APPENDIX B: UCCE Salmon Creek Watershed Water Quality Monitoring Results

Salmon Creek Integrated Coastal Watershed Management Plan
Appendix B:

Salmon Creek Watershed Water Quality Monitoring Results

Prepared for:

Gold Ridge Resource Conservation District

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Cover Photos: 1) Gold Ridge RCD staff Chris Choo, Brittany Heck and Devii Rao at the Salmon Creek School water quality monitoring site. 2) YSI instrument. Photos by David Lewis, UCCE.

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INTRODUCTION

Stream and river water quality is highly variable in undisturbed and disturbed watersheds. Geology, groundwater and surface contributions, climate, soils, vegetation type and cover, and distribution of native fauna form a complex web of inter-related factors that contribute to unique physical and chemical water properties for each stream system. Waterbodies often exhibit concentrations of naturally occurring "constituents" to which flora and fauna have adapted. Anthropogenic changes to land use, inputs of natural and synthetic chemicals, and of human and domestic animal wastes further compound the complexity of causal factors and obscure underlying natural conditions. Water quality monitoring may not answer our questions about past impacts but it can provide us with a set of baseline conditions that will allow us to track changes over time and better understand the positive and negative impacts of our actions on the watershed.

Initial assessments of Salmon Creek water quality indicate that sediment delivery from non-point sources is one of the primary issues impairing ecological function of the stream corridor and estuary (CDFG, 2004). Stream ambient water quality data has been, and continues to be, collected by the Salmon Creek Watershed Council (SCWC) through a volunteer monitoring program funded by the California Department of Fish and Game in 2003. Prior to 2007, however, *standardized* water quality monitoring data was not available for the Salmon Creek Watershed. At that time, Gold Ridge RCD supplemented the existing volunteer water quality monitoring program with one that utilized standard, scientifically-acceptable data collection methods. This assessment was intended to provide information for watershed management and pollution prevention, with a focus on salmonid health and habitat restoration.

This chapter discusses past water quality monitoring within the watershed and Gold Ridge RCD's recent efforts to provide baseline water quality data for Salmon Creek and its tributaries. It also provides a summary of data findings. The Watershed Management Advisor for the Sonoma County University of California Cooperative Extension (UCCE) performed the water quality data evaluation and prepared this section of the report. UCCE was incorporated into the program to provide a scientific approach to spatial and trend analysis for all data collected through Summer 2008.

Past Monitoring

Volunteers

Volunteer water quality monitoring provides critical data and an opportunity for community involvement in watershed management. The effort in the Salmon Creek watershed has received, and continues to receive, a tremendous amount of support from local volunteers. A volunteer water quality monitoring program was originally established through California Department of Fish and Game (DFG) funding in 2003. The program sought to collect baseline data that could be used to determine how water quality issues might contribute to the decline of salmonid populations in the watershed.

Volunteers were recruited by Gold Ridge RCD through public meetings, local media, and the Salmon Creek Watershed Council (SCWC). Volunteers received classroom education about the program and the general concepts of water quality monitoring. Each volunteer selected a specific site or set of sites to monitor once a month at a set time and received at least two onsite training sessions in the use and troubleshooting of the sampling equipment

Over the past four and a half years, approximately 20 volunteers have monitored 13 sites along mainstem Salmon Creek, the estuary and four of the major tributaries (Figure 1).

