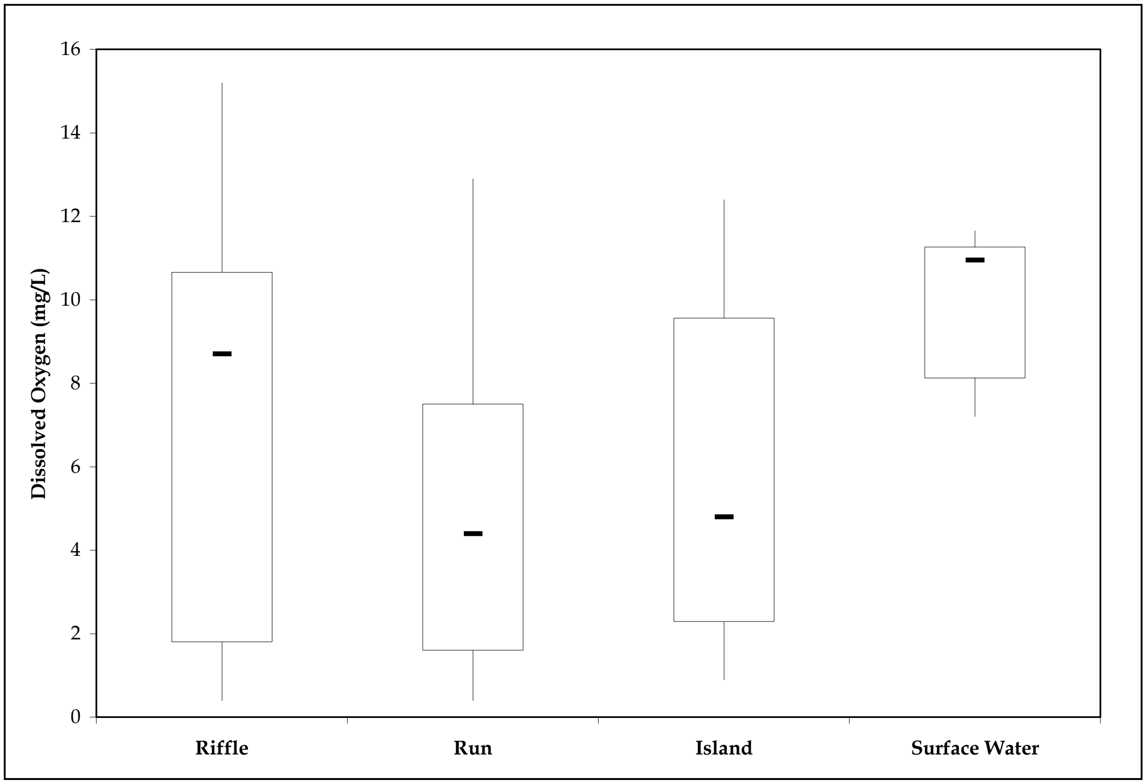

FIGURE 24: Box and whisker plot of DO vs. streambed feature.

Although the variability in this data set is high, the median DO concentration in the riffles is highest at 8.7 mg/l, aside from the surface water samples with a median of 11.0 mg/l. The run and the island data sets have a lower median DO at 4.4 and 4.8 mg/l, respectively. Each data set has a high variability as seen by the interquartile range. The higher median DO concentration in the riffle may indicate that due to the turbulent nature of riffles, more surface water interacts with the hyporheic zone, therefore replenishing the supply of DO more readily in riffles than in the other morphological areas of the stream.

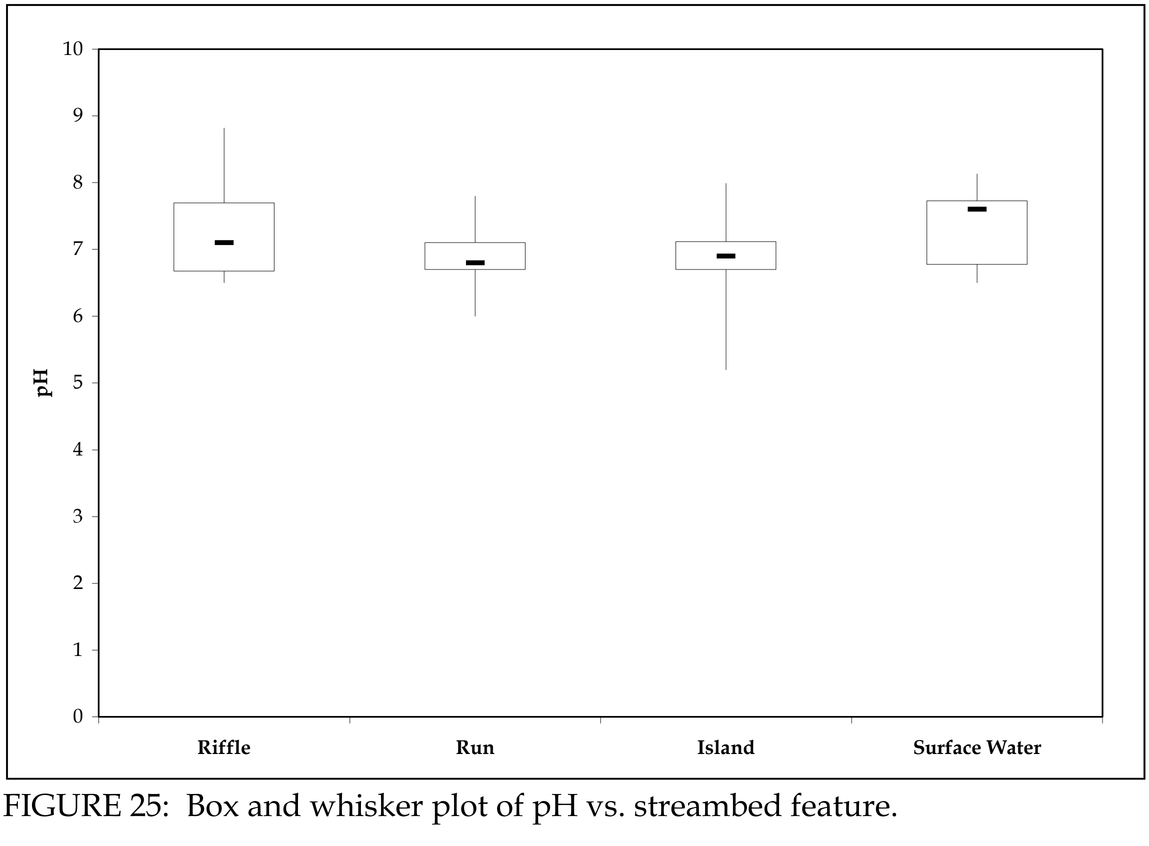

FIGURE 25: Box and whisker plot of pH vs. streambed feature.

Figure 25 shows that pore water sampled from riffles may bee slightly more basic than samples collected from runs or the island. The median values are 7.1, 6.8, 6.9, and 7.6 in the riffle, run, island, and surface water samples, respectively. The largest variability occurs in the riffle data set; however, all of the data sets have relatively low variability. The slightly elevated pH in the riffles and the similar variability between the riffles and the surface water indicates that the residence time of pore water in the riffles is small; there is insufficient time for the acidity of the surface water to change significantly as the water quickly passes through the hyporheic zone.

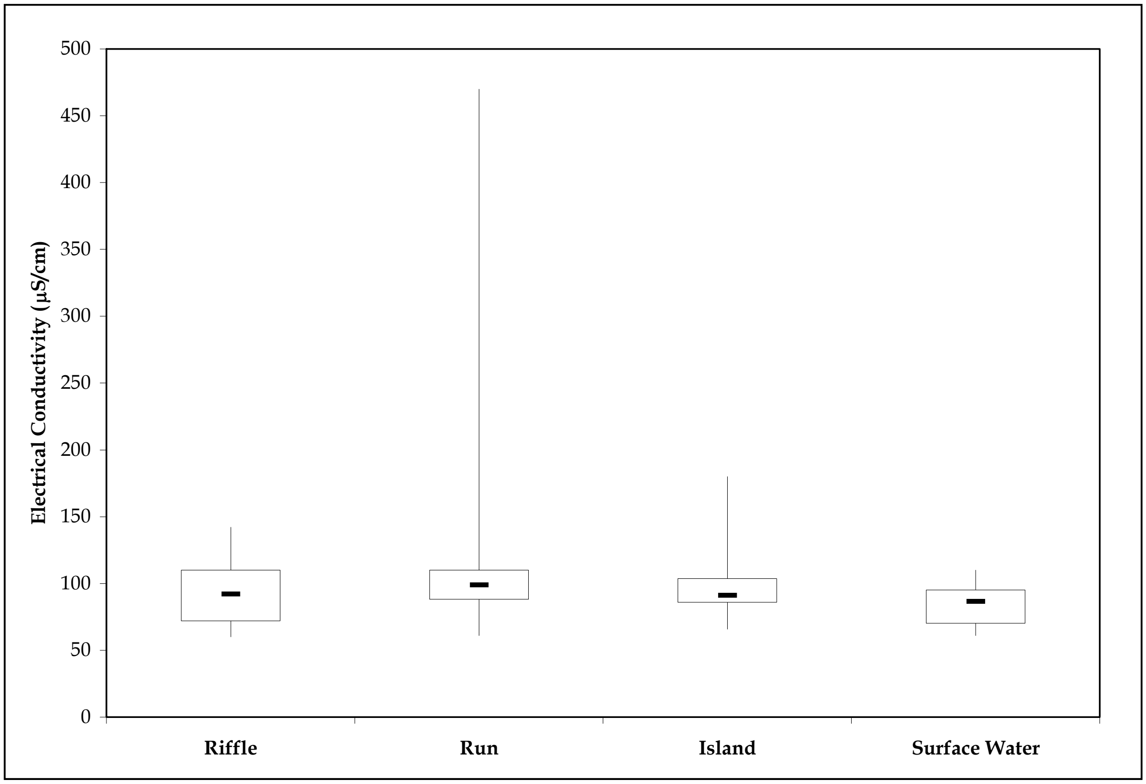

FIGURE 26: Box and whisker plot of EC vs. streambed feature.

Except for the outliers skewing the downstream run samples, little statistical difference exists in EC between the different stream morphologies. The medians are approximately the same (92, 99, 91, and 86 μS/cm for the riffle, run, island, and surface water samples, respectively). In addition, the variability in electrical conductivity data is low for each of the morphological designations.

3.3 Pore Water Geochemistry

Water samples collected from the streambed gravels of the Cosumnes River were analyzed in the laboratory for the major, naturally occurring, dissolved constituents of water including sodium, potassium, magnesium, calcium, chloride, sulfate, and nitrate and dissolved organic carbon (DOC). However, due to the improper preservation of samples to be analyzed for nitrate, nitrate data will not be presented or discussed. In addition to the above analytes, bicarbonate concentrations were calculated, based on charge balance using a PHREEQ based software program called AquaChem v. 3.7 (Waterloo Hydrogeologic, 1997). Table 5 presents the results of the naturally occurring major ions and DOC for each sample collected.

Site Number	Depth (ft bgs)	Season Sampled	DOC (± 0.2) (mg/l)	Na$^+$ (± 0.5) (mg/l)	K$^+$ (± 0.1) (mg/l)	Ca^{2+} (± 0.1) (mg/l)	Mg^{2+} (± 0.4) (mg/l)	Cl$^-$ (± 0.2) (mg/l)	SO$_4^{2+}$ (± 0.3) (mg/l)	HCO$_3^-$ (mg/l)
1	1	Spring 2002	1.2	4.7	1.0	2.9	3.5	1.9	2.4	32
		Summer 2002	1.6	7.1	1.2	5.0	3.8	3.2	4.1	42
		Winter 2003	Cannot locate monitoring point							
	2	Spring 2002	1.0	3.2	1.1	3.0	3.3	2.2	3.0	26
		Summer 2002	1.2	6.4	1.1	5.1	3.7	2.4	1.9	44
		Winter 2003	Cannot locate monitoring point							
	9	Spring 2002	1.1	4.6	1.1	2.5	3.3	1.6	3.0	30
		Summer 2002	1.4	5.3	1.4	3.9	3.8	2.7	1.2	39
		Winter 2003	Cannot locate monitoring point							
2	Surface water	Spring 2002	1.6	3.3	0.92	2.8	3.4	2.0	2.9	27
	1	Spring 2002	1.8	3.6	0.93	2.7	3.6	2.2	2.8	28
		Summer 2002	1.2	5.9	1.2	5.4	4.3	2.8	2.9	
		Winter 2003	1.3	4.3	1.1	4.3	4.7	3.9	7.8	31
	2	Spring 2002	1.3	3.6	0.9	2.6	3.5	1.6	2.0	30
		Summer 2002	1.0	6.1	1.2	5.5	4.3	2.9	3.3	45
		Winter 2003	1.4	4.4	1.2	4.3	4.5	3.7	6.4	33
	9	Spring 2002	1.1	3.3	1.0	2.8	3.4	2.3	4.7	24
		Summer 2002	1.0	5.9	1.2	5.5	3.8	1.8	2.8	45
		Winter 2003	Insufficient water to collect sample							
3	1	Spring 2002	1.2	3.6	0.9	2.7	3.3	2.2	3.0	27
		Summer 2002	1.1	5.8	1.2	5.4	3.7	2.3	3.1	42
		Winter 2003	1.5	4.4	1.0	4.3	4.7	4.0	7.1	32
	2	Spring 2002	1.1	3.5	0.9	2.8	3.5	2.1	2.7	28
		Summer 2002	0.9	6.4	1.2	5.4	3.9	1.8	5.4	43
		Winter 2003	1.5	4.2	1.1	4.4	4.6	3.6	6.8	33
	9	Spring 2002	1.3	4.3	1.0	2.4	3.2	1.9	0.9	30
		Summer 2002	1.4	5.6	1.4	3.8	3.2	Contaminated w/ nitric acid		
		Winter 2003	1.1	4.2	1.0	3.7	3.7	4.8	14	15

TABLE 5: Laboratory analytical results.

Site Number	Depth (ft bgs)	Season Sampled	DOC (± 0.2) (mg/l)	Na$^+$ (± 0.5) (mg/l)	K$^+$ (± 0.1) (mg/l)	Ca^{2+} (± 0.1) (mg/l)	Mg^{2+} (± 0.4) (mg/l)	Cl$^-$ (± 0.2) (mg/l)	SO$_4^{2+}$ (± 0.3) (mg/l)	HCO$_3^-$ (mg/l)
4	Surface Water	Winter 2003	1.8	4.1	0.9	4.0	4.7	3.0	5.0	35
	1	Spring 2002	1.3	4.9	1.7	4.2	3.0	1.9	2.6	34
		Summer 2002	1.2	5.8	1.4	4.9	4.1	2.9	3.1	42
		Winter 2003	1.4	4.3	1.0	4.1	4.6	3.2	6.0	34
	2	Spring 2002	1.3	5.0	1.7	4.2	3.0	2.1	2.7	34
		Summer 2002	1.1	6.0	1.2	5.2	4.0	0.7	2.2	48
		Winter 2003	1.5	4.9	1.0	4.1	4.5	2.9	5.4	36
	9	Spring 2002	1.6	6.2	2.8	5.8	3.5	2.8	0.6	46
		Summer 2002	1.1	5.6	1.5	5.4	4.0	2.5	nd	47
		Winter 2003	1.5	4.8	1.2	4.7	3.8	4.1	5.4	32
5	1	Spring 2002	0.8	5.2	2.0	4.5	3.3	1.7	3.9	36
		Summer 2002	1.0	5.8	1.2	5.4	3.7	3.4	3.1	43
		Winter 2003	1.3	5.1	1.2	4.4	4.5	3.9	6.9	34
	2	Spring 2002	1.0	5.5	2.0	4.7	3.6	1.3	2.3	42
		Summer 2002	1.0	5.7	1.2	5.2	3.8	3.6	3.5	39
		Winter 2003	Piezometer missing							
	9	Spring 2002	1.2	5.3	2.3	6.6	4.5	1.8	3.4	49
		Summer 2002	1.2	5.3	1.3	5.6	3.5	2.1	2.9	41
		Winter 2003	1.0	4.9	1.0	4.6	4.3	4.1	6.4	33
6	1	Spring 2002	1.1	5.0	1.7	4.1	2.9	1.4	2.2	35
		Summer 2002	Cannot locate monitoring point							
		Winter 2003								
	2	Spring 2002	1.1	3.8	1.8	4.1	3.1	1.7	2.6	32
		Summer 2002	Cannot locate monitoring point							
		Winter 2003								
	9	Spring 2002	1.5	3.8	1.8	4.1	3.2	1.3	2.1	34
		Summer 2002	Cannot locate monitoring point							
		Winter 2003								

TABLE 5 (continued)

Site Number	Depth (ft bgs)	Season Sampled	DOC (± 0.2) (mg/l)	Na^+ (± 0.5) (mg/l)	K^+ (± 0.1) (mg/l)	Ca^{2+} (± 0.1) (mg/l)	Mg^{2+} (± 0.4) (mg/l)	Cl^- (± 0.2) (mg/l)	SO_4^{2+} (± 0.3) (mg/l)	HCO_3^- (mg/l)
7	Surface Water	Summer 2002	1.8	5.7	1.3	5.1	4.2	2.2	3.1	44
	1	Spring 2002	1.4	3.5	1.7	3.9	3.2	1.5	2.6	31
		Summer 2002	1.0	5.6	1.2	5.2	3.5	3.6	3.2	38
		Winter 2003	1.5	4.6	1.2	4.5	4.1	3.0	5.7	34
	2	Spring 2002	1.8	3.1	1.9	3.8	3.8	1.0	1.2	36
		Summer 2002	Piezometer missing							
		Winter 2003								
	9	Spring 2002	1.1	5.7	2.8	8.3	6.1	2.5	6.6	58
		Summer 2002	0.7	5.4	1.6	5.4	4.3	2.8	2.6	44
		Winter 2003	0.9	4.8	1.1	5.3	4.6	4.9	7.8	34
8	1	Spring 2002	Water too deep to sample							
		Summer 2002	0.7	4.8	1.0	5.3	3.9	2.2	2.9	41
		Winter 2003	Water too deep to sample							
	2	Spring 2002	Water too deep to sample							
		Summer 2002	0.6	5.4	1.0	5.7	3.7	1.8	2.5	44
		Winter 2003	Water too deep to sample							
	9	Spring 2002	Water too deep to sample							
		Summer 2002	0.7	6.4	0.8	6.5	4.3	2.4	3.0	50
		Winter 2003	Water too deep to sample							
9	1	Spring 2002	1.9	3.7	3.0	8.3	6.8	1.1	1.9	65
		Summer 2002	1.0	5.8	1.2	5.1	3.7	2.0	3.9	41
		Winter 2003	1.4	4.7	1.2	4.1	4.8	4.3	7.5	32
	2	Spring 2002	1.1	4.1	2.8	6.6	6.1	1.4	1.3	58
		Summer 2002	1.0	5.5	1.2	5.1	3.7	2.3	5.5	38
		Winter 2003	1.1	4.7	1.2	4.2	4.8	4.4	7.7	32
	9	Spring 2002	1.1	4.9	2.5	9.3	6.6	2.0	1.8	69
		Summer 2002	0.9	5.5	1.3	4.2	3.5	1.9	3.2	34
		Winter 2003	0.9	4.8	1.0	4.7	5.0	4.5	7.9	38
10	1	Spring 2002	0.8	3.8	1.8	3.8	3.3	1.4	2.3	33
		Summer 2002	1.3	5.6	1.3	5.5	4.0	2.1	3.5	44
		Winter 2003	1.4	4.8	1.1	3.9	3.9	3.0	6.6	31
	2	Spring 2002	1.0	4.4	2.1	4.1	3.3	1.3	1.9	36
		Summer 2002	2.2	5.4	1.3	5.7	4.0	2.2	3.3	44
		Winter 2003	1.3	5.1	1.2	3.9	4.3	2.9	6.0	34
	9	Spring 2002	0.8	4.2	1.7	4.2	3.2	1.6	3.5	33
		Summer 2002	0.9	5.2	1.3	5.2	4.0	2.1	3.3	42
		Winter 2003	1.1	4.8	0.8	5.1	4.7	3.1	6.8	38

TABLE 5 (continued)

Site Number	Depth (ft bgs)	Season Sampled	DOC (± 0.2) (mg/l)	Na^+ (± 0.5) (mg/l)	K^+ (± 0.1) (mg/l)	Ca^{2+} (± 0.1) (mg/l)	Mg^{2+} (± 0.4) (mg/l)	Cl^- (± 0.2) (mg/l)	SO_4^{2+} (± 0.3) (mg/l)	HCO_3^- (mg/l)
11	1	Spring 2002	Cannot locate monitoring point, water too fast							
		Summer 2002	1.4	5.8	1.1	4.9	3.8	2.3	3.5	41
		Winter 2003	Cannot locate monitoring point, water too fast							
	2	Spring 2002	Cannot locate monitoring point, water too fast							
		Summer 2002	0.9	5.3	1.1	4.7	3.8	2.5	4.6	37
		Winter 2003	Cannot locate monitoring point, water too fast							
	9	Spring 2002	Cannot locate monitoring point, water too fast							
		Summer 2002	Insufficient water to collect sample							
		Winter 2003	Cannot locate monitoring point, water too fast							
12	Surface Water	Spring 2002	1.2	4.6	1.6	3.6	2.8	1.3	1.7	33
	1	Spring 2002	0.8	5.0	1.9	4.8	3.6	1.6	2.2	40
		Summer 2002	0.9	8.0	2.2	13	11	6.6	22	77
		Winter 2003	1.5	4.5	0.8	4.2	4.1	3.7	8.3	28
	2	Spring 2002	0.9	4.7	1.9	4.0	3.2	1.7	2.5	34
		Summer 2002	1.1	7.9	2.1	16	13	6.3	24	94
		Winter 2003	0.8	4.3	0.9	4.4	4.3	2.5	7.3	33
	9	Spring 2002	1.0	8.7	14	19	13	6.5	19	110
		Summer 2002	Insufficient water to collect sample							
		Winter 2003	Insufficient water to collect sample							
13	1	Spring 2002	1.0	4.2	1.6	3.4	3.2	1.4	0.2	35
		Summer 2002	1.1	5.1	1.2	6.3	4.8	1.6	3.4	50
		Winter 2003	1.7	4.9	1.0	3.4	3.7	2.5	5.0	31
	2	Spring 2002	0.9	3.7	1.9	4.0	3.9	1.5	0.6	38
		Summer 2002	1.0	4.8	1.3	5.9	4.5	1.6	3.3	46
		Winter 2003	1.5	4.3	0.8	3.6	3.9	2.8	6.3	29
	9	Spring 2002	1.1	5.1	1.8	5.9	6.1	3.4	13	40
		Summer 2002	Insufficient water to collect sample							
		Winter 2003	Insufficient water to collect sample							
14	1	Spring 2002	1.0	3.4	1.7	3.6	3.1	1.6	1.4	31
		Summer 2002	1.6	6.5	1.9	12	12	2.5	8.4	98
		Winter 2003	1.6	4.3	1.1	3.4	3.7	2.6	5.0	30
	2	Spring 2002	1.1	5.3	1.5	3.8	3.4	1.4	0.9	39
		Summer 2002	1.7	6.8	1.8	12	7.2	2.3	8.3	75
		Winter 2003	1.5	4.5	0.7	3.7	4.5	3.1	6.8	32
	9	Spring 2002	Insufficient water to collect sample							
		Summer 2002								
		Winter 2003								

TABLE 5 (continued)

Site Number	Depth (ft bgs)	Season Sampled	DOC (± 0.2) (mg/l)	Na^+ (± 0.5) (mg/l)	K^+ (± 0.1) (mg/l)	Ca^{2+} (± 0.1) (mg/l)	Mg^{2+} (± 0.4) (mg/l)	Cl^- (± 0.2) (mg/l)	SO_4^{2+} (± 0.3) (mg/l)	HCO_3^- (mg/l)
15	1	Spring 2002	0.8	3.6	1.7	4.1	3.4	1.6	2.5	33
		Summer 2002	1.6	6.2	1.5	6.1	4.9	2.3	3.6	51
		Winter 2003	1.4	4.6	0.8	4.5	4.3	3.3	6.9	
	2	Spring 2002	Piezometer missing							
		Summer 2002								
		Winter 2003								
	9	Spring 2002	0.8	5.9	2.8	8.3	8.3	3.0	6.1	70
		Summer 2002	0.9	5.3	1.1	4.6	4.7	2.5	4.6	42
		Winter 2003	0.5	6.2	1.1	8.0	7.1	3.3	5.4	64
16	1	Spring 2002	Did not sample during this event							
		Summer 2002	Piezometer missing							
		Winter 2003	Cannot locate monitoring point							
	2	Spring 2002	Did not sample during this event							
		Summer 2002	1.9	6.4	1.9	47	11	2.1	6.2	210
		Winter 2003	Cannot locate monitoring point							
	9	Spring 2002	Did not sample during this event							
		Summer 2002	2.4	7.3	2.0	13	13	1.8	8.3	110
		Winter 2003	Cannot locate monitoring point							
17	1	Spring 2002	Did not sample during this event							
		Summer 2002	Cannot locate monitoring point							
		Winter 2003	1.5	4.3	1.0	3.4	3.9	2.7	5.4	30
	2	Spring 2002	Did not sample during this event							
		Summer 2002	Cannot locate monitoring point							
		Winter 2003	1.2	5.5	1.0	3.5	4.4	3.6	9.6	29
	9	Spring 2002	No Piezometer installed							
		Summer 2002								
		Winter 2003								

TABLE 5 (continued)

Site Number	Depth (ft bgs)	Season Sampled	DOC (± 0.2) (mg/l)	Na^+ (± 0.5) (mg/l)	K^+ (± 0.1) (mg/l)	Ca^{2+} (± 0.1) (mg/l)	Mg^{2+} (± 0.4) (mg/l)	Cl^- (± 0.2) (mg/l)	SO_4^{2+} (± 0.3) (mg/l)	HCO_3^- (mg/l)
18	Surface Water	Summer 2002	1.6	25	2.8	31	23	4.9	30	230
		Winter 2003	1.7	3.5	0.8	3.3	3.7	1.9	4.1	29
	1	Spring 2002	Did not sample during this event							
		Summer 2002	1.4	23	2.6	nd	23	5.0	35	120
		Winter 2003	1.6	6.7	0.9	7.2	6.2	2.8	4.2	61
	2	Spring 2002	Did not sample during this event							
		Summer 2002	1.5	5.7	1.2	5.9	5.9	2.9	4.9	51
		Winter 2003	1.8	8.1	1.0	9.7	8.6	3.6	4.8	82
	9	Spring 2002	No Piezometer installed							
		Summer 2002								
		Winter 2003								

DOC – Dissolved Organic Carbon
Na^+ - dissolved sodium ion
K^+ - dissolved potassium ion
Ca^{2+} - dissolved calcium ion
Mg^{2+} - dissolved magnesium ion
Cl^- - dissolved chloride ion
SO_4^{2-} - dissolved sulfate ion
HCO_3^- - dissolved bicarbonate ion, calculated from charge balance of each sample
ft bgs – feet below ground surface
mg/l – milligrams per liter
nd – not detected

TABLE 5 (continued)

The following sections present comparisons of the data contained in Table 5. Data were analyzed to determine variability with seasonal, longitudinal, vertical, and morphological groupings. Significant variations are presented below, including box and whisker plots, and all statistical analyses are contained in Appendix D. Box and whisker plots for all ions and DOC are included in Appendix E.

3.3.1 Seasonal Variability of Water Chemistry

3.3.1.1 Trends in Ion Chemistry

Statistical differences exist in the cation and anion geochemistry when analyzed with respect to the season. Statistical results have been tabulated and are included in Table D-1 of Appendix D. The figures for other ratio comparisons as well as box and whisker plots for each ion analyzed for seasonal variability are included in Appendix E.

Initial analyses indicated that the differences in cation results are primarily seen in sodium and calcium concentrations (rather than potassium and magnesium), which varied significantly between many samples. Therefore the ratios of sodium to calcium concentrations in each sample were examined. The following figures present some of the representative differences in ion chemistry. Figure 27 shows that during the spring the relative abundance of sodium and calcium is generally low. Concentrations of both sodium and calcium generally increase in the winter and are the highest in the summer. The box and whisker plot in Figure 28 shows that the median Na/Ca ratio for all three seasons is approximately 1.0; variability is lowest in the winter and highest in the spring.

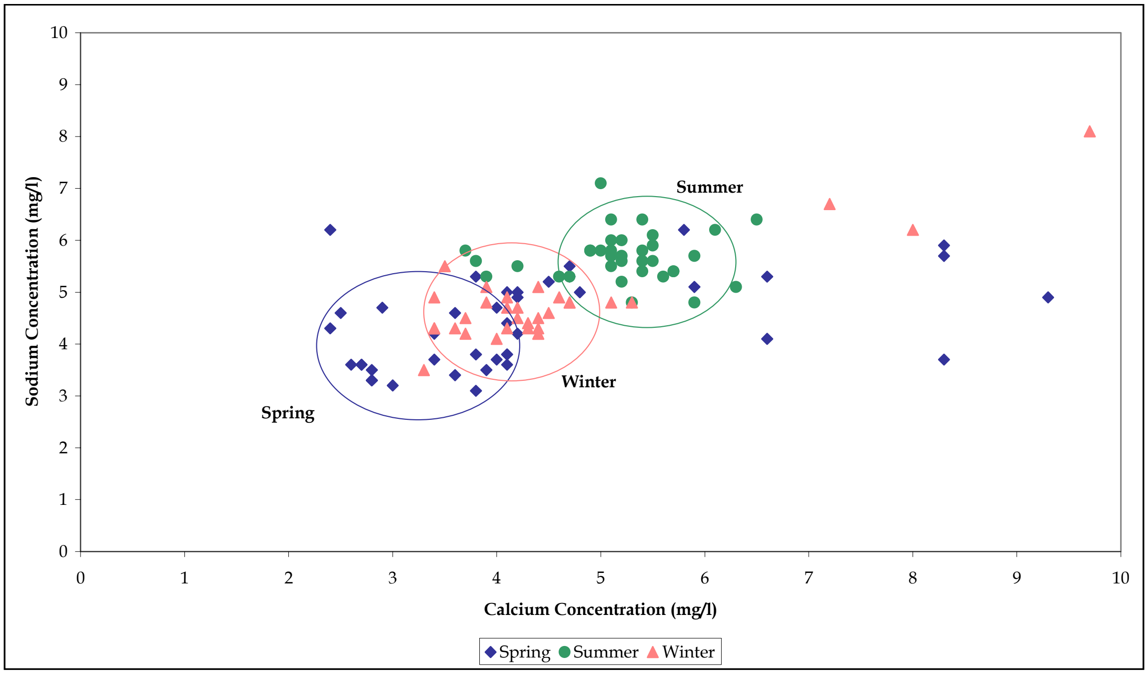

FIGURE 27: Relationship of calcium and sodium concentrations to seasons.

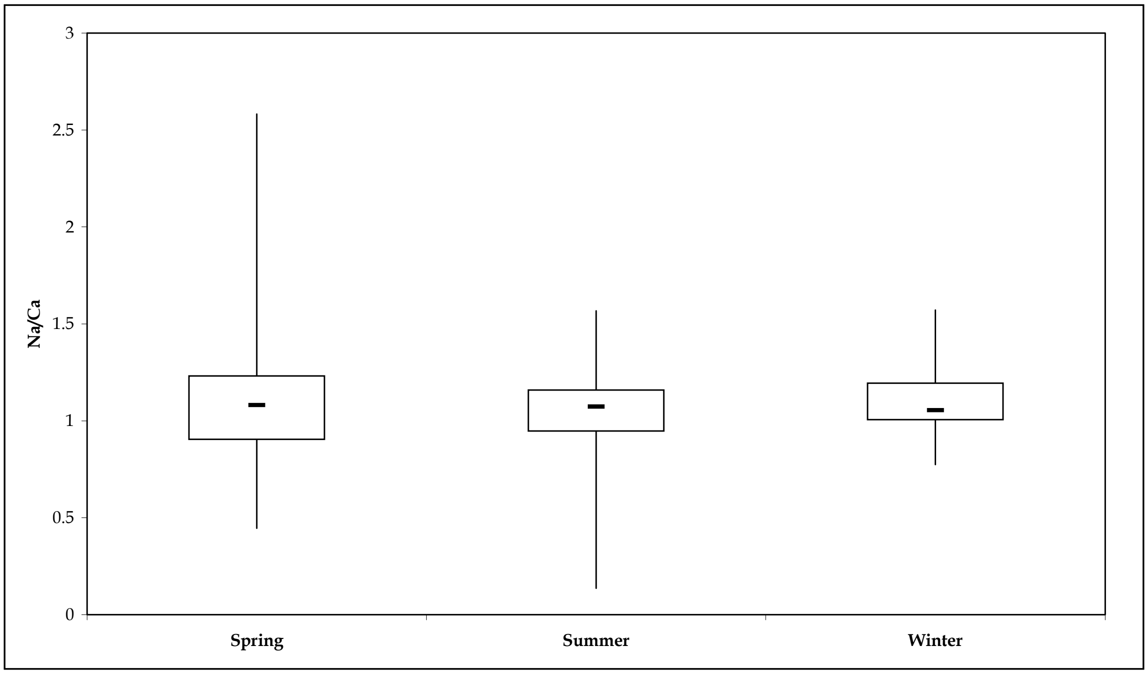

FIGURE 28: Box and whisker plot of Na/Ca ratio with respect to seasons.

The relative abundance of sodium and calcium does not significantly change throughout the year, although, as seen in Figure 27, the concentrations do vary from season to season. In the summer, less exchange between the surface water and the pore water and lower surface water velocity in the summer lead to dissolution of Na and Ca that was in the mineral phase. In the winter, increased surface and pore water exchange starts to deplete the system of dissolved ions. The high surface water and pore water exchange that occurs in the spring leads to shorter residence times and therefore lower dissolved ion concentrations.

Obvious trends exist in seasonal changes in the concentrations of chloride and sulfate. Figures 29 and 30 show the box and whisker plots for seasonal analysis of chloride and sulfate, repsectively.

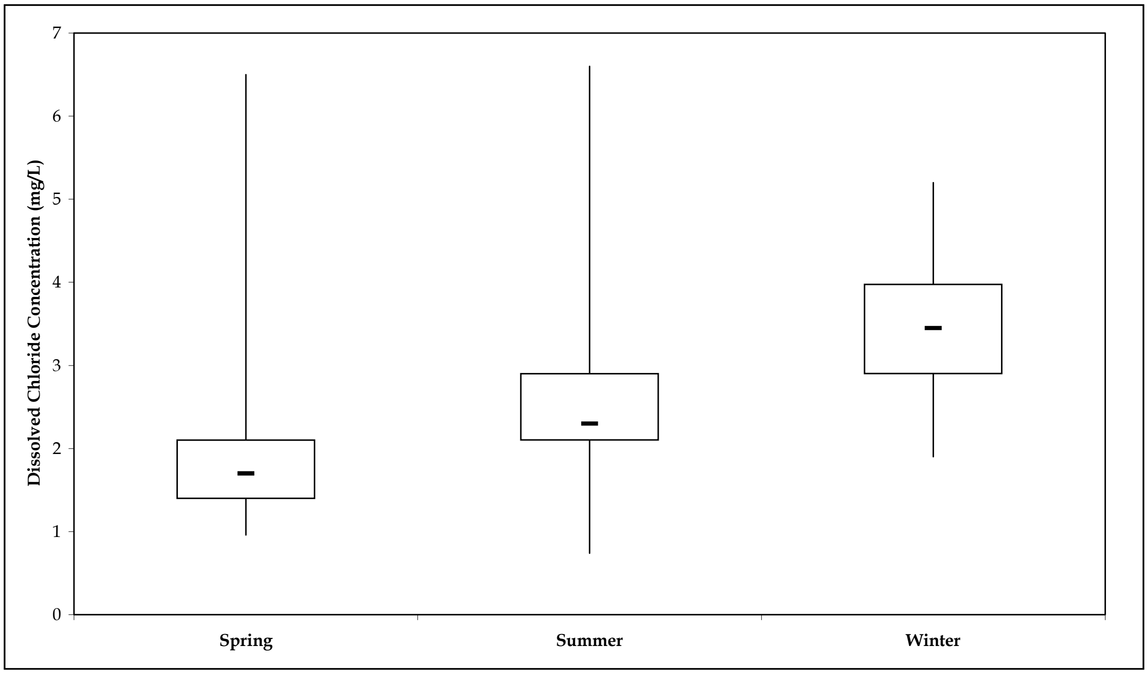

FIGURE 29: Box and whisker plot of seasonal variability in chloride.

Figures 29 and 30 show that the median chloride and sulfate concentrations are lowest in the spring and highest in the winter. The variability in each data set, as seen by the interquartile range, is similar between the seasons. While spring and summer follow the general trends as discussed above with respect to residence times and exchange reactions; chloride and sulfate concentrations in the winter appear to be anomalously high. These higher concentrations of chloride and sulfate may be due to outside sources such as surface water runoff from nearby or upstream pastures, golf courses, and highways.

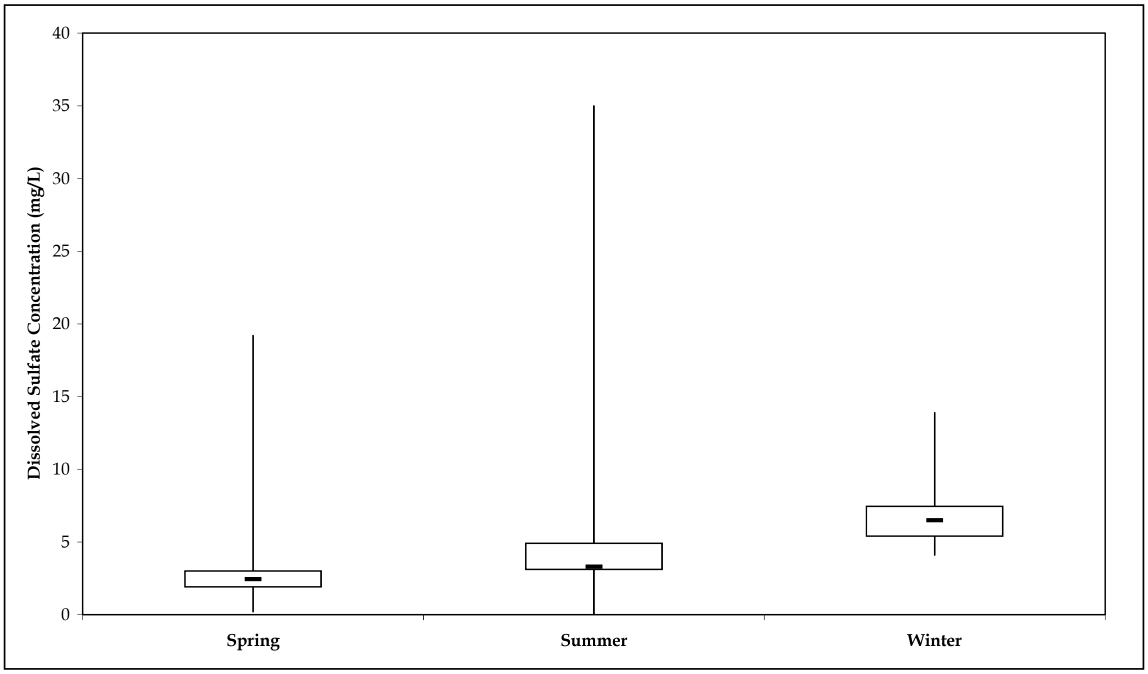

FIGURE 30: Box and whisker plot of seasonal variability in sulfate.

3.3.1.1 Dissolved Organic Carbon Trends

Figure 31 shows that the median DOC in the winter (1.42 mg/l) is significantly higher than in the spring or summer (1.11 and 1.13 mg/l, respectively). Increases in discharge due to storms can significantly increase DOC concentrations within the stream (Mulholland and Hill, 1997). This increase in DOC in the winter is possibly due to the influx of detritus that collected along the banks of the Cosumnes River throughout the summer and late fall. In addition, increased stream flows create within-stream disturbances, therefore leading to increased DOC (Casey and Farr, 1982).

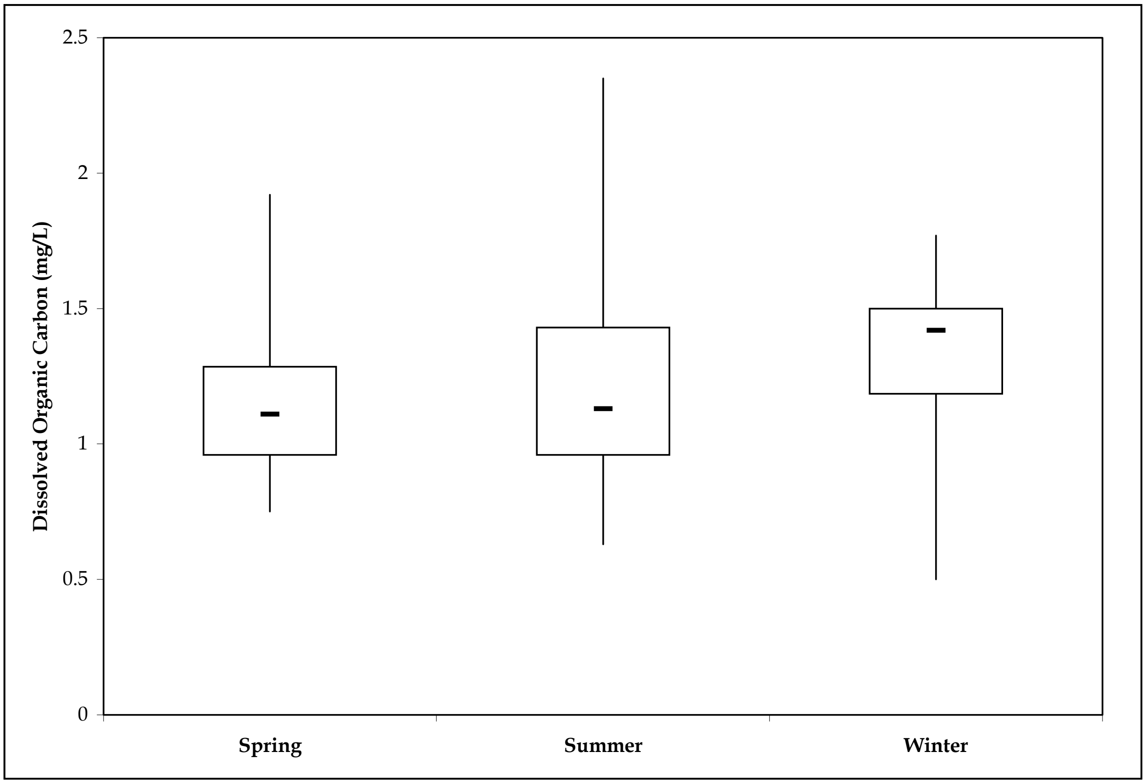

FIGURE 31: Box and whisker plot of seasonal variability in DOC.

3.3.2 Longitudinal Variability of Water Chemistry

3.3.2.1 Trends in Ion Chemistry

The most significant variation between upstream versus downstream samples is that the downstream median for each ion is higher than the upstream median. Some of this apparent difference may be a result of significantly high outliers in the downstream data that are skewing the data. Figure 32 is an example of a typical upstream versus downstream statistical comparison.

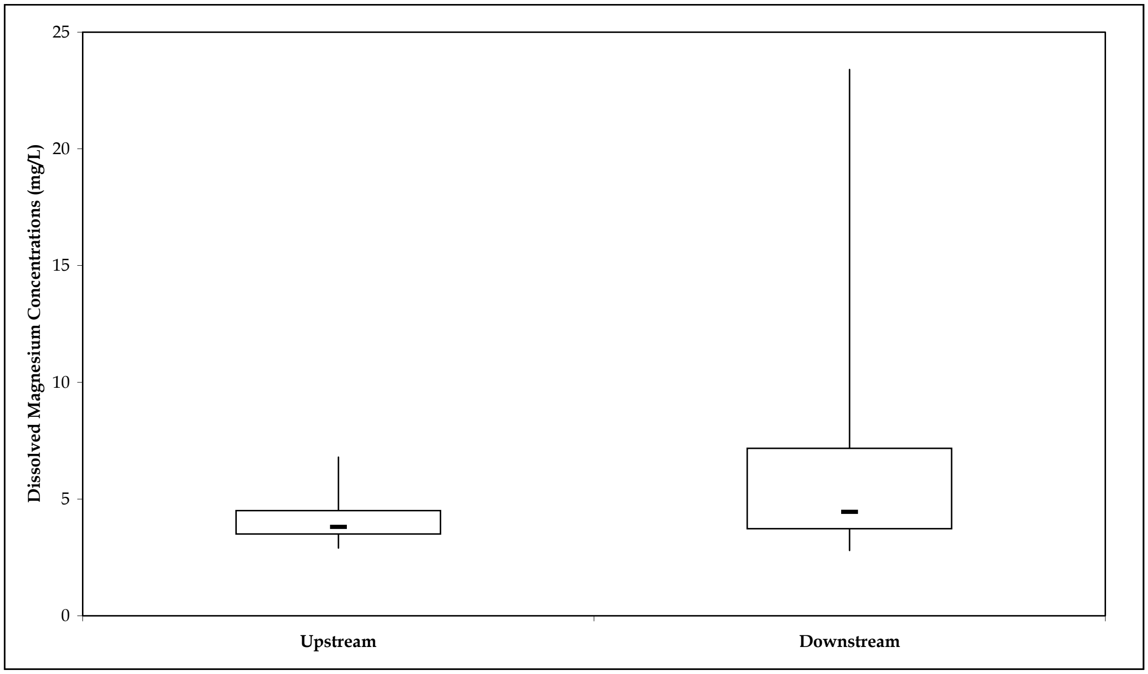

FIGURE 32: Box and whisker plot of longitudinal variation in magnesium, a representative ion.

Figure 32 shows that the downstream median is higher than the upstream median. The interquartile range is also greater in the downstream samples, and there are significant outliers in the downstream samples, both of which are typical of the other ions analyzed. A summary of the statistical results for the longitudinal variability in the geochemistry data is included in Table D-2 in Appendix D. Box and whisker plots for the remaining ions are included in Appendix E.

3.3.2.2 Dissolved Organic Carbon Trends

Analysis of DOC data for the upstream and downstream samples indicates that there is little statistical difference between the two areas. Figure 33 is a box and whisker plot for the longitudinal variability in DOC.

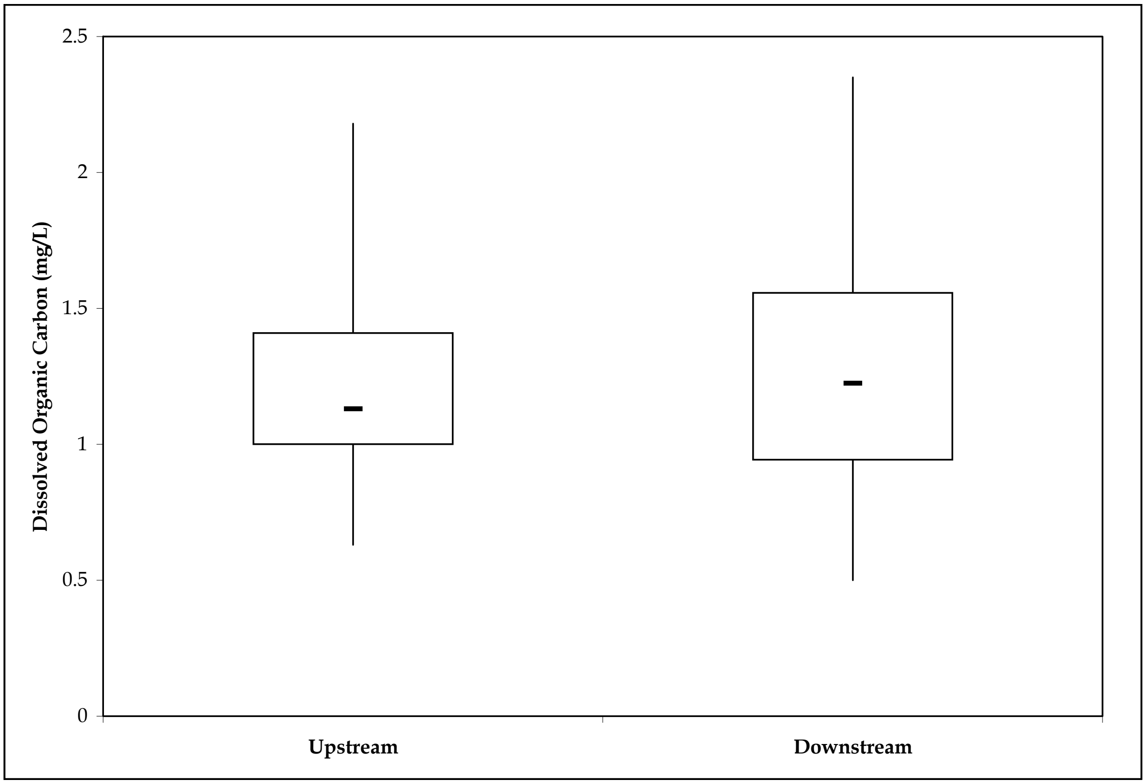

FIGURE 33: Box and whisker plot of longitudinal variability in DOC.

The variability of the downstream samples is greater than the upstream samples as seen by the interquartile range in Figure 33. As previously mentioned, the underlying geology changes significantly in the general area of MP11. In this area, the Cosumnes River becomes less confined by bedrock and has a wider floodplain. The wider floodplain supports more vegetation and therefore more detritus is present when stream flows increase. In addition, the median DOC concentration may be slightly higher (1.2 mg/l vs. 1.1 mg/l) in the downstream portion of the study area. Research typically shows this to be the case, as non-labile (refractory) forms of organic carbon accumulate in a downstream direction (Hynes, 1983).

3.3.3 Variability of Water Chemistry with Depth in the Gravel

3.3.3.1 Trends in Ion Chemistry

Results show that major ion concentrations in surface water, 1-, 2-, and 9-foot depths are quite similar. The medians for each ion within each sampling interval are not significantly different, the interquartile ranges are similar, and the skewness is similar for each ion and each depth. Figure 34 presents a representative box and whisker plot of chloride concentrations with depth in the gravel.

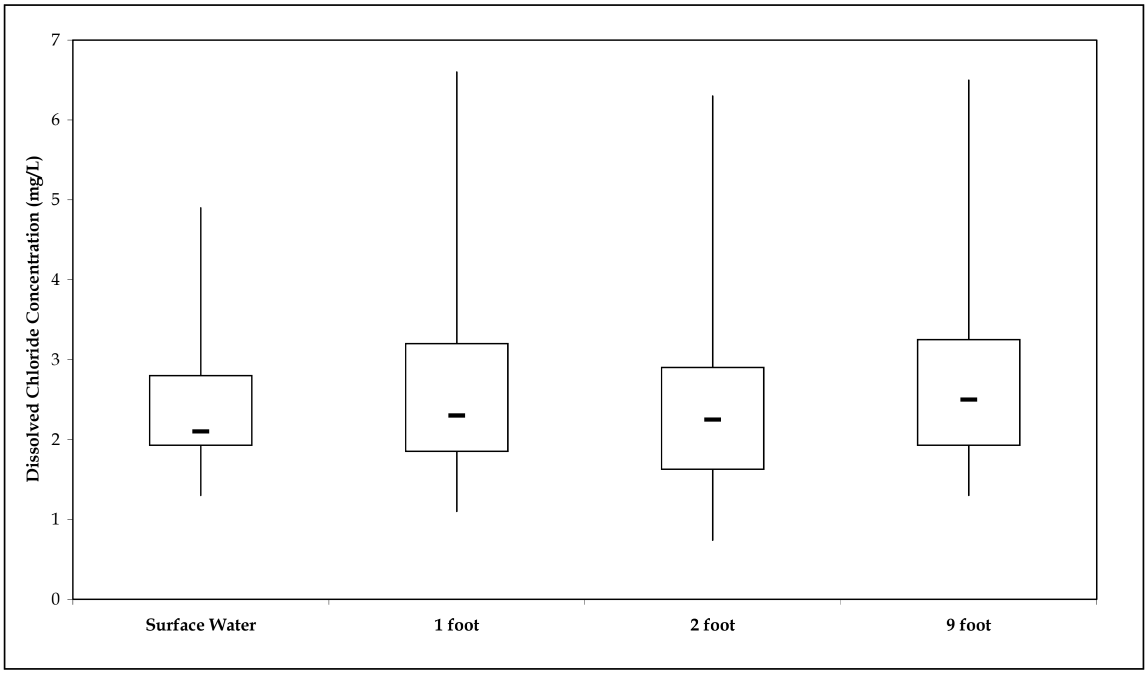

FIGURE 34: Box and whisker plot of variability between vertical sampling intervals for chloride, a representative ion.

Table D-3 in Appendix D contains a summary of the statistical results. Box and whisker plots for the remaining vertical statistical comparisons of the ions are included in Appendix E.

Although significant trends do not exist for individual ions when analyzed with respect to sample depth, trends are apparent in the ratio of sulfate and bicarbonate. Figure 35 present a comparison of sulfate and bicarbonate to depth of sampling interval within the streambed gravels.

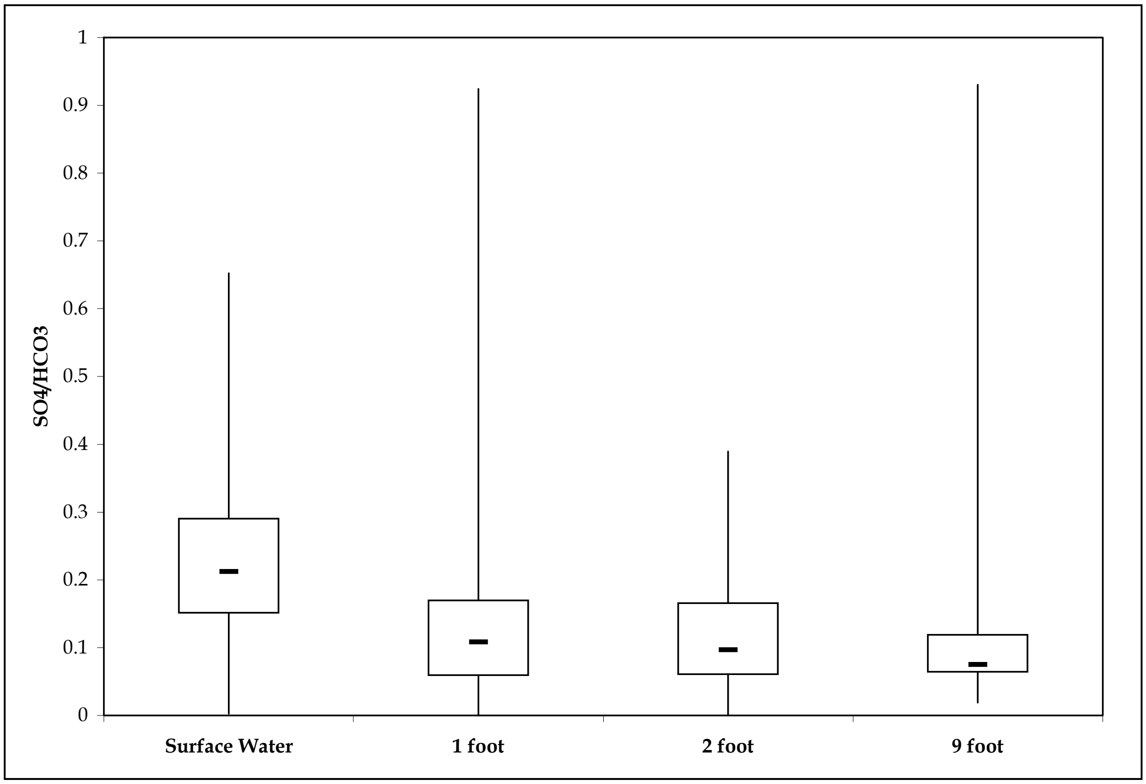

FIGURE 35: Box and whisker plot of SO_4/HCO_3 ratio with respect to depth of sampling interval.

Figure 35 shows that there is a slight decreasing trend in the relative abundance of sulfate, with respect to bicarbonate, with increasing depth. The highest SO_4/HCO_3 ratio is in the surface water with a value of 0.21. The median SO_4/HCO_3 ratio in the 9-foot sampling interval is 0.07. The 1-foot and 2-foot sampling intervals have similar medians (0.11 and 0.10, respectively) and variability. The difference between the surface water samples and the 9-foot samples indicates that the relative abundance of sulfate is significantly different within the two environments. The decreasing concentrations of sulfate with depth may be an indication of microbial activity. As dissolved oxygen is depleted with depth, microbial processes require other electron donors. After dissolved oxygen, sulfate is one of the first electron donors to be consumed in the microbial processes. Hydrogen sulfide is a byproduct of biological sulfate consumption; the rotten egg odor of hydrogen sulfide was observed several times during the sampling process.

3.3.3.2 Dissolved Organic Carbon Trends

Statistical analysis of DOC by depth indicates that median DOC concentrations decrease with increasing depth in the streambed. The box and whisker plot in Figure 36 shows this trend.

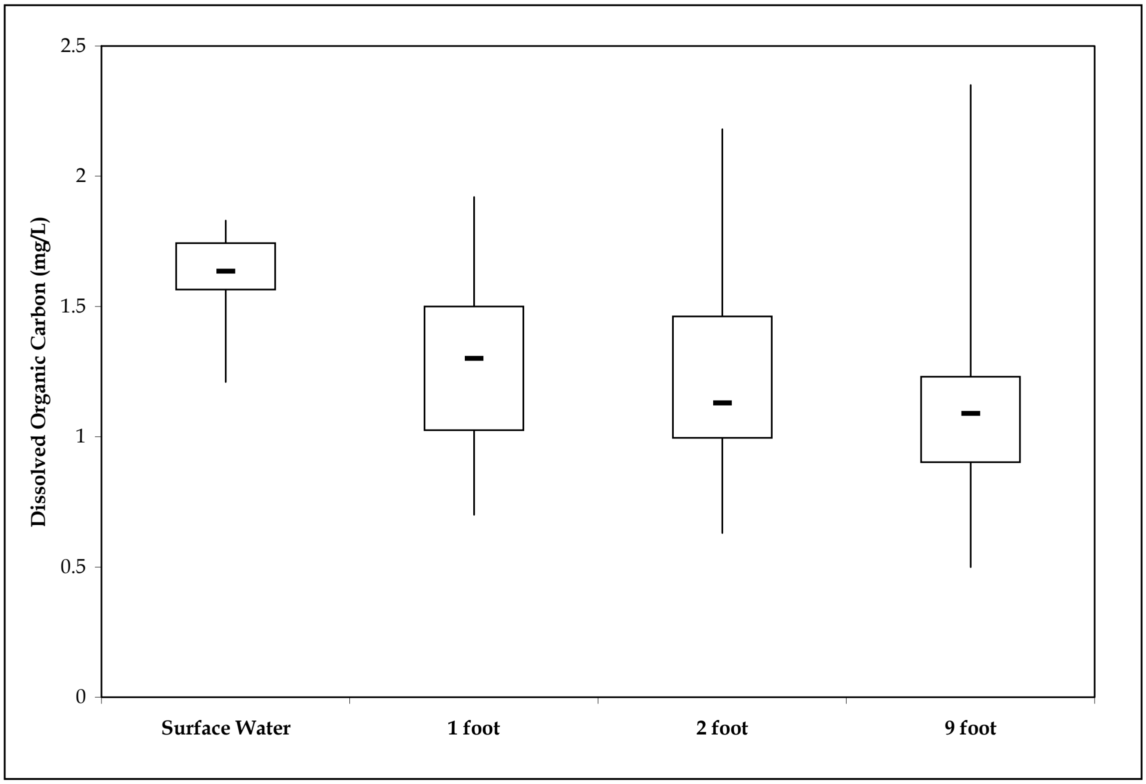

FIGURE 36: Box and whisker plot of variability in DOC between vertical sampling intervals.

Figure 36 shows that the highest median concentration of DOC can be found in the surface water at 1.6 mg/l. The DOC continues to decrease with increasing depth with a median of 1.3 mg/l for the one-foot sampling depth, 1.1 mg/l for the two-foot sampling depth, and 1.1 mg/l for the nine-foot sampling depth. This trend is logical; if DOC originates from the decay of detritus picked up by the stream during high flows, then the surface water should have relatively high DOC. The one-foot sampling interval has the most interaction with the surface water and should therefore have chemistry that is most similar to surface water chemistry. The two-foot and nine-foot sampling intervals have less interaction with the surface water, resulting in lower concentrations of DOC at depth.

3.3.4 Variability of Water Chemistry Due to Streambed Morphology

3.3.4.1 Trends in Ion Chemistry

In general, the median ion concentrations (with the exception of sulfate) are similar between all streambed features (run, riffle, and island samples) when all data are compared. Figure 37 is a representative box and whisker plot of the variability seen between the different stream features.

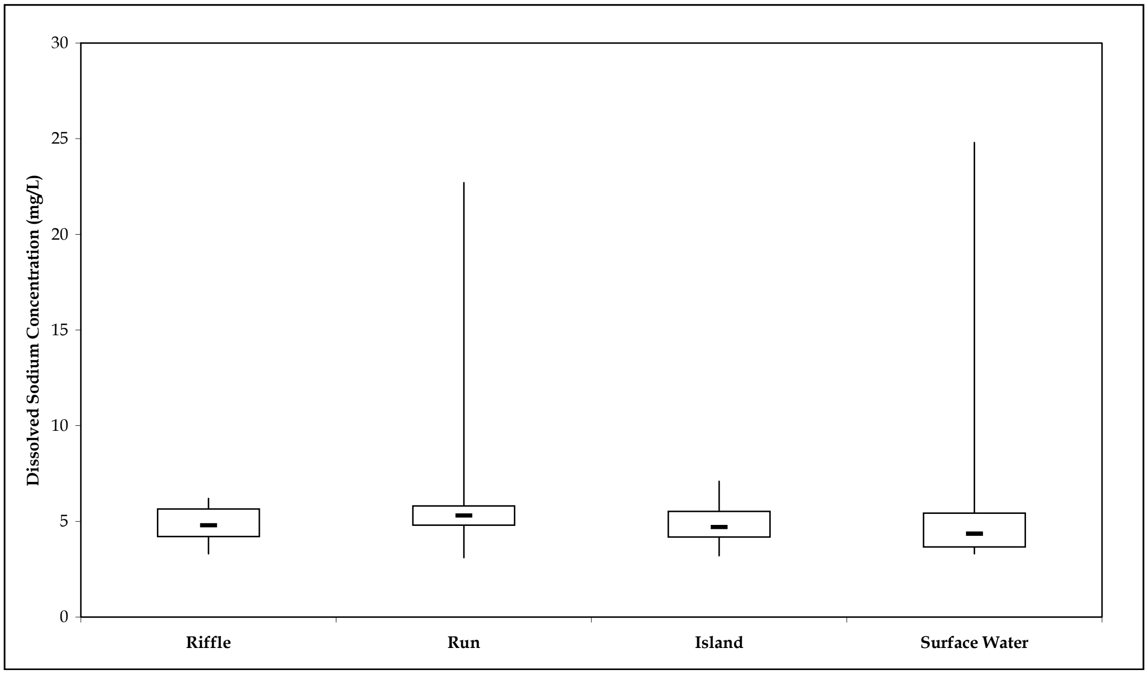

FIGURE 37: Box and whisker plot of variability in sodium between streambed features.

Major ion chemistry generally has greater variability in the runs and surface water samples; however, median values are similar between the different morphological groupings. A summary of the statistical results for morphological variation is included in Table D-4 of Appendix D. Box and whisker plots for all ions are included in Appendix E.

3.3.4.2 Dissolved Organic Carbon Trends

Few statistically significant differences exist between the morphological areas examined in the study. The box and whisker plot in Figure 38 shows that, again, the surface water has the highest median DOC concentration. However, the median concentration for the riffle (1.1 mg/l), run (1.2 mg/l), and island (1.1 mg/l) samples are not significantly different, nor is the variability of the results.

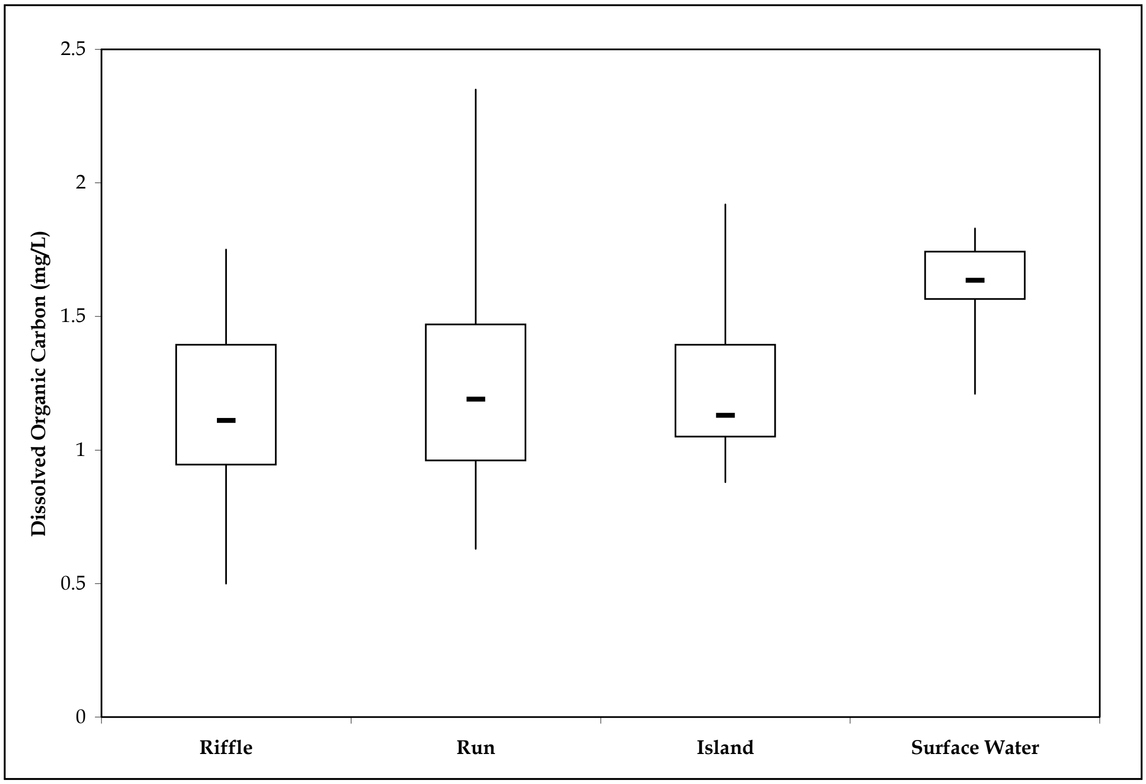

FIGURE 38: Box and whisker plot of differences in DOC in relation to streambed morphology.

The slight increase in the median DOC concentration in the run samples could be due to the less turbulent flow regime that exists in runs. Less turbulence allows the detritus to settle out of the water column. The detritus would continue to decay on the bottom of the streambed, and DOC would increase in these areas. However, the perceived increase in DOC concentrations in this data set is not great enough to be considered significant.

3.4 Vertical Hydraulic Gradient

During the summer 2002 and winter 2003 sampling events, vertical hydraulic gradient was measured at all monitoring points, except MP6, which could not be found during those sampling events. Gradient measurements were focused on the one- and two-foot intervals; however, during the winter sampling event, some gradient measurements were made at the nine-foot intervals. In addition to measuring the vertical gradient at a given monitoring point, the direction of the gradient was also determined. Table 6 presents the results of the gradient measurements and whether water in the hyporheic zone was upwelling, downwelling, or even (no obvious upwelling or downwelling, i.e. gradients less than 0.005) at the time of measurement.

Monitoring Point	**Depth (ft)**	**Sampling Season**	**Difference (inches)**	**Gradient (dH/dL)**	**Upwelling/ Downwelling**
1	1	Summer 2002	1.6	-0.14	Down
	2	Summer 2002	1.6	-0.07	Down
2	1	Summer 2002	1.9	0.16	Up
		Winter 2003	1.1	0.09	Up
	2	Summer 2002	4.2	0.18	Up
		Winter 2003	1.5	0.06	Up
3	1	Winter 2003	3.4	0.28	Up
	2	Winter 2003	1.7	0.07	Up
	9	Winter 2003	1.9	0.02	Up

TABLE 6: Summary of vertical hydraulic gradient data; gradients less than 0.005 were considered to be even.

Monitoring Point	Depth (ft)	Sampling Season	Difference (inches)	Gradient (dH/dL)	Upwelling/ Downwelling
4	1	Summer 2002	0.78	-0.06	Down
		Winter 2003	0.12	-0.01	Down
	2	Summer 2002	0.97	-0.04	Down
		Winter 2003	0.62	-0.03	Down
	9	Winter 2003	0.94	-0.01	Down
5	1	Summer 2002	1.3	0.11	Up
		Winter 2003	0.56	0.05	Up
	2	Summer 2002	1.25	0.05	Up
	9	Winter 2003	0.94	0.01	Up
7	1	Summer 2002	0.16	-0.01	Down
		Winter 2003	0.00	0.00	Even
	2	Summer 2002	0.00	0.00	Even
	9	Winter 2003	0.31	0.00	Even
8	1	Summer 2002	0.06	0.01	Up
	2	Summer 2002	0.09	0.00	Even
9	1	Summer 2002	1.12	0.09	Up
		Winter 2003	0.25	0.02	Up
	2	Summer 2002	1.09	0.05	Up
		Winter 2003	0.25	0.01	Up
	9	Winter 2003	0.19	0.00	Even
10	1	Summer 2002	0.16	-0.01	Down
		Winter 2003	0.12	-0.01	Down
	2	Summer 2002	0.12	-0.01	Down
		Winter 2003	0.06	0.00	Even
	9	Winter 2003	0.50	-0.01	Down
11	1	Summer 2002	0.75	-0.06	Down
	2	Summer 2002	1.21	-0.05	Down
12	1	Summer 2002	0.09	0.01	Up
		Winter 2003	0.19	0.02	Up
	2	Summer 2002	0.12	0.01	Up
		Winter 2003	0.12	0.01	Up
13	1	Summer 2002	0.06	0.01	Up
		Winter 2003	0.38	0.03	Up
	2	Summer 2002	0.03	0.00	Even
		Winter 2003	0.31	0.01	Up
14	1	Summer 2002	0.16	0.01	Up
		Winter 2003	0.12	0.01	Up
	2	Summer 2002	0.09	0.00	Even
		Winter 2003	0.25	-0.01	Down

Table 6 (continued)

Monitoring Point	**Depth (ft)**	**Sampling Season**	**Difference (inches)**	**Gradient (dH/dL)**	**Upwelling/ Downwelling**
15	1	Summer 2002	0.59	-0.05	Down
		Winter 2003	0.19	0.16	Up
	2	Summer 2002	0.00	0.00	Even
16	1	Summer 2002	0.12	-0.01	Down
	2	Summer 2002	0.12	-0.01	Down
17	1	Summer 2002	0.03	0.00	Even
		Winter 2003	0.12	-0.01	Down
	2	Summer 2002	0.00	0.00	Even
		Winter 2003	0.12	-0.01	Down
18	1	Summer 2002	0.00	0.00	Even
		Winter 2003	0.00	0.00	Even
	2	Summer 2002	0.00	0.00	Even
		Winter 2003	0.12	0.01	Up

TABLE 6 (continued)

Figures 39 through 42 present the results of the vertical gradient analysis for one- and two-foot sampling intervals during the summer and winter sampling events.

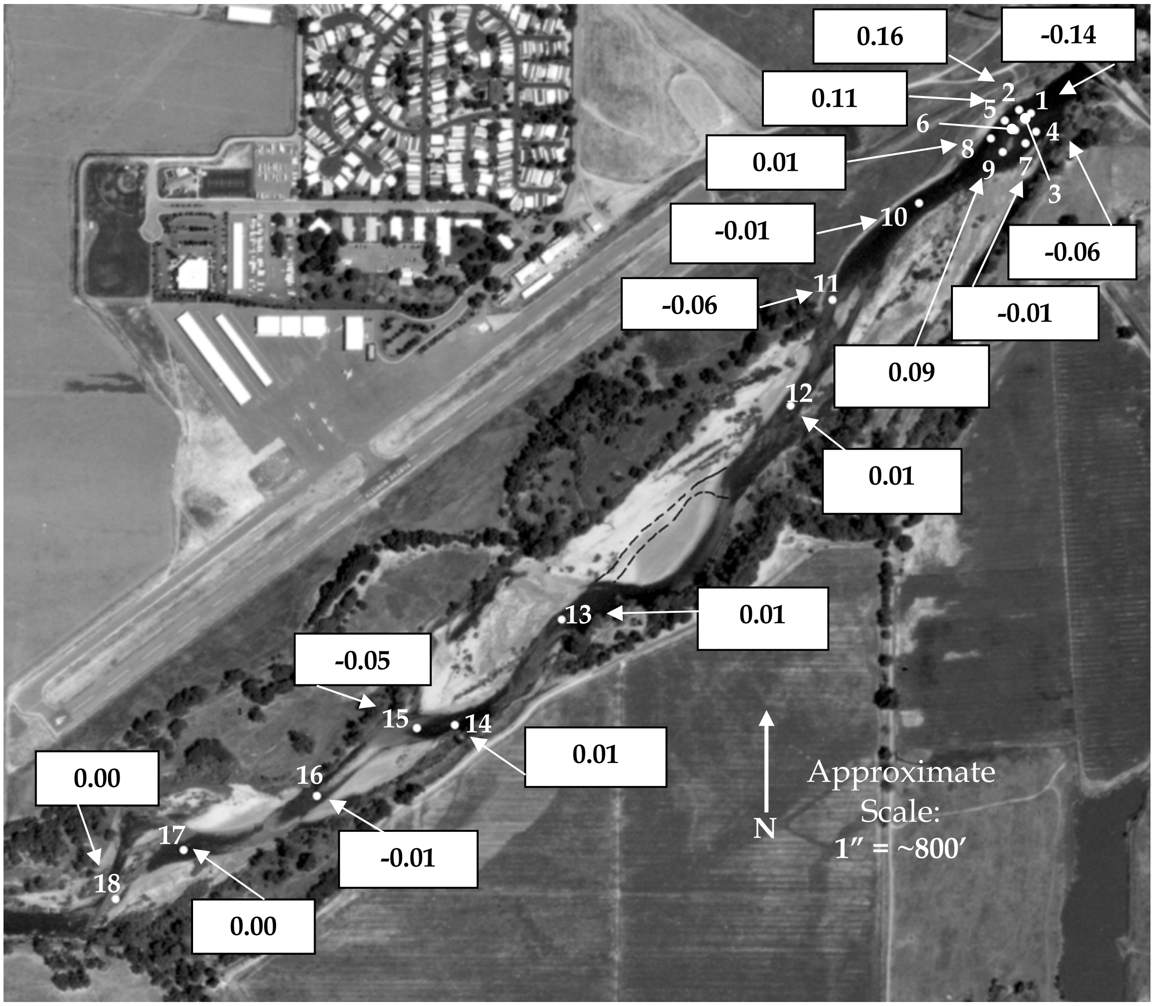

FIGURE 39: Vertical gradient results for summer 2002, 1-foot sampling interval. Discharge was approximately 10 to 12 cfs.

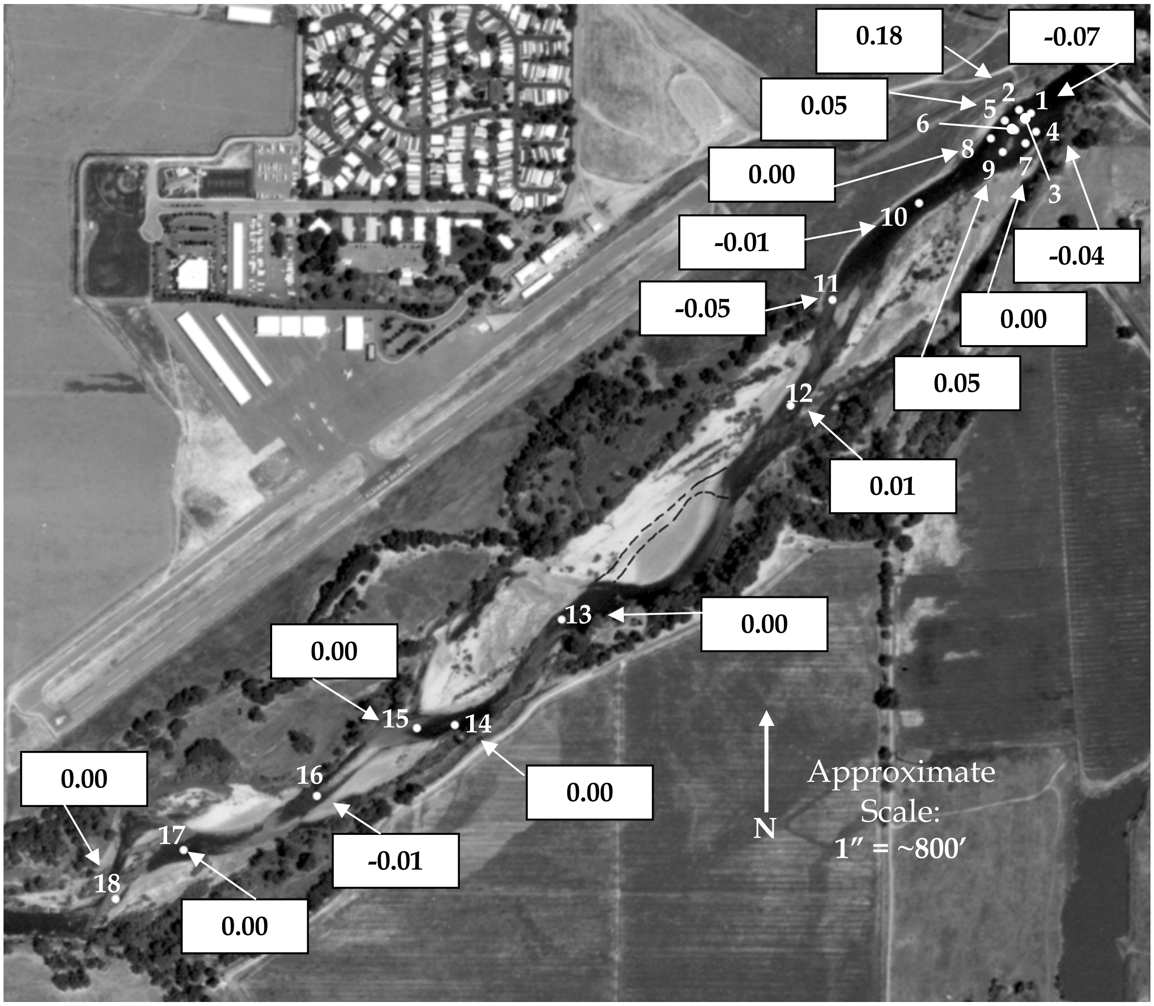

FIGURE 40: Vertical gradient results for summer 2002, 2-foot sampling interval. Discharge was approximately 10 to 12 cfs.

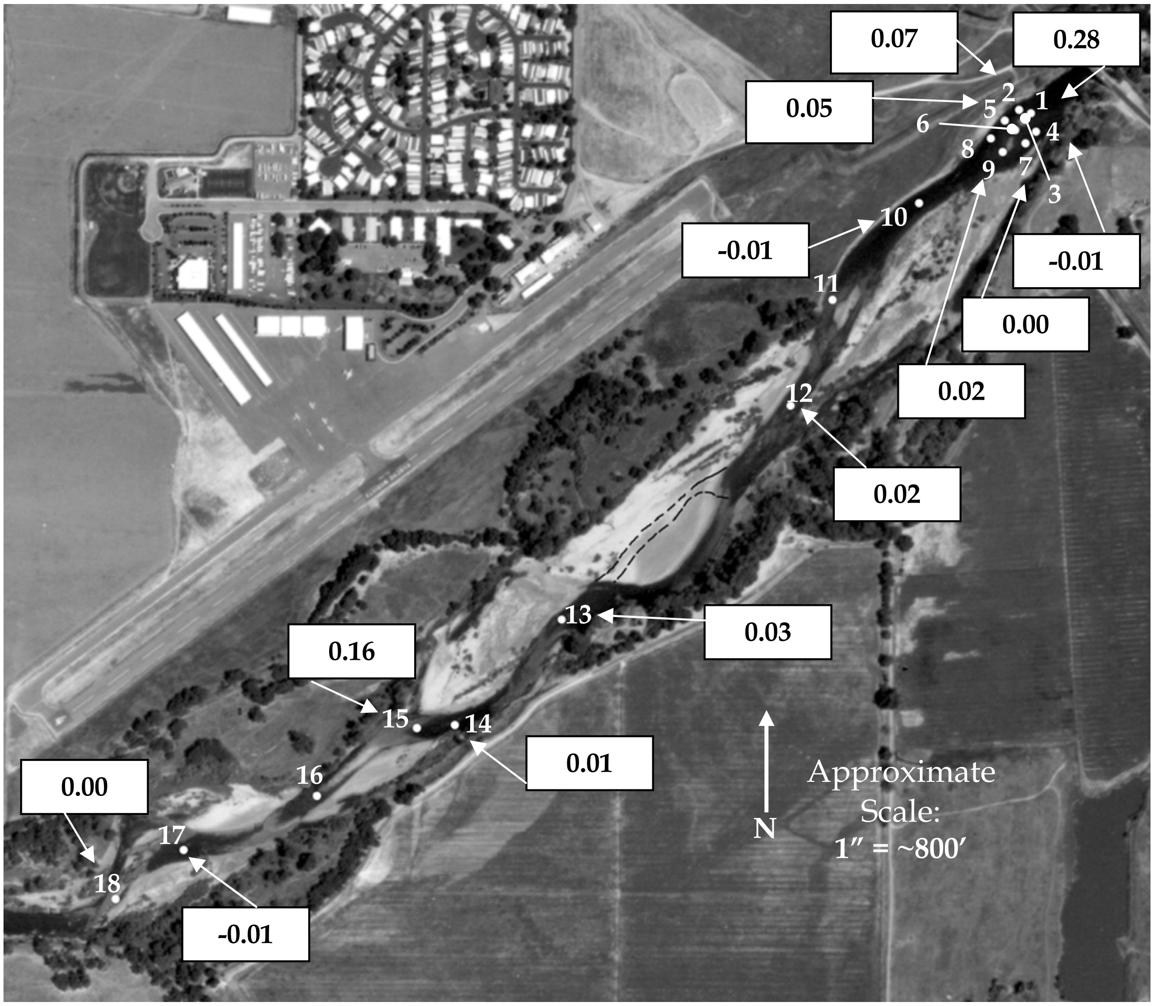

FIGURE 41: Vertical gradient results for winter 2003, 1-foot sampling interval. Discharge was 315 to 320 cfs.

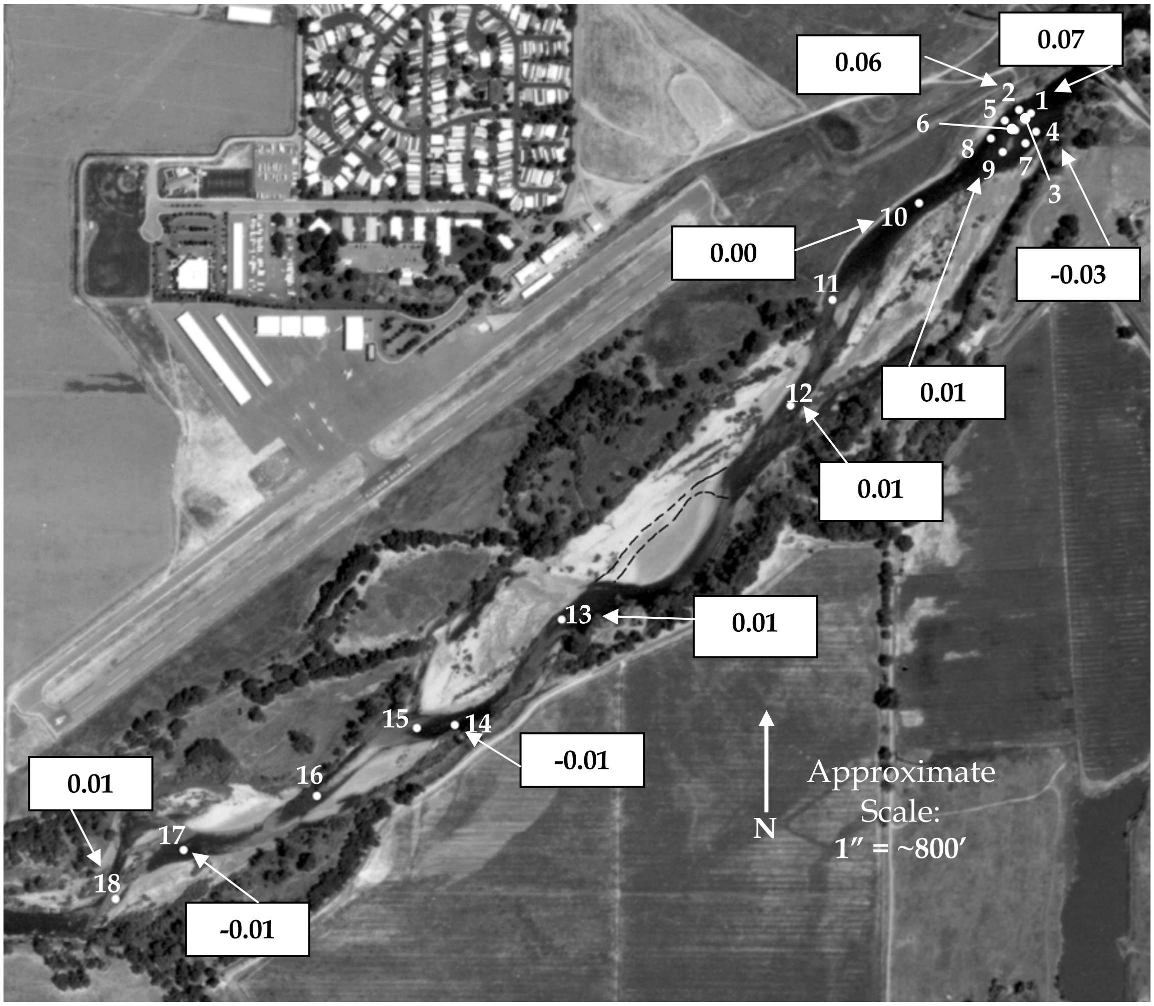

FIGURE 42: Vertical gradient results for winter 2003, 2-foot sampling interval. Discharge was 315 to 320 cfs.

3.4.1 Seasonal Variability in Vertical Hydraulic Gradient

Table 7 presents a comparison of the vertical hydraulic gradient results with respect to seasonal changes.

Season	Total Number of Samples	Vertical Hydraulic Gradient			
		Median	Upwelling	Downwelling	Even
Summer	26	0.0005	38.5%	42.3%	19.2%
Winter	22	0.008	59.1%	27.3%	13.6%

TABLE 7: Comparison of seasonal vertical hydraulic gradient results.

The median vertical gradient for the winter was 0.008 whereas the median gradient in the summer was 0.0005. In addition, in the summer 38.5% of the gradient measurements were found to be upwelling and 42.3% of the measurements were downwelling. In contrast, in the winter 59.1% of the gradient measurements were upwelling and only 27.3% were downwelling. In the winter time the hyporheic zone is more likely to be upwelling than in the summer time. This is may be due to a localized perched aquifer that is quickly recharged by rainfall and then discharges into the stream. In the summer time, the water table above the perched zone drops and the stream loses water to the perched groundwater.

Figure 43 compares the variability of the vertical hydraulic gradient results with respect to season. This figure shows that variability in vertical hydraulic gradient due to seasonal changes between the summer and winter is low. However, the median vertical gradient is about an order of magnitude greater in the winter than in the summer. This is not as expected. In general winter high flows result in smaller vertical gradients, or rates of exchange within the hyporheic zone. One potential explanation for this anomaly may be due to the local perched groundwater. Figure 43 shows that in the winter the stream is primarily a gaining stream, as indicated by the positive hydraulic gradients. If the perched groundwater table was high enough hydraulic gradients may be higher than expected due to the increased pressure head of the water table; no groundwater elevations were collected in conjunction with this study.

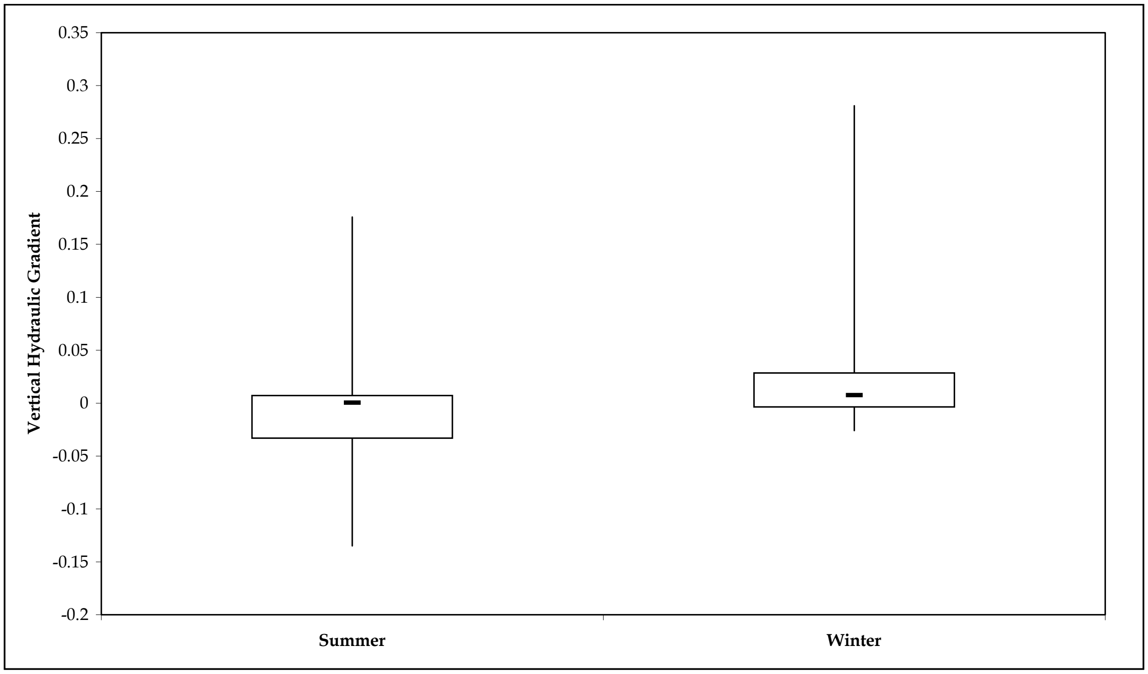

FIGURE 43: Box and whisker plot of seasonal variability of vertical hydraulic gradient.

3.4.2 Variability in Vertical Gradient Between Longitudinal Sampling Locations

Table 8 presents a comparison of the longitudinal changes in vertical hydraulic gradient.

Longitudinal Location	Total Number of Samples	Vertical Hydraulic Gradient			
		Median	Upwelling	Downwelling	Even
Upstream	26	0.004	50%	38%	12%
Downstream	22	0.004	45%	27%	27%

TABLE 8: Comparison of longitudinal vertical hydraulic gradient results.

The median vertical gradient for all samples collected in both the upstream and downstream portions of the study area was 0.004. In the upstream portion, 50% of the gradients were upwelling and 38% were downwelling. In the downstream portion of the study area, 45% of the gradients were upwelling and 27% were downwelling. 27% of the measured piezometers in the downstream two thirds of the study area had a vertical gradient between 0.005 and –0.005 whereas only 11.5% of the sampling points in the upstream third of the study area had no vertical hydraulic gradient. In addition, the box and whisker plot shown in Figure 44 indicates that although the median vertical hydraulic gradients are not significantly different, the interquartile range, or the variability in the results is greater in the upstream sampling locations. It is likely that the underlying geology and stream features, including the island, affects the differences in the percentage of upwelling and downwelling, and in each portion of the study area.