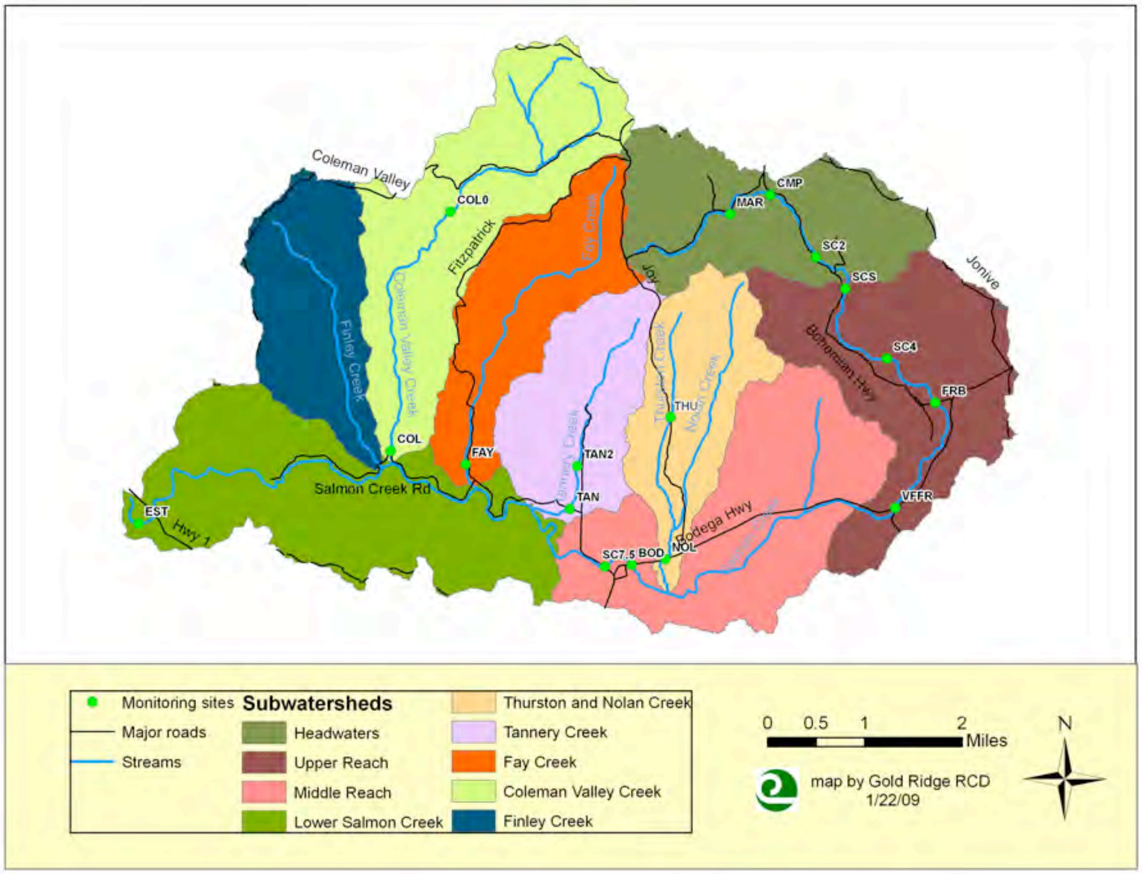

Figure 1: Salmon Creek watershed water quality monitoring sites and subwatersheds.

Water quality sampling efforts continued by a committed group of citizens even after the Gold Ridge RCD began collecting data using its own staff in October 2007. Volunteer sampling at seven of these sites is ongoing today, long after the grant funds have been exhausted. Gold Ridge RCD has taken over monitoring responsibilities at three of the original volunteer sites.

Other Organizations

In order to maintain the integrity of the program by insuring that scientific and uniform standards in data collection and analysis were met, Prunuske Chatham, Inc. (PCI) was contracted to train volunteer monitors, oversee data collection and analyze data in keeping with professional standards. They also calibrated and maintained the sampling equipment according to the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP) standards until until 2007 and the start of Gold Ridge RCD's water quality monitoring program. In addition, PCI staff collected storm-related turbidity readings during the 2004-2005 rainy season at 10 sites on the mainstem and 4 tributary locations. That data is included in the results section of this report.

The North Coast Regional Water Quality Control Board (RWQCB) generously loaned the volunteer program essential equipment and provided SWAMP training for calibration, cleaning, and use of the equipment

Gold Ridge RCD's Current Monitoring Effort

Gold Ridge RCD designed a project to supplement the existing volunteer water quality monitoring program by conducting additional monitoring of streams in the Salmon Creek watershed using Gold Ridge RCD field staff. This assessment was intended to provide scientific support for watershed management and pollution prevention. It is anticipated that the information generated from this effort will enable identification of reach- or site-specific restoration and/or remediation actions and development of guidelines for evaluating potential impacts of proposed projects within the watershed. The resulting data will be made available to the public for purposes of watershed education, as well as to resource management agencies.