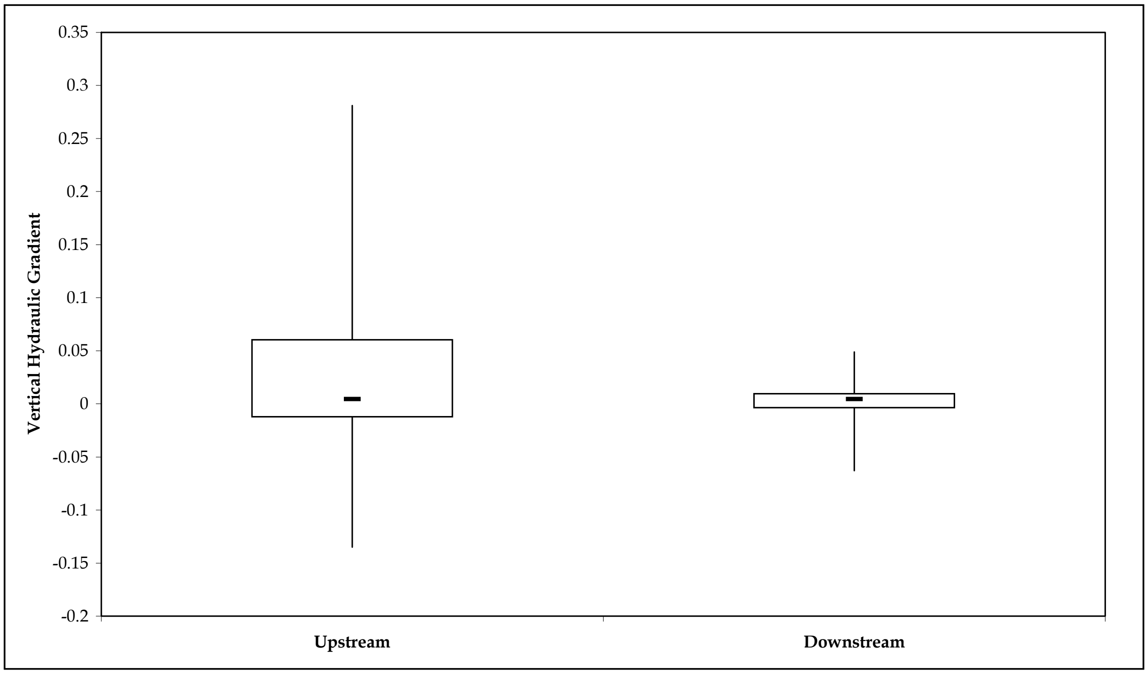

FIGURE 44: Box and whisker plot of longitudinal variability in vertical hydraulic gradient results.

3.4.3 Variability in Vertical Gradient Between Vertical Sampling Intervals

Table 9 presents a comparison of the vertical hydraulic gradient results with respect to sampling depth.

Sample Interval	Total Number of Samples	Vertical Hydraulic Gradient			
		Median	Upwelling	Downwelling	Even
1 foot	25	0.005	52%	36%	12%
2 foot	23	0.004	44%	35%	22%
9 foot	6	0.002	33%	33%	33%

TABLE 9: Comparison of vertical hydraulic gradient with respect to gravel depth.

The median vertical gradient for samples collected from the one-foot sampling interval was 0.005; for the samples collected from the two-foot sampling interval the median vertical gradient was 0.004. The median vertical hydraulic gradient in the 9-foot sampling interval was 0.002, with 33% of the sampling locations upwelling and 33% downwelling. In the one-foot sampling interval 52% of the measured monitoring points were upwelling and 36% were downwelling. In the two-foot sampling interval, 44% were upwelling and 35% were downwelling.

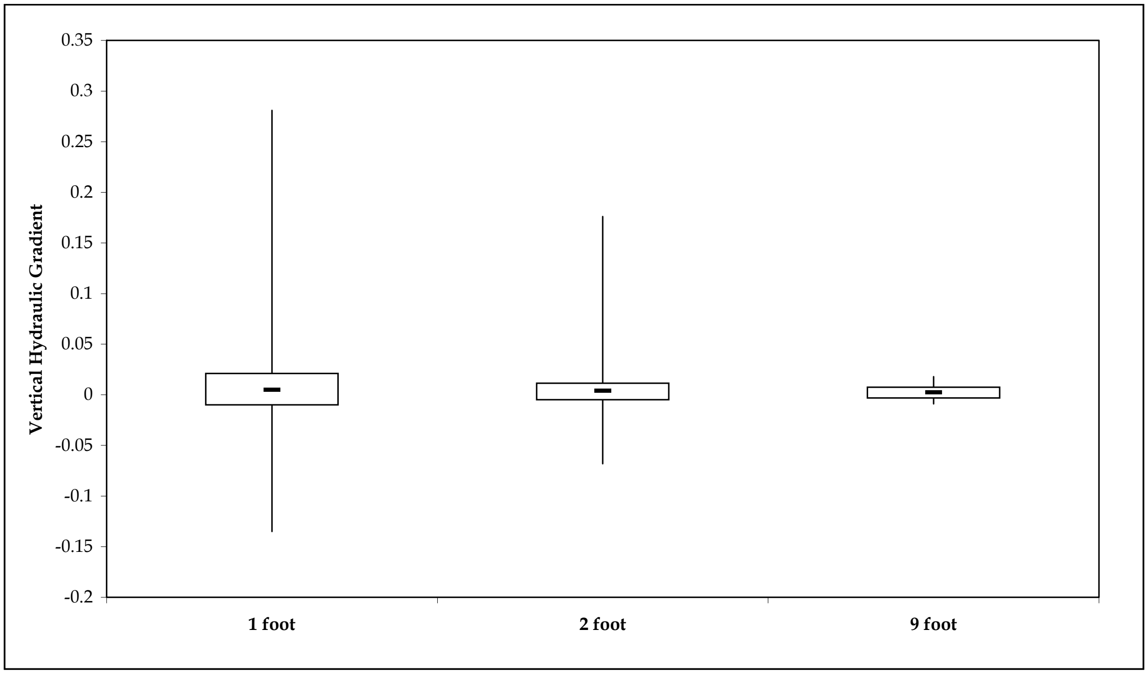

FIGURE 45: Box and whisker plot of variability in vertical hydraulic gradient with respect to depth in stream gravels.

Figure 45 shows that the median vertical hydraulic gradient results are similar for all three sampling depths, although the median vertical hydraulic gradient is greater in the 1-foot sampling interval. The variability of the vertical hydraulic gradient in the 1-foot sampling interval is also greater than in the 2- or 9-foot intervals. The 9-foot sampling interval is more likely to have an even or no vertical hydraulic gradient than the 2- or 1-foot intervals, and the 1-foot sampling interval is least likely to have an even vertical hydraulic gradient. The increased variability and vertical gradient in the 1-foot interval is due to the increased exchange with the surface water that occurs in the shallow gravels of the hyporheic zone.

3.4.4 Variability in Vertical Gradient Due to Streambed Morphology

Table 10 and Figure 46 present a comparison of vertical hydraulic gradient results with respect to morphological groupings.

Stream Morphology	Total Number of Samples	Vertical Hydraulic Gradient			
		Median	Upwelling	Downwelling	Even
Riffle	12	0.003	50%	42%	8.3%
Run	28	0.002	39%	36%	25%
Island	8	0.03	75%	25%	0%

TABLE 10: Comparison of vertical hydraulic gradient results with respect to morphological groupings.

The median vertical gradients for the riffle, run, and island samples were 0.003, 0.002, and 0.03, respectively. The riffle, run, and island monitoring points were found to be upwelling 50%, 39%, and 75% of the time, respectively. Downwelling occurred in the riffles, runs, and island 42%, 36%, and 25% of the time, respectively, in the measured mini-piezometers. Runs were likely to have an even vertical hydraulic gradient – or no difference in pressure head between the surface of the streambed and the depth of the mini-piezometer 25% of the time. In addition, Figure 46 shows that runs have very little variability and that 50% of the results (as indicated by the interquartile range) fall between –0.01 and 0.006. However, riffles only had an 8.3% chance of having no change in pressure head, and variability is much greater with 50% of the results ranging from –0.02 to 0.04. Therefore, riffles were more likely than runs to have a vertical hydraulic gradient greater than 0.005 for upwelling sites or less than –0.005 for downwelling sites. This is significant because a larger vertical hydraulic gradient, as is more likely found in the riffles, indicates that water is flowing quickly through the hyporheic zone replenishing the dissolved oxygen and removing waste. In the runs, a lack of vertical flow may indicate that the water in the hyporheic zone is not being readily replenished.

FIGURE 46: Box and whisker plot of variability in vertical hydraulic gradient with respect to morphological groupings.

3.5 Comparison of Natural Water Chemistry and Upwelling Versus Downwelling Areas in the Hyporheic Zone

In order to compare water chemistry and vertical hydraulic gradient further, field parameters and water chemistry have been analyzed with respect to upwelling and downwelling conditions in the hyporheic zone.

3.5.1 Field Parameters and Upwelling Versus Downwelling

DO, pH, and EC were each compared to whether the mini-piezometer was upwelling or downwelling at the time the sample was collected. Figures 47 to 49 present the results of this comparison.

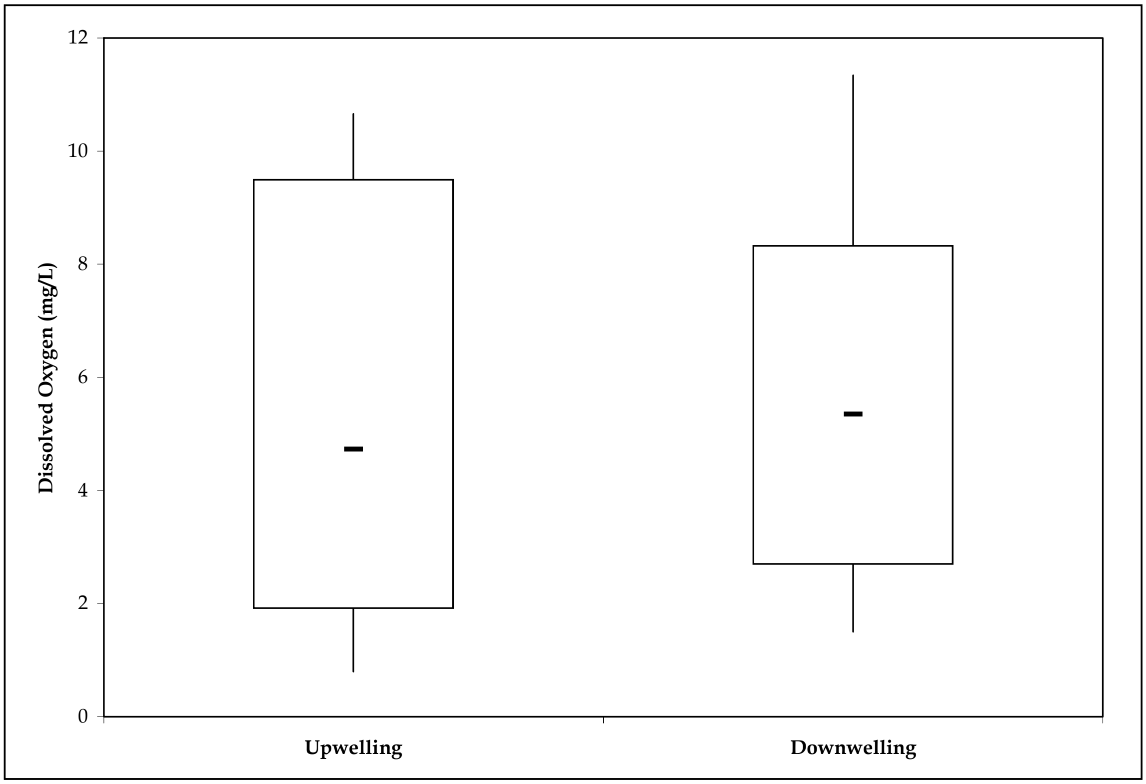

FIGURE 47: Box and whisker plot of variability in DO relative to direction of vertical hydraulic gradient.

As expected, the median DO concentration is greater in the downwelling locations; however, the interquartile range, as seen in Figure 47, for both the upwelling and downwelling locations is great. The large interquartile range for both upwelling and downwelling areas in the hyporheic zone indicates that significant differences in dissolved oxygen do not exist with respect to the direction of vertical flow.

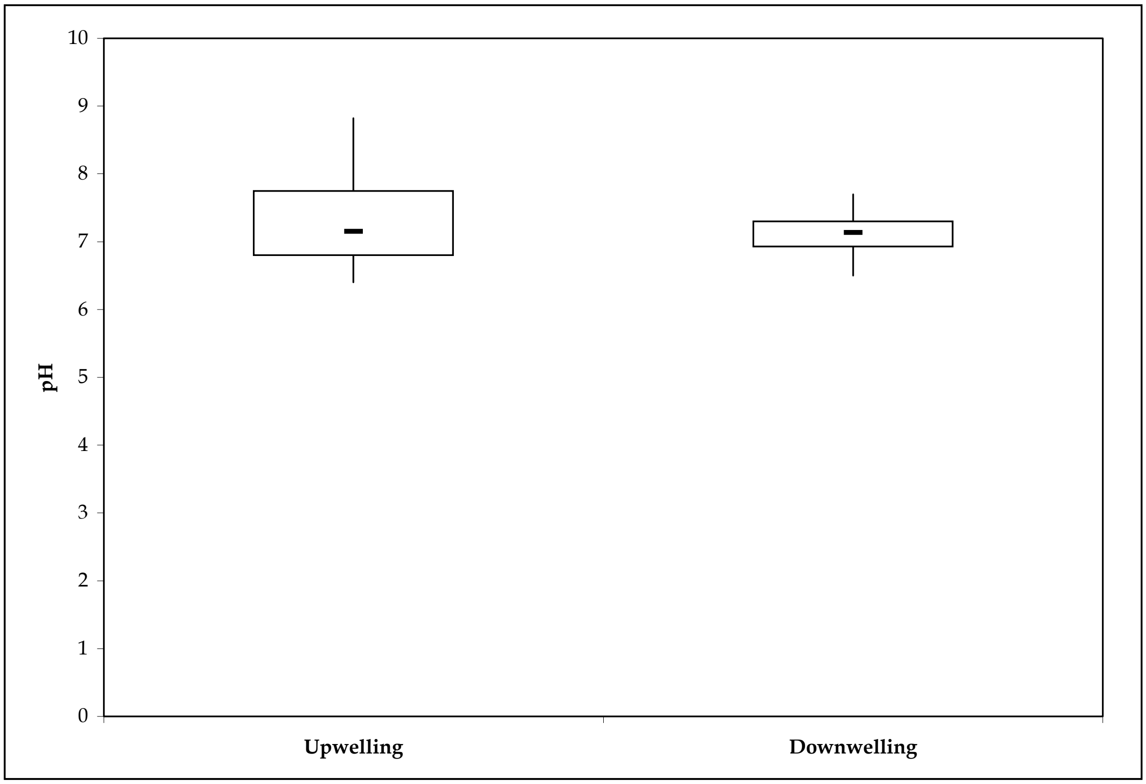

FIGURE 48: Box and whisker plot of variability in pH relative to direction of vertical hydraulic gradient.

Figure 48 shows that the median pH values for upwelling and downwelling areas are 7.15 and 7.14, respectively. Although the variability is greater in the areas that were determined to be upwelling, there is little significant differences in pH based on the direction of vertical flow.

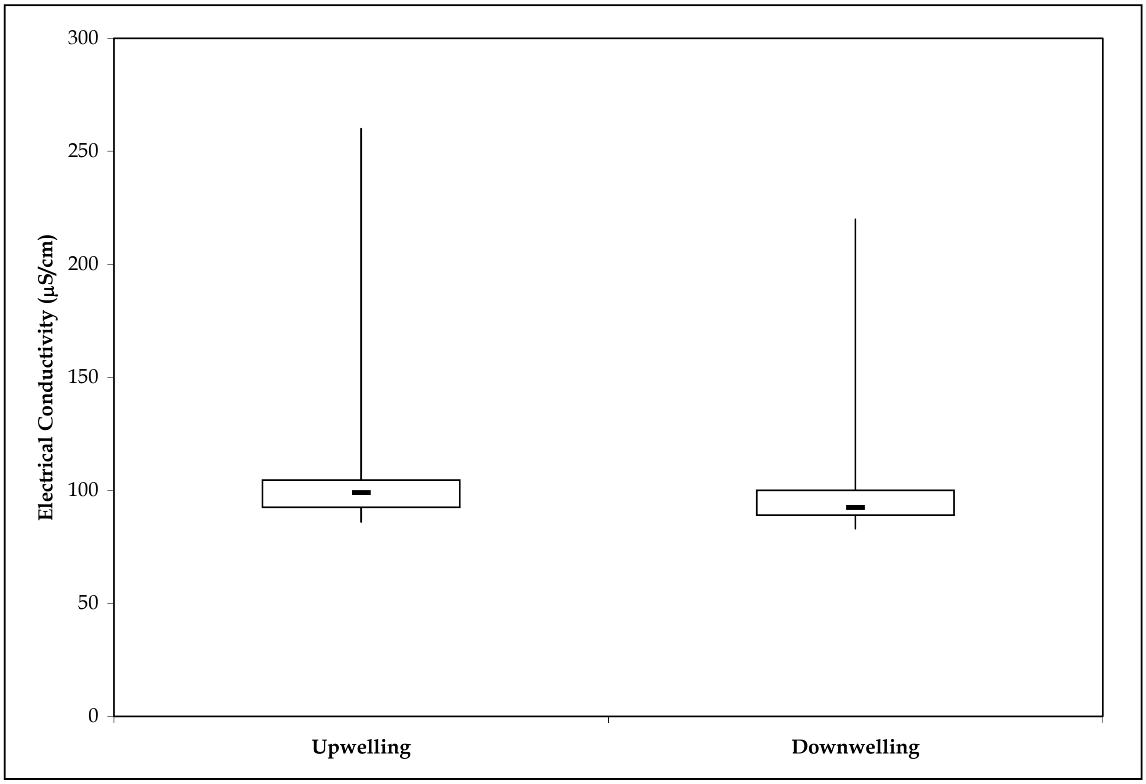

FIGURE 49: Box and whisker plot of variability in EC relative to direction of vertical hydraulic gradient.

Figure 49 shows that the median EC value for the areas of upwelling is 99 µS/cm and the median for areas of downwelling is 92.5 µS/cm. The interquartile ranges are about the same. Therefore, no significant differences exist in electrical conductivity relative to areas in the hyporheic zone that are upwelling or downwelling.

3.5.2 Pore Water Geochemistry and Upwelling Versus Downwelling

In order to determine if a relationship between the natural chemistry of the water in the hyporheic zone and the direction of the vertical hydraulic gradient exists, comparisons were made between water chemistry and upwelling vs. downwelling of each mini-piezometer.

3.5.2.1 Trends in Ion Chemistry

Figure 50 is a box and whisker plot of dissolved sodium, a representative ion. Box and whisker plots for the remaining cations are included in Appendix E.

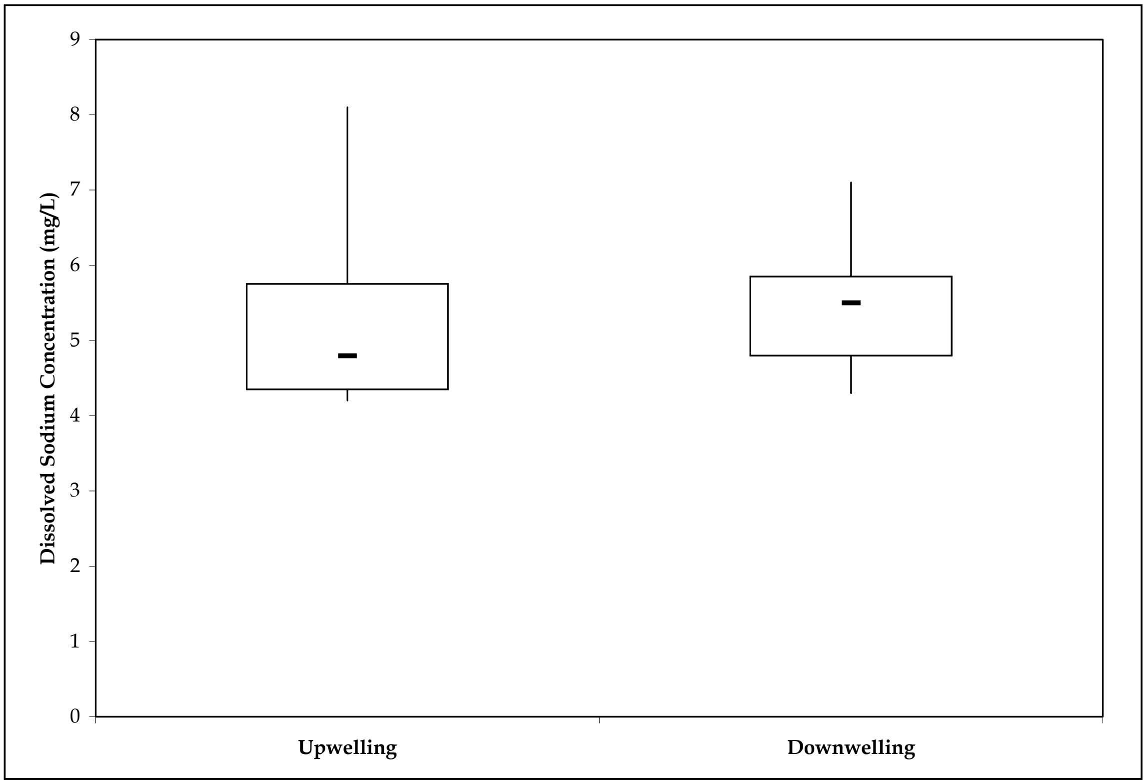

FIGURE 50: Box and whisker plot of dissolved sodium concentrations, a representative cation, compared to upwelling vs. downwelling of water in the hyporheic zone.

In general, there are no obvious differences in cation concentrations when compared to the direction of vertical flow through the hyporheic zone. Median concentrations for sodium, potassium, and calcium are greater in downwelling areas and median the magnesium concentration is greater in the upwelling areas. However, the interquartile ranges for each ion are similar between both downwelling and upwelling areas. Therefore, slight differences in median concentrations are not likely significant.

Initial review of the results when compared to areas of upwelling and downwelling indicate a significant relationship between sodium and calcium concentrations. Figures 51 and 52 present a comparison of sodium and calcium concentrations based on whether a sampling location was upwelling or downwelling.

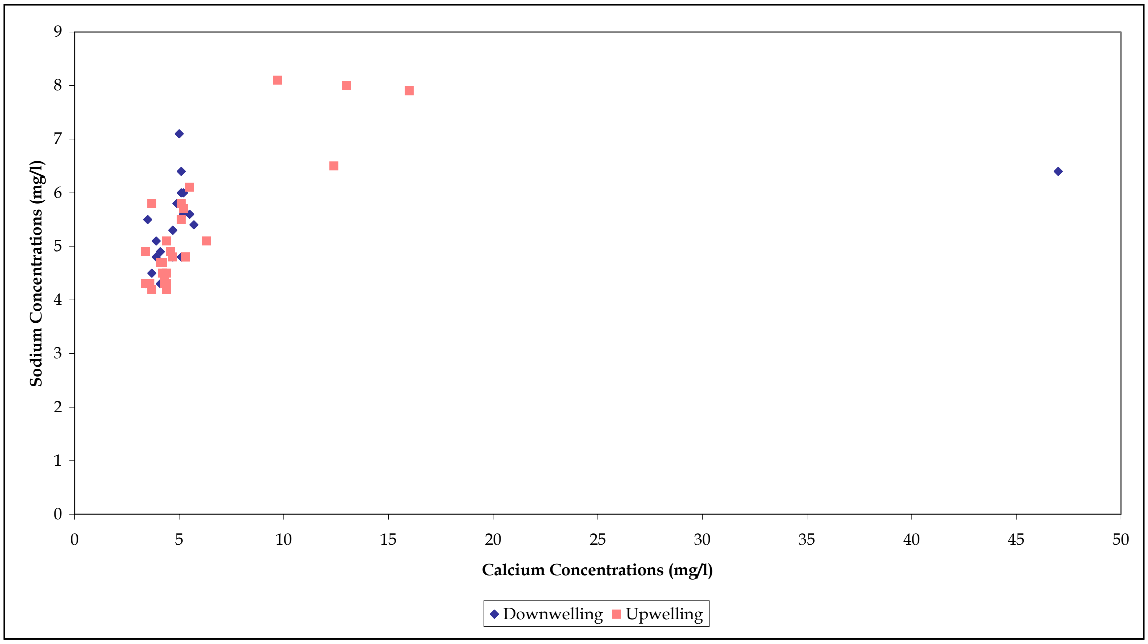

FIGURE 51: Relationship of sodium and calcium concentrations to upwelling versus downwelling.

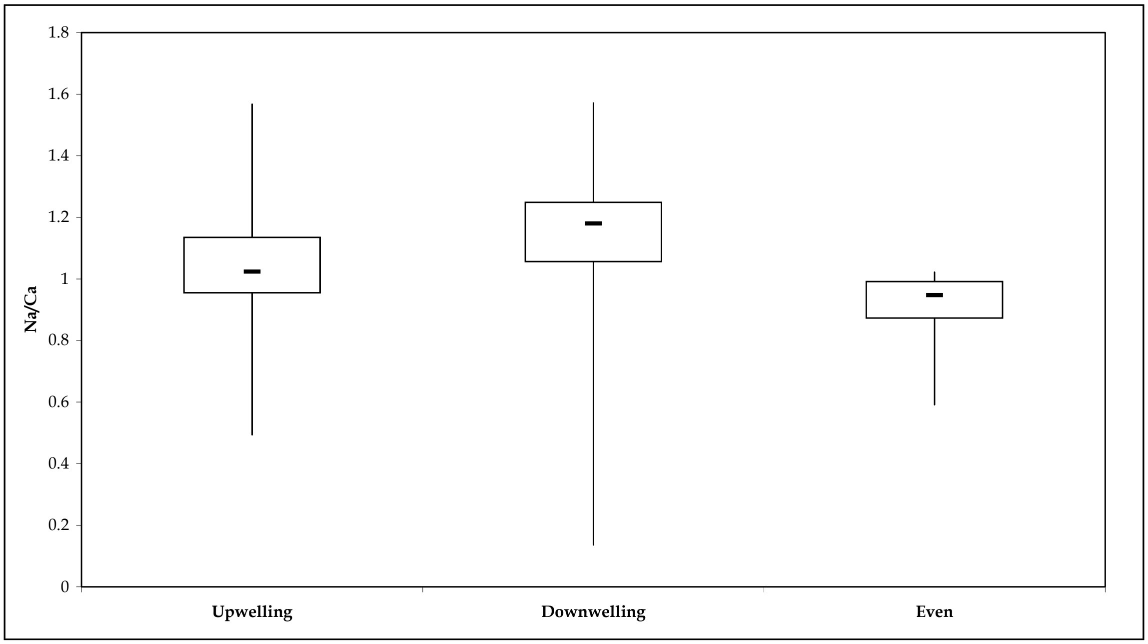

FIGURE 52: Box and whisker plot of Na/Ca ratio with respect to direction of vertical hydraulic gradient.

Figure 51 shows that calcium is more likely to be elevated in upwelling areas. Figure 52 shows that the median Na/Ca ratio is significantly lower in areas that are upwelling (indicating a relative abundance of calcium) and much higher in areas that are downwelling (indicating a relative abundance of sodium).

The relative abundance of calcium is greater than sodium in the 9-foot sampling interval; and the relative abundance of sodium is greater than calcium in the surface water. This information combined with the upwelling and downwelling information presented in Figure 52 indicates that areas that are upwelling are more likely to have water chemistry similar to the 9-foot sampling interval, rather than the surface water; and areas that are downwelling are more likely to have water chemistry similar to the surface water.

Figure 53 is a box and whisker plot of sulfate compared to direction of vertical hydraulic gradient. Box and whisker plots for chloride and bicarbonate are included in Appendix E. For both sulfate and chloride the median concentration is greater in areas of upwelling. However, the median bicarbonate concentration is greater in downwelling areas. Intuitively, areas that are known to be downwelling should have water chemistry more similar to surface water chemistry, and areas that are upwelling should be more similar to water chemistry at depth (for this study, the 9-foot sampling interval). Variability in the data set obscures this trend until samples are grouped according to upwelling and downwelling conditions.

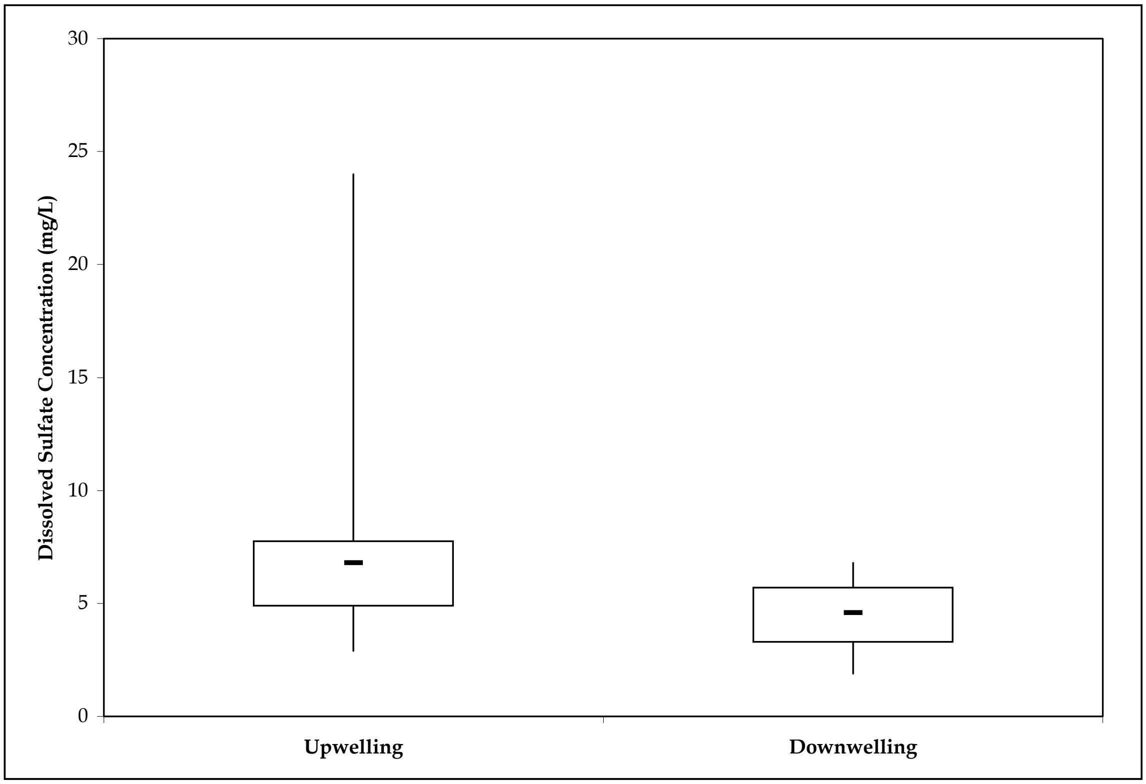

FIGURE 53: Box and whisker plot of sulfate, a representative ion, compared to upwelling and downwelling vertical hydraulic gradients.

3.5.2.2 Water Type

Piper diagrams of water chemistry in areas that are upwelling, downwelling, and have no vertical gradient (even) are included in Figure 54. Although water types appear similar on Piper diagrams of upwelling vs. downwelling, two water types are present: Mg-Ca-Na-HCO_3 water and Mg-Na-Ca-HCO_3 water.

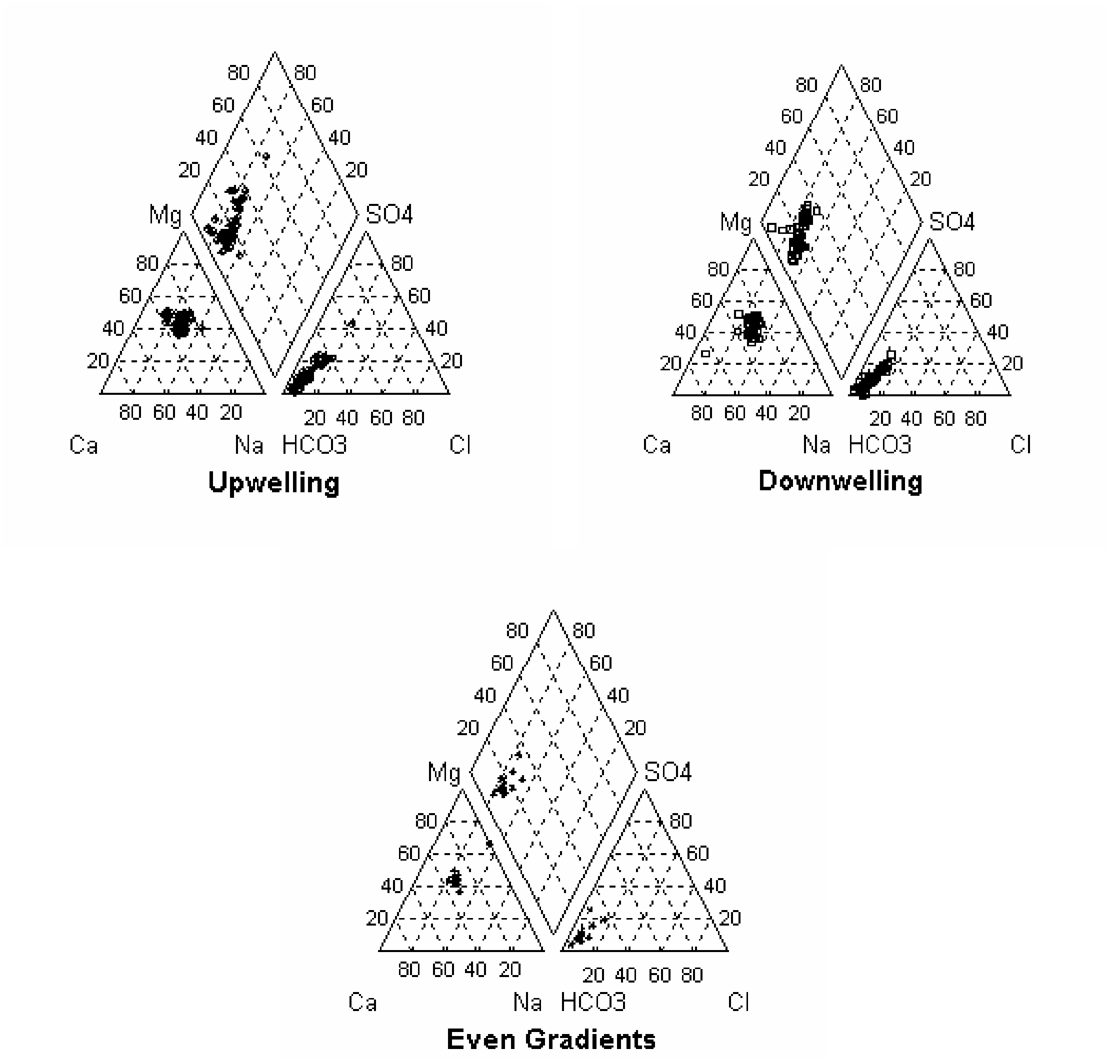

FIGURE 54: Piper diagram of gradient direction (upwelling/downwelling) and major ion chemistry.

Table 11 presents a comparison of water types and vertical hydraulic gradient. The median vertical hydraulic gradient for samples with the water type of Mg-Ca-Na-HCO_3 was 0.005 with 56% of these sampling locations upwelling and 24% downwelling. Samples with water type of Mg-Na-Ca-HCO_3 had median vertical hydraulic gradients of –0.01 with 29% of theses sampling locations upwelling and 64% downwelling. The interquartile range, as seen in Figure 55, shows that the vertical hydraulic gradient is strongly positive (upwelling) for samples classified as Mg-Ca-Na-HCO_3. In contrast, the interquartile range of vertical hydraulic gradient for samples classified as Mg-Na-Ca-HCO_3 is predominately negative and therefore downwelling. This implies that the source of dissolved calcium is related to subsurface input, and that dissolved sodium has a surface source.

Water Type	**Total Number of Samples**	**Vertical Hydraulic Gradient**			
		Median	**Upwelling**	**Downwelling**	**Even**
Mg-Ca-Na-HCO_3	25	0.005	56%	24%	20%
Mg-Na-Ca-HCO_3	14	-0.01	29%	64%	7.1%
Other	9	0.005	55.5%	22%	22%

TABLE 11: Comparison of water type to vertical hydraulic gradient.

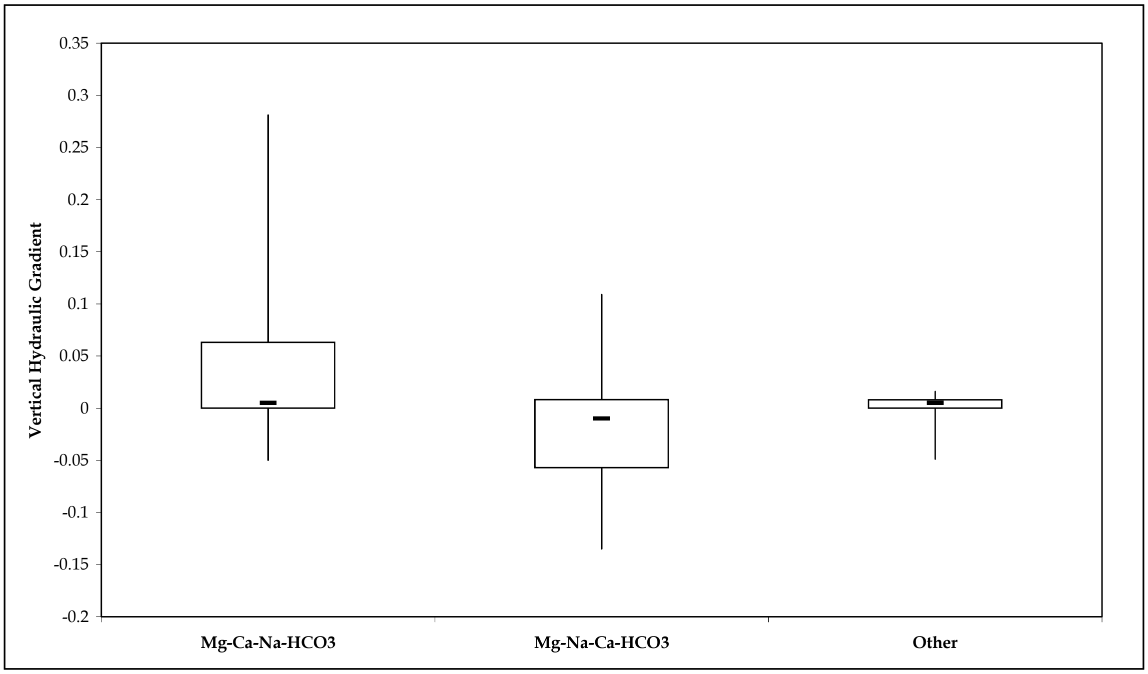

FIGURE 55: Box and whisker plot of variability in vertical hydraulic gradient with respect to water type.

3.5.2.3 Dissolved Organic Carbon Trends

Figure 56 is a box and whisker plot of dissolved organic carbon compared to areas where the vertical hydraulic gradient was either upwelling or downwelling. The figure shows that the median DOC for downwelling areas is significantly greater at 1.40 mg/l than in areas of upwelling at 1.14 mg/l.

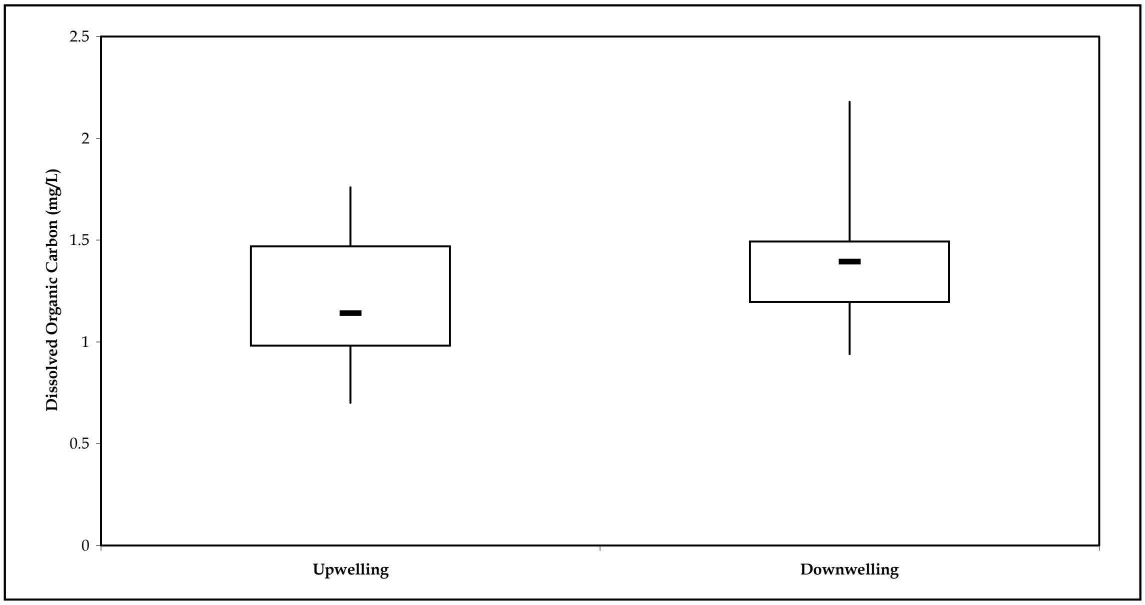

FIGURE 56: Box and whisker plot of DOC compared to upwelling versus downwelling areas.

In addition, the interquartile range is smaller, indicating less variability in the results, in the downwelling areas as opposed to the upwelling areas. This is in agreement with the comparison of depth of sampling interval and DOC concentrations, discussed in section 3.3.3.2. As previously discussed, DOC originates from the decay of organic matter which is relatively abundant in the surface water of the stream, but not at depth. DOC concentrations decrease with depth; therefore upwelling water typically has less DOC than downwelling surface water.

3.6 Hydraulic Conductivity Results

During the summer 2002 sampling event, hydraulic conductivity values were calculated for the one- and two-foot sampling intervals at select monitoring points. Data were collected using the Terhune Mark VI standpipe, as described in section 2.1.2.2, and were used to calculate the hydraulic conductivity results. Table 12 presents the results of the calculations. Figures 57 and 58 present the hydraulic conductivity results for the one- and two-foot sampling intervals during the summer 2002 sampling event.

Monitoring Point	Depth (feet)	Hydraulic Conductivity (feet/day)
1	1	6,100
	2	Not Measured
2	1	1,400
	2	Not Measured
4	1	1,600
	2	2,300
5	1	8,700
	2	Not Measured
7	1	400
	2	950
8	1	1,100
	2	210
9	1	5,300
	2	5,600
10	1	900
	2	50
11	1	10
	2	10

TABLE 12: Summary of hydraulic conductivity results, summer 2002.

Monitoring Point	Depth (feet)	Hydraulic Conductivity (feet/day)
12	1	320
	2	820
13	1	2,400
	2	890
14	1	810
	2	500
15	1	4,300
	2	1,300
16	1	590
	2	2,300
17	1	2,400
	2	8,000
18	1	790
	2	60

TABLE 12 (continued)

At the one-foot depth, hydraulic conductivity ranged from 10 feet/day to 8,700 feet/day. At the two-foot depth, hydraulic conductivity ranged from 10 feet/day to 8,000 feet/day. Heterogeneity within the streambed gravels of the hyporheic zone is probably responsible for the large spatial variability in hydraulic conductivities of the subsurface (Cey, 1998). Only two sampling locations (MP5-1 and MP17-2) exceeded the established 7,900 feet/day to indicate that salmonid embryo survival was likely in these areas (Barnard and McBain, 1994). However, salmonid embryo survival was not included as part of this study; therefore predicting the rate of embryo survival is not possible based solely on hydraulic conductivity data collected during this study.

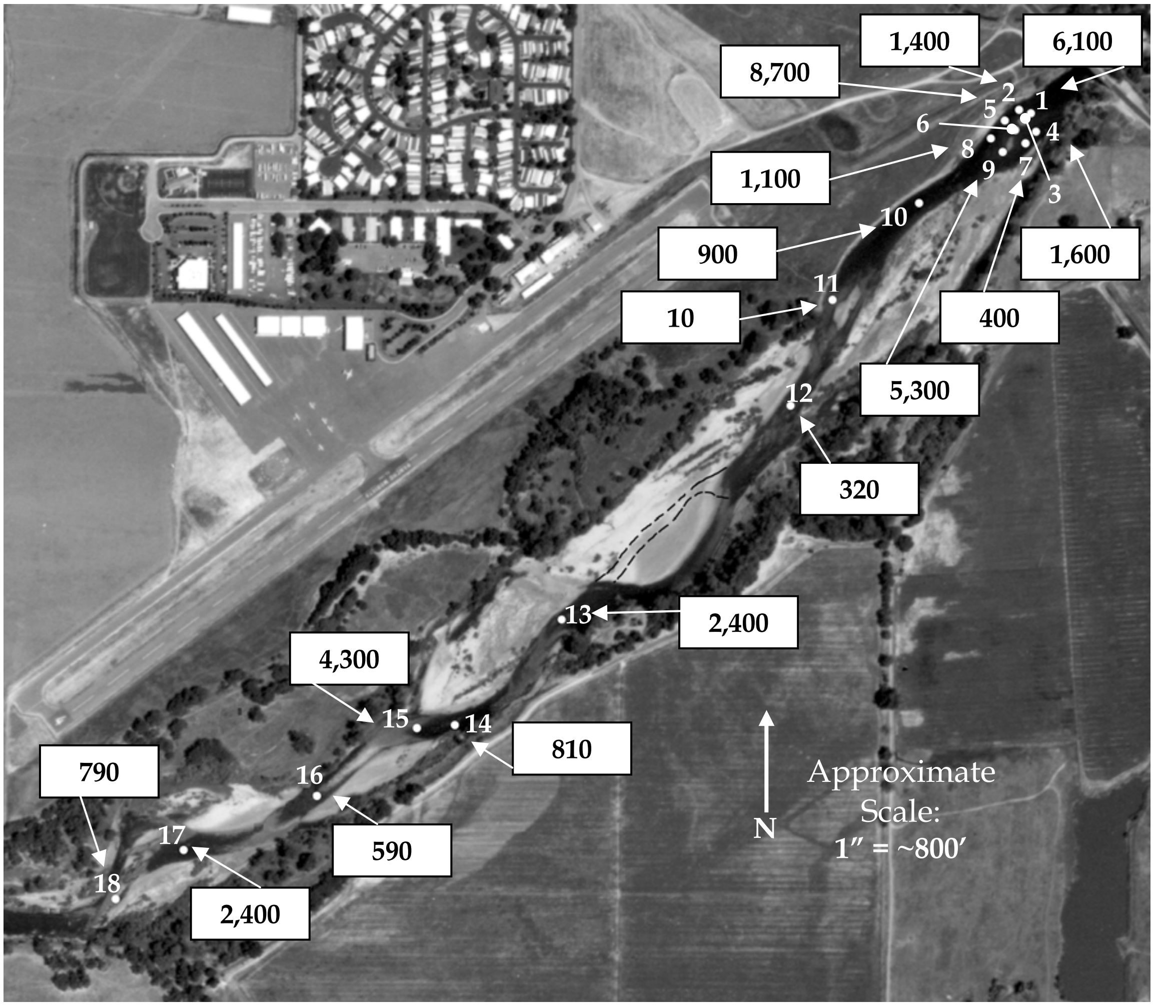

FIGURE 57: Hydraulic conductivity (feet/day) results for summer 2002 sampling event, 1-foot interval.

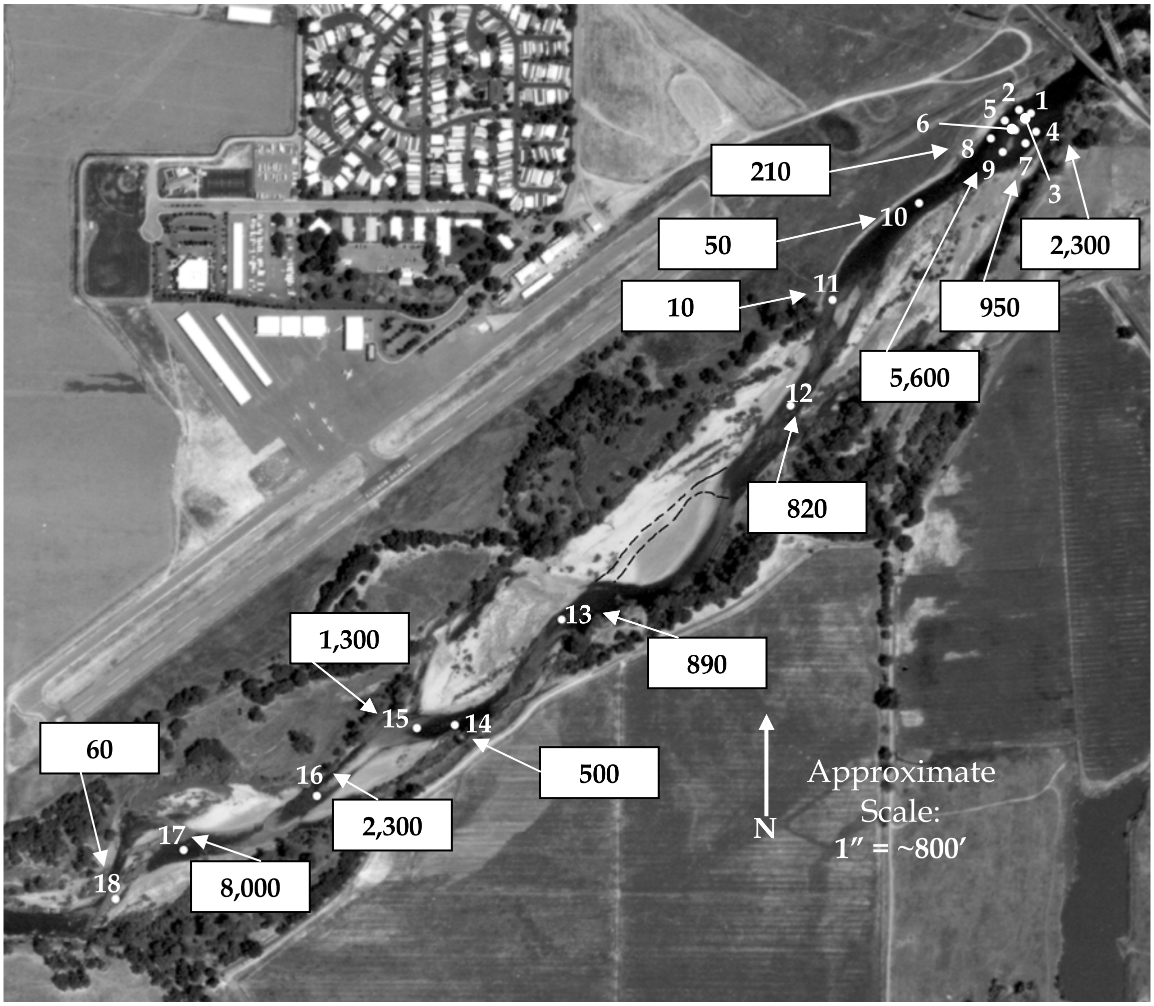

FIGURE 58: Hydraulic conductivity (feet/day) results for summer 2002 sampling event, 2-foot interval.

3.6.1 Comparison of Hydraulic Conductivity to Longitudinal Sampling Locations

Figure 59 presents a box and whisker plot of hydraulic conductivity results compared between the upstream and downstream areas of the study reach.

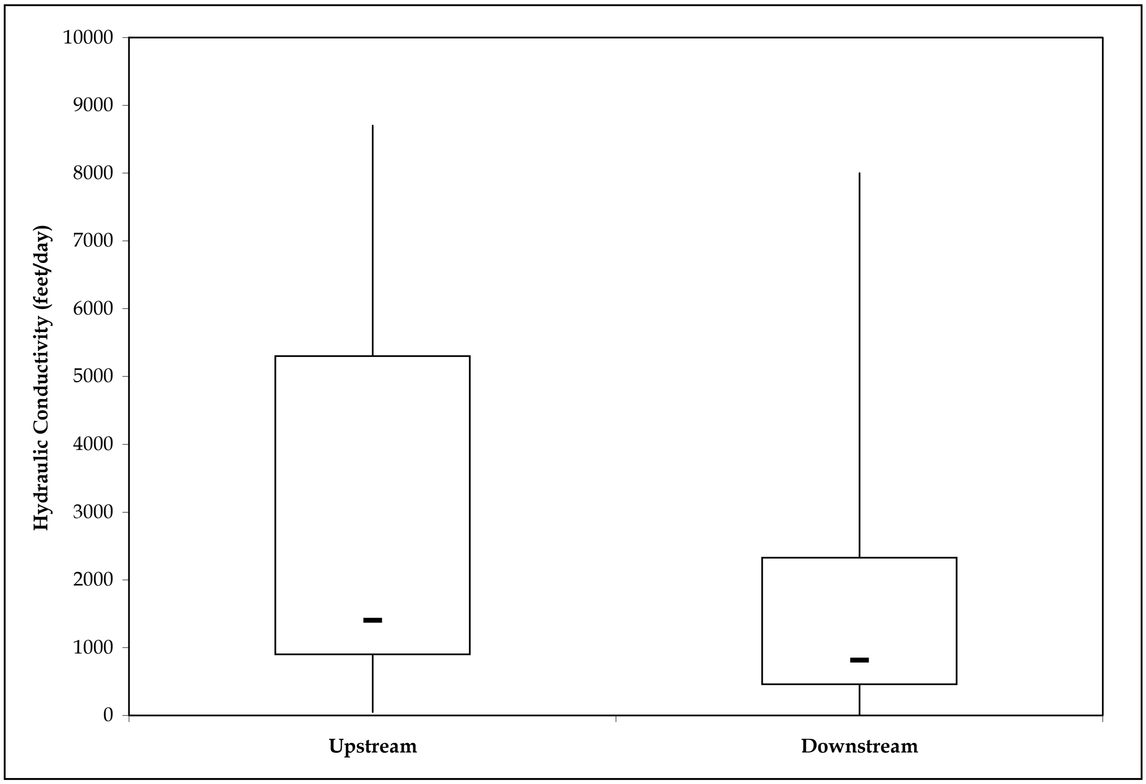

FIGURE 59: Box and whisker plot of hydraulic conductivity compared to longitudinal areas of the study reach.

The median hydraulic conductivities for the upstream and downstream reaches are not significantly different (1,400 and 815 feet/day, respectively). Although there is overlap in the range of hydraulic conductivity values between upstream and downstream areas, the variability in the interquartile range is significantly less in the downstream reach of the study area. This indicates that the streambed gravels in the downstream two thirds of the study area are more likely to have a lower hydraulic conductivity and are less variable than the streambed gravels in the upstream third of the study area. The underlying geologic control is undoubtedly responsible for this difference; reworked gravels from the Mehrten

Formation (upstream) are highly permeable and highly variable. Stream sediment derived from the Laguna Formation (downstream) has lower permeability and may have lower variability.

3.6.2 Comparison of Hydraulic Conductivity to Vertical Sampling Interval

A comparison of hydraulic conductivity and sampling depth in the streambed gravels is included in Figure 60.

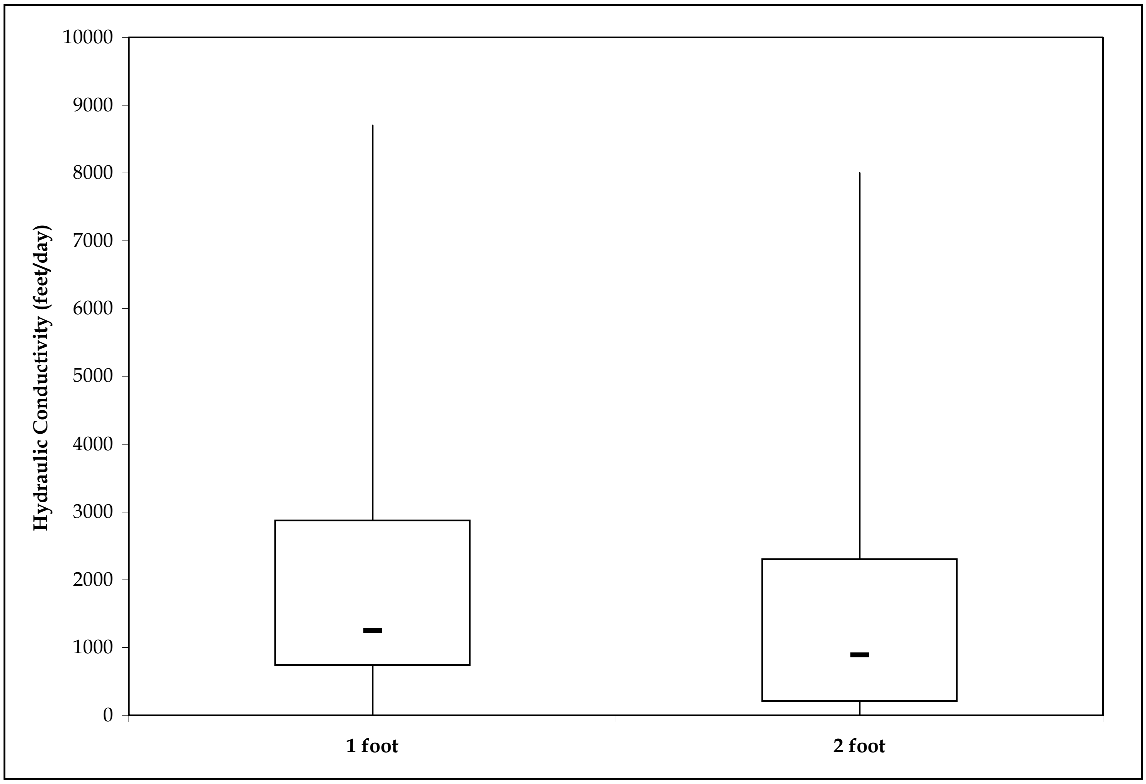

FIGURE 60: Box and whisker plot of hydraulic conductivity and vertical sampling intervals.

The box and whisker plot in Figure 61 indicates that statistically, hydraulic conductivities between the 1-foot and 2-foot sampling intervals are not significantly different.

3.6.3 Comparison of Hydraulic Conductivity and Streambed Morphology

A comparison of hydraulic conductivity and streambed morphology, as seen in Figure 61, shows that statistically, no significant differences in hydraulic conductivity exist between riffles and runs, although the median is higher in riffles. Figure 61 appears to show that the island has significantly higher hydraulic conductivities than the other morphological groupings, however it should be noted that only three hydraulic conductivity measurements account for the island portion of the plot. The island may also be reworked, dredged deposits or coarse gravel deposited by bridge scour. Either scenario would explain the higher permeability measured on the island.

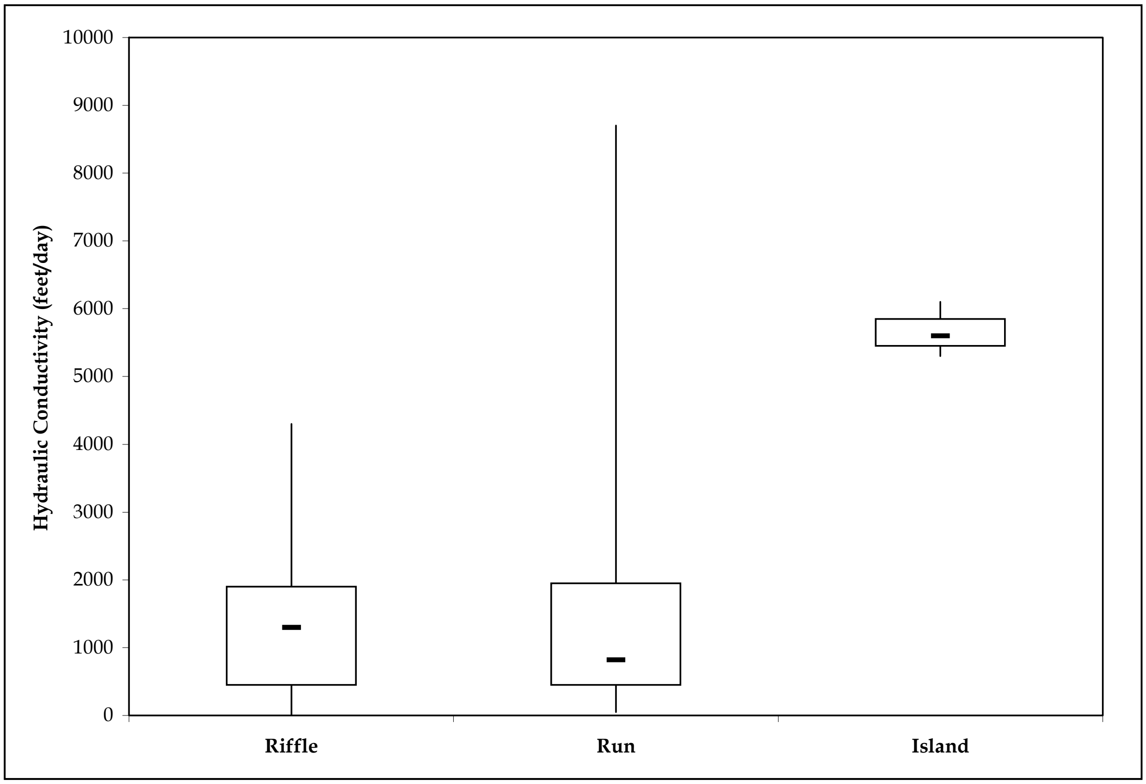

FIGURE 61: Box and whisker plot of hydraulic conductivity and streambed morphologies.

3.6.4 Comparison of Hydraulic Conductivity and Direction of Vertical Hydraulic Gradient

A comparison of hydraulic gradient and upwelling versus downwelling areas is presented in Figure 62.

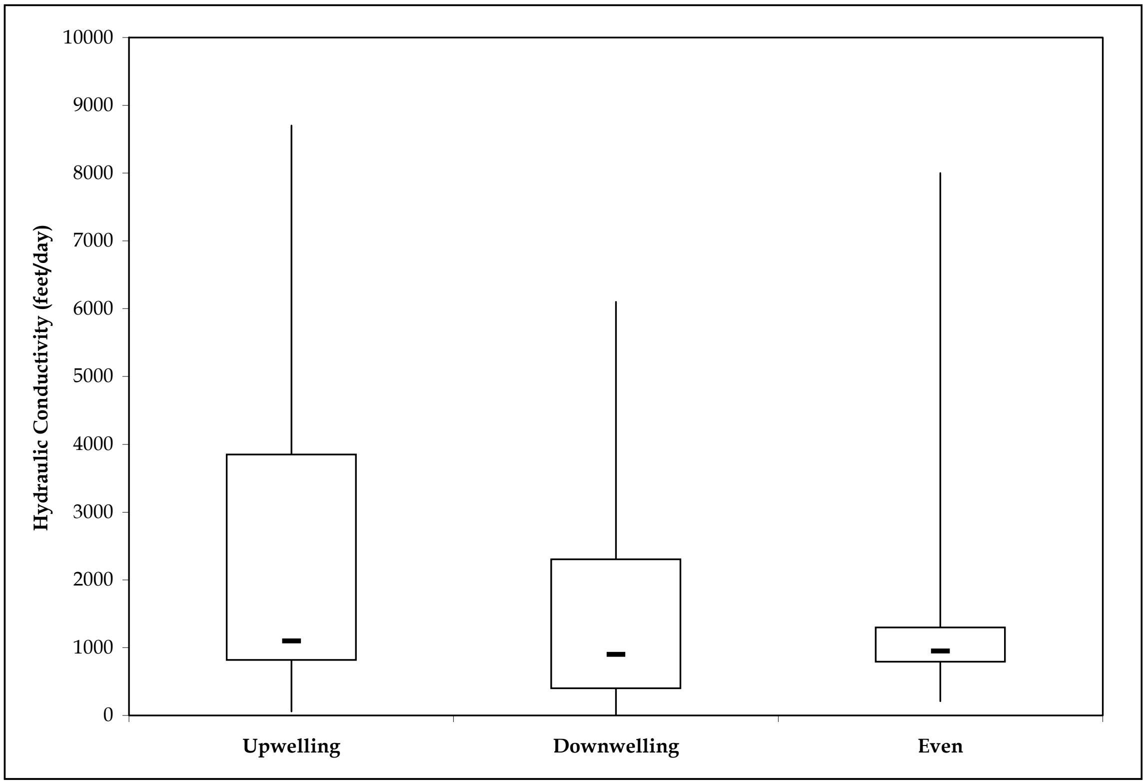

FIGURE 62: Box and whisker plot of hydraulic conductivity and direction of vertical gradient.

The box and whisker plot in Figure 62 shows that the median hydraulic conductivities for areas of upwelling, downwelling, and even vertical hydraulic gradient are not significantly different. However, the variability in hydraulic gradient in areas of upwelling is greater than areas of downwelling. This weak association may be due to the infiltration of fine material in the pores of downwelling zones.

4.0 Summary

The factors of varying seasons, upstream vs. downstream location within the study area, depth within the hyporheic zone, and morphological features within the streambed greatly affect the physical characteristics and natural water chemistry of the hyporheic zone of the Cosumnes River. The effects of these four factors may significantly contribute to the suitability of streambed gravels for salmon spawning habitat.

4.1 Seasonal Relationships Between Water Chemistry and Vertical Hydraulic Gradient

The most significant effect of seasonal variation on the water chemistry of the Cosumnes River is on dissolved oxygen. The median concentration of DO in the summer decreases by as much as 7 mg/l when compared to the winter and spring. Significantly lower flows in the Cosumnes River during the summer prevent adequate circulation of fresh water through the hyporheic zone, therefore depleting the availability of DO in the streambed. DO concentrations are also much lower in warm summer surface water. Although sampling frequency of this study does not show high-resolution changes, it is likely that as soon as the rainy season begins, surface water cools, and the flows in the Cosumnes River increase, DO is quickly returned to the system.

In addition to DO, changes within the streambed caused by the different seasons also affect the concentrations of chloride and sulfate in the pore water of the hyporheic zone. Chloride and sulfate concentrations are both highest in the winter and lowest in the spring. One possible explanation would be the influx of nutrient rich sediments and detritus to the Consumes River as the river reconnects and the river stage rises. Then, as the river equilibrates throughout the winter and into spring, concentrations decrease due to a dilution effect.

Comparisons of sodium and calcium ratios to sampling season indicate little differences between the spring, summer, and winter. However, the measured concentrations of sodium and calcium do increase proportionally from the spring to the winter and then summer, with the summer having the highest sodium and calcium concentrations. In addition, the ratio of sulfate to bicarbonate indicates that a relative abundance of sulfate exists in the summer and winter. This may be an effect of seasonal changes in flows. Increased flows and flooding can dramatically change the spatial extent and interstitial flow through the hyporheic zone, thus altering the residence time and the exchange rate of water in near-surface streambed gravels (Wondzell, 1999). These changes, due to changes in the stream flow, greatly affect the geochemistry of the hyporheic zone. The majority of the pore water samples are classified as sodium rich in the spring. However, analysis of Na/Ca ratio indicates that the relative abundance of sodium and calcium does not change with the different seasons and therefore the seasonal changes in water type are not significant.

In the winter chloride and sulfate concentrations are the highest, as are dissolved organic carbon concentrations. In addition, the vertical hydraulic gradient is slightly higher in the winter and is primarily upwelling, rather than downwelling. In the summer chloride and sulfate concentrations are relatively low, dissolved oxygen is low, the relative abundance of sodium compared to calcium concentrations increase, bicarbonate concentrations increase, and the vertical hydraulic gradient is primarily downwelling. The differences in the direction of vertical hydraulic gradient (upwelling versus downwelling) are probably due to the elevated groundwater levels or perched aquifers that contribute to the stream when winter rainfall recharges the shallow, unconfined surface interval.

4.2 Longitudinal Relationships Between Water Chemistry and Vertical Hydraulic Gradient

The median concentration of every ion analyzed was greater in the downstream samples than the upstream samples. Dissolved organic carbon was also higher in the downstream two thirds of the study reach.

The downstream two thirds of the study reach was more likely to have neutral vertical hydraulic gradient than the upstream portion and was more likely to have a relatively low hydraulic conductivity. The differences between areas that are upwelling and downwelling are related to the fundamental differences in the underlying geologic units. The altered (dredged) remnants of the Mehrten Formation (upstream) are highly permeable and sit directly on impermeable metavolcanics. Water flows freely through these coarser sediments, and interacts with the stream. The downstream two thirds of the study reach has lower gradients, and is underlain by impermeable silty clays of the Laguna Formation. Stream sediments that overlie the the Laguna Formation are less permeable. The basic difference in underlying geologic units may be the single most important controlling factor in the attraction of salmon spawning on the Cosumnes River. Salmon swim upstream until they leave fine, low gradient sediments of the Central Valley, and encounter coarser, more permeable gravel.

It appears that ion and DOC concentrations increase in areas where there is no significant vertical hydraulic. Longer residence times in areas with extremely low vertical hydraulic gradients would allow the major ionic chemistry to become more concentrated.

4.3 Relationships Between Vertical Sampling Depth, Water Chemistry, and Vertical Hydraulic Gradient

Dissolved oxygen is the field parameter most strongly influenced by depth. DO shows a significant decrease from the surface water to the samples collected from the 9-foot sampling points. Electrical conductivity follows the opposite trend and increases with depth.

The majority of water samples were classified as Mg-Ca-Na-HCO_3. However, this water type was most likely to occur in the 9-foot sampling interval; the comparison of the Na/Ca ratio indicated that the relative abundance of calcium increased at the 9-foot sampling interval. Mg-Na-Ca-HCO_3 was most likely to occur in the 1-foot sampling interval and the surface water. In addition, the relative abundance of sulfate also increased with depth.

Vertical hydraulic gradient decreased slightly with depth. Lower vertical hydraulic gradients can increase the residence time of water in the subsurface. The longer residence time of water moving through the subsurface, in areas where hydraulic gradients are lower, may be related to decreases in dissolved oxygen concentrations and increases in electrical conductivity and the relative calcium abundance.

4.4 Relationships Between Streambed Morphological Changes, Water Chemistry, and Vertical Hydraulic Gradient

DO concentrations also appear to be affected by streambed morphology. Although both riffles and runs have a wide variability in DO concentration, the median DO concentration for riffles is significantly higher than the median concentration for runs. Samples classified as island samples are similar to run samples, but have a higher variability. The higher median DO concentrations in riffle monitoring points are likely due to higher permeability and shorter exchange pathways in the turbulent environment of a riffle.

Typically, median ion concentrations were higher in the monitoring points installed in a run. The relative abundance of both sodium and sulfate are greater in riffle groupings.

Although vertical hydraulic gradient does not significantly change between riffles and runs, riffles are more likely to be upwelling, and runs are more likely to have no vertical hydraulic gradient.

The difference between riffles and runs is the residence time of water flowing through the hyporheic zone. Runs are more likely to have a low vertical hydraulic gradient, lower dissolved oxygen, and a greater relative abundance of calcium and bicarbonate. Riffles, which are more likely to have higher, upwelling vertical hydraulic gradients are more likely to have higher concentrations of dissolved oxygen, and a greater relative abundance of sodium and sulfate.

4.5 Relationship Between Upwelling and Downwelling Areas and Water Chemistry

Areas in the hyporheic zone that were found to be upwelling also had higher concentrations of magnesium, sulfate, and chloride. The relative abundance of calcium is greater in upwelling areas and the predominate water type is Mg-Ca-Na-HCO_3. Since the relative abundance of calcium was greatest in the 9-foot sampling interval, it is not surprising that upwelling areas have a greater relative abundance of calcium than downwelling areas.

Areas that were found to be downwelling through the hyporheic zone had slightly greater concentrations of dissolved oxygen, greater concentrations of sodium, potassium, calcium, and bicarbonate. The relative of abundance of sodium, compared to calcium, is greater in areas of downwelling and the Mg-Na-Ca-HCO_3 water type is more likely to occur in downwelling areas.

5.0 Conclusions

As previously discussed, factors that affect egg survival include DO concentrations, which should be higher than 5.2 mg/l to assure survival (Sowden, 1985), the presence of vertically flowing water through the substrate (Bjornn, 1991 and Geist, 1998), and streambed morphology that includes pool-riffle transitions (Bjornn, 1991). Considering these conditions when analyzing the data set, it is found that DO is typically above 5.2 mg/l in the spring and winter, in the upstream portion of the site, in the one- and two-foot sampling depths, and riffles. Therefore, it is more likely that eggs will survive in the upstream portion of the study area, in riffles rather than runs. Monitoring points found to be downwelling are more likely to be similar to the surface water chemistry and areas that are upwelling are more likely to be similar to groundwater. It is possible that in addition to elevated DO concentrations, the need for the vertical movement of water, and riffle morphology, the water chemistry should be similar to the composition of the surface water to ensure viable spawning habitat. The presence of trace elements such as iron, manganese, other metals, or organic compounds may also affect the suitability of spawning habitat, although these factors were not examine in the present study.

Areas that are primarily downwelling have similar chemistry to the surface water, whereas monitored areas that are primarily upwelling tend to have water chemistry that is similar to the groundwater (as determined by the nine-foot sampling interval). It is also possible that the salmon prefer the areas where chemistry or physical conditions are similar to the accustomed (surface water) surroundings, including ion chemistry, pH, dissolved oxygen, and temperature. At depth, dissolved oxygen and temperature can change dramatically. As the groundwater flows upward into the stream it mixes with the water of the hyporheic zone, but remains different from the surface water.

Water samples collected in the Cosumnes River were found to have a relative abundance of calcium as opposed to sodium. This low sodium to calcium ratio occurred most frequently in areas of upwelling, during the winter, in the upstream portion of the study area, and in runs. However, these samples with low sodium to calcium ratios had DO levels too low to support the likely survival of eggs and alevine more than 50% of the time. Water samples with higher sodium to calcium ratio, or a relative abundance of sodium were most likely to occur in riffles, during the winter, in the upstream third of the study reach, and in areas that were downwelling. The sample locations with the higher ratio of sodium to calcium typically had sufficient DO concentrations to support the survival of eggs and alevine more than 70% of the time. This second set of conditions (downwelling, riffles, winter, upstream, and with a relative abundance of sodium) seems best suited for spawning habitat.

This research shows that there is the possibility of a relationship between water chemistry and redd site selection. If such a relationship exists it would become crucial to incorporate such information into projects not only for salmon habitat restoration but all streambed restoration projects. If the salmon are affected by natural water chemistry, then other species are also likely to be dependent upon variations in the natural chemistry of the water.

Appendix A

Calibration Curves

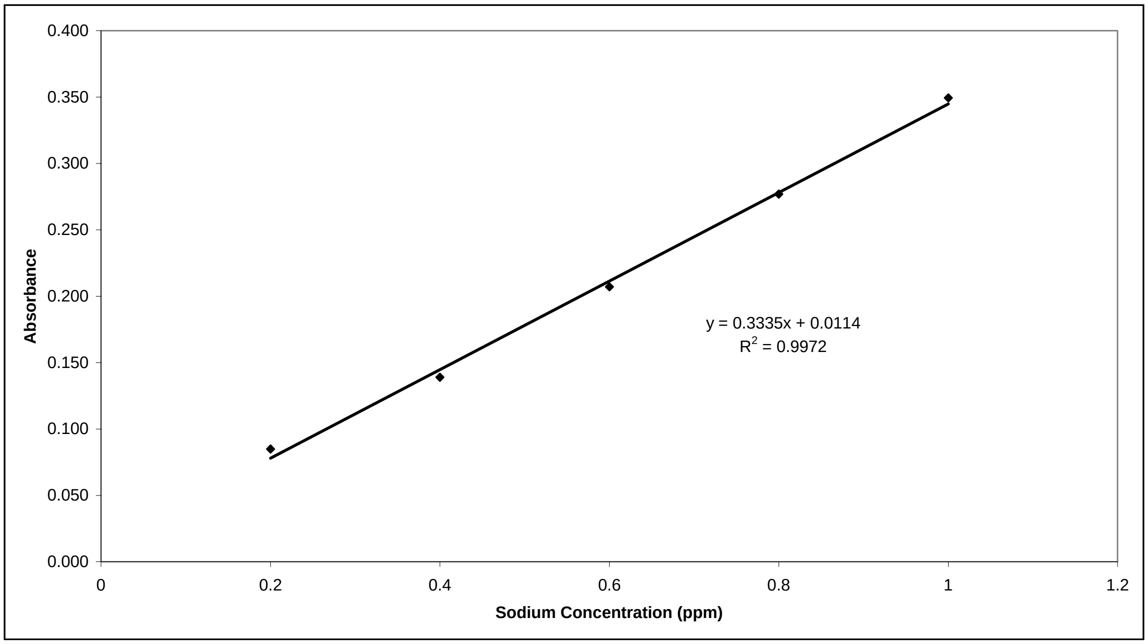

FIGURE A-1: Sodium calibration curve, spring 2002.

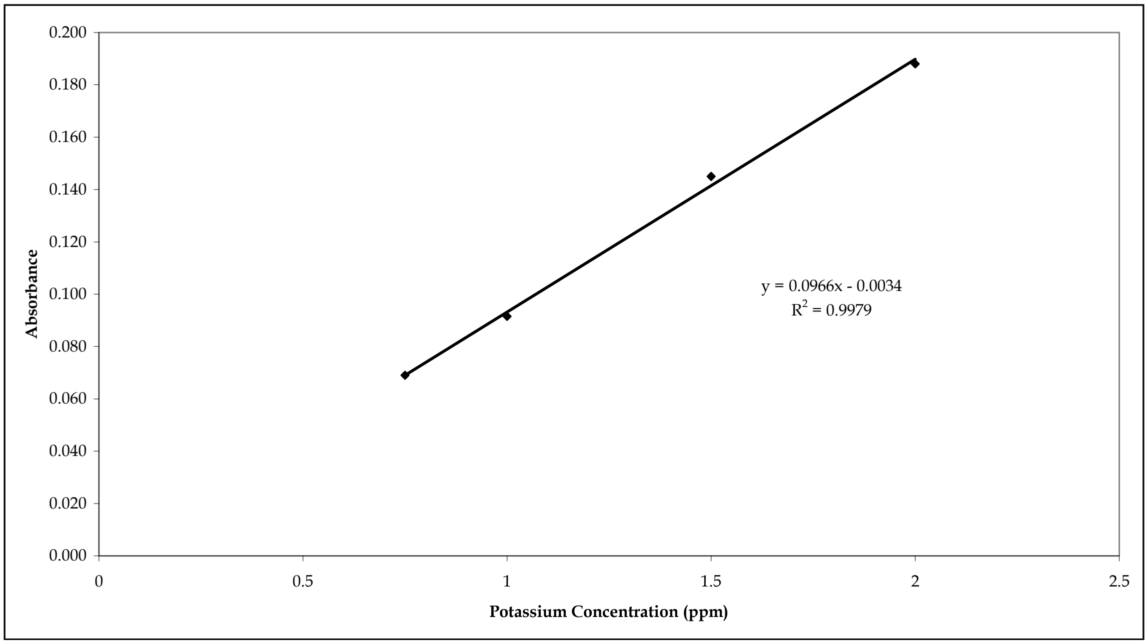

FIGURE A-2: Potassium calibration curve, spring 2002.

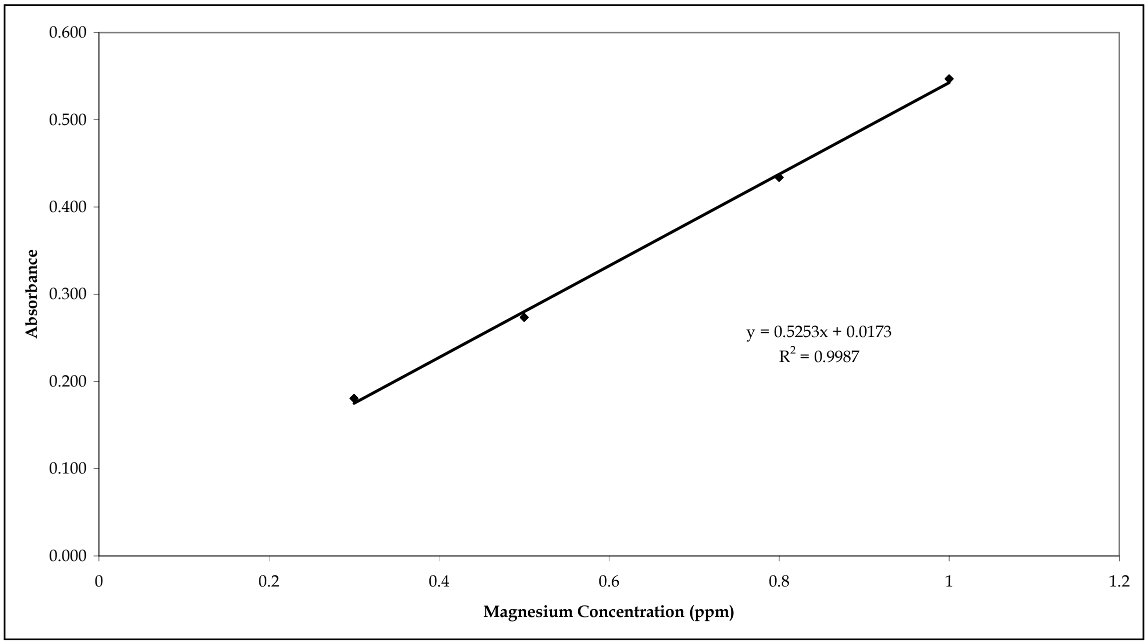

FIGURE A-3: Magnesium calibration curve, spring 2002.

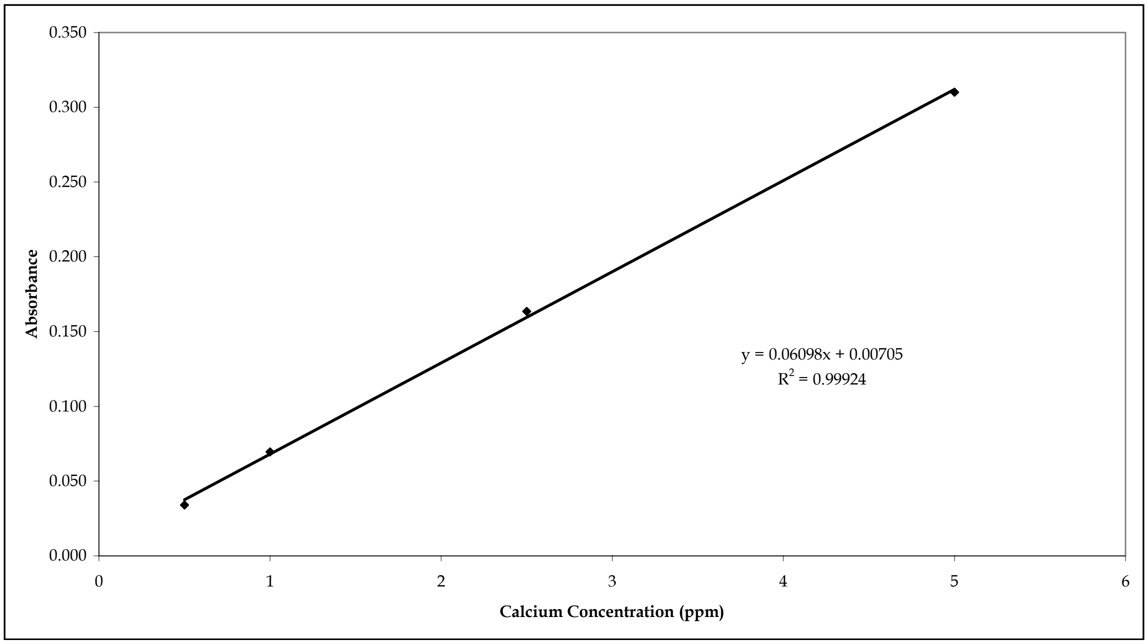

FIGURE A-4: Calcium calibration curve, spring 2002.

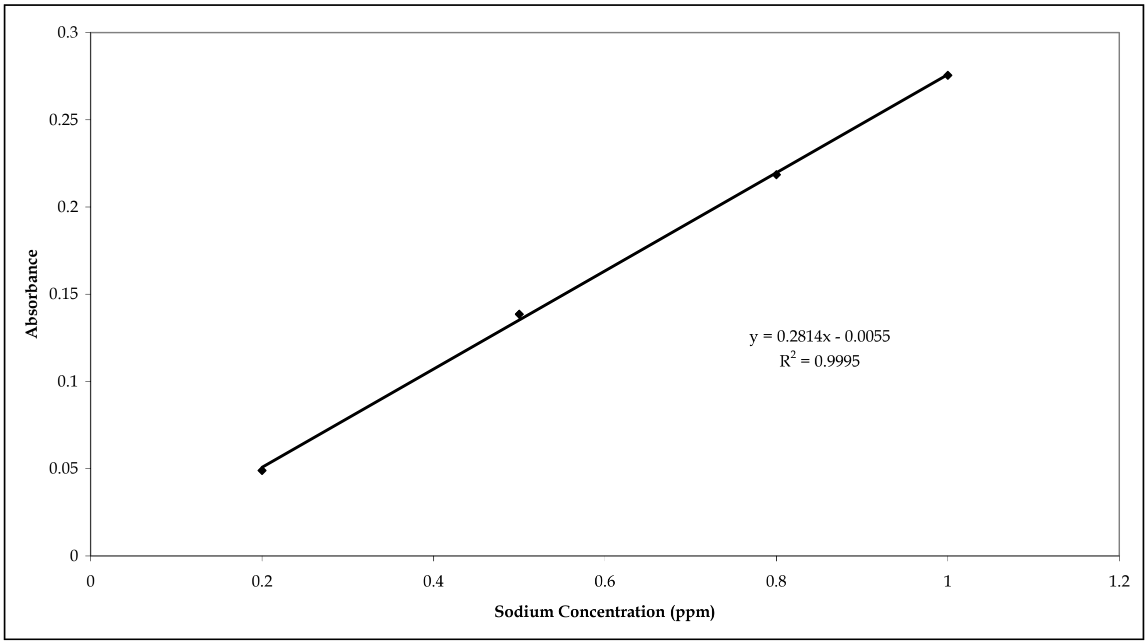

FIGURE A-5: Sodium calibration curve, summer 2002.

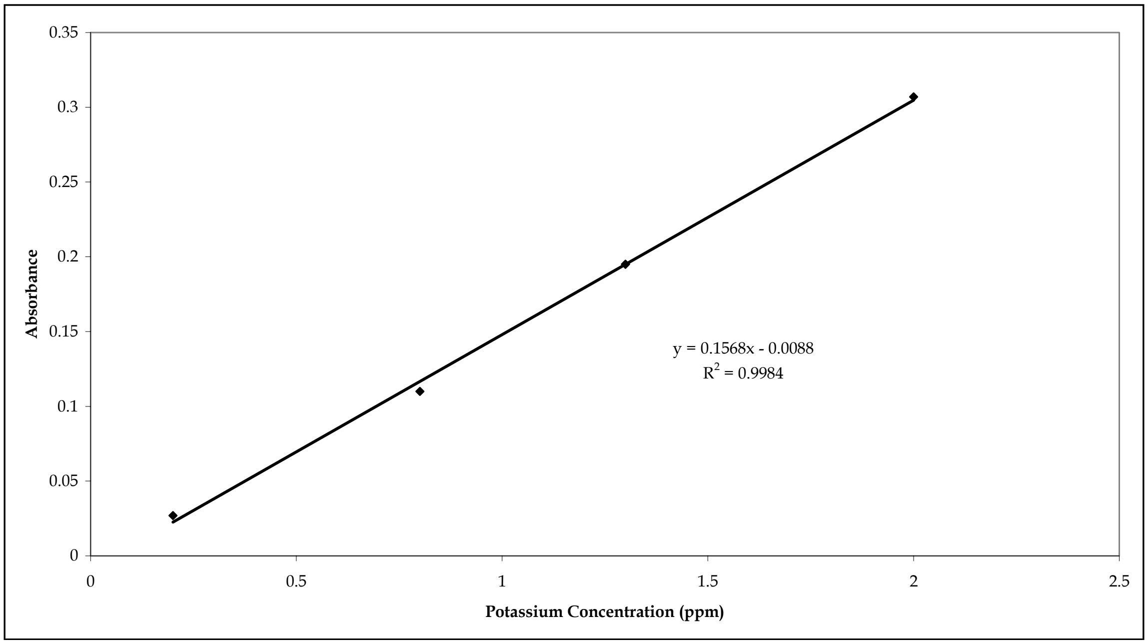

FIGURE A-6: Potassium calibration curve, summer 2002.

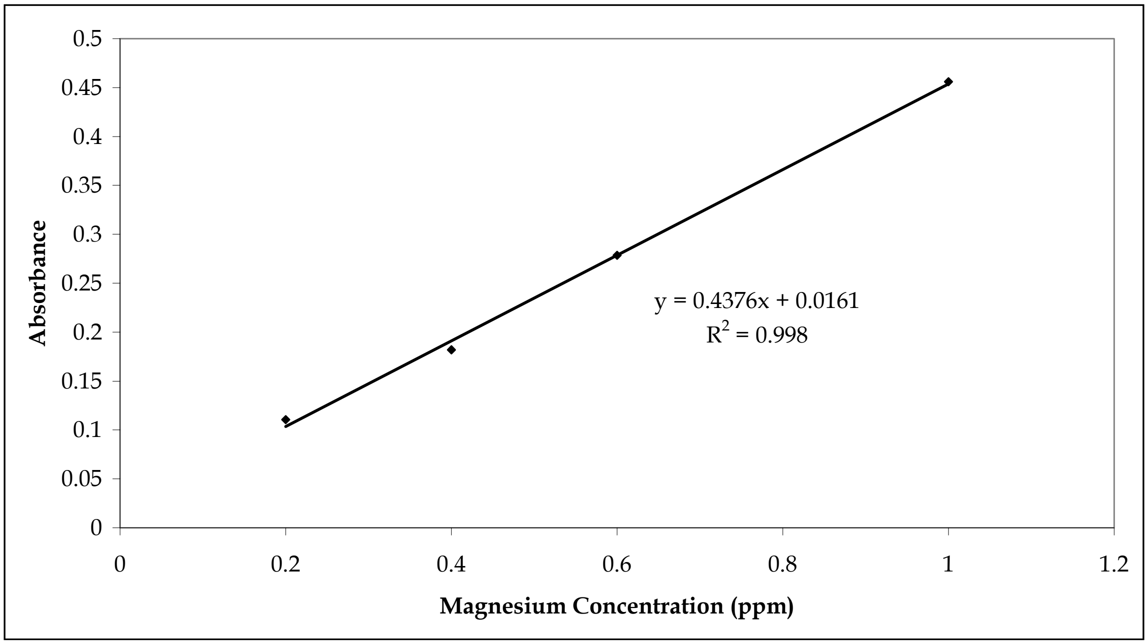

FIGURE A-7: Magnesium calibration curve, summer 2002.

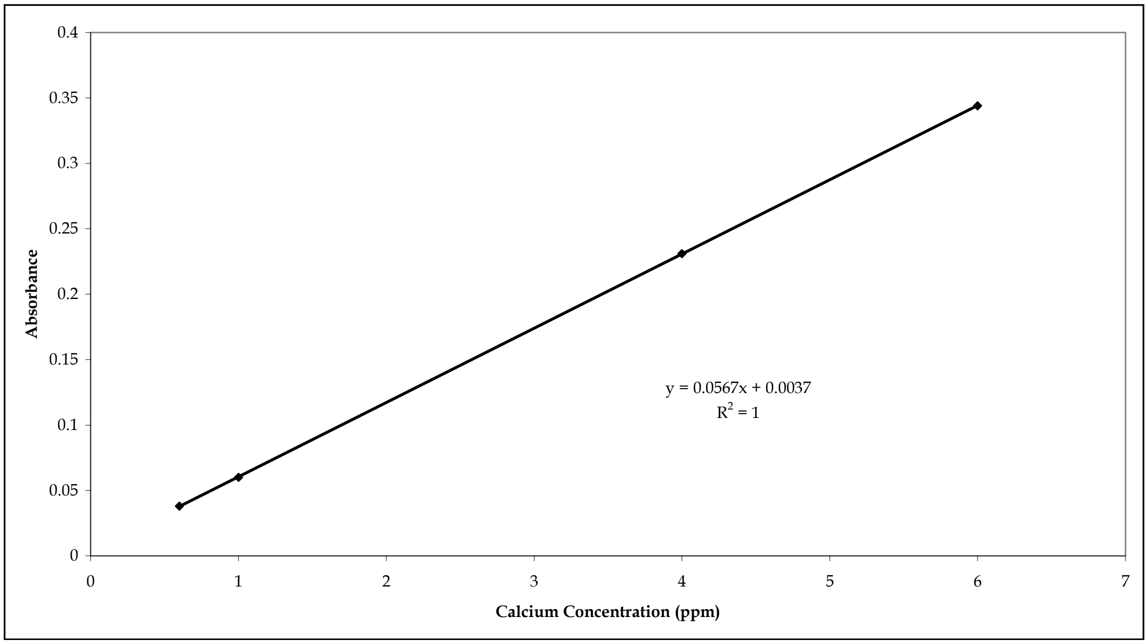

FIGURE A-8: Calcium calibration curve, summer 2002.