In February 2007, Gold Ridge RCD drafted the Quality Assurance Project Plan & Monitoring Plan for Collection of Baseline Hydrologic Monitoring in the Salmon Creek Watershed, Sonoma County, CA (QAPP). This document carefully outlines the monitoring plan and requirements for sampling methods, handling and custody procedures, analytical methods, quality control, equipment testing, inspection, maintenance and calibration, data acquisition, data management, review, verification and validation and reconciliation of data quality objectives. The QAPP was reviewed and approved by the California State Water Resources Control Board QAPP staff and accordingly meets SWAMP standards. These measures and objectives are therefore considered adequate for the determination of general water quality conditions, with a potential application of the data to Section 305(b) reporting purposes. It is important to note that the historic and continued volunteer monitoring, though it aimed for SWAMP compliance, was unable to meet all SWAMP requirements due primarily to funding restrictions.

In October 2007, Gold Ridge RCD staff began a year-long ambient water quality monitoring program collecting water quality samples using the methodologies and specific requirements described in the QAPP. They began sampling concurrently with volunteers at four of the historic volunteer sites, took over sampling responsibilities at another three historic sites and established monitoring at three new sites, for a total of ten sites. The RCD sites include five along the mainstem of Salmon Creek, one on Coleman Creek, one on Fay Creek, one on Tannery Creek and one in the estuary.

Watershed Plan Water Quality Monitoring Objectives

The purpose of the water quality monitoring program established by Gold Ridge RCD in 2007 was to assess the freshwater habitat conditions within the Salmon Creek watershed, establish current baseline conditions and provide a foundation for evaluating future conditions. The program was developed with salmonid standards in mind. The specific objectives of sampling at the selected locations are to:

- Use the water quality monitoring data as a benchmark for developing watershed-wide Best Management Practices (BMPs) and enhancement strategy.

The data collected will provide a guide for the systematic development of restoration projects;
- Establish baseline values that characterize current freshwater habitat conditions at reference locations throughout the watershed; and
- Assess the efficacy and necessity of future water quality improvement projects by comparing the baseline data collected under this monitoring plan to future, post-project monitoring data.

The following assumptions and practices were an important part of the water quality monitoring plan:

- Sampling conditions in the 2007/2008 season will be considered representative of typical conditions within the watershed.
- Sampling crews will sample all locations within the watershed in a systematic and timely manner to maximize sample comparability.
- Storm sampling crews will collect samples at multiple times during a single storm event, including the peak runoff window, when possible.
- A minimum of three to four storms will be sampled.
- Water quality parameters were selected that facilitate characterization of baseline and storm conditions for the watershed.
- There will be at least 8 sampling sites for both storm and baseflow water quality monitoring.

One intended outcome of this effort was an assessment of the degree of impairment for each parameter sampled based on beneficial uses determined by the North Coast RWQCB. The following beneficial uses have been established in the Salmon Creek Hydrologic Area: municipal and domestic supply, agricultural supply, industrial service supply, groundwater recharge, navigation, water contact recreation, non-contact water recreation, commercial and sport fishing, cold freshwater habitat, estuarine habitat, wildlife, rare, threatened or endangered species, migration of aquatic organisms, and spawning, reproduction and/or early development (NCRWQCB 2007). Generally, the most stringent criteria established by the North Coast RWQCB and the EPA *for the specific water quality constituents sampled* during the Salmon Creek water quality monitoring, including temperature, pH and dissolved oxygen, are relative to the uses of cold freshwater habitat and spawning, reproduction and/or early development. Both of these beneficial uses address the needs of salmonids. Both federally- and state-mandated criteria were considered in evaluating the water quality data results and are included in the discussion.

An additional intended outcome was the establishment of target values for the parameters in question. To this end, UCCE associates reviewed a substantial selection of the available literature, particularly that discussing water quality criteria and thresholds for salmonids (Raleigh et al. 1984, McMahon 1983, USEPA 1986, Newcombe 2003, MacDonald et al. 1991, Reiser and Bjornn 1979, CDFO 2000, NCRWQCB 2008, NCRWQCB 2006, Groot and Margolis 1991, Schwartz et al. 2008, Welsh et al. 2001). Because the water quality monitoring efforts were developed with salmonid standards in mind, results utilized coho and steelhead habitat, breeding and spawning standards to determine suitable water quality. Steelhead trout (*Oncorhynchus mykiss*) are the predominant salmonid species found in Salmon Creek and its tributary streams. Coho salmon (*Oncorhynchus kisutch*) occurred there historically and adult coho were planted in the mainstem in late 2008 by DFG's Russian River Coho Salmon Captive Broodstock Program (RRCSCBB) in an effort to replenish a self sustaining run.