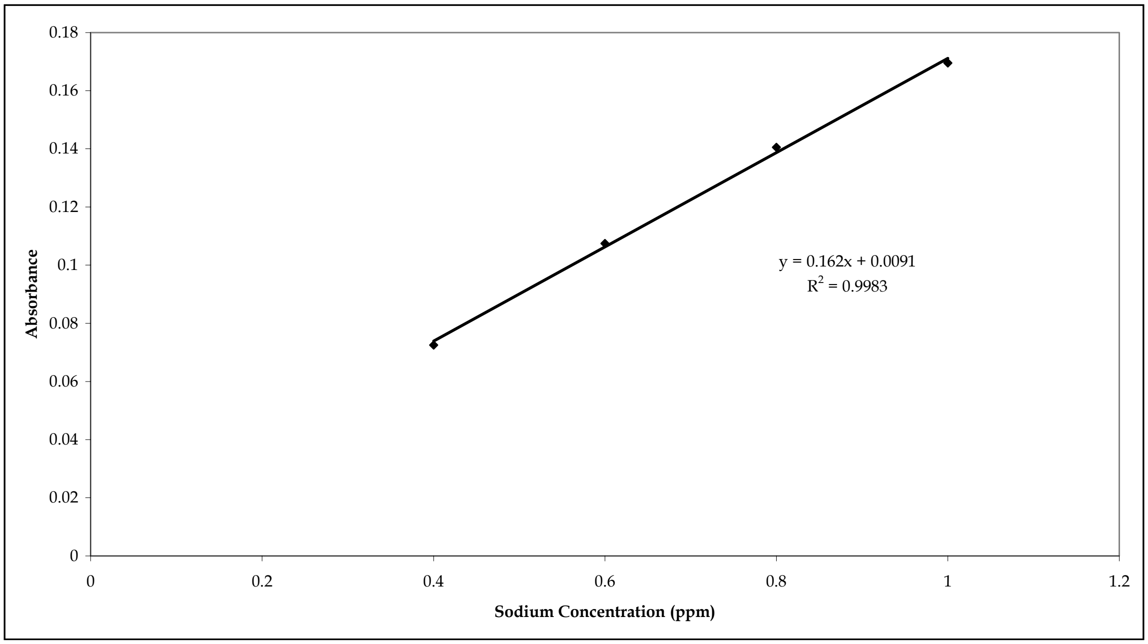

FIGURE A-9: Sodium calibration curve, winter 2003.

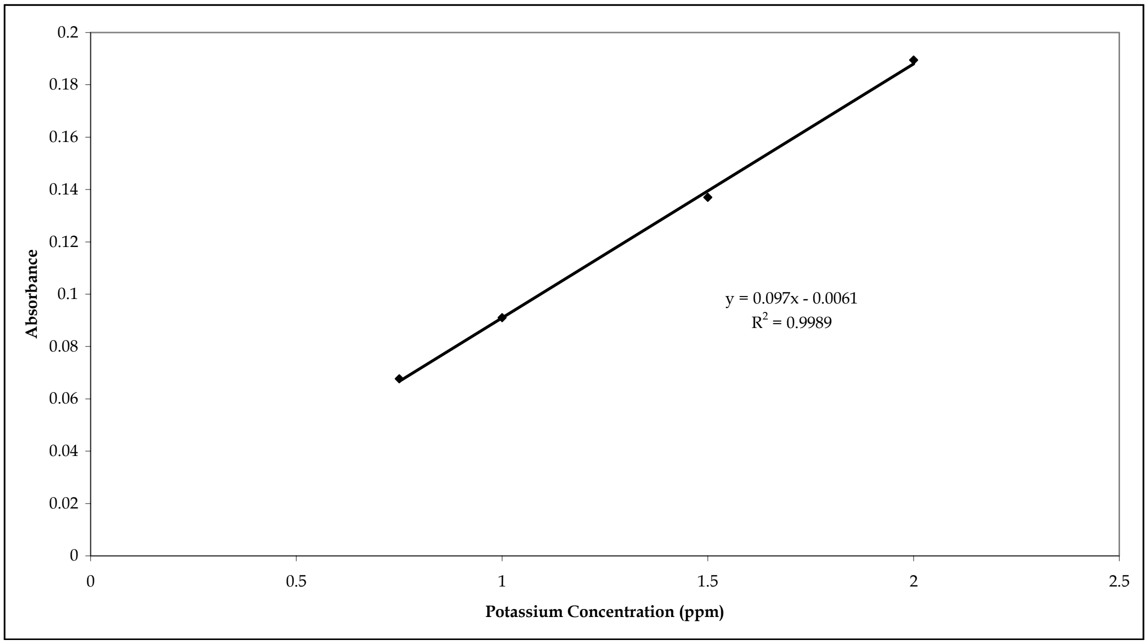

FIGURE A-10: Potassium calibration curve, winter 2003.

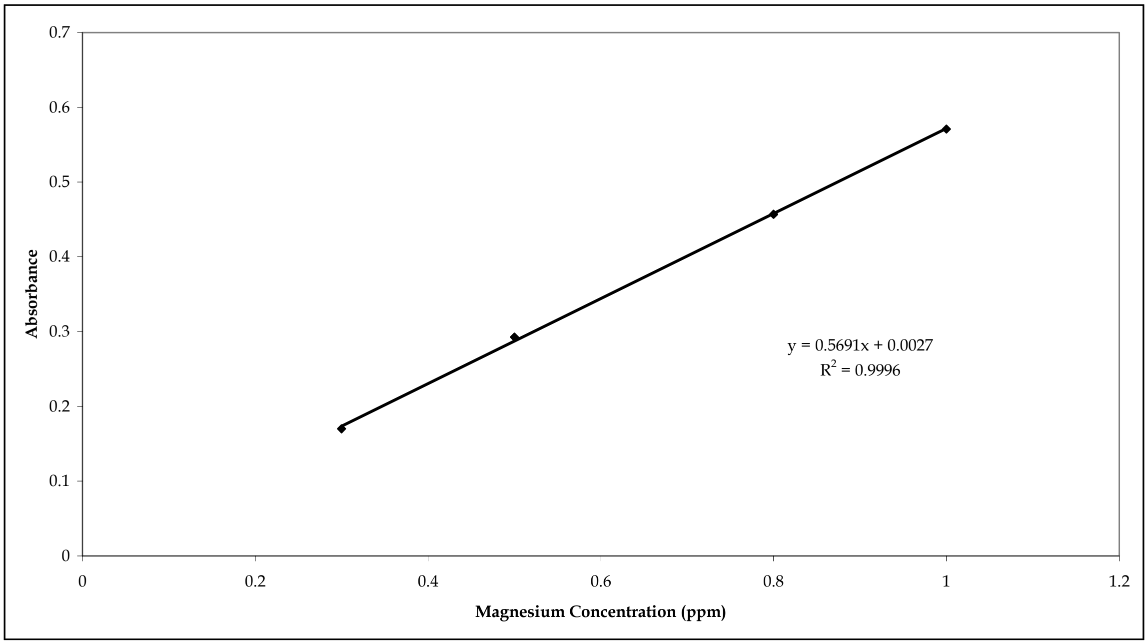

FIGURE A-11: Magnesium calibration curve, winter 2003.

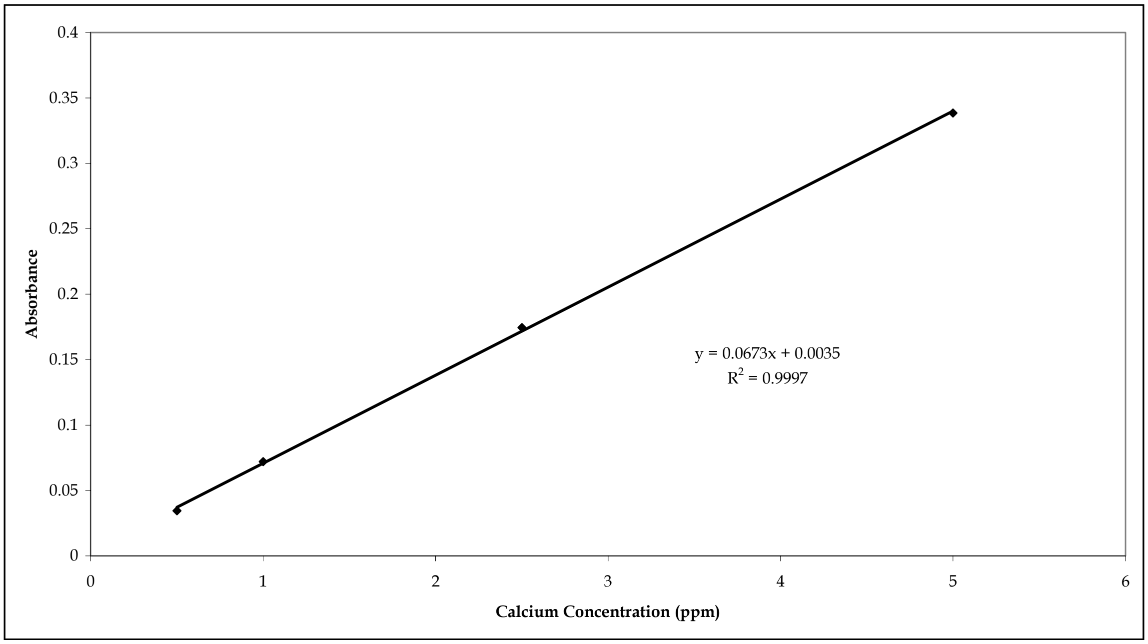

FIGURE A-12: Calcium calibration curve, winter 2003.

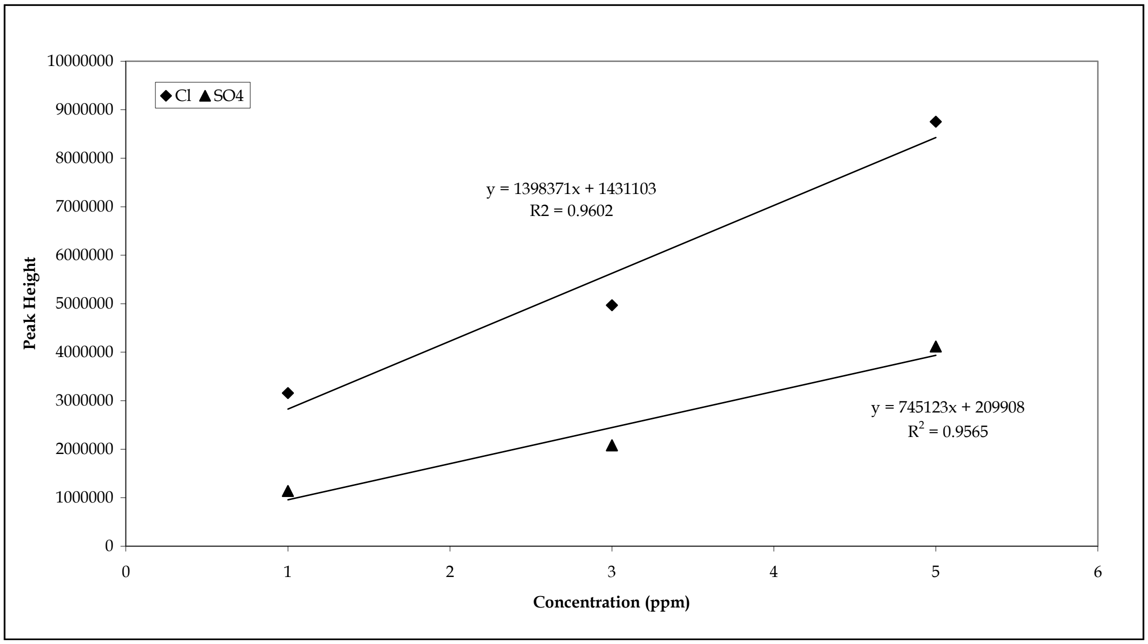

FIGURE A-13: IC calibration curve, day one analysis, spring 2002.

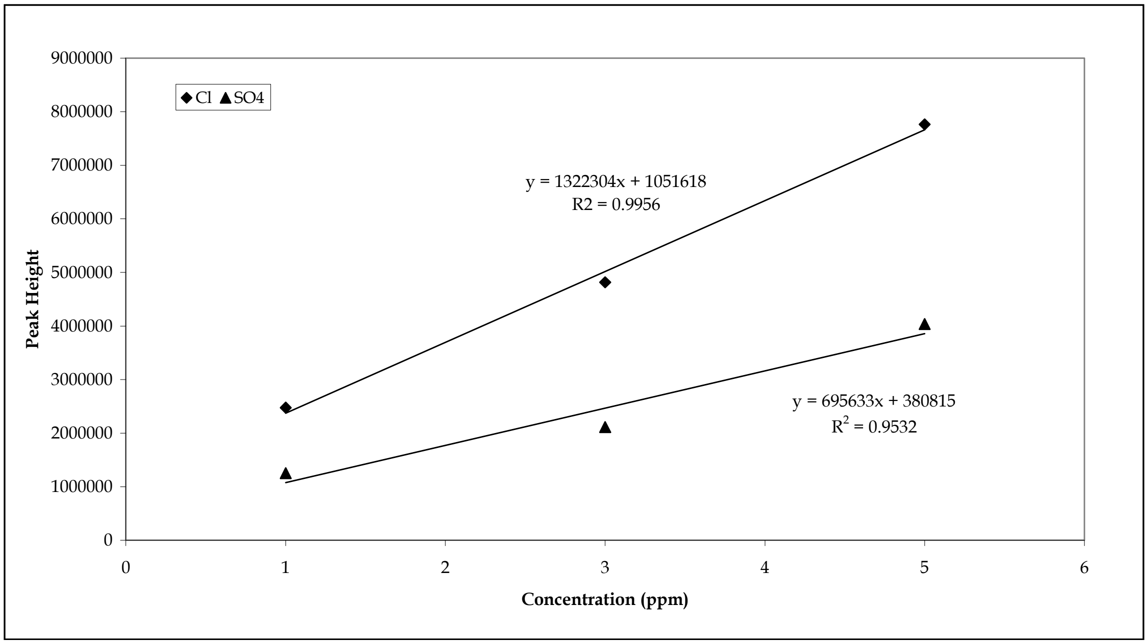

FIGURE A-14: IC calibration curve, day two analysis, spring 2002.

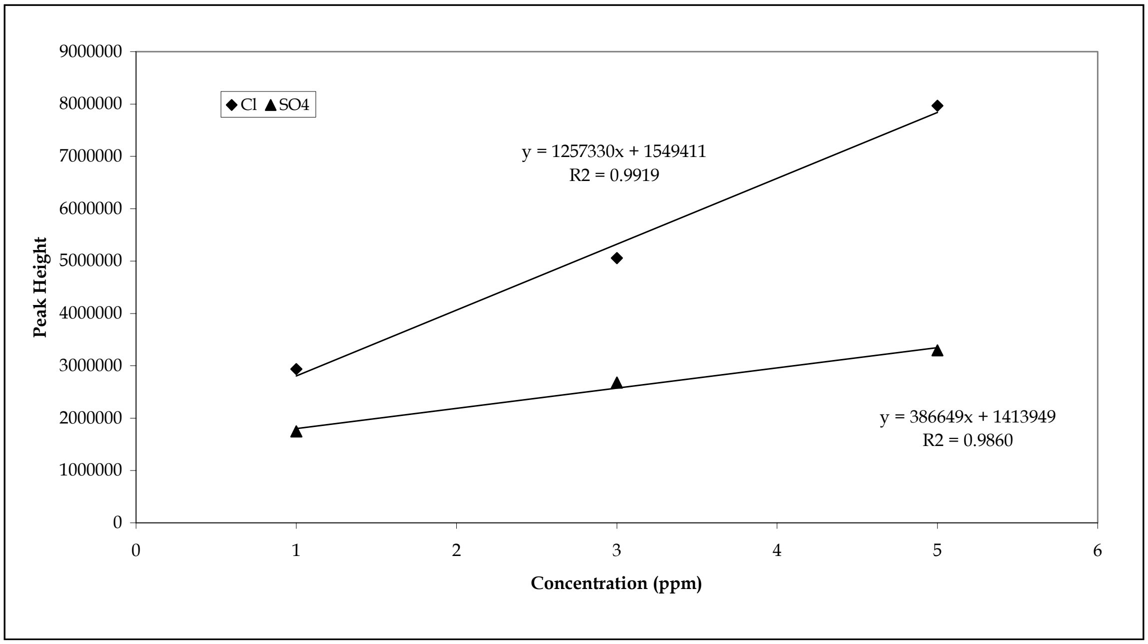

FIGURE A-15: IC calibration curve, day three analysis, spring 2002.

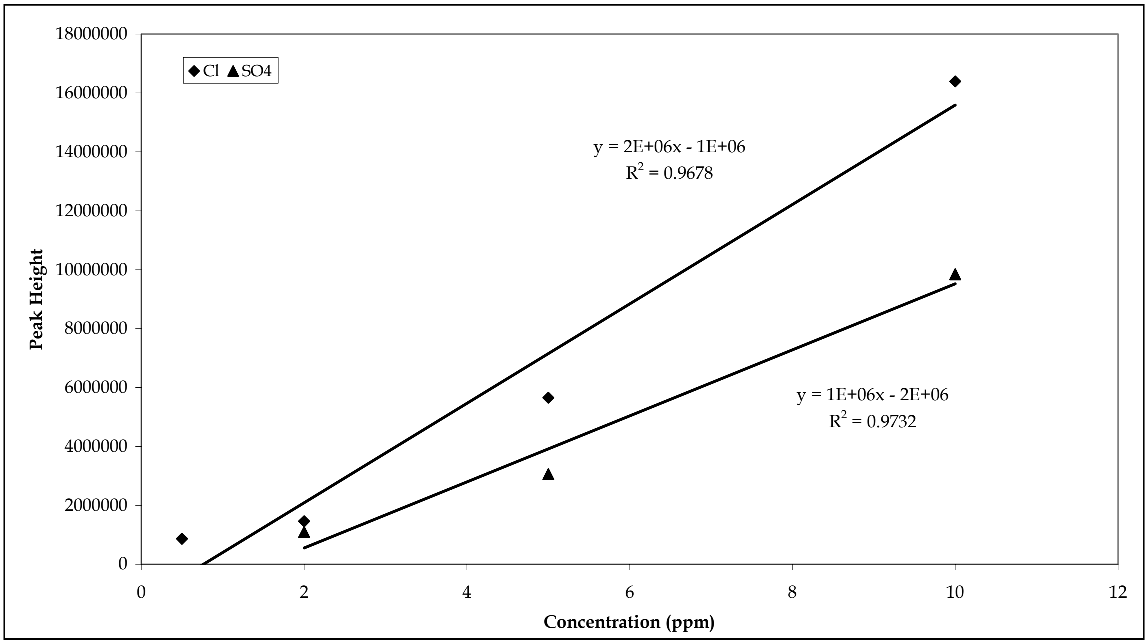

FIGURE A-16: IC calibration curve, day one analysis, summer 2002.

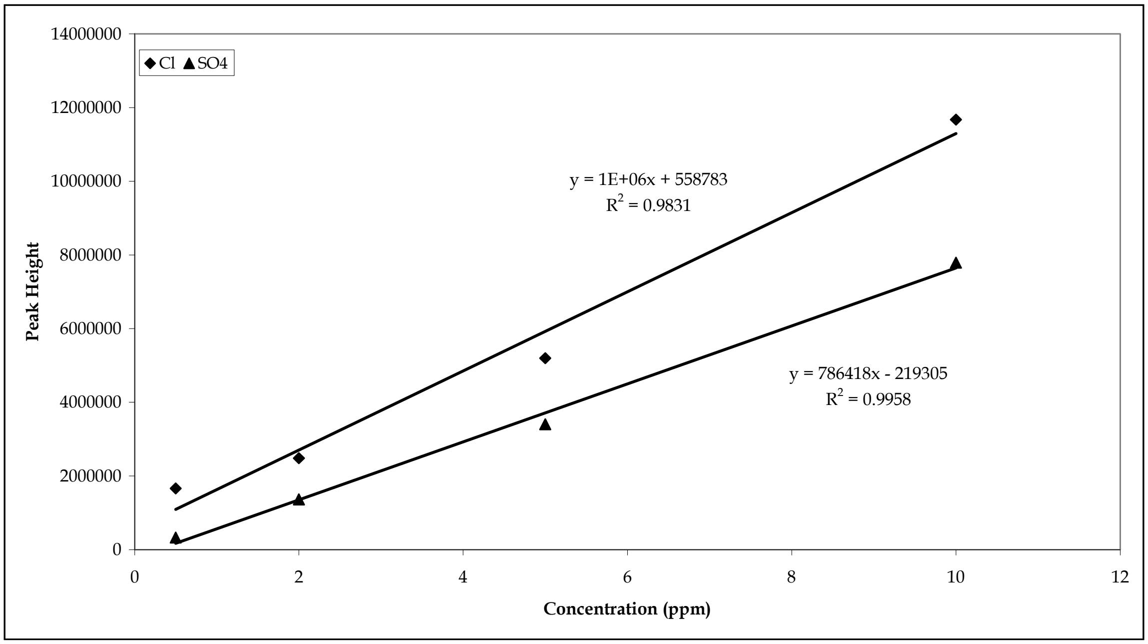

FIGURE A-17: IC calibration curve, day two analysis, summer 2002.

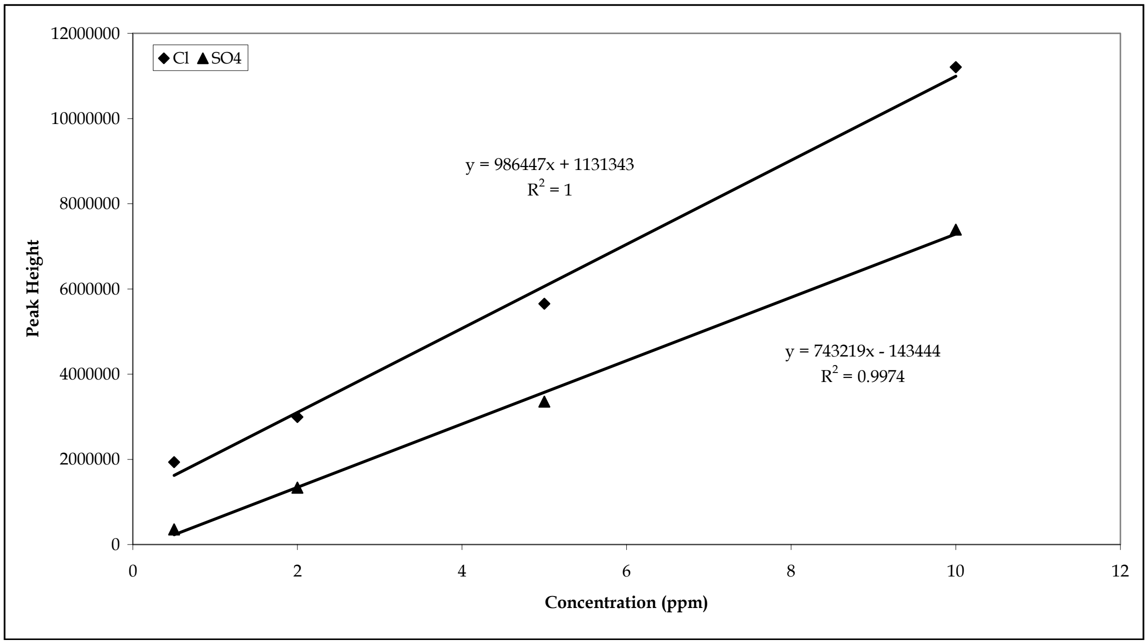

FIGURE A-18: IC calibration curve, day three analysis, summer 2002.

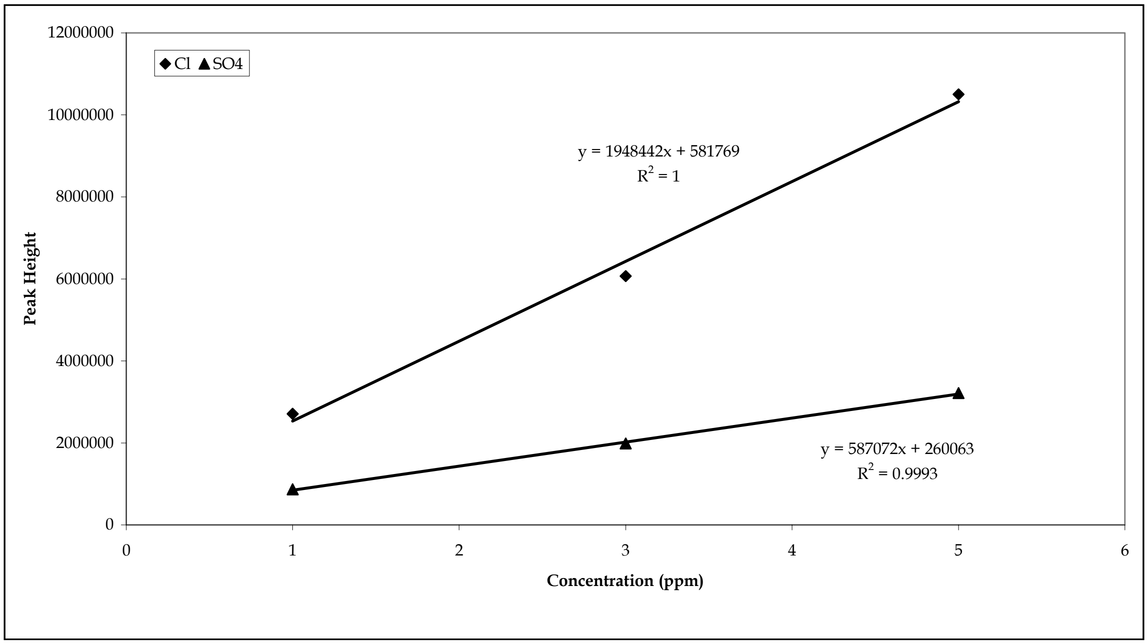

FIGURE A-19: IC calibration curve, day four analysis, summer 2002.

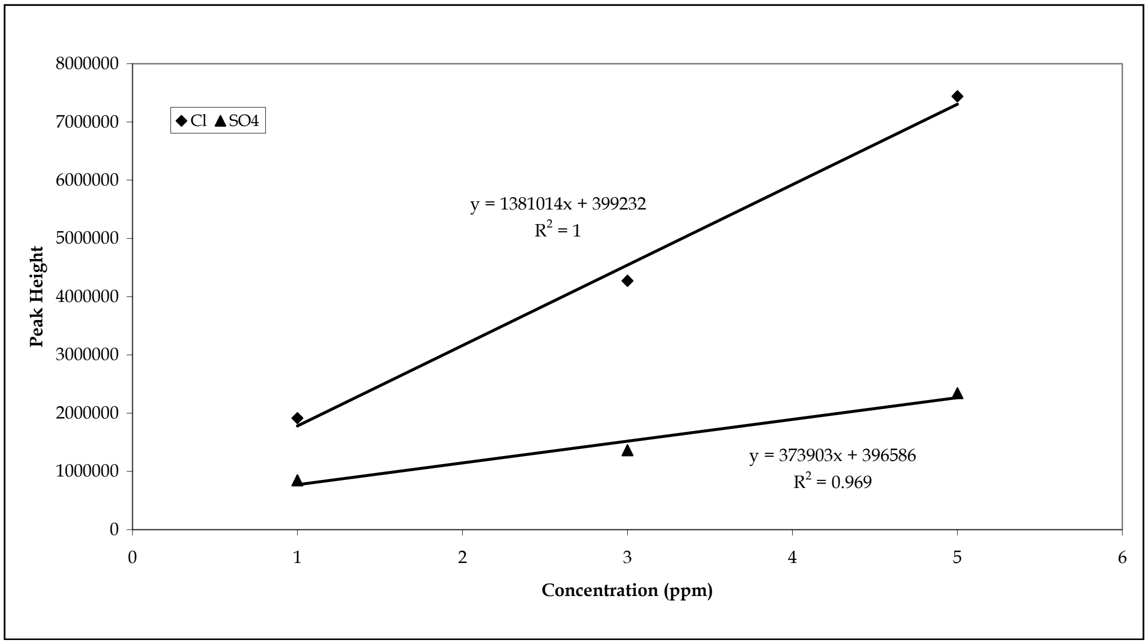

FIGURE A-20: IC calibration curve, day five analysis, summer 2002.

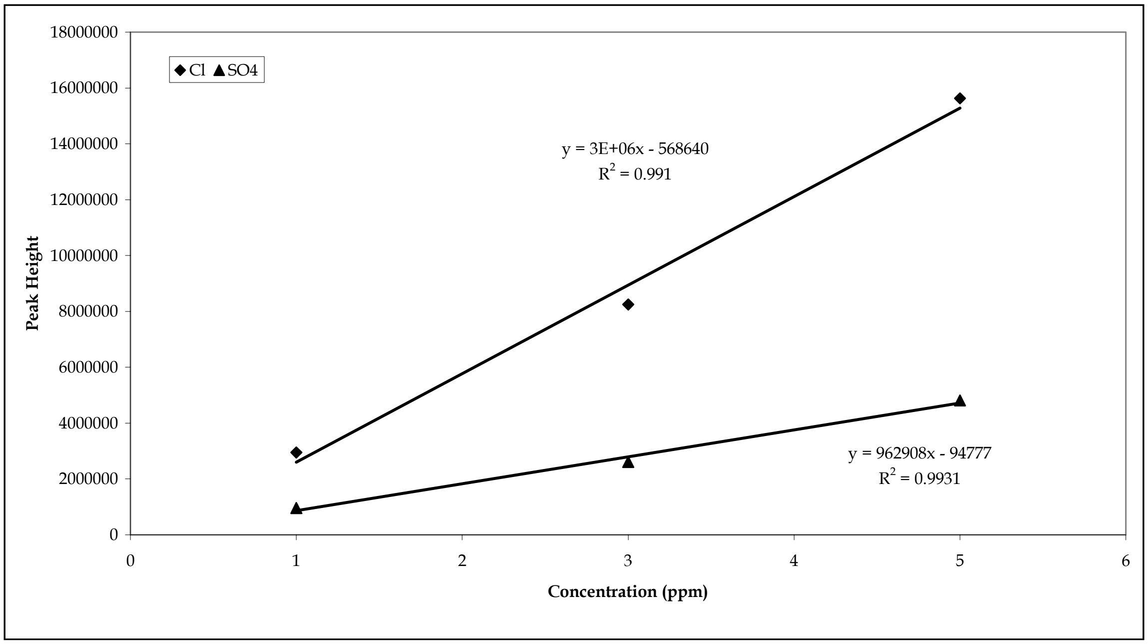

FIGURE A-21: IC calibration curve, day one analysis, winter 2003.

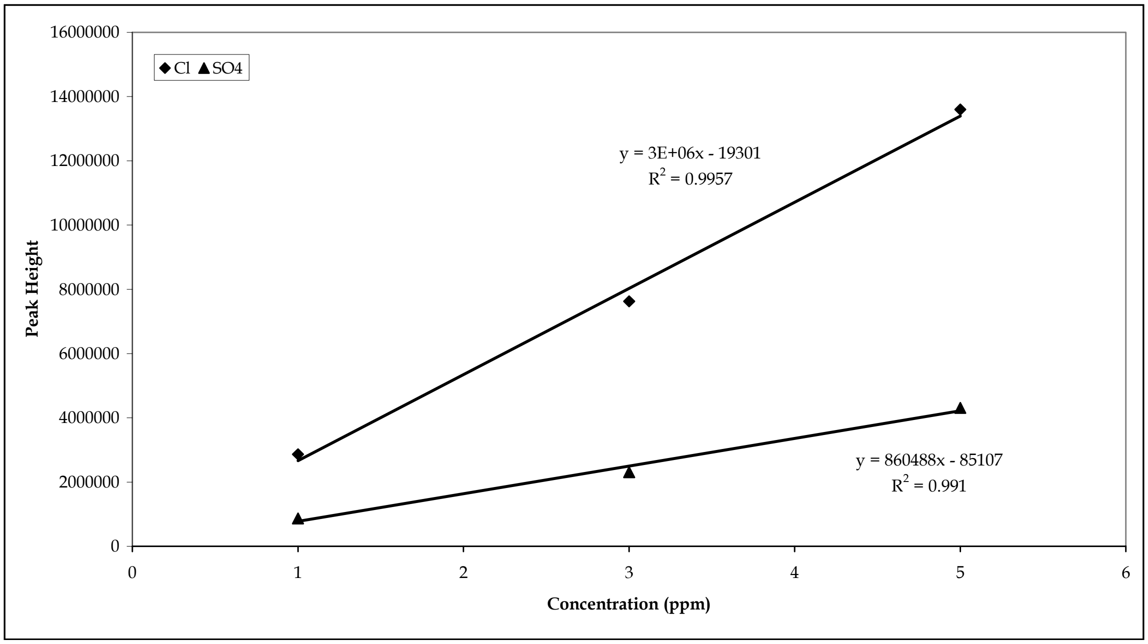

FIGURE A-22: IC calibration curve, day two analysis, winter 2003.

Appendix B

Statistical Results of Field Parameter Analysis

		Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance
DO	**Spring 2002**	8.33	0.58	8.70	7.20	3.69	13.58
	Summer 2002	2.39	0.29	1.65	1.40	1.85	3.43
	Winter 2003	7.30	0.58	8.21	10.66	3.36	11.29
pH	**Spring 2002**	6.65	0.06	6.70	6.80	0.35	0.13
	Summer 2002	6.88	0.05	6.90	7.10	0.32	0.10
	Winter 2003	7.44	0.08	7.41	7.75	0.46	0.21
EC	**Spring 2002**	83.63	5.33	72	66	34.15	1166.44
	Summer 2002	132.36	13.56	97.5	110	87.87	7721.06
	Winter 2003	102.73	3.04	99	99	17.46	305.02

TABLE B-1: Comparison of variability in field parameters between seasons.

		Interquartile Range	Skew-ness	Mini-mum	Maxi-mum	Count	Confidence Level at 90%
DO	**Spring 2002**	6.40	-0.05	1.70	15.20	41	0.97
	Summer 2002	1.30	1.60	0.40	7.20	42	0.48
	Winter 2003	5.44	-0.62	1.44	11.65	33	0.99
pH	**Spring 2002**	0.22	-2.21	5.20	7.40	32	0.11
	Summer 2002	0.40	0.26	6.40	7.60	42	0.08
	Winter 2003	0.64	0.75	6.66	8.82	33	0.13
EC	**Spring 2002**	21	3.12	60	240	41	8.98
	Summer 2002	19	2.84	86	470	42	22.82
	Winter 2003	7	2.45	80	173	33	5.15

TABLE B-1 (continued)

		Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance
DO	**Upstream**	5.97	0.45	5.90	4.80	3.91	15.30
	Down-stream	5.72	0.69	4.73	1.70	4.31	18.58
pH	**Upstream**	6.96	0.05	6.90	6.80	0.43	0.19
	Down-stream	7.03	0.12	6.85	6.40	0.63	0.40
EC	**Upstream**	91.61	2.09	93	66	18.38	337.95
	Down-stream	136.51	15.26	102	110	95.30	9081.15

TABLE B-2: Comparison of variability in field parameters between upstream and downstream monitoring points.

		Interquartile Range	Skew-ness	Mini-mum	Maxi-mum	Count	Confidence Level at 90%
DO	**Upstream**	7.66	0.13	0.40	12.90	777	0.74
	Down-stream	7.46	0.69	1.40	15.20	39	1.16
pH	**Upstream**	0.44	-0.44	5.20	7.99	77	0.08
	Down-stream	0.88	1.06	6.40	8.82	30	0.20
EC	**Upstream**	23	1.24	63	180	77	3.49
	Down-stream	53	2.26	60	470	39	25.73

TABLE B-2 (continued)

		Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance
DO	**Surface Water**	9.88	0.86	10.95	7.20	2.10	4.39
	1 ft	7.22	0.61	7.26	4.80	3.99	15.92
	2 ft	5.95	0.66	5.70	7.20	3.99	15.88
	9 ft	3.10	0.48	1.78	1.30	2.64	6.98
pH	**Surface Water**	7.35	0.28	7.60	6.50	0.69	0.47
	1 ft	7.07	0.10	7.06	6.90	0.62	0.39
	2 ft	6.96	0.06	6.80	6.80	0.38	0.15
	9 ft	6.82	0.06	6.85	6.70	0.29	0.09
EC	**Surface Water**	84.5	7.60	86.5	NA	18.62	346.70
	1 ft	104.63	9.73	91	63.82	63.82	4073.24
	2 ft	110.57	12.41	91	75.47	75.47	5695.03
	9 ft	109.37	6.88	102.5	37.70	37.70	1421.55

TABLE B-3: Comparison of variability in field parameters with depth.

		Interquartile Range	Skew-ness	Mini-mum	Maxi-mum	Count	Confidence Level at 90%
DO	**Surface Water**	3.14	-0.90	7.20	11.65	6	1.72
	1 ft	7.28	0.03	0.80	15.20	43	1.02
	2 ft	7.72	0.30	1.10	14.20	37	1.11
	9 ft	2.98	1.28	0.40	10.20	30	0.82
pH	**Surface Water**	0.95	-0.60	6.50	8.13	6	0.56
	1 ft	0.63	-0.08	5.20	8.82	38	0.17
	2 ft	0.40	1.09	6.40	8.08	35	0.11
	9 ft	0.44	0.07	6.30	7.44	28	0.09
EC	**Surface Water**	25	0.01	61	110	6	15.32
	1 ft	24.5	4.29	60	450	43	16.37
	2 ft	26	3.53	66	470	37	20.95
	9 ft	17.5	2.60	66	240	30	11.70

TABLE B-3 (continued)

		Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance
DO	**Surface Water**	9.88	0.86	10.95	7.20	2.10	4.39
	Island	5.77	0.70	4.80	4.80	3.70	13.70
	Run	5.00	0.48	4.40	1.40	3.62	13.10
	Riffle	7.07	0.97	8.70	1.80	4.87	23.70
pH	**Surface Water**	7.35	0.28	7.60	6.50	0.69	0.47
	Island	6.94	0.10	6.90	6.90	0.53	0.28
	Run	6.88	0.05	6.80	6.70	0.34	0.11
	Riffle	7.22	0.14	7.10	6.50	0.63	0.39
EC	**Surface Water**	84.50	7.60	86.5	NA	18.62	346.70
	Island	94.29	4.48	91	66	23.69	561.17
	Run	121.70	10.77	99	100	81.30	6610.18
	Riffle	91.76	4.13	92	110	20.64	426.19

TABLE B-4: Comparison of variability in field parameters between streambed morphologies.

		Interquartile Range	Skew-ness	Mini-mum	Maxi-mum	Count	Confidence Level at 90%
DO	**Surface Water**	3.14	-0.90	7.20	11.65	6	1.72
	Island	7.28	0.27	0.90	12.40	28	1.19
	Run	5.90	0.48	0.40	12.90	57	0.80
	Riffle	8.86	0.15	0.40	15.20	25	1.67
pH	**Surface Water**	0.95	-0.60	6.50	8.13	6	0.56
	Island	0.42	-0.78	5.20	7.99	28	0.17
	Run	0.40	0.14	6.00	7.80	53	0.08
	Riffle	1.02	0.82	6.50	8.82	20	0.24
EC	**Surface Water**	25	0.01	61	110	6	15.32
	Island	18	1.65	66	180	28	7.63
	Run	22	2.94	61	470	57	18.01
	Riffle	38	0.30	30	142	25	7.06

TABLE B-4 (continued)

Appendix C

Box and Whisker Plots of Field Parameter Relationships

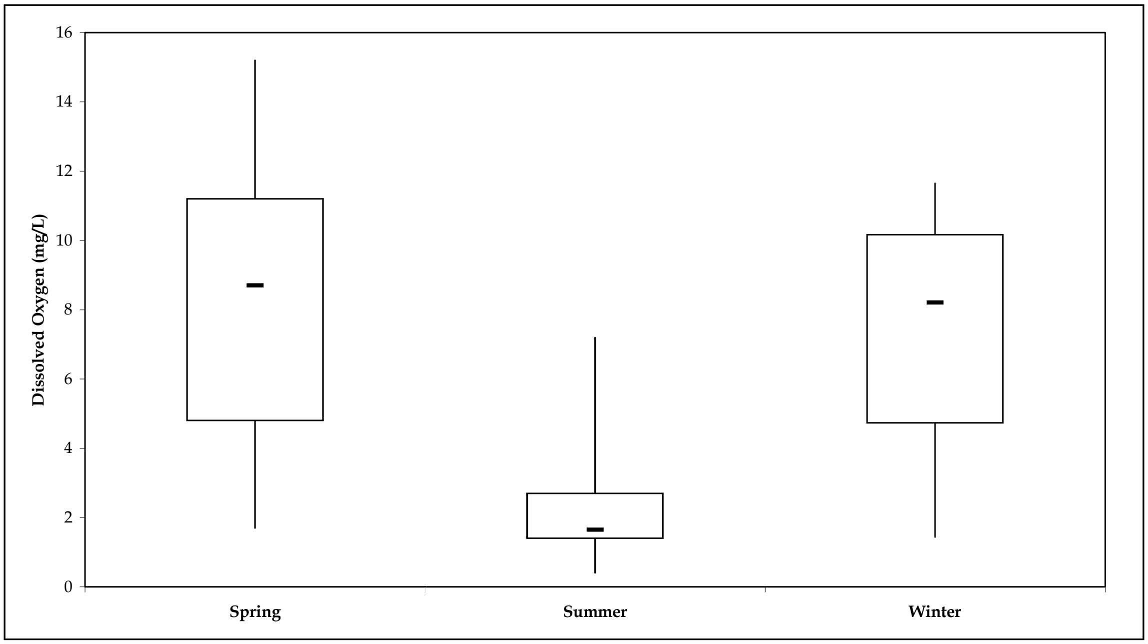

FIGURE C-1: Box and whisker plot of seasonal variability in DO.

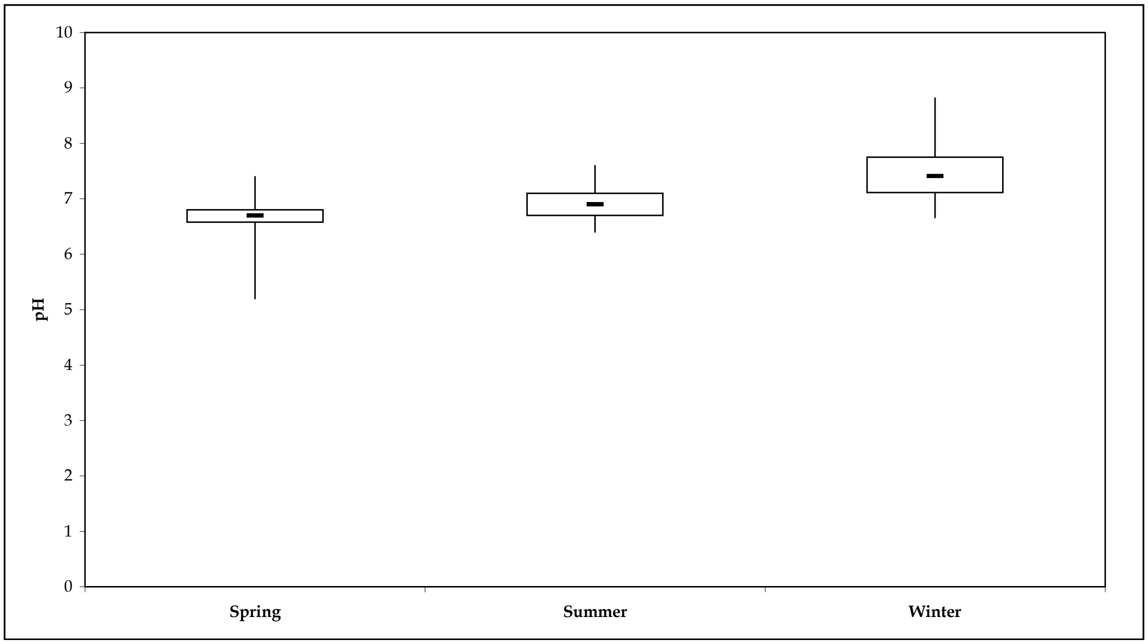

FIGURE C-2: Box and whisker plot of seasonal variability pH.

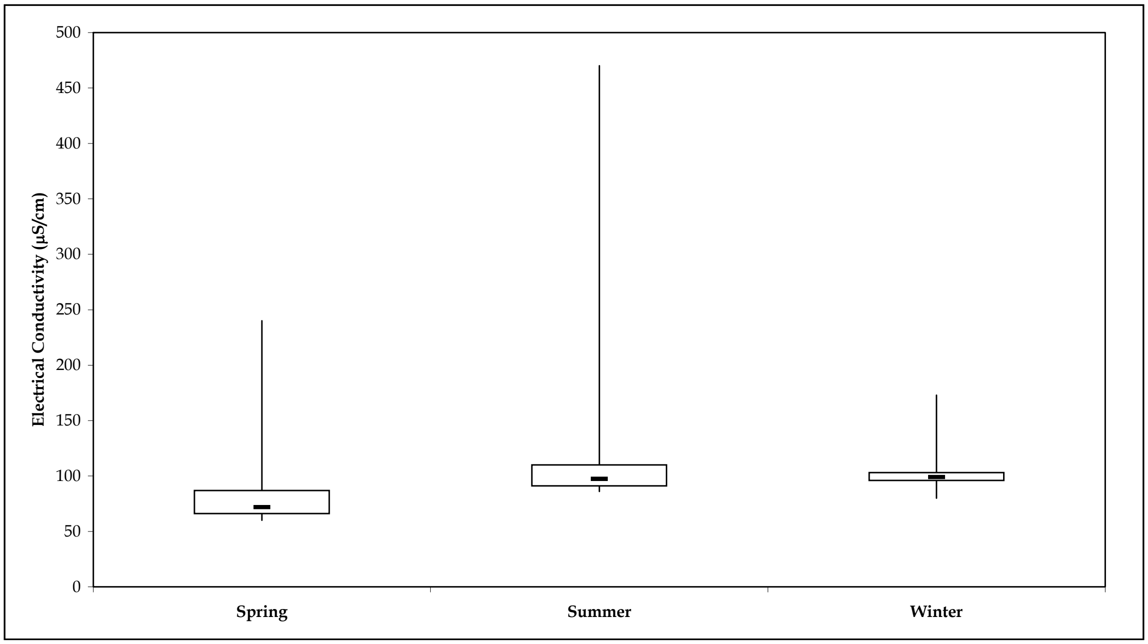

FIGURE C-3: Box and whisker plot of seasonal variability in EC.

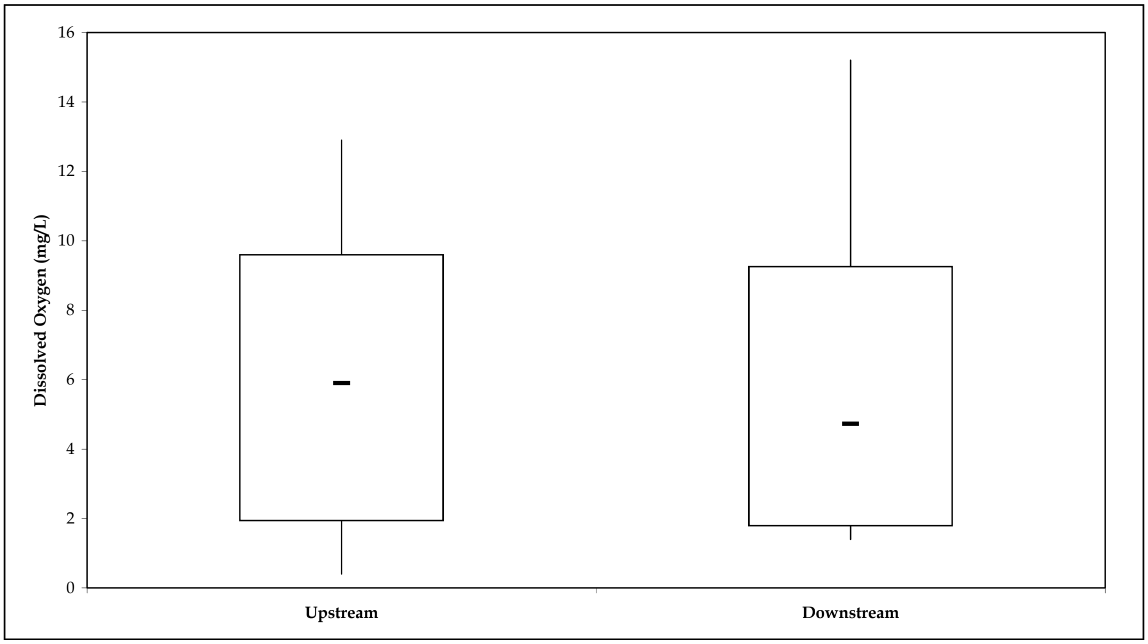

FIGURE C-4: Box and whisker plot of upstream vs. downstream DO values.

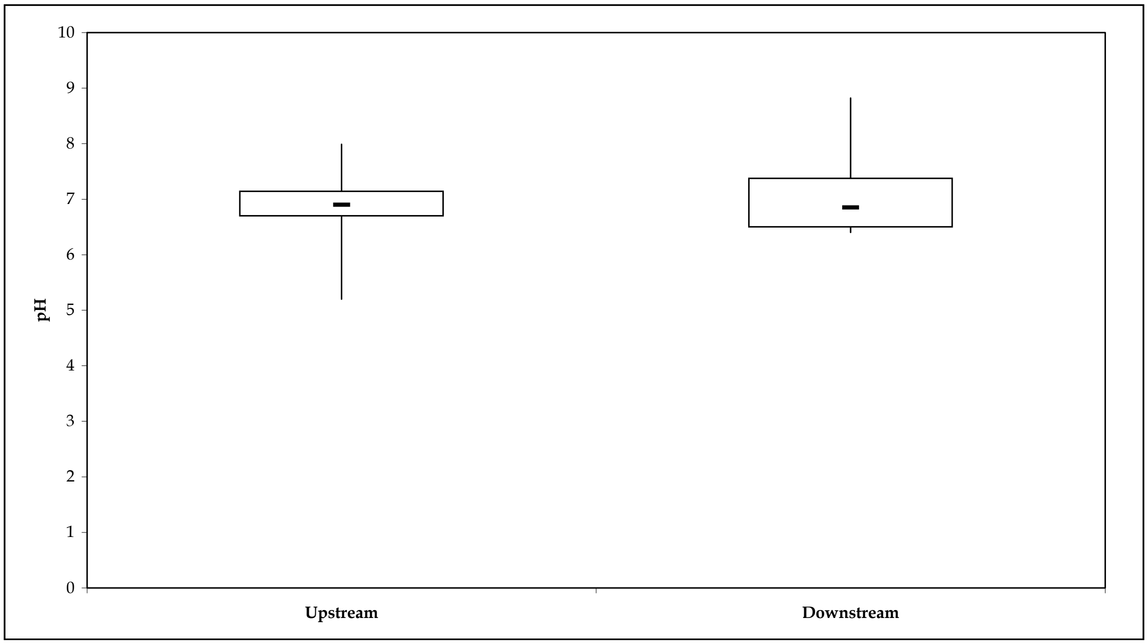

FIGURE C-5: Box and whisker plot of upstream vs. downstream pH values.

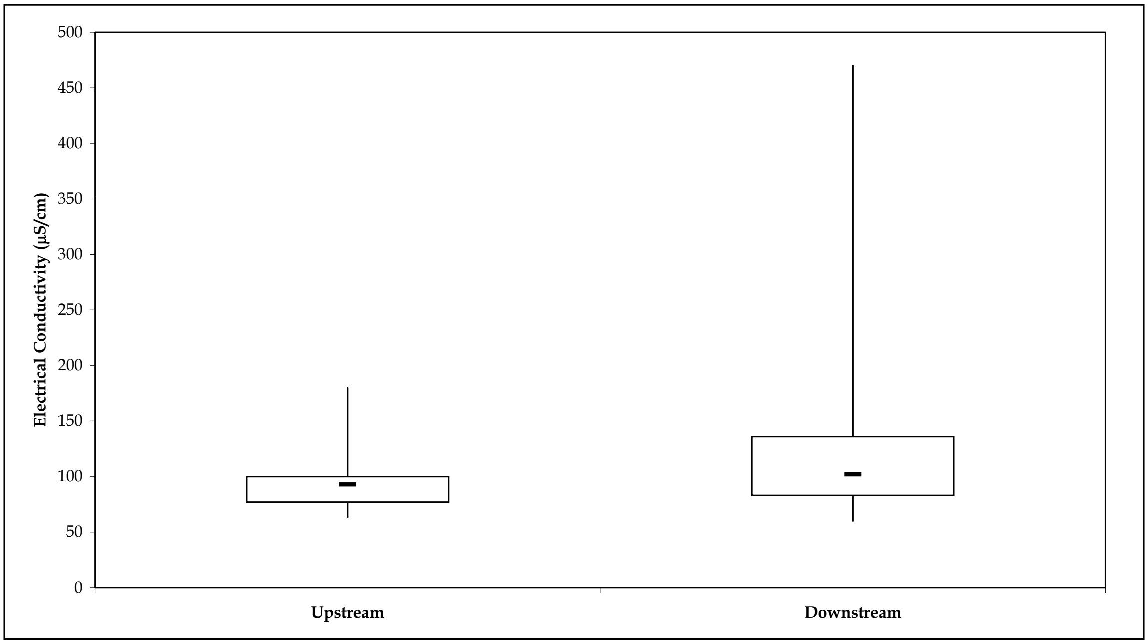

FIGURE C-6: Box and whisker plot of upstream vs. downstream EC values.

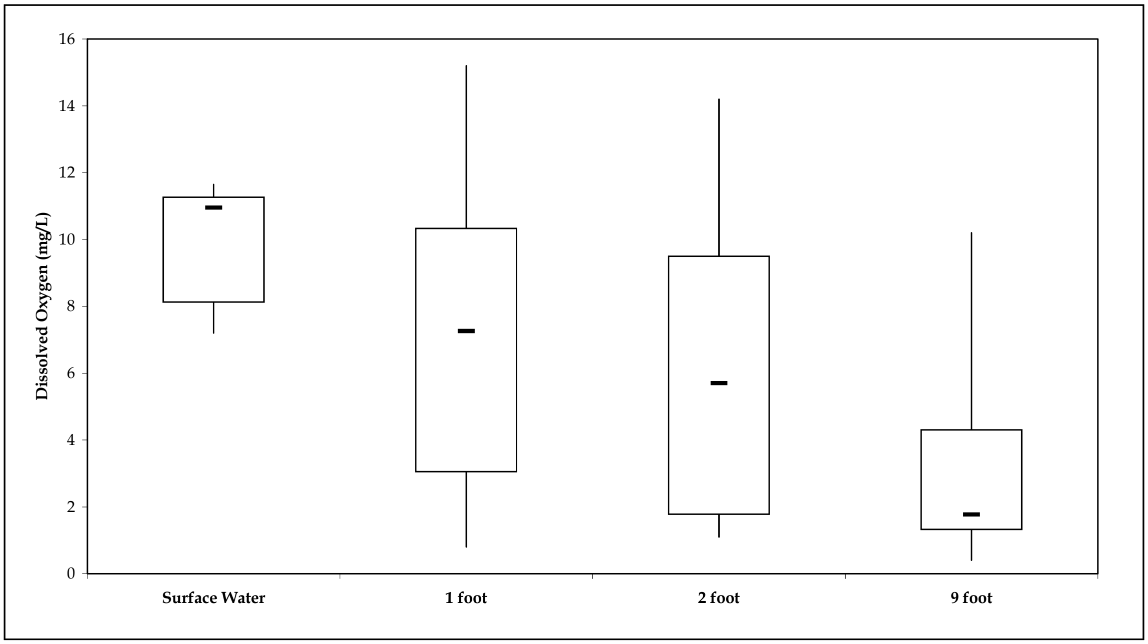

FIGURE C-7: Box and whisker plot of DO vs. depth in gravel.

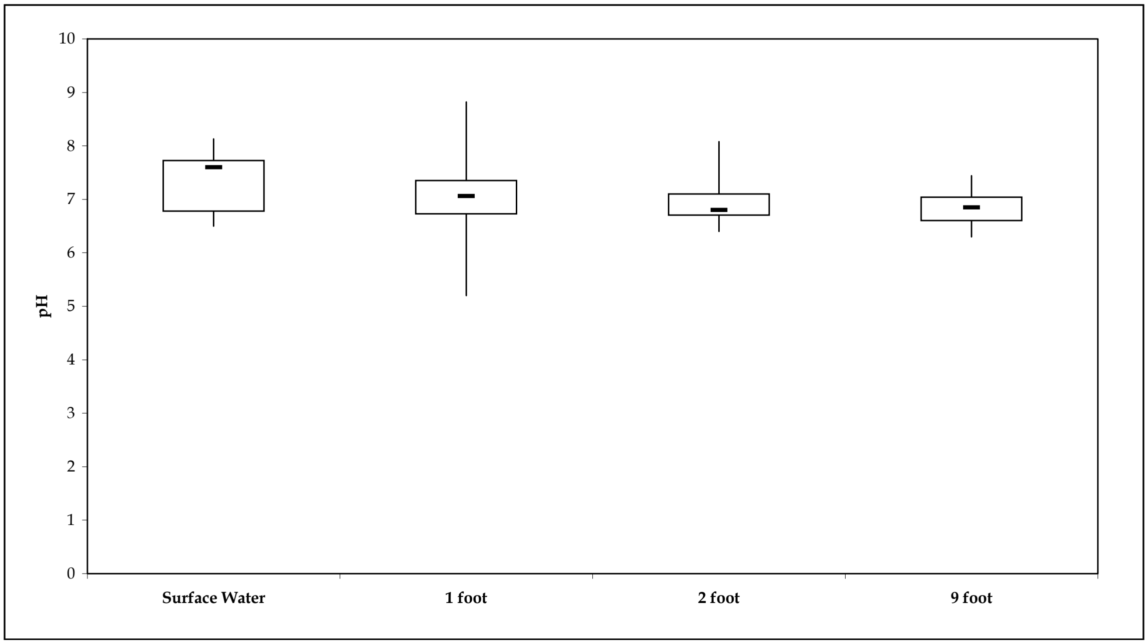

FIGURE C-8: Box and whisker plot of pH vs. depth in gravel.

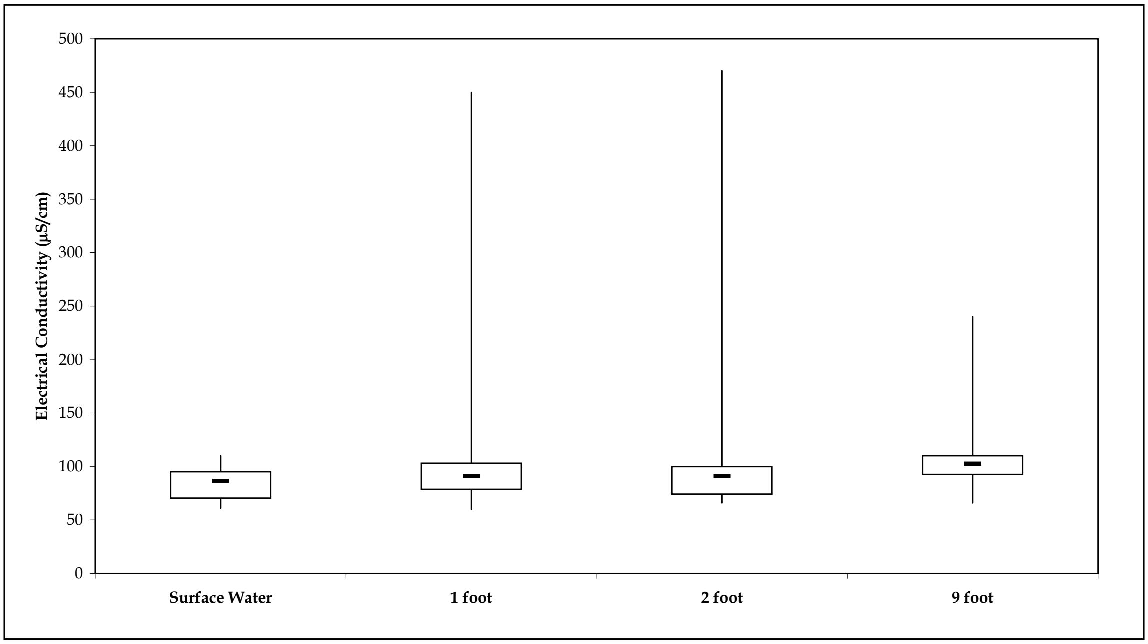

FIGURE C-9: Box and whisker plot of EC vs. depth in gravel.

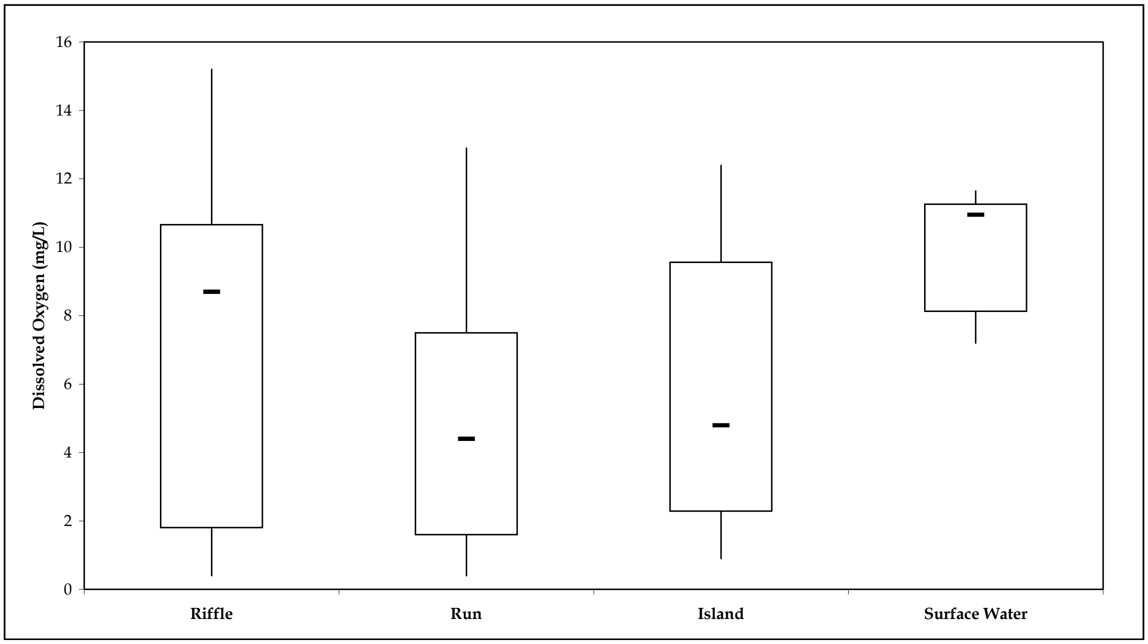

FIGURE C-10: Box and whisker plot of DO vs. morphological stream feature.

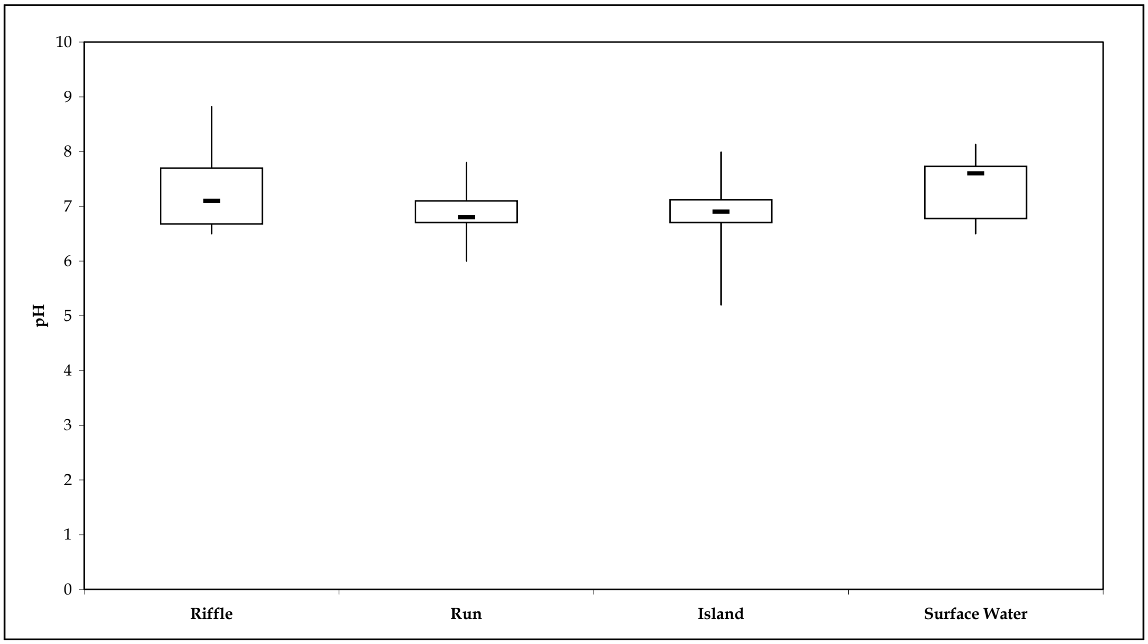

FIGURE C-11: Box and whisker plot of pH vs. morphological stream feature.

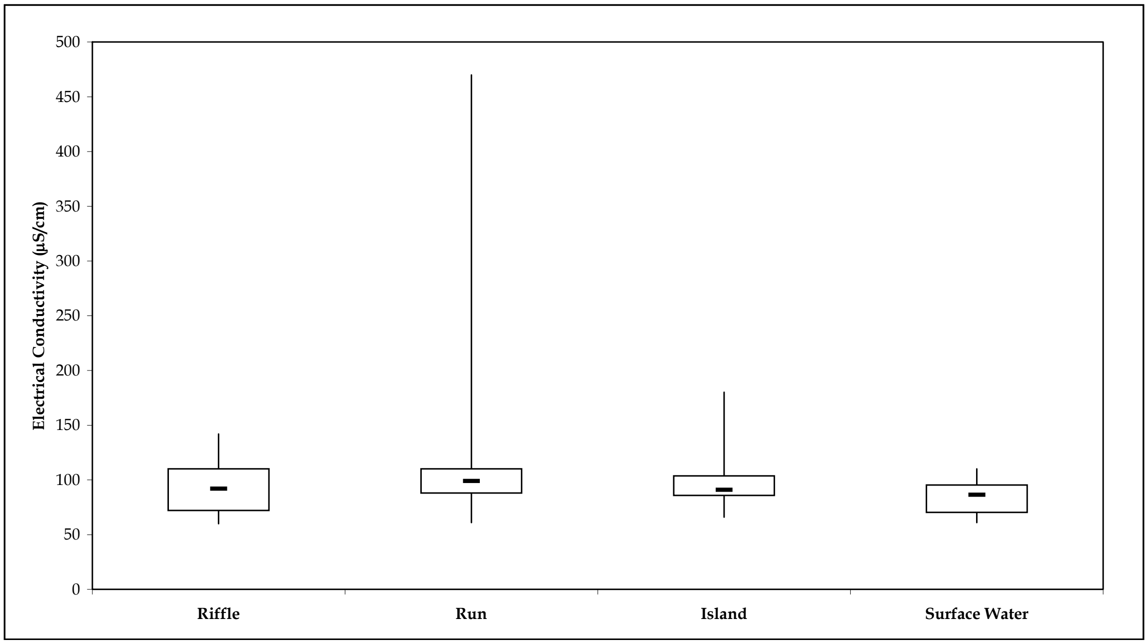

FIGURE C-12: Box and whisker plot of EC vs. morphological stream feature.

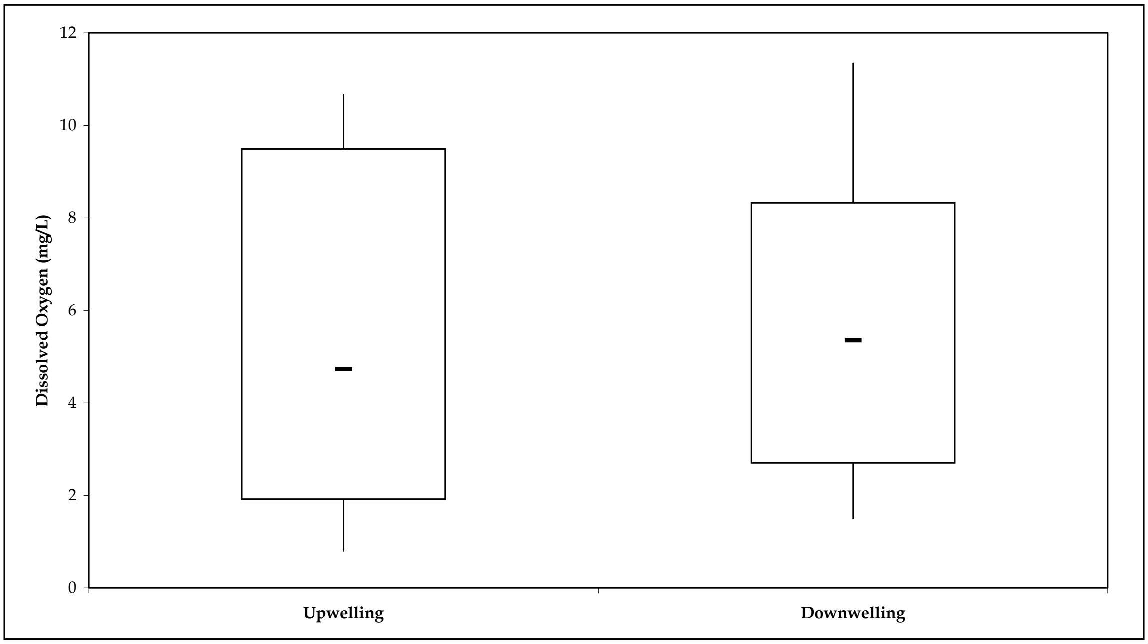

FIGURE C-13: Box and whisker plot of DO vs. upwelling and downwelling.

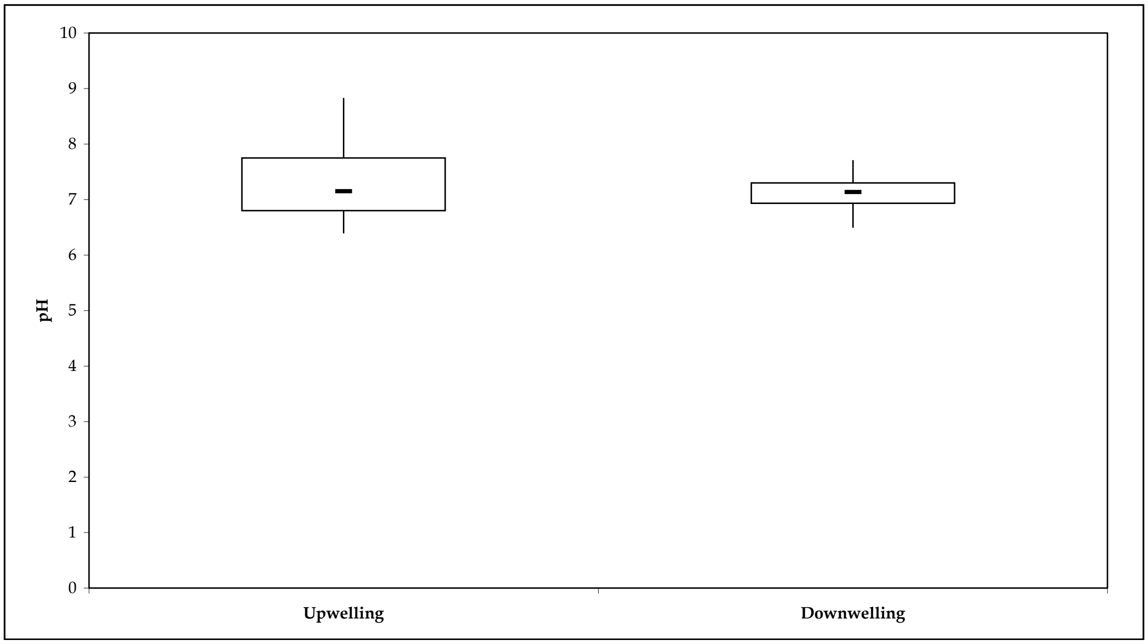

FIGURE C-14: Box and whisker plot of pH vs. upwelling and downwelling.

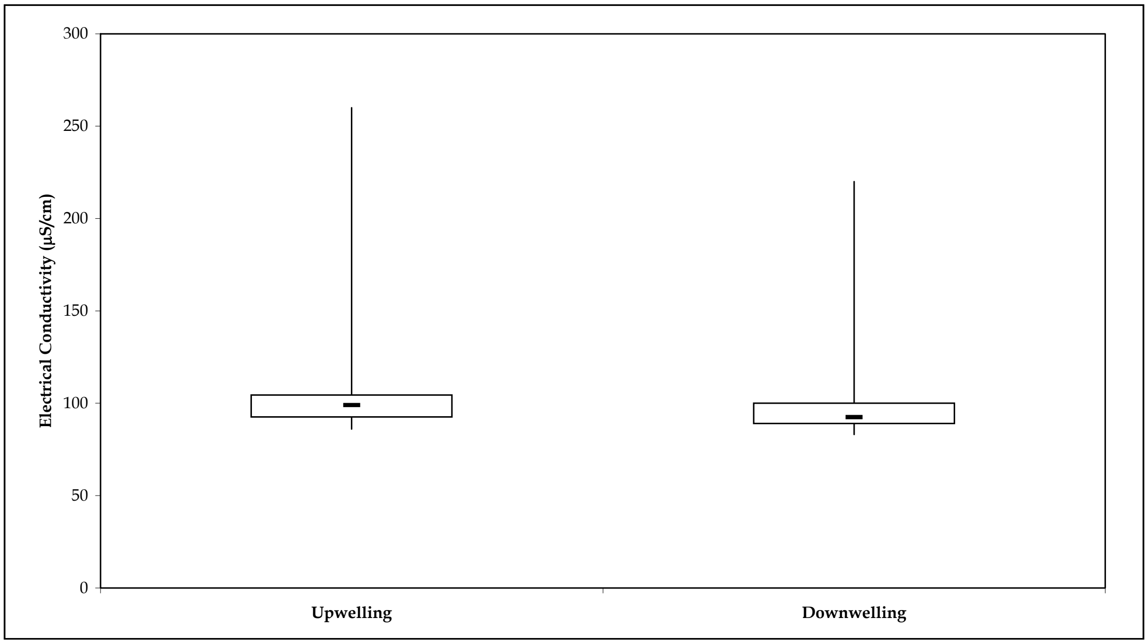

FIGURE C-15: Box and whisker plot of EC vs. upwelling and downwelling.

Appendix D

Statistical Analysis of Water Chemistry

		Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance
Na	**Spring 2002**	4.50	0.17	4.35	3.60	1.09	1.18
	Summer 2002	6.73	0.59	5.80	5.80	3.87	15.01
	Winter 2003	4.76	0.14	4.55	4.30	0.83	0.69
K	**Spring 2002**	2.01	0.30	1.70	1.70	1.94	3.75
	Summer 2002	1.41	0.06	1.30	1.20	0.42	0.17
	Winter 2003	1.02	0.02	1.00	1.00	0.14	0.02
Mg	**Spring 2002**	4.06	0.29	3.40	3.20	1.90	3.63
	Summer 2002	5.96	0.71	4.00	3.80	4.65	21.63
	Winter 2003	4.58	0.17	4.50	4.50	0.98	0.96
Ca	**Spring 2002**	4.69	0.44	4.05	4.10	2.87	8.23
	Summer 2002	7.59	1.19	5.40	5.10	7.78	60.54
	Winter 2003	4.49	0.23	4.25	4.40	1.34	1.78
Cl	**Spring 2002**	1.90	0.14	1.70	1.60	0.88	0.78
	Summer 2002	2.66	0.18	2.30	2.30	1.17	1.38
	Winter 2003	3.48	0.13	3.45	3.90	0.78	0.60
SO_4	**Spring 2002**	3.14	0.50	2.45	3.00	3.26	10.60
	Summer 2002	6.10	1.18	3.30	3.30	7.58	57.41
	Winter 2003	6.64	0.31	6.50	5.40	1.80	3.23
HCO_3	**Spring 2002**	39.35	2.47	34.17	NA	16.03	256.94
	Summer 2002	59.61	6.51	43.98	NA	41.70	1738.60
	Winter 2003	34.88	2.00	32.33	NA	11.67	136.28

TABLE D-1: Comparison of variability in seasonal major element abundances.

		Interquartile Range	Skew-ness	Mini-mum	Maxi-mum	Count	Confidence Level at 90%
Na	**Spring 2002**	1.45	1.47	3.10	8.70	42	0.28
	Summer 2002	0.95	4.26	4.80	24.80	43	0.99
	Winter 2003	0.58	2.47	3.50	8.10	34	0.24
K	**Spring 2002**	0.80	5.59	0.91	13.70	42	0.50
	Summer 2002	0.25	1.76	0.79	2.80	43	0.11
	Winter 2003	0.17	-0.23	0.72	1.20	34	0.04
Mg	**Spring 2002**	0.40	3.28	2.80	13.20	42	0.49
	Summer 2002	1.05	2.74	3.20	23.40	43	1.19
	Winter 2003	0.75	2.74	3.70	8.60	34	0.28
Ca	**Spring 2002**	1.60	3.48	2.40	19.20	42	0.74
	Summer 2002	0.85	3.93	0.00	47.00	43	2.00
	Winter 2003	0.73	2.64	3.30	9.70	34	0.39
Cl	**Spring 2002**	0.70	3.70	0.96	6.50	42	0.23
	Summer 2002	0.80	1.96	0.74	6.60	41	0.31
	Winter 2003	1.08	0.33	1.90	5.20	34	0.23
SO_4	**Spring 2002**	1.10	3.71	0.20	19.20	42	0.85
	Summer 2002	1.80	2.81	0.00	35.00	41	1.99
	Winter 2003	2.05	2.02	4.10	13.90	34	0.52
HCO_3	**Spring 2002**	9.12	2.81	24.42	112.2	42	4.16
	Summer 2002	8.90	3.08	37.30	231.1	41	10.97
	Winter 2003	4.04	2.75	15.06	81.90	34	3.39

TABLE D-1 (continued)

		Mean	**Standard Error**	**Median**	**Mode**	**Standard Deviation**	**Sample Variance**
Na	**Up-stream**	4.91	0.10	4.90	4.80	0.89	0.79
	Down-stream	6.25	0.65	5.20	4.30	4.18	17.49
K	**Up-stream**	1.38	0.06	1.20	1.20	0.50	0.25
	Down-stream	1.76	0.30	1.45	1.10	1.97	3.86
Mg	**Up-stream**	4.00	0.09	3.80	3.50	0.79	0.62
	Down-stream	6.53	0.74	4.45	3.90	4.81	23.17
Ca	**Up-stream**	4.60	0.15	4.40	4.10	1.28	1.64
	Down-stream	7.65	1.28	4.65	3.40	8.28	68.49
Cl	**Up-stream**	2.50	0.11	2.20	2.20	0.98	0.95
	Down-stream	2.86	0.22	2.50	2.50	1.40	1.97
SO_4	**Up-stream**	3.91	0.26	3.10	3.00	2.29	5.24
	Down-stream	7.56	1.20	5.00	8.30	7.70	59.31
HCO_3	**Up-stream**	37.92	1.00	35.88	NA	8.71	75.80
	Down-stream	58.54	7.03	40.00	NA	45.04	2028.61

TABLE D-2: Comparison of upstream vs. downstream variability in major element abundances.

		Interquartile Range	**Skew-ness**	**Mini-mum**	**Maxi-mum**	**Count**	**Confidence Level at 90%**
Na	**Up-stream**	1.30	-0.10	3.10	7.10	77	0.17
	Down-stream	2.00	3.74	3.40	24.80	42	1.09
K	**Up-stream**	0.60	1.65	0.79	3.00	77	0.09
	Down-stream	0.90	5.72	0.72	13.70	42	0.51
Mg	**Up-stream**	1.00	1.49	2.90	6.80	77	0.15
	Down-stream	3.45	2.25	2.80	23.40	42	1.25
Ca	**Up-stream**	1.30	0.99	2.40	9.30	77	0.24
	Down-stream	4.20	3.37	0.00	47.00	42	2.15
Cl	**Up-stream**	1.23	0.64	0.74	4.90	76	0.19
	Down-stream	1.50	1.39	1.30	6.60	41	0.37
SO_4	**Up-stream**	2.95	1.41	0.00	13.90	76	0.44
	Down-stream	4.80	2.23	0.20	35.00	41	2.03
HCO_3	**Up-stream**	10.52	1.00	15.06	68.71	76	1.66
	Down-stream	38.40	2.47	27.93	231.09	41	11.84

TABLE D-2 (continued)

		Mean	**Standard Error**	**Median**	**Mode**	**Standard Deviation**	**Sample Variance**
Na	**Surface Water**	7.67	3.44	4.35	NA	8.44	71.19
	1 ft	5.36	0.43	4.85	5.80	2.87	8.22
	2 ft	5.09	0.19	5.05	5.30	1.16	1.34
	9 ft	5.34	0.18	5.30	4.80	1.03	1.06
K	**Surface Water**	1.40	0.30	1.12	NA	0.74	0.55
	1 ft	1.38	0.07	1.20	1.20	0.47	0.22
	2 ft	1.38	0.08	1.20	1.20	0.47	0.22
	9 ft	1.88	0.41	1.30	1.00	2.27	5.16
Mg	**Surface Water**	7.03	3.28	3.95	NA	8.04	64.71
	1 ft	4.78	0.49	3.90	3.90	3.28	10.76
	2 ft	4.65	0.34	3.95	4.50	2.12	4.51
	9 ft	4.93	0.45	4.00	3.20	2.49	6.22
Ca	**Surface Water**	8.30	4.55	3.80	NA	11.15	124.27
	1 ft	4.73	0.33	4.30	3.40	2.18	4.76
	2 ft	6.22	1.17	4.40	4.10	7.22	52.17
	9 ft	5.85	0.60	5.20	4.20	3.35	11.21
Cl	**Surface Water**	2.55	0.52	2.10	NA	1.28	1.63
	1 ft	2.64	0.17	2.30	1.60	1.11	1.23
	2 ft	2.48	0.19	2.25	2.90	1.17	1.37
	9 ft	2.81	0.22	2.50	2.10	1.20	1.44
SO_4	**Surface Water**	7.80	4.46	3.60	NA	10.93	119.54
	1 ft	5.30	0.87	3.60	3.10	5.72	32.73
	2 ft	4.74	0.64	3.40	3.30	3.97	15.79
	9 ft	5.09	0.77	3.45	5.40	4.21	17.69
HCO_3	**Surface Water**	66.62	32.98	33.98	NA	80.79	6526.40
	1 ft	41.29	2.84	34.27	NA	18.60	345.93
	2 ft	45.52	4.92	37.52	NA	30.36	921.65
	9 ft	45.91	3.93	40.69	NA	21.55	464.27

TABLE D-3: Comparison of major element abundances by depth.

		Interquartile Range	Skew-ness	Mini-mum	Maxi-mum	Count	Confidence Level at 90%
Na	**Surface Water**	1.78	2.39	3.3	24.8	6	6.94
	1 ft	1.50	5.36	3.4	22.7	44	0.73
	2 ft	1.33	0.61	3.1	8.1	38	0.32
	9 ft	1.00	1.03	3.3	8.7	31	0.31
K	**Surface Water**	0.60	1.72	0.84	2.8	6	0.61
	1 ft	0.62	1.54	0.84	3	44	0.12
	2 ft	0.78	0.98	0.72	2.8	38	0.13
	9 ft	0.75	4.99	0.79	13.7	31	0.69
Mg	**Surface Water**	1.10	2.41	2.8	23.4	6	6.62
	1 ft	1.20	4.45	2.9	22.9	44	0.83
	2 ft	0.88	2.8	3	13	38	0.58
	9 ft	1.35	2.43	3.2	13.2	31	0.76
Ca	**Surface Water**	1.45	2.42	2.8	31	6	9.17
	1 ft	1.42	2.19	0	13	44	0.55
	2 ft	1.48	5.19	2.6	47	38	1.98
	9 ft	2.05	2.54	2.4	19.2	31	1.02
Cl	**Surface Water**	0.88	1.54	1.3	4.9	6	1.05
	1 ft	1.35	1.33	1.1	6.6	43	0.28
	2 ft	1.28	1.26	0.74	6.3	38	0.32
	9 ft	1.33	1.37	1.3	6.5	30	0.37
SO_4	**Surface Water**	1.83	2.39	1.7	30	6	8.99
	1 ft	3.00	4.06	0.2	35	43	1.47
	2 ft	3.93	3.2	0.6	24	38	1.09
	9 ft	3.90	1.75	0	19.2	30	1.3
HCO_3	**Surface Water**	11.51	2.42	27.22	231.09	6	66.46
	1 ft	11.06	2.90	26.74	122.11	43	4.77
	2 ft	11.60	4.33	26.59	205.80	38	8.31
	9 ft	15.31	1.96	15.06	112.22	30	6.68

TABLE D-3 (continued)

		Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance
Na	**Surface Water**	7.67	3.44	4.35	NA	8.44	71.19
	Island	4.85	0.19	4.70	4.70	1.00	0.99
	Run	5.68	0.33	5.30	4.80	2.54	6.43
	Riffle	4.80	0.18	4.80	4.30	0.93	0.87
K	**Surface Water**	1.40	0.3	1.12	NA	0.74	0.55
	Island	1.37	0.10	1.20	1.20	0.55	0.30
	Run	1.70	0.22	1.30	1.20	1.68	2.83
	Riffle	1.28	0.08	1.10	1.10	0.42	0.18
Mg	**Surface Water**	7.03	3.28	3.95	NA	8.04	64.71
	Island	4.02	0.20	3.70	3.70	1.04	1.09
	Run	5.33	0.47	4.05	4.00	3.54	12.55
	Riffle	4.39	0.22	3.90	3.90	1.16	1.35
Ca	**Surface Water**	8.30	4.55	3.8	NA	11.15	124.27
	Island	4.41	0.31	4.15	4.10	1.62	2.62
	Run	6.52	0.83	4.85	4.20	6.32	39.95
	Riffle	4.60	0.28	4.30	3.40	1.48	2.19
Cl	**Surface Water**	2.55	0.52	2.1	NA	1.28	1.63
	Island	2.49	0.21	2.10	1.90	1.08	1.16
	Run	2.75	0.17	2.50	2.10	1.31	1.73
	Riffle	2.52	0.15	2.50	1.60	0.78	0.61
SO_4	**Surface Water**	7.80	4.46	3.6	NA	10.93	119.54
	Island	4.02	0.56	3.00	3.00	2.90	8.43
	Run	5.67	0.78	3.50	2.30	5.96	35.56
	Riffle	4.73	0.52	4.60	5.40	2.67	7.12
HCO_3	**Surface Water**	66.62	32.98	33.98	NA	80.79	6526.40
	Island	37.26	2.20	33.72	NA	11.46	131.27
	Run	49.73	3.97	40.34	NA	30.22	913.55
	Riffle	38.17	2.19	34.03	NA	11.15	124.28

TABLE D-4: Comparison of major element abundances between streambed morphological features.

		Interquartile Range	Skew-ness	Mini-mum	Maxi-mum	Count	Confidence Level at 90%
Na	**Surface Water**	1.78	2.39	3.3	24.8	6	6.94
	Island	1.35	0.41	3.20	7.10	28	0.32
	Run	1.00	5.50	3.10	22.70	58	0.56
	Riffle	1.45	0.08	3.30	6.20	27	0.31
K	**Surface Water**	0.60	1.72	0.84	2.8	6	0.61
	Island	0.40	1.98	0.91	3.00	28	0.18
	Run	0.80	6.57	0.72	13.70	58	0.37
	Riffle	0.45	2.06	0.80	2.80	27	0.14
Mg	**Surface Water**	1.10	2.41	2.8	23.4	6	6.62
	Island	1.33	1.53	2.90	6.80	28	0.34
	Run	1.00	2.97	3.00	22.90	58	0.78
	Riffle	0.95	2.05	3.20	8.30	27	0.38
Ca	**Surface Water**	1.45	2.42	2.8	31	6	9.17
	Island	1.58	1.40	2.40	9.30	28	0.52
	Run	1.58	5.00	0.00	47.00	58	1.39
	Riffle	2.10	0.94	2.60	8.30	27	0.49
Cl	**Surface Water**	0.88	1.54	1.3	4.9	6	1.05
	Island	1.10	0.98	1.10	4.80	27	0.35
	Run	1.38	1.26	0.74	6.60	58	0.29
	Riffle	1.18	0.29	1.40	3.90	26	0.26
SO_4	**Surface Water**	1.83	2.39	1.7	30	6	8.99
	Island	3.30	1.76	0.90	13.90	27	0.95
	Run	4.00	3.18	0.00	35.00	58	1.31
	Riffle	2.63	1.07	0.20	12.80	26	0.89
HCO_3	**Surface Water**	11.51	2.42	27.22	231.09	6	66.46
	Island	9.81	1.27	15.06	68.71	27	3.76
	Run	13.54	3.15	28.31	205.80	58	6.64
	Riffle	14.23	1.38	24.42	69.67	26	3.73

TABLE D-4 (continued)

Appendix E

Box and Whisker Plots of Water Chemistry Relationships

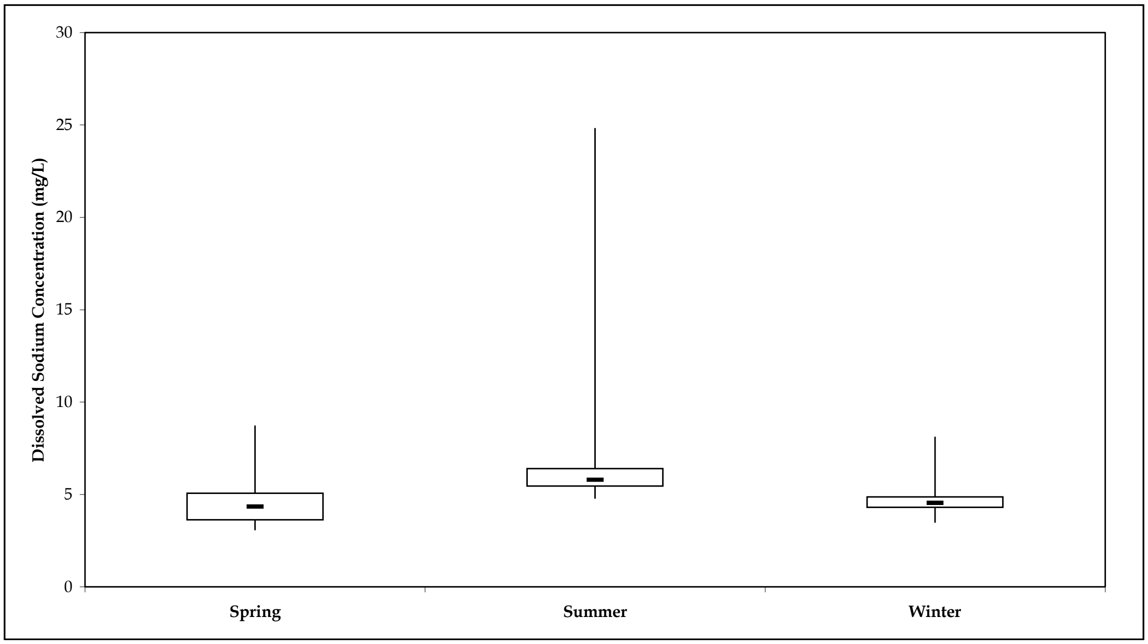

FIGURE E-1: Box and whisker plot of seasonal variability in sodium concentrations.