METHODS

Site Selection

Initial site selection within the Salmon Creek Watershed was based primarily on ongoing public access. Public bridges were used for access to a majority of the sampling sites. During the development of the citizen monitoring effort, several volunteers requested to test on their own property and these requests were granted. At that time (2003), Gold Ridge RCD made limited, unsuccessful efforts to locate additional sites along mainstem Salmon Creek in the reach between Freestone and Bodega, and between Bodega and the Estuary.

When Gold Ridge RCD began their renewed effort in 2007, they decided to focus on seven of the 13 original volunteer sites. Gold Ridge RCD's project manager and staff also met with landowners to continue ongoing access to three additional sites on private property. The following criteria were evaluated during the selection of past and new locations to insure that the most appropriate sites were included: access is safe, permission to cross private property is granted, sample may be taken in main river current or where homogeneous mixing of water occurs, sample is representative of the portion of the water body of interest, location complements or supplements baseline data, and location represents an area that has a water quality improvement practice either recently implemented or scheduled for implementation in the next year (QAPP, 2007).

Table 1: Summary of water quality monitoring site location.

Site	Subwatershed	Site Description
MAR	Headwaters	Salmon Creek at Marra Rd
CMP	Headwaters	Salmon Creek at Scout Camp Rd
SC2	Headwaters	Salmon Creek at Bohemian Lane
SCS	Headwaters	Salmon Creek at Salmon Creek School
SC4	Upper	Salmon Creek at Freestone Flat Rd Bridge
FRB	Upper	Salmon Creek at Bohemian Highway in Freestone
VFFR	Upper	Salmon Creek at Bodega Highway & Vallery Ford Freestone Rd
SC7.5	Middle	Salmon Creek at Salmon Creek Rd
BOD	Middle	Salmon Creek at Bodega Highway near Bodega
EST	Estuary	Salmon Creek at Bean Avenue
THU	Nolan Creek	Thurston Creek at Joy Rd Shatkin
NOL	Nolan Creek	Nolan Creek at Bodega Highway
TAN	Tannery Creek	Tannery Creek Bridge at Salmon Creek Rd
TAN2	Tannery Creek	Tannery Creek off Tannery Creek Rd
FAY	Fay Creek	Fay Creek at Salmon Creek Rd
COL0	Coleman Creek	Upper Coleman Creek approx 1/4 mile downstream of Coleman Valley Rd
COL	Coleman Creek	Coleman Valley Creek at Salmon Creek Rd

Sample Collection Protocol

Volunteer Sampling Methods

In April 2004, volunteers began collecting temperature, pH, dissolved oxygen, phosphate, nitrate, free and total chlorine, conductivity, salinity, and turbidity data for Salmon Creek and its tributaries. These parameters were selected to match the effort and experience levels of the volunteers. Where possible, the volunteer monitoring program aimed for compliance with SWAMP protocols. However, this program did not have access to a lab or funding to support sample analysis by an independent laboratory. Therefore, the volunteer program was limited to tests that could be conducted in the field. All equipment was purchased with this in mind, in addition to the goal of keeping operation and maintenance costs to a minimum. Equipment and reagents for tests were purchased with grant funds and the reagents were replenished with fundraising efforts. Testing procedure, cleaning, and calibration methods were standardized in order to produce as little variance as possible. Volunteers were provided with laminated instructions for each test to limit user error.

The program borrowed a portable YSI 600XL multi-parameter sonde and YSI 650 data collector from the RWQCB. This equipment was configured to collect temperature, pH, conductivity, salinity, and dissolved oxygen. SWAMP training for calibration, cleaning, and use of the equipment were provided to PCI staff by Peter Otis of the RWQCB, and by PCI to all program volunteers.

After several months, when the RWQCB needed their equipment back, a YSI 55 was loaned to the program by PCI. The YSI 55 measured all the same parameters as the YSI 600 except for pH. The YSI 55 required user calibration for altitude adjustments to measure dissolved oxygen, which was performed by volunteers prior to each use.

Hach PocketPal™ testers were used to measure pH and conductivity. The testers were calibrated weekly to ensure that they remained reliable. These meters were purchased prior to borrowing the YSI 55 and the results from the meters and YSI appeared comparable.