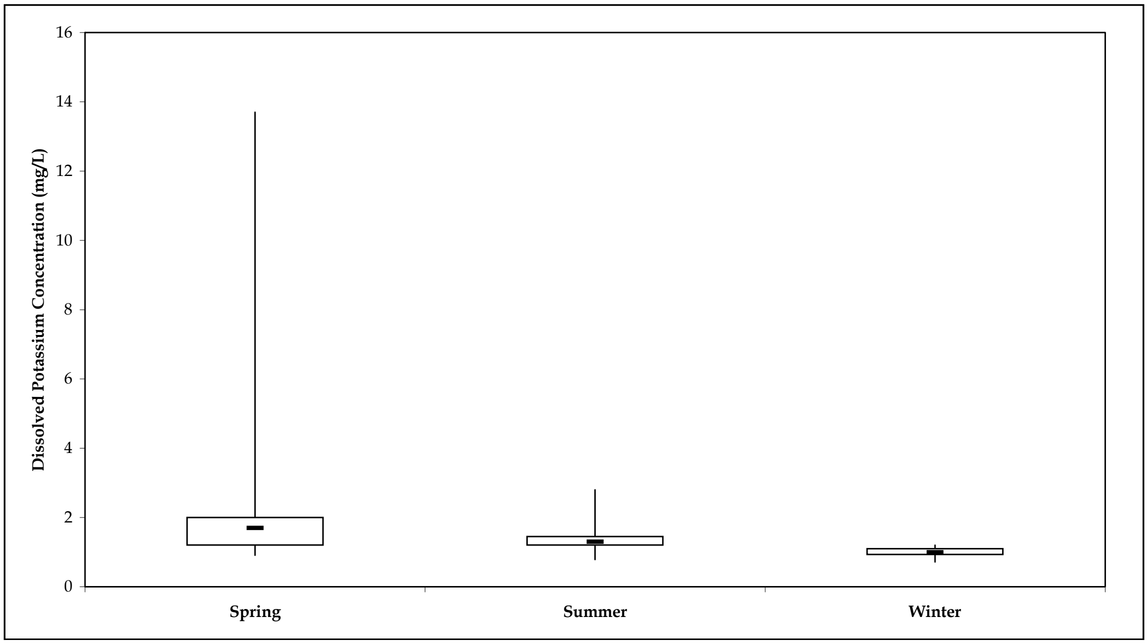

FIGURE E-2: Box and whisker plot of seasonal variability in potassium concentrations.

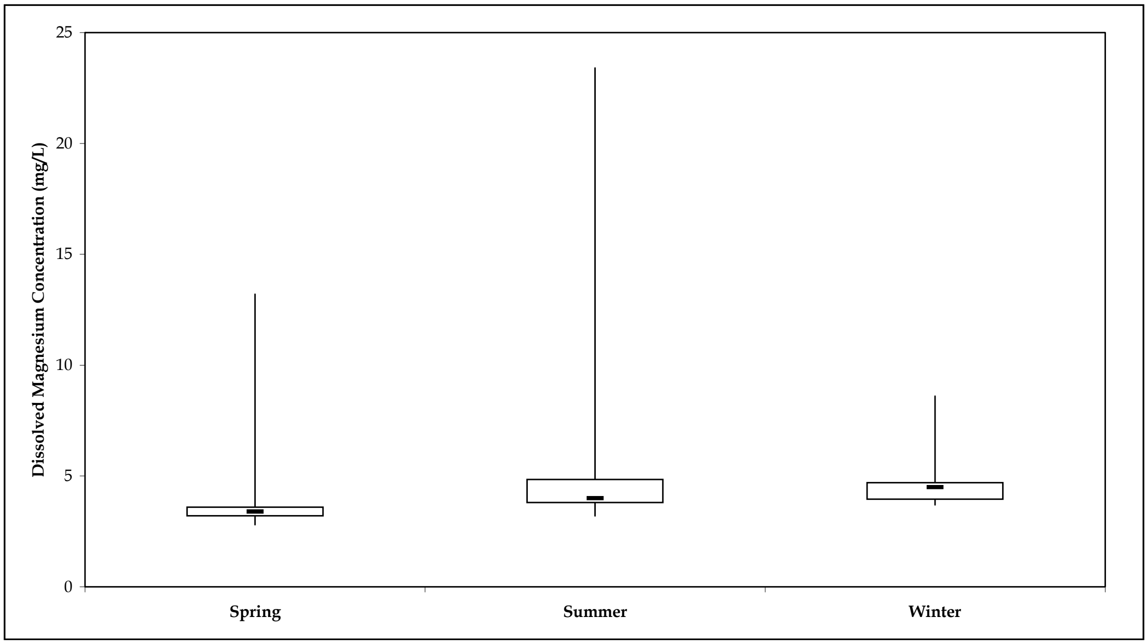

FIGURE E-3: Box and whisker plot of seasonal variability in magnesium concentrations.

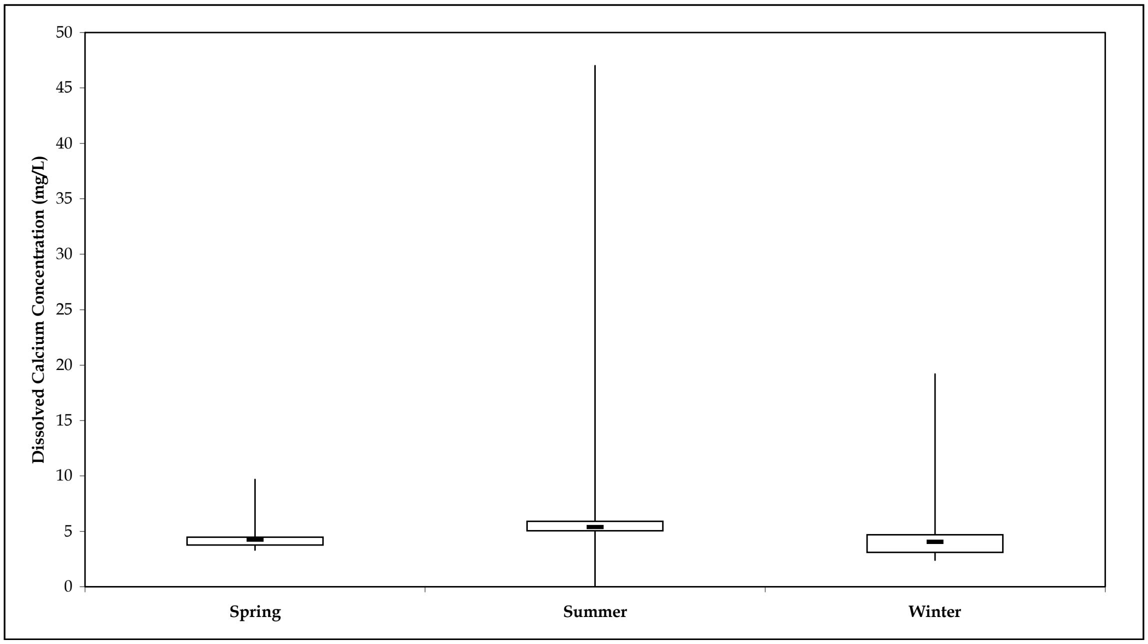

FIGURE E-4: Box and whisker plot of seasonal variability in calcium concentrations.

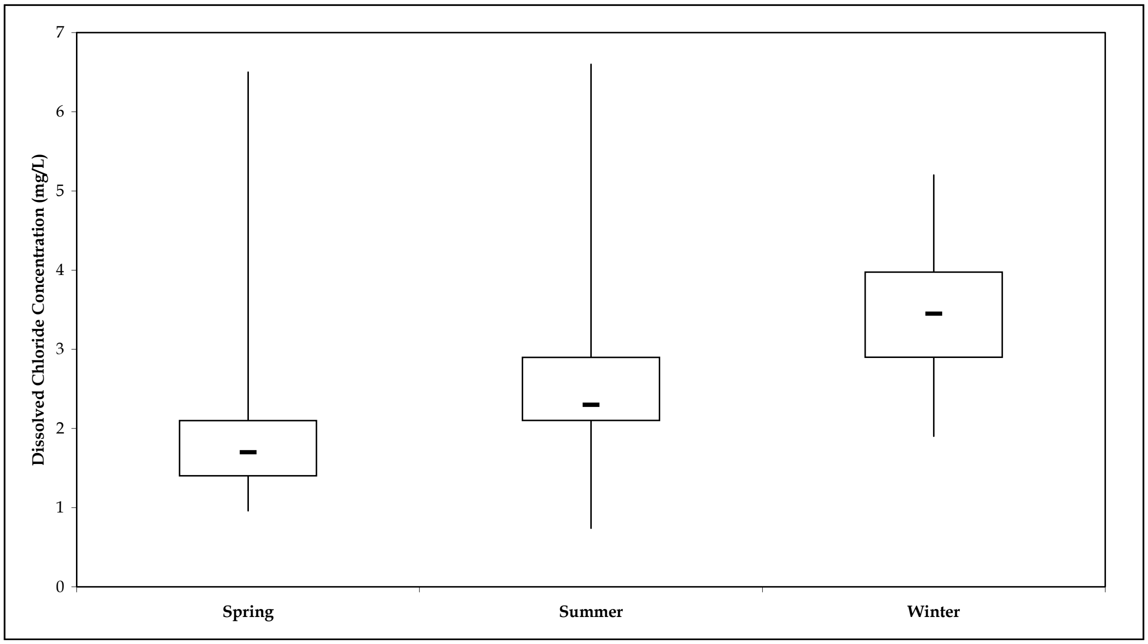

FIGURE E-5: Box and whisker plot of seasonal variability in chloride concentrations.

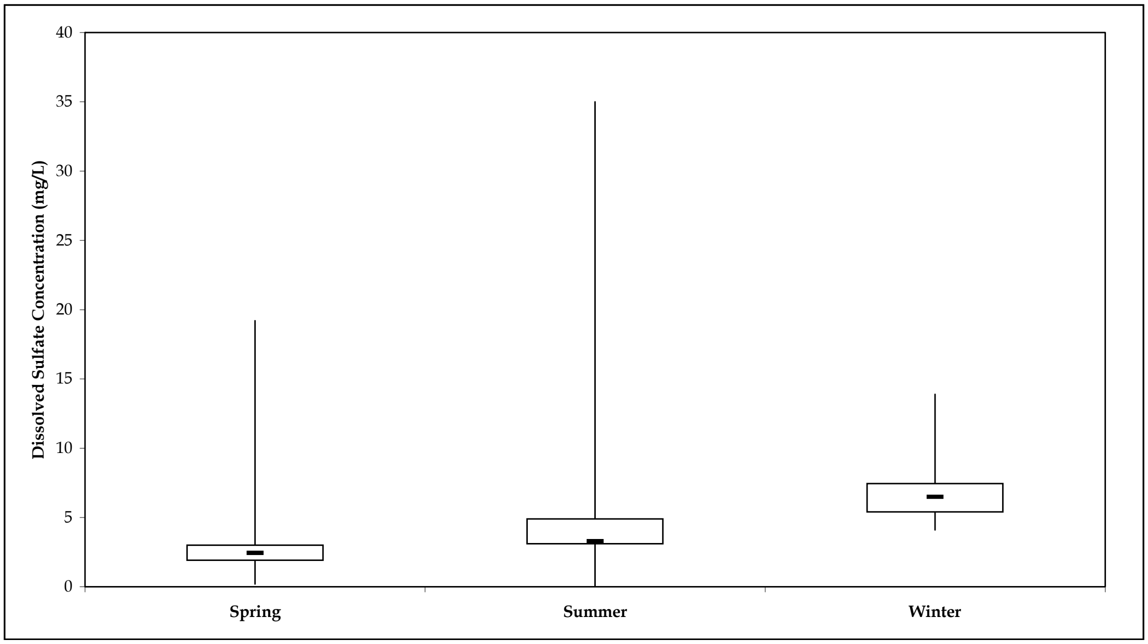

FIGURE E-6: Box and whisker plot of seasonal variability in sulfate concentrations.

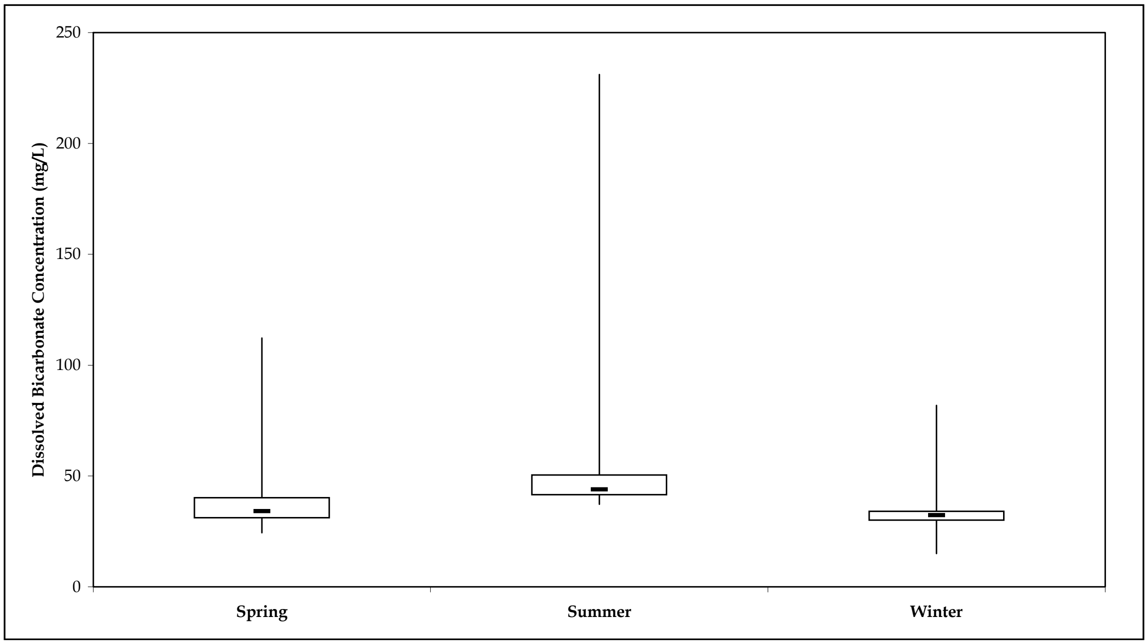

FIGURE E-7: Box and whisker plot of seasonal variability in calculated bicarbonate concentrations.

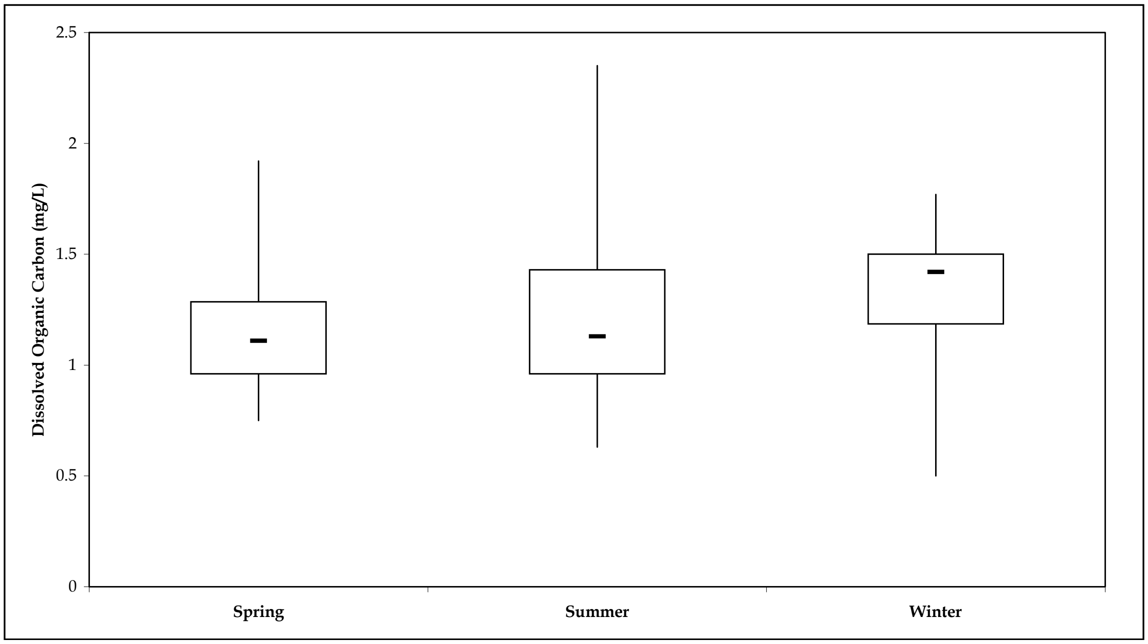

FIGURE E-8: Box and whisker plot of seasonal variability in dissolved organic carbon concentrations.

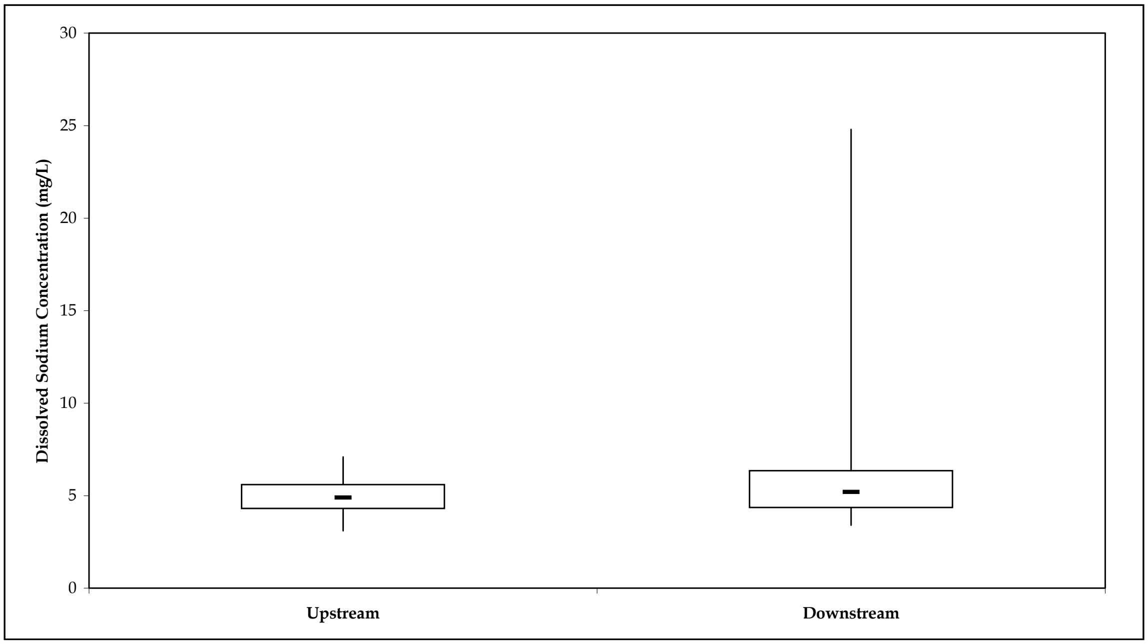

FIGURE E-9: Box and whisker plot of upstream vs. downstream sodium concentrations.

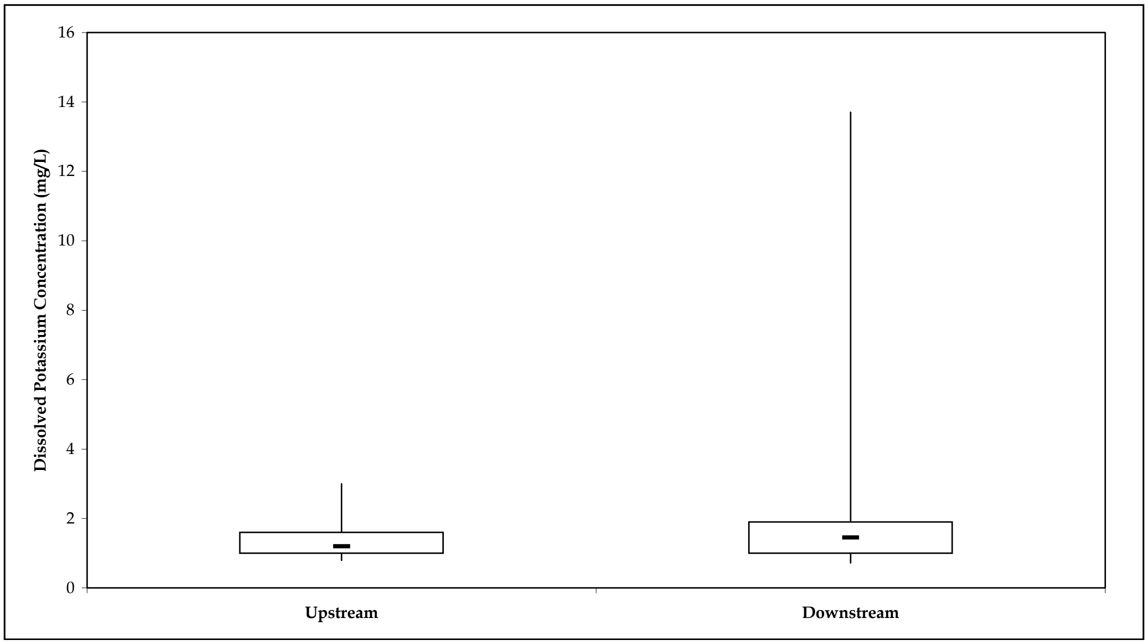

FIGURE E-10: Box and whisker plot of upstream vs. downstream potassium concentrations.

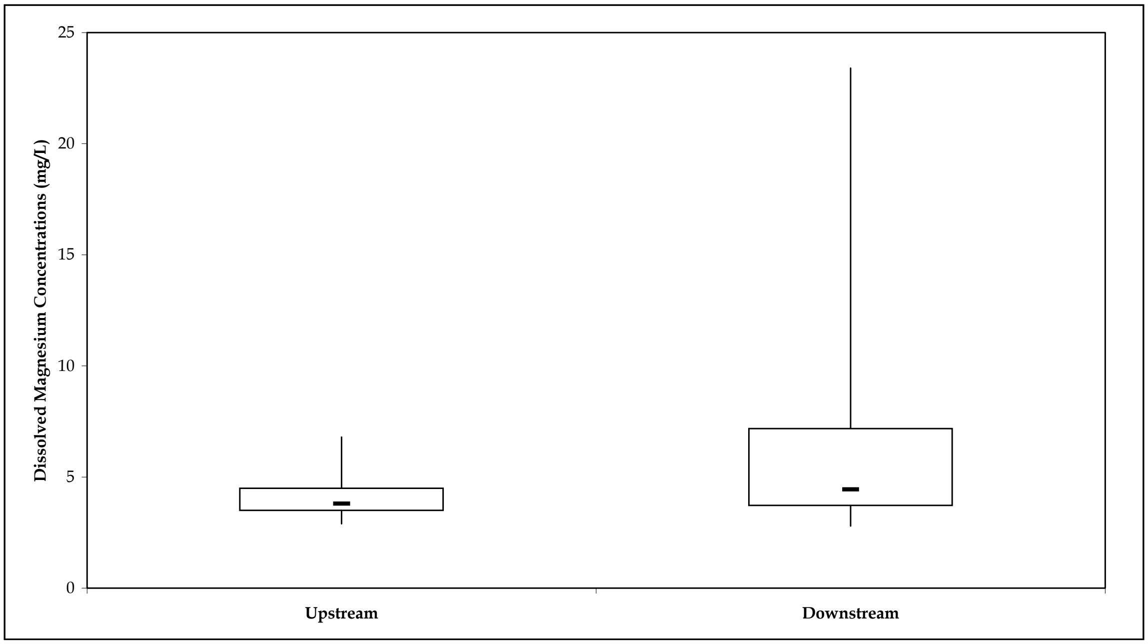

FIGURE E-11: Box and whisker plot of upstream vs. downstream magnesium concentrations.

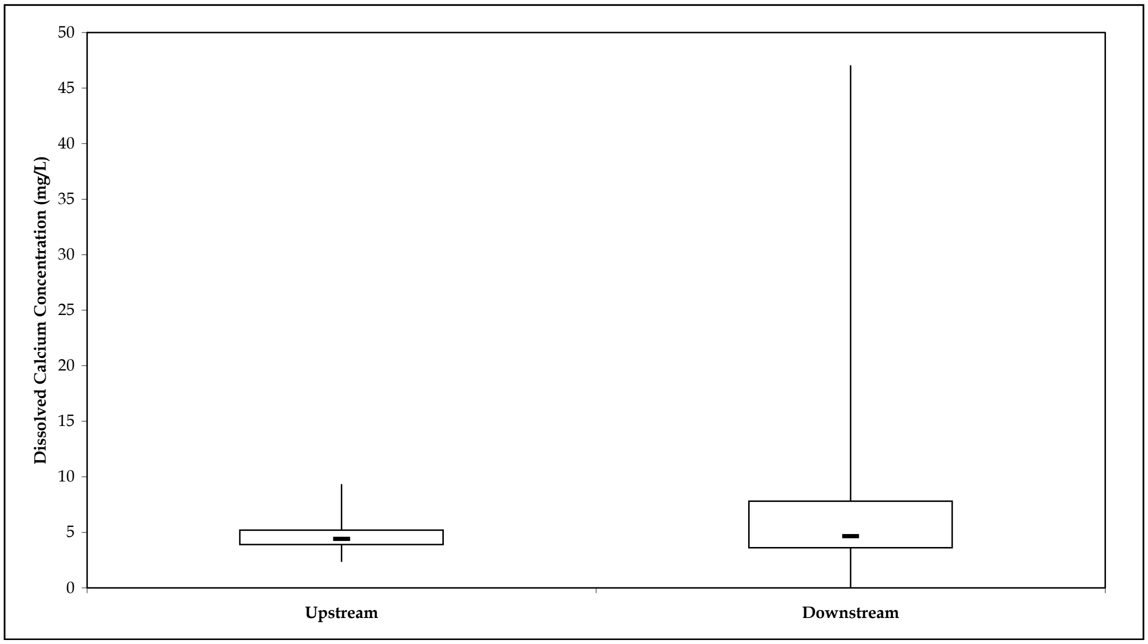

FIGURE E-12: Box and whisker plot of upstream vs. downstream calcium concentrations.

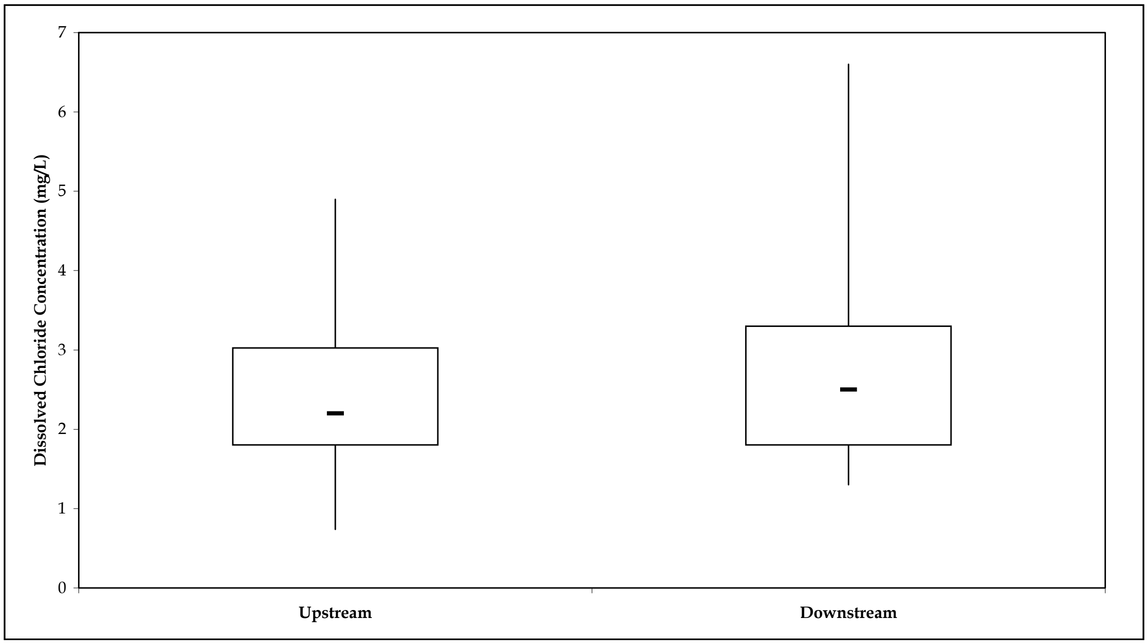

FIGURE E-13: Box and whisker plot of upstream vs. downstream chloride concentrations.

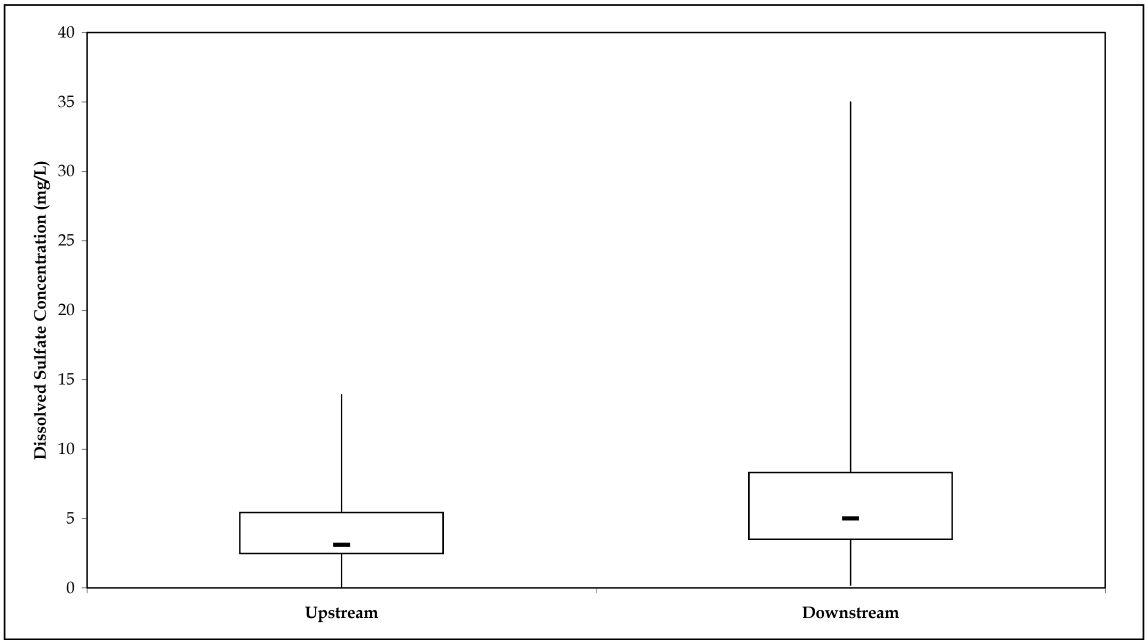

FIGURE E-14: Box and whisker plot of upstream vs. downstream sulfate concentrations.

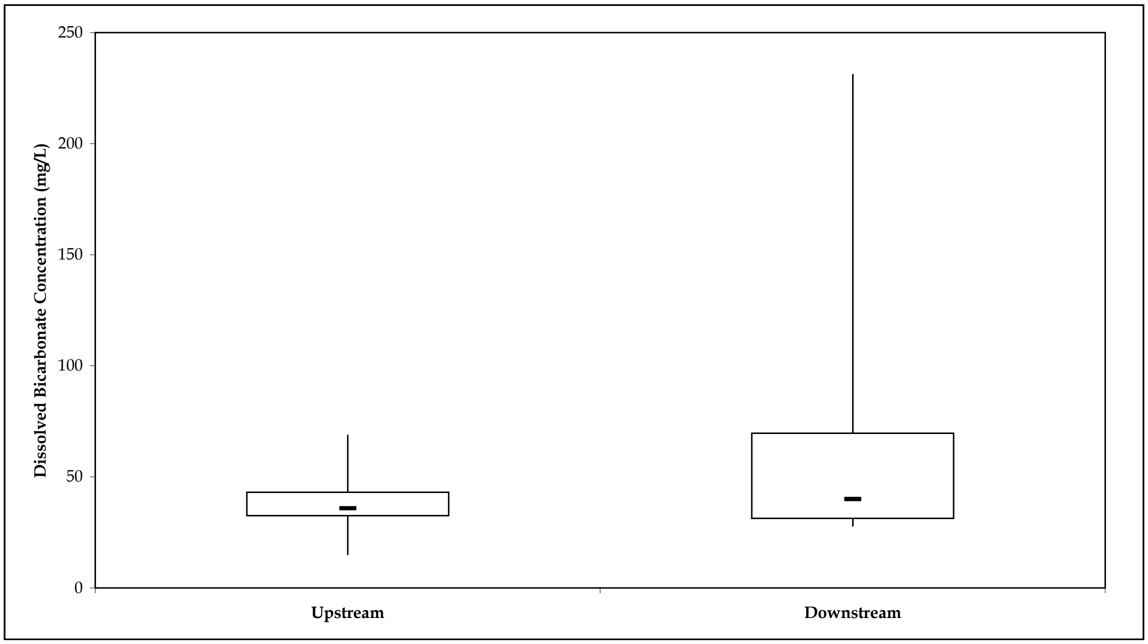

FIGURE E-15: Box and whisker plot of upstream vs. downstream calculated bicarbonate concentrations.

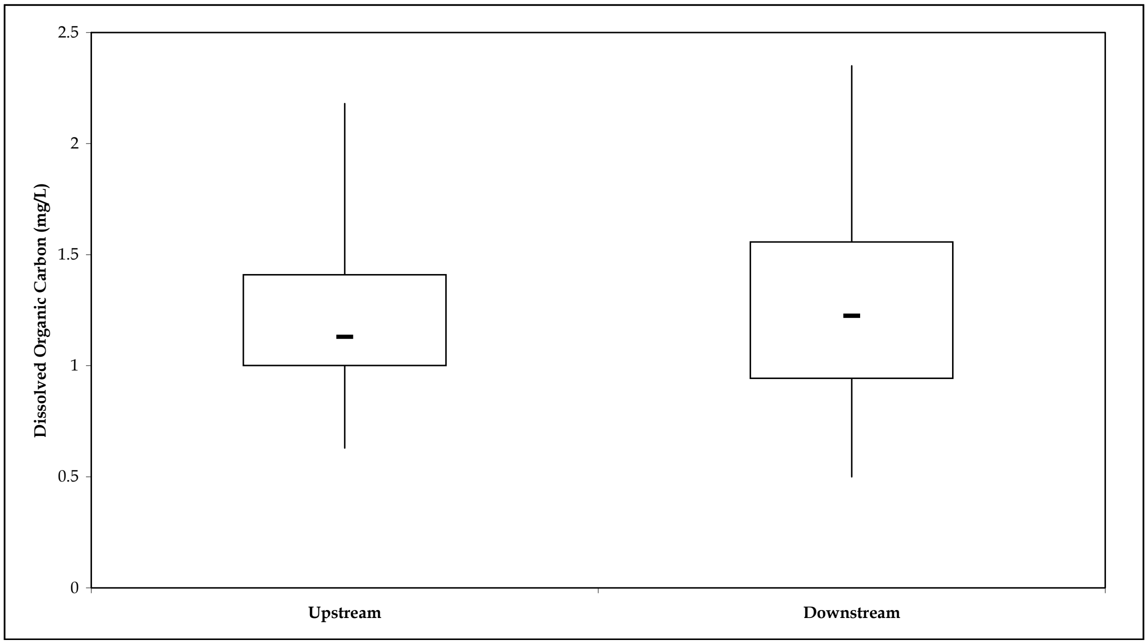

FIGURE E-16: Box and whisker plot of upstream vs. downstream dissolved organic carbon concentrations.

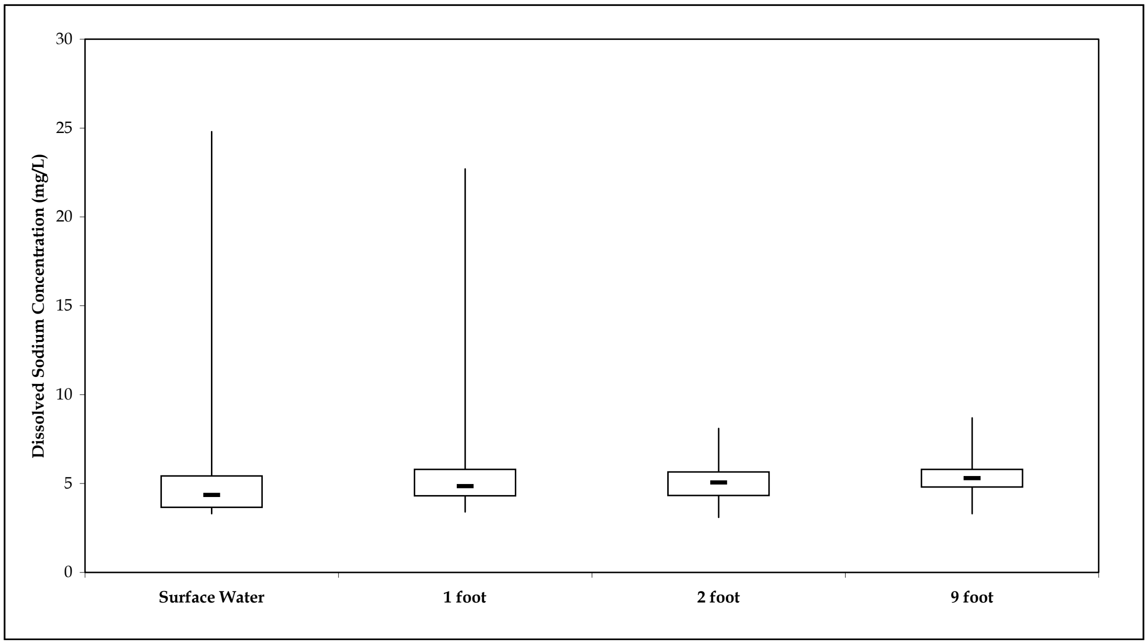

FIGURE E-17: Box and whisker plot of sodium concentrations vs. depth.

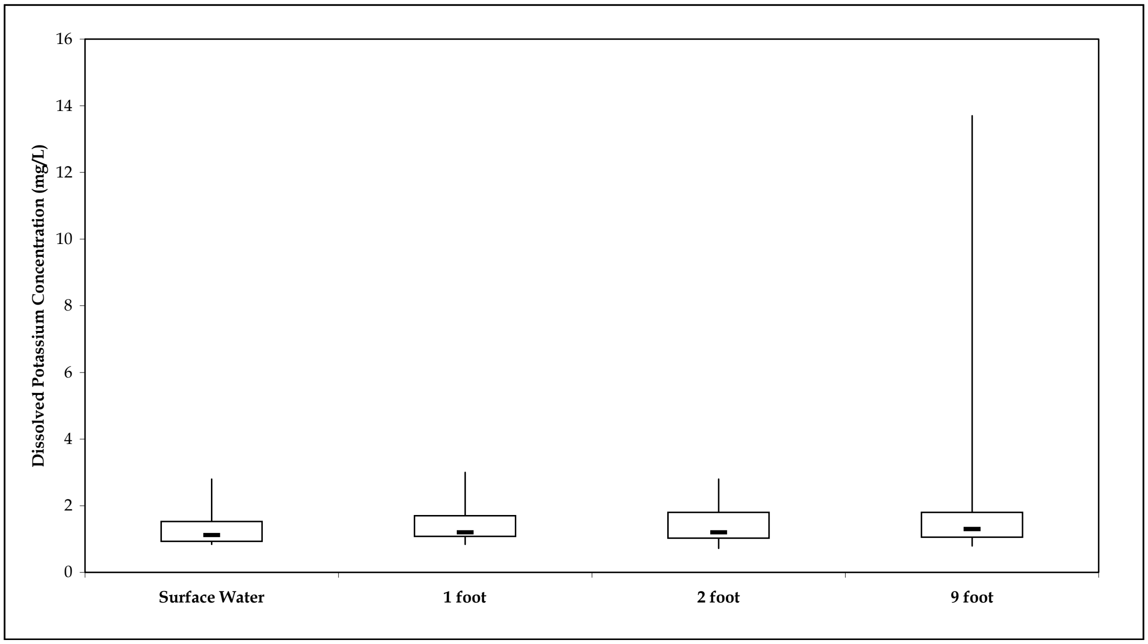

FIGURE E-18: Box and whisker plot of potassium concentrations vs. depth.

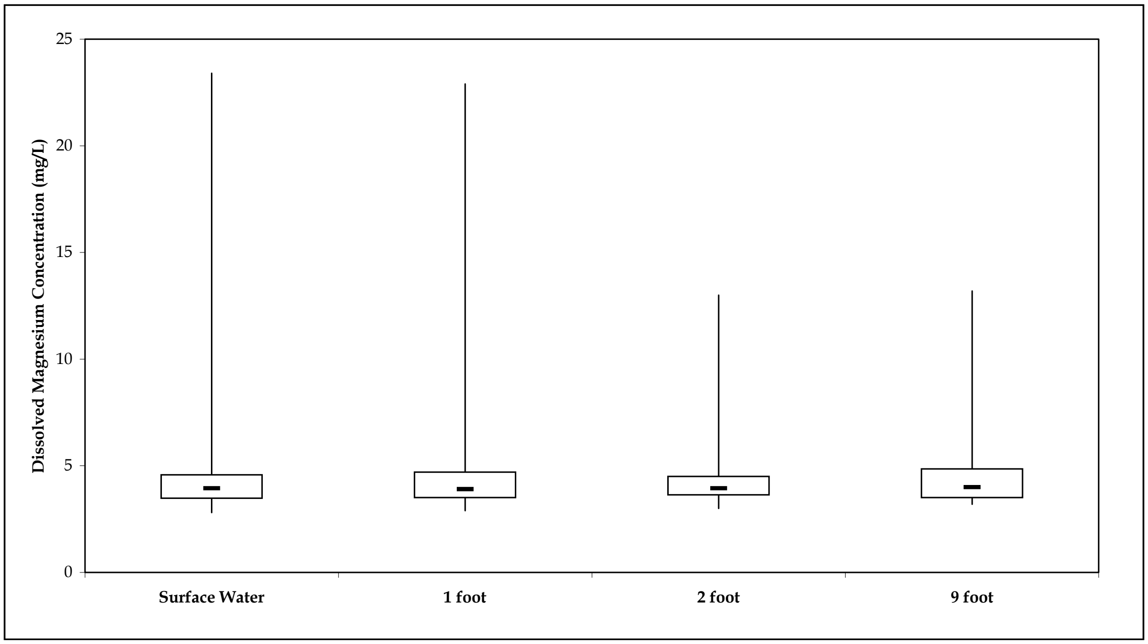

FIGURE E-19: Box and whisker plot of magnesium concentrations vs. depth.

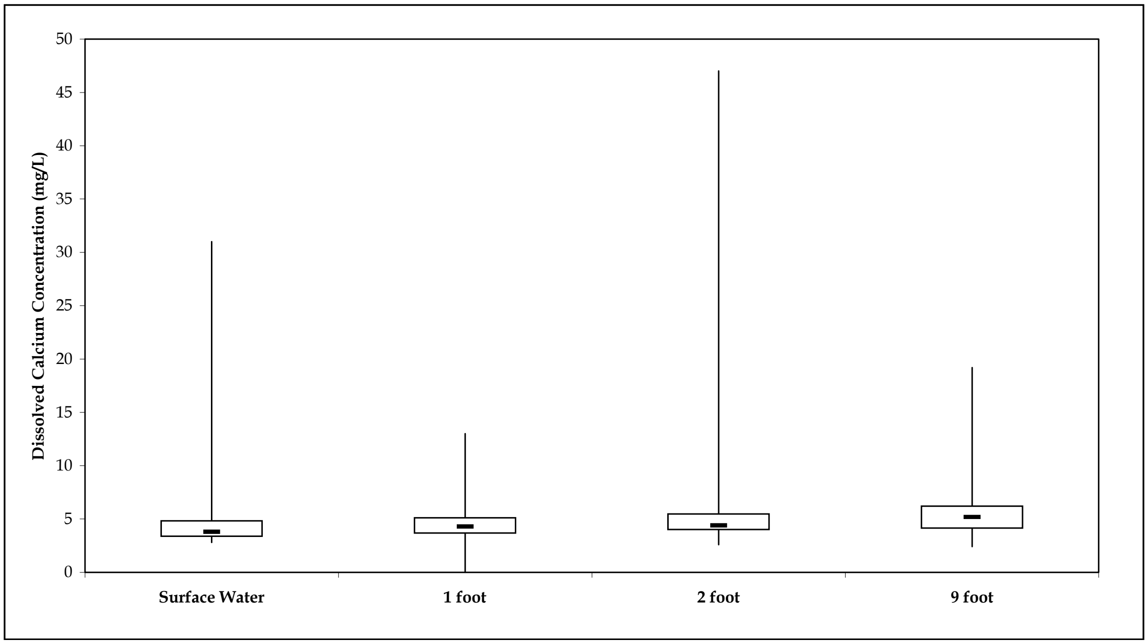

FIGURE E-20: Box and whisker plot of calcium concentrations vs. depth.

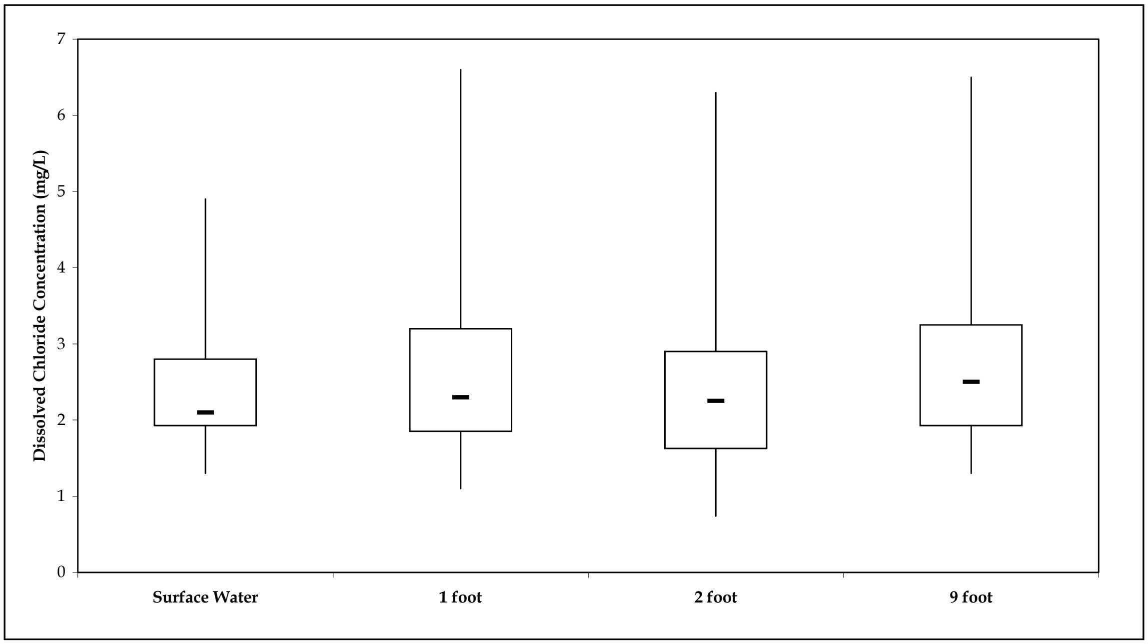

FIGURE E-21: Box and whisker plot of chloride concentrations vs. depth.

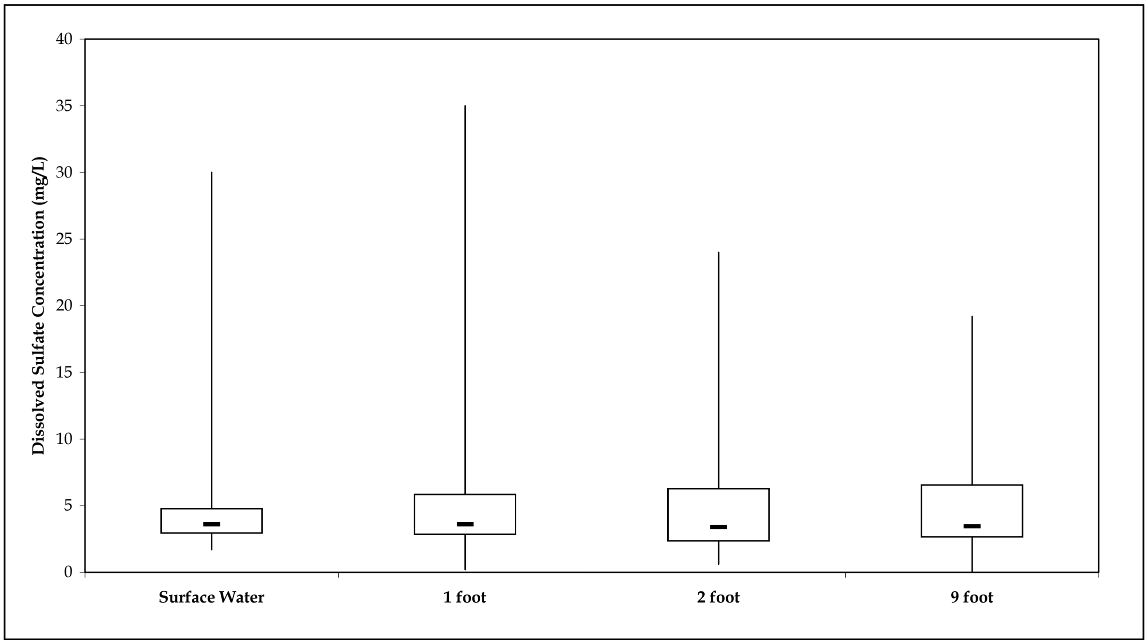

FIGURE E-22: Box and whisker plot of sulfate concentrations vs. depth.

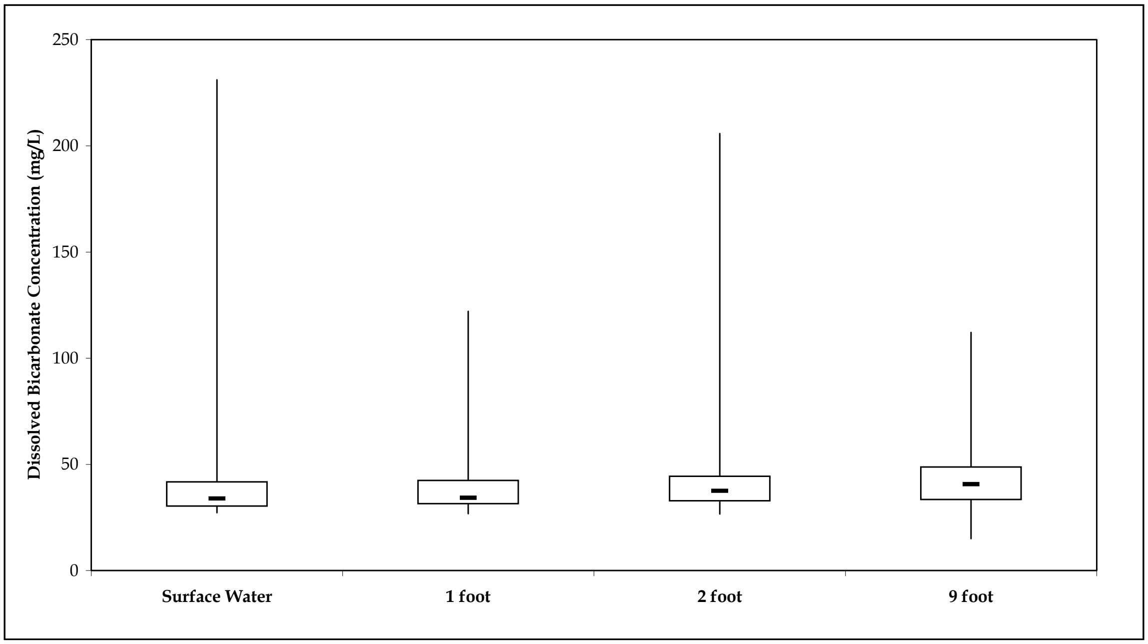

FIGURE E-23: Box and whisker plot of calculated bicarbonate concentrations vs. depth.

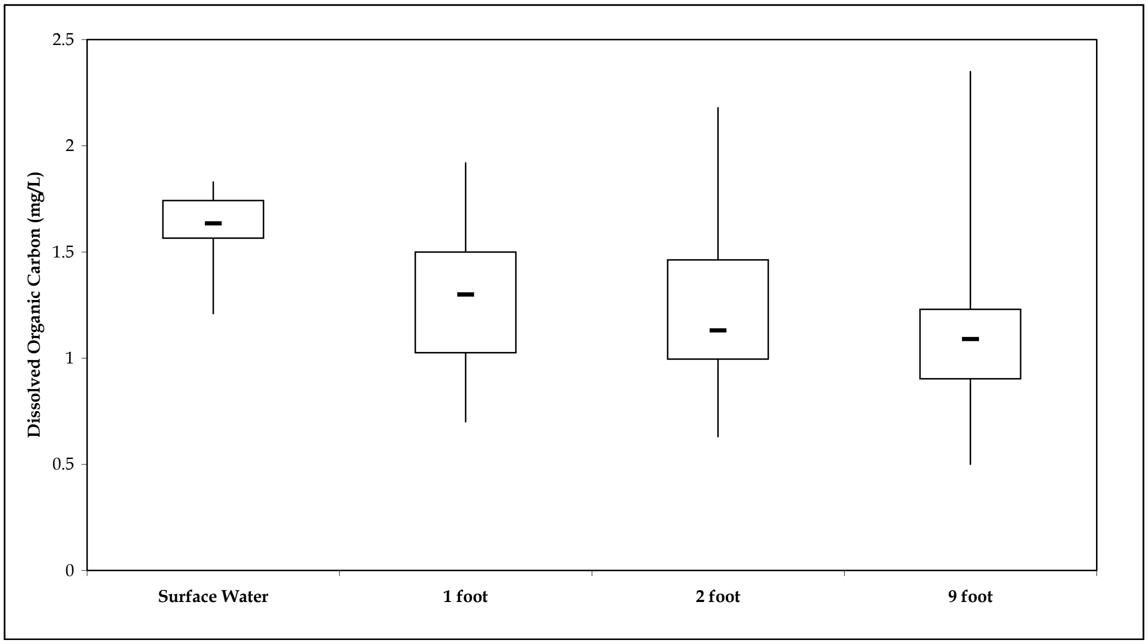

FIGURE E-24: Box and whisker plot of dissolved organic carbon concentrations vs. depth.

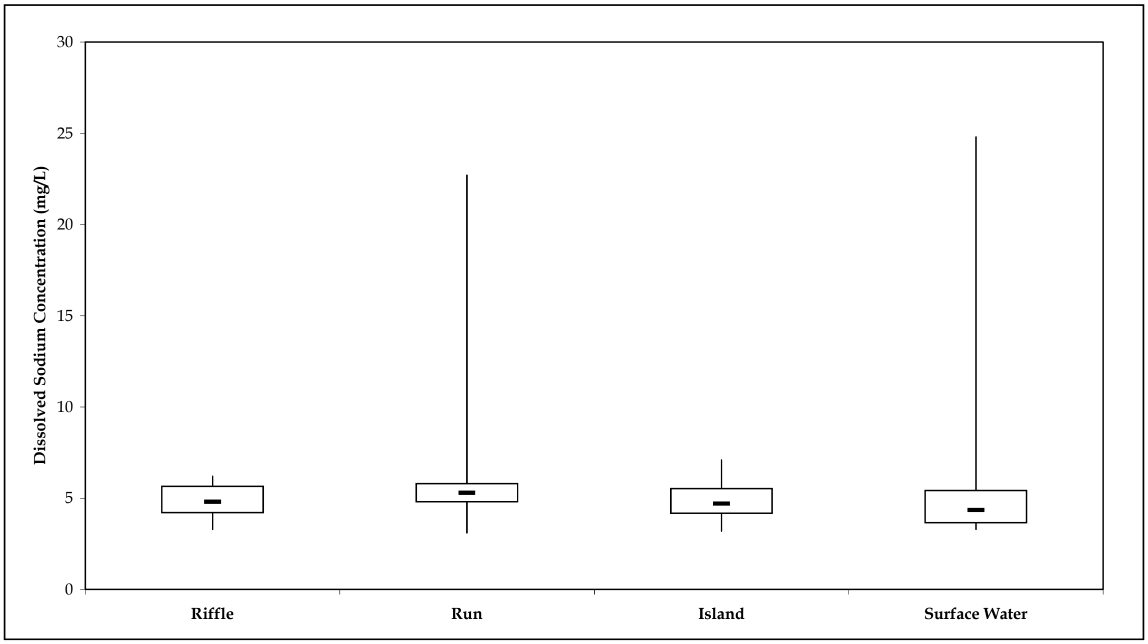

FIGURE E-25: Box and whisker plot of sodium concentrations vs. streambed morphology.

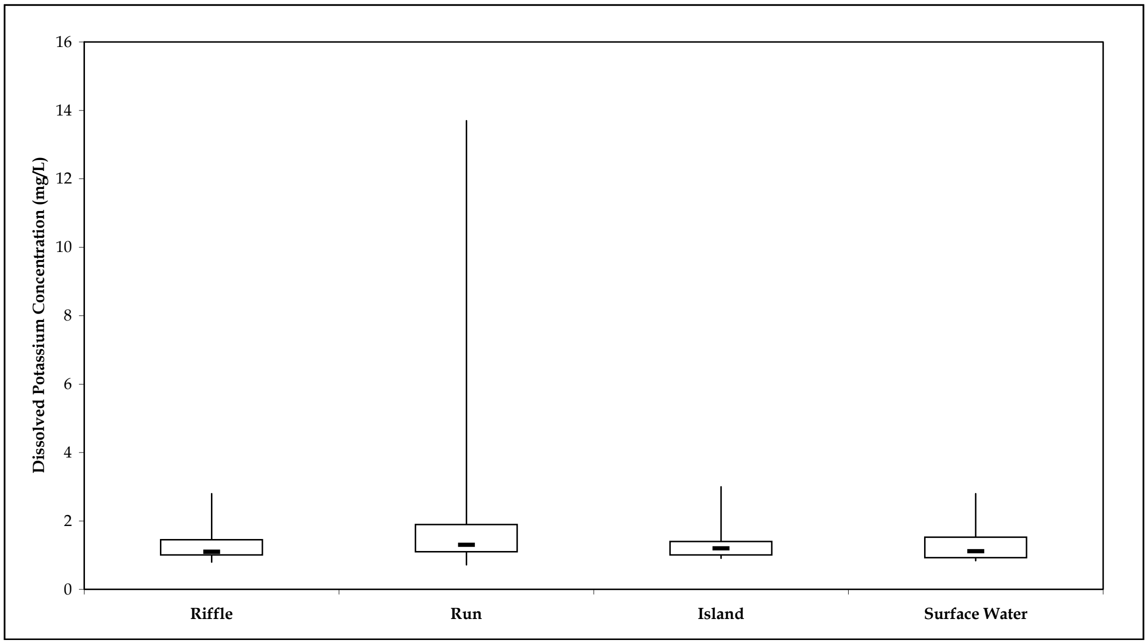

FIGURE E-26: Box and whisker plot of potassium concentrations vs. streambed morphology.

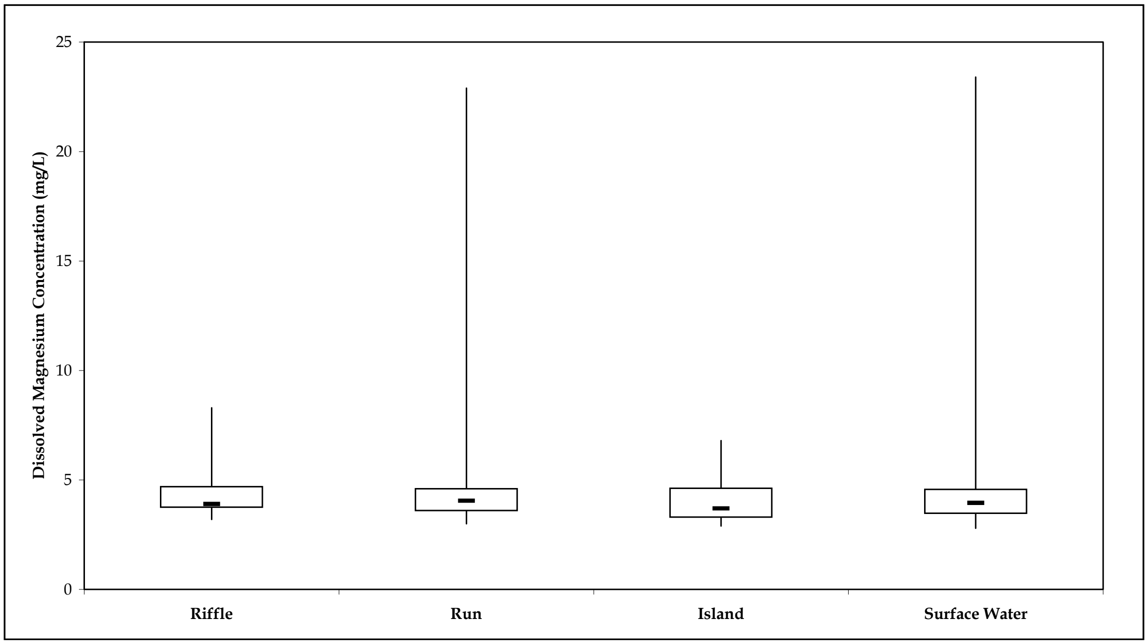

FIGURE E-27: Box and whisker plot of magnesium concentrations vs. streambed morphology.

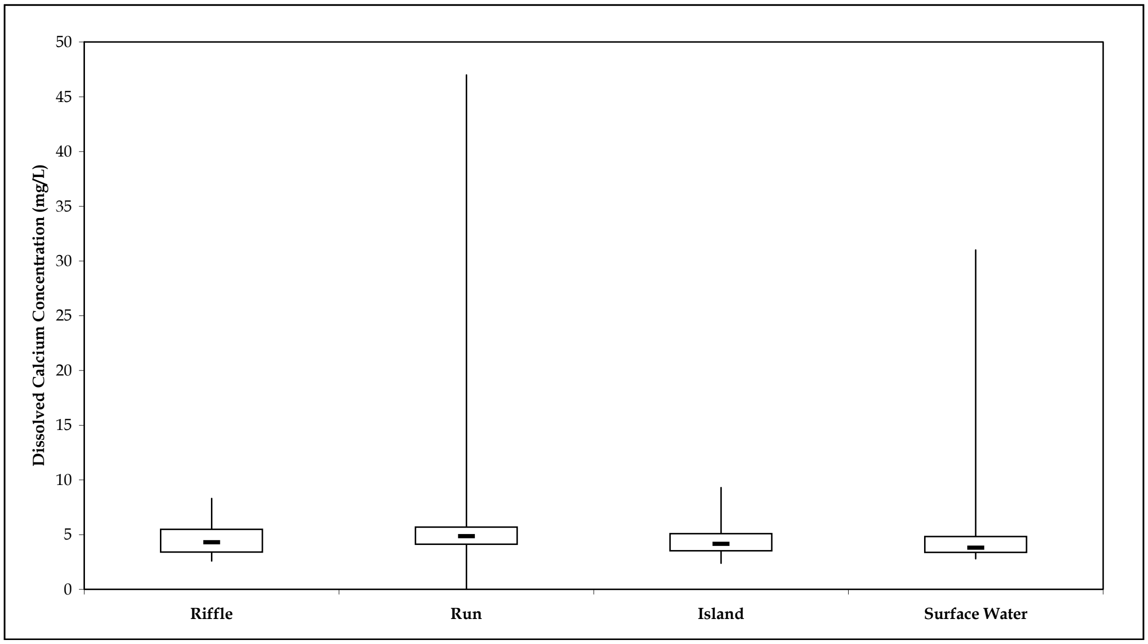

FIGURE E-28: Box and whisker plot of calcium concentrations vs. streambed morphology.

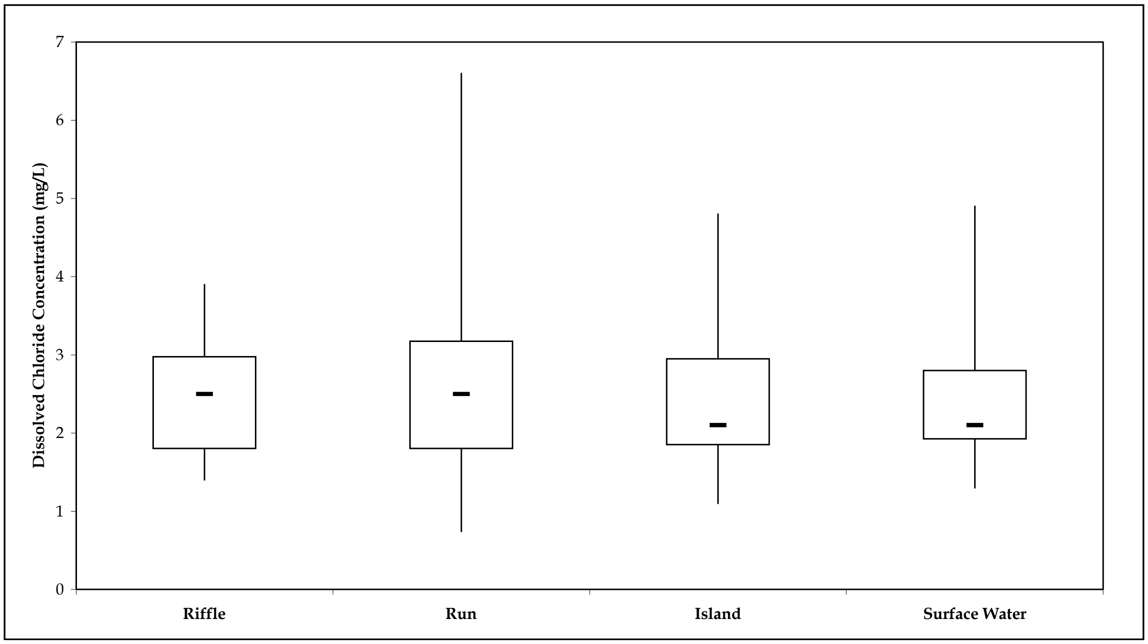

FIGURE E-29: Box and whisker plot of chloride concentrations vs. streambed morphology.

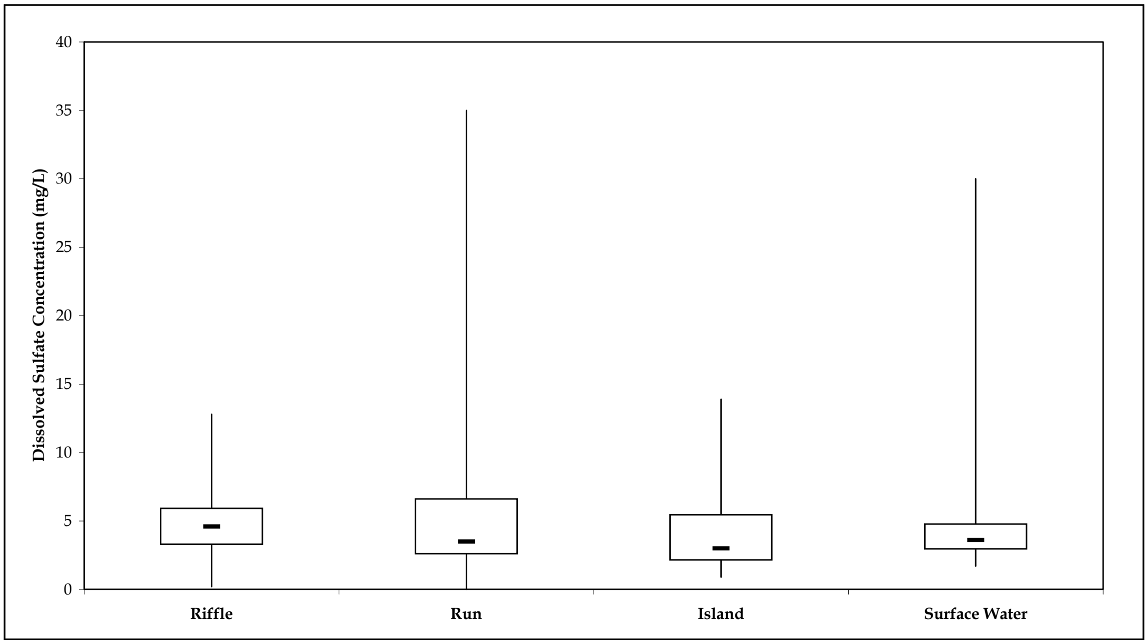

FIGURE E-30: Box and whisker plot of sulfate concentrations vs. streambed morphology.

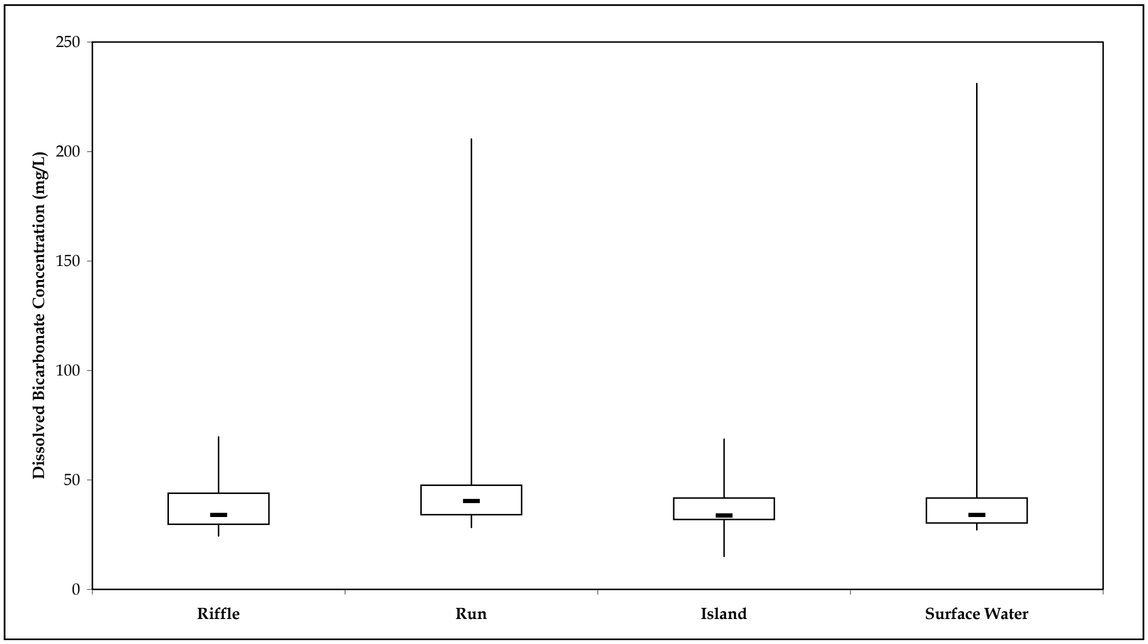

FIGURE E-31: Box and whisker plot of calculated bicarbonate concentrations vs. streambed morphology.

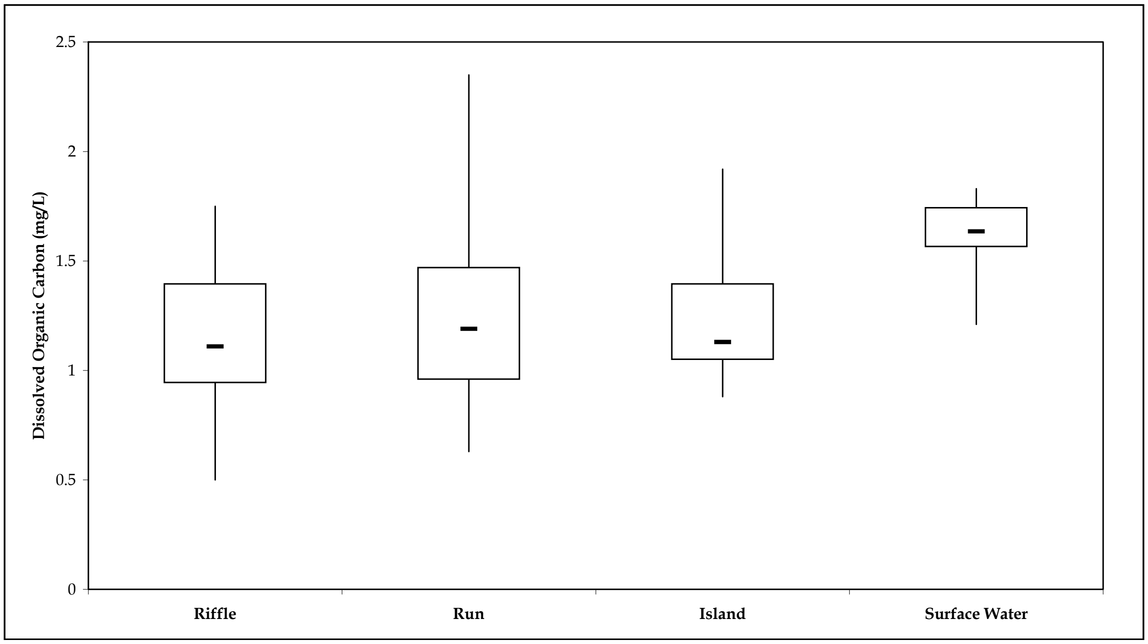

FIGURE E-32: Box and whisker plot of dissolved organic carbon concentrations vs. streambed morphology.

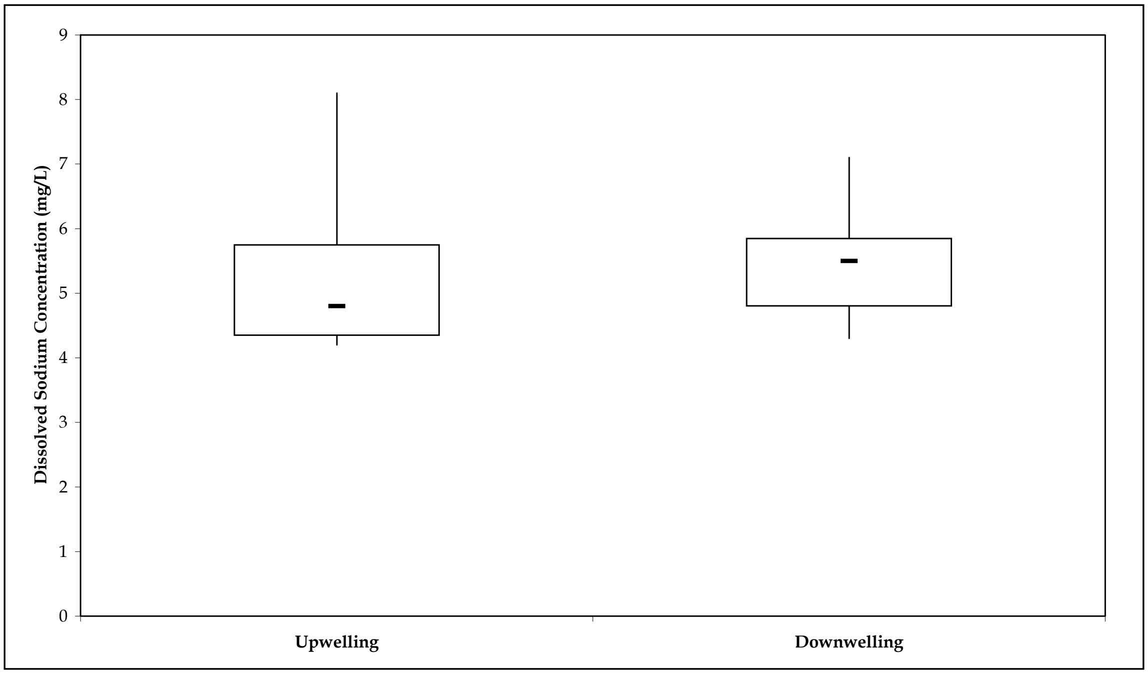

FIGURE E-33: Box and whisker plot of sodium concentrations vs. upwelling and downwelling.

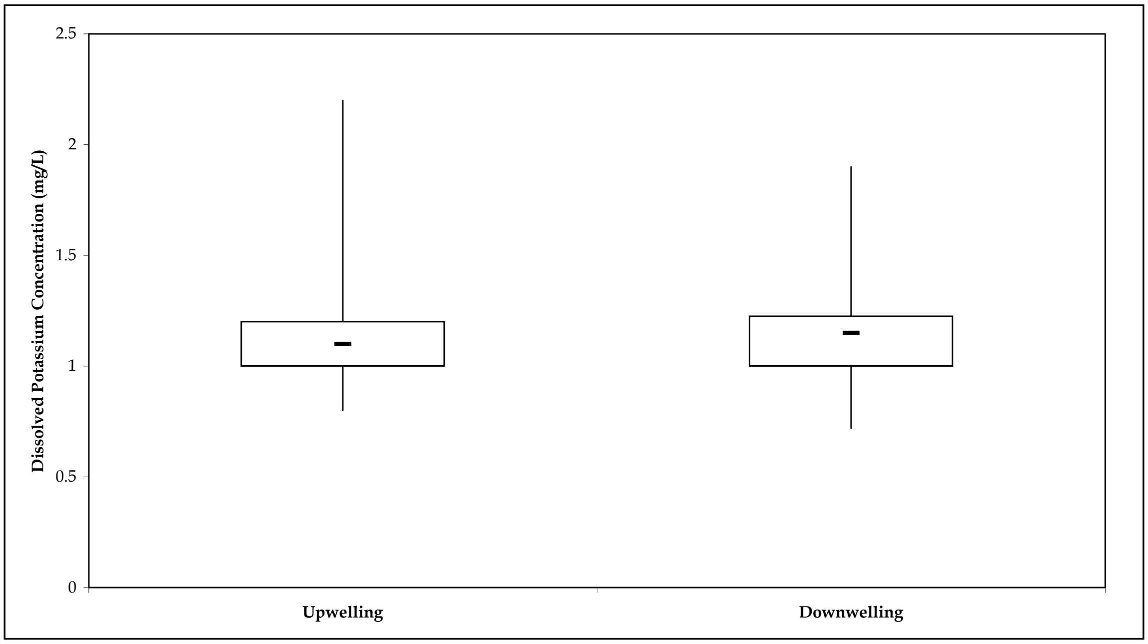

FIGURE E-34: Box and whisker plot of potassium concentrations vs. upwelling and downwelling.

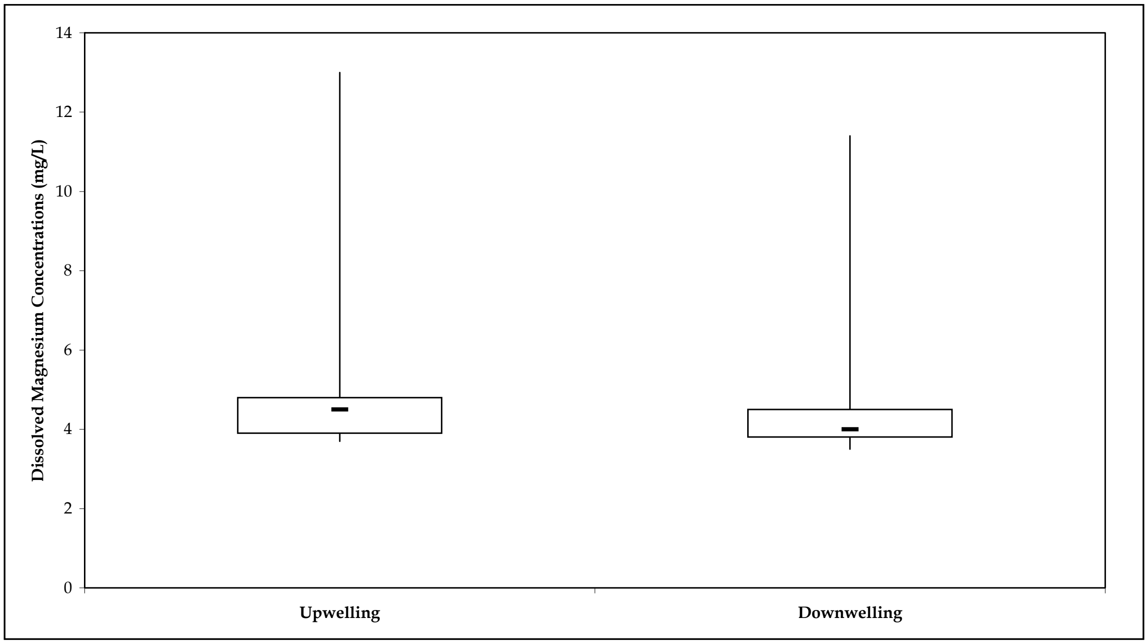

FIGURE E-35: Box and whisker plot of magnesium concentrations vs. upwelling and downwelling.

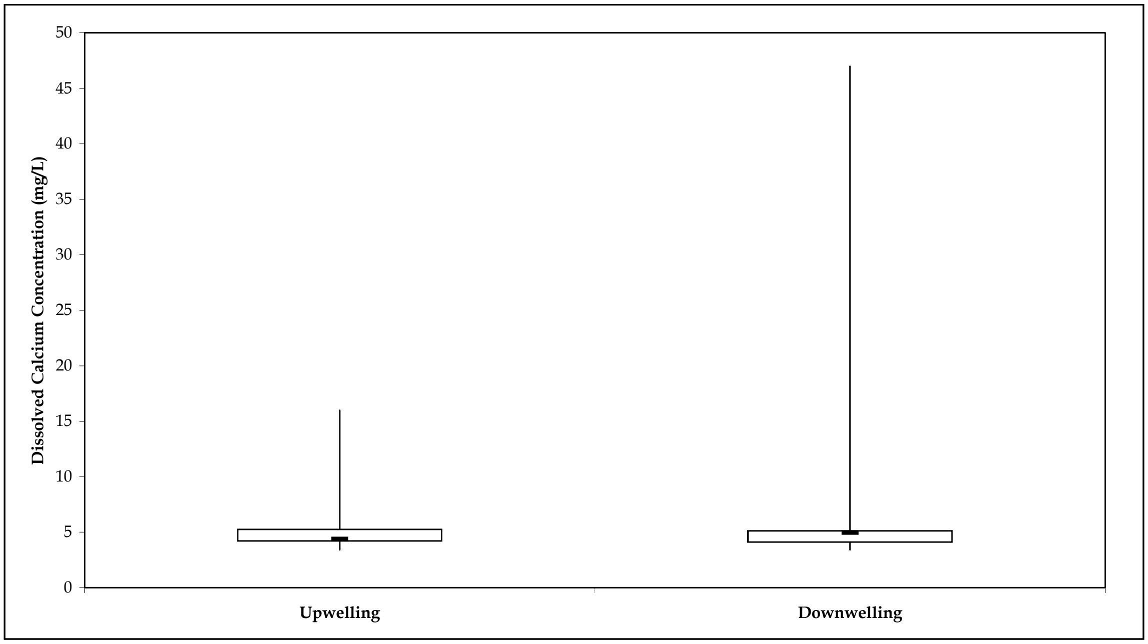

FIGURE E-36: Box and whisker plot of calcium concentrations vs. upwelling and downwelling.

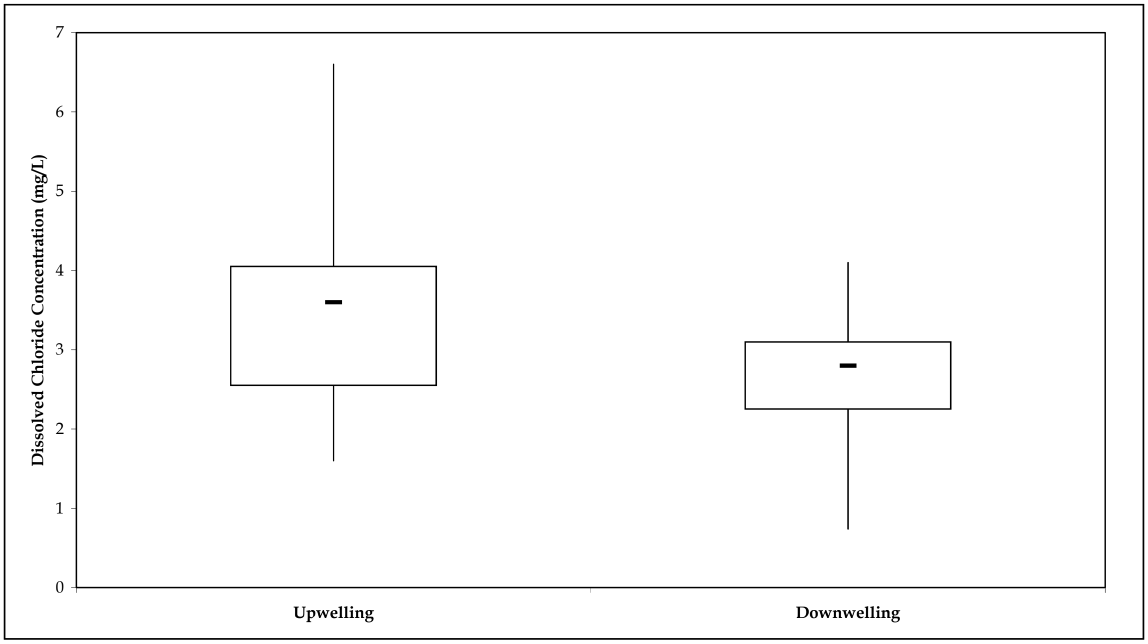

FIGURE E-37: Box and whisker plot of chloride concentrations vs. upwelling and downwelling.

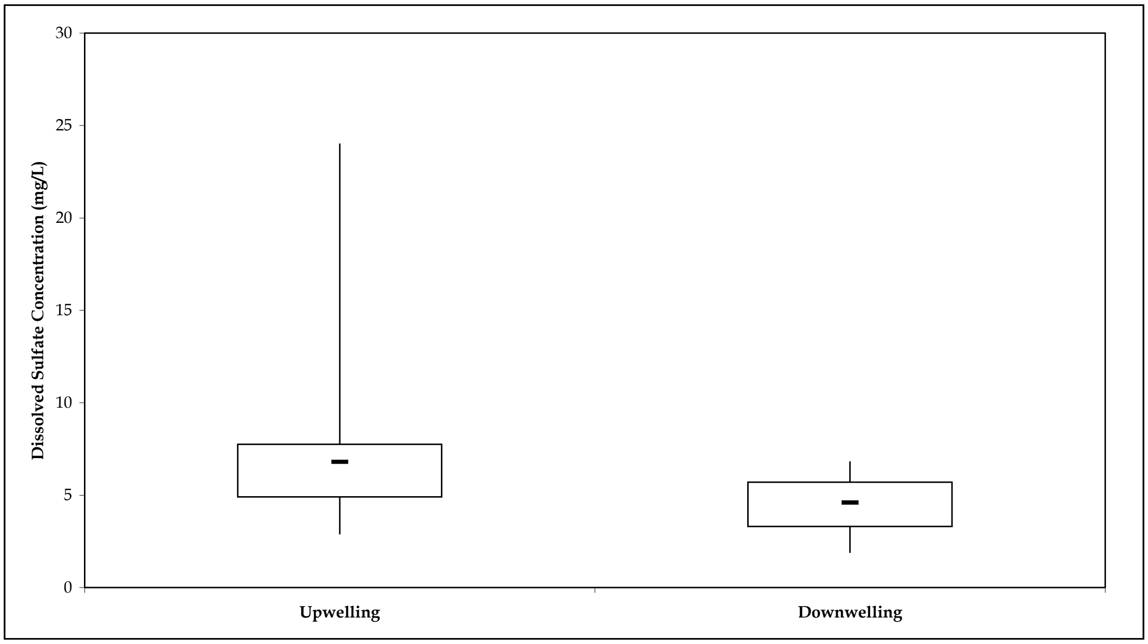

FIGURE E-38: Box and whisker plot of sulfate concentrations vs. upwelling and downwelling.

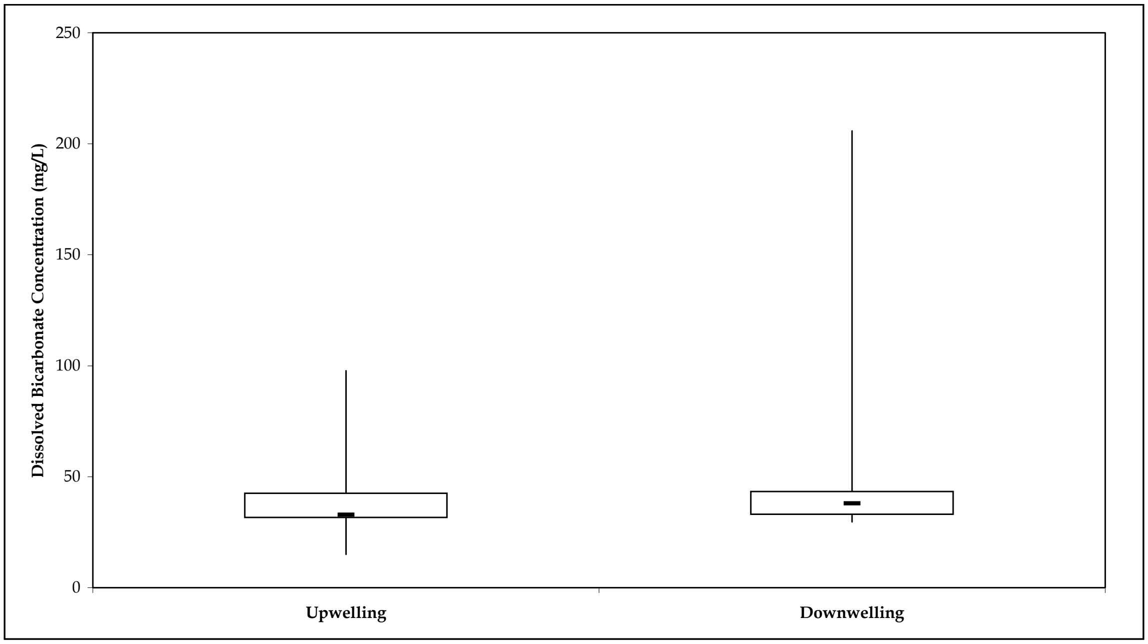

FIGURE E-39: Box and whisker plot of calculated bicarbonate concentrations vs. upwelling and downwelling.

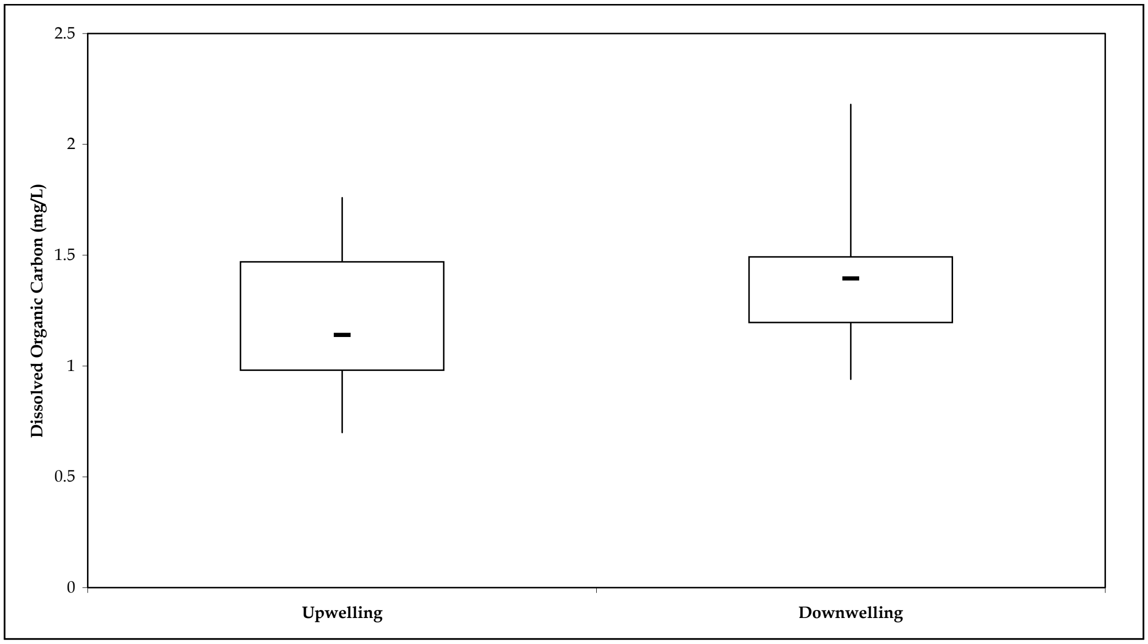

FIGURE E-40: Box and whisker plot of dissolved organic carbon vs. upwelling and downwelling.

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