Turbidity was measured using a Hach 2100P portable turbidimeter, which measured how cloudy the water appeared using a beam of light projected through the sample in a glass vial. The Model 2100P measures turbidity from 0.01 to 1000 NTU operating on the nephelometric principle of turbidity measurement. The glassware was cleaned by volunteers prior to each reading to limit fouling from fingerprints or dirt. Each vial was marked with an arrow to align the vial with the meter and labeled to ensure repeated use of the same vial. The glassware and the turbidimeter were cleaned and checked weekly by PCI staff. The turbidimeter was calibrated using a Hach's StablCal Formazin standard every 3 months, with a monthly check against Hach's Gelex calibration product. The monthly measurement checked for drift greater than 5%.

Funding restrictions resulted in the purchase of a Hach color wheel to test for nutrients and total chlorine. This technique requires the user to match the color of the treated sample with the color on the gradient color wheel. The tests have a built-in compensation for any background color in the water sample, but leave a notable margin for interpreting the results. Testing with a color wheel, as opposed to a portable colorimeter, increased the subjectivity and margin of error for tests of phosphate, nitrate and chlorine. To decrease subjectivity as much as possible, the protocol required both monitors at each site to analyze their samples separately and confidentially before comparing the results, re-sampling if necessary, and reaching an agreement about the final value recorded.

In Summer 2006, the Salmon Creek Watershed Council received additional funding to purchase a portable colorimeter to replace the color wheels. In July 2006, volunteers began using a Hach colorimeter, instead of the color wheel, to test for free or total chlorine (based on location), nitrate, and phosphate with increased precision.

Air and water temperatures were also measured during data collection. Volunteers were equipped with a pocket thermometer in addition to the internal thermometer on the YSI probe.

Gold Ridge RCD Sampling Methods

Gold Ridge RCD field staff made monthly visits to each of the ten monitoring sites to sample for temperature, pH, dissolved oxygen, phosphorous, nitrate, conductivity, salinity, turbidity and TSS. In addition, they conducted storm event sampling two times during wet weather periods (at least 0.5 inches of rainfall in a 12-hour period). Water quality samples were collected, stored, transported, measured, and analyzed in accordance with SWAMP-approved protocols. Data collection methods followed standard protocols established and endorsed by the Environmental Protection Agency, North Coast RWQCB and U.S. Geologic Survey. Industry-standardized equipment was used to measure water quality parameters. The program's companion QAPP provides the detailed measures that were followed to ensure data collection accuracy, precision and repeatability. This includes instrument calibration, duplicate measurements of field parameters, sample trip blanks and duplicate field sample collection and submission for analyses and audits.

Water quality grab samples were collected and analyzed for turbidity in the field using a Hach 2100P Turbidimeter. This is a handheld turbidity meter, which operates by measuring the amount of light that passes through the sample jar. The Model 2100P measures turbidity from 0.01 to 1000 NTU operating on the nephelometric principle of turbidity measurement. As with the volunteer sampling, the glassware and the turbidimeter were cleaned and checked weekly. The turbidimeter was calibrated using a Hach's StablCal Formazin standard every 3 months, with a monthly check against Hach's Gelex calibration product. The monthly measurement checked for drift greater than 5%.

Dissolved oxygen, pH, conductivity, and temperature were measured with a YSI 600-model meter. The YSI is a handheld display and attached sensor wand used to measure water quality parameters. It was calibrated for dissolved oxygen prior to each use to adjust for altitude and barometric pressure. It was also calibrated for pH weekly and turbidity monthly.

Grab samples for nitrate nitrogen and total phosphorous were collected using a sterile plastic bottle and sent to an independent professional laboratory.

Suspended sediment grab samples were taken with a DH-48 sediment sampler at multiple times throughout the study period. The DH-48 is an isokinetic depth integrated sampler used to collect total suspended solids (TSS) samples. TSS samples were sent to an independent professional laboratory for analysis.

Sample Analyses

Because the volunteer monitoring program did not have funding to support sample analysis by an independent laboratory, analytical tests for all parameters sampled were performed by trained volunteers in the field using accepted equipment and methods.

For the Gold Ridge RCD effort:

- Turbidity, dissolved oxygen, pH, temperature and conductivity measurements were analyzed in the field by trained Gold Ridge RCD field staff using industry-standardized equipment.

- Nutrient samples were collected using a sterile plastic bottle and analyzed for nitrate as nitrogen and total phosphorous by Analytical Sciences, a state-certified professional laboratory in Petaluma (CA Lab Accredition #2303). Nitrate was analyzed using Environmental Protection Agency (EPA) method 300.0, with a reporting detection limit of 0.15 mg/L. Phosphorous was analyzed using EPA method 200.7, with a reporting detection limit of 0.10 mg/L.

- TSS samples were also analyzed by Analytical Sciences using Standard Method 2540D. Reporting detection limits for TSS were 5.0 mg/L.

Data Management & Analysis

In 2008, all data from both the volunteer and Gold Ridge RCD's monitoring programs were submitted to UCCE. Under the guidance of the Watershed Program Advisor, research associates compiled, organized and analyzed the data. Some data refinement was necessary to insure accuracy during analysis. All temperatures recorded in Fahrenheit were converted to Celsius and conductivity measurements taken in different units using the same equipment were converted to microsiemens for consistency. The data from the current study will be made available to the SWRCB's SWAMP database by Gold Ridge RCD in a format suitable for input into the STORET system.

Statistical analysis of the dataset was conducted to identify significant differences between sample sites. To prepare the dataset for analysis, the non-detectable (ND) readings for phosphorous, nitrate and TSS were assigned a value equal to half the detection limit to allow for statistical analysis (i.e., if the reporting limit was 0.10, a value of 0.05 was assigned). Since the samples were collected at various days and times with varying effects from recent storm events, we summarized rainfall data for each sample collected (storm size, antecedent ppt., and time since rainfall), using Bodega Marine Lab and Occidental automated rain gauges. Ambient temperature was collected at the time of water sampling and this was also used to assist in spatial analysis to detect differences between sites and subwatersheds. Linear Mixed Effects (LME) models were created for each parameter using S-Plus software (version 6.1) using non-parametric methods, because water quality data usually does not have a normal distribution. We cross checked the statistical results from the LME models with Wilcoxon tests (JMP statistical software) in a one-way analysis of variance using the data collected at similar times on the same day across sample sites.

RESULTS & DISCUSSION

Turbidity & Total Suspended Solids

Turbidity is essentially the cloudiness of water, assessed in nephelometric turbidity units (ntu)—a measure of light scattering by suspended clay particles. Turbidity for all sites sampled ranged from zero to 240 ntu (Appendix A). The lowest measurements in the combined Gold RCD and volunteer sampling data set were taken at the EST, SC2, SC4 and TAN sites. This data was from year-round sampling, with only a handful of storm events. The highest reading of 240 ntu was taken at the SCS site during the 12/30/05 storm. This storm totaled less than one inch precipitation, with more than two inches of antecedent precipitation in the three proceeding days.

PCI also measured turbidity during their supplemental storm sampling effort. These values ranged from 13 to 1000 ntu. The lowest values were recorded at the SCMP and COL sites, with the highest value also recorded at the COL site on 5/18/05. Total rainfall for that storm was 2.1 inches, with no antecedent precipitation.

Total suspended solids (TSS) refers to the portion of the sediment load that is suspended in the water column. TSS was measured at nine sites (with a significantly smaller sample size than turbidity) and ranged from 2.5 to 42 mg/L (Appendix A). The lowest values were from the BOD and EST sites and the highest value was from NOL.

In general, streams are typified by naturally low levels of turbidity (less than 5 ntu), outside of rainy periods (CCWI 2008). For this reason, "turbidity is regarded by many as the single most sensitive measure of the effects of land use on streams." (MacDonald et al. 1991). Human activities that disturb land and increase impervious surfaces, such as agricultural and residential development and road building, increase sediment input to streams during rain storms that create turbid conditions.

Excess turbidity reduces light, which decreases aquatic plant life, reducing benthic organisms and ultimately fish populations. High turbidity levels also affect salmonids by causing reduced feeding rates, reduced growth rates, damage to gills, and fatality.

The detrimental effects of turbidity on fishes increase in relationship to the persistence, or duration, of turbid conditions. Newcombe (2003) found that turbidity levels of 55 ntu caused significant impairment to clear water fishes after one day and severe impairment after four months. Turbidity levels above 150 ntu caused significant impairment after three hours and severe impairment after 2 weeks. Turbidity levels above 400 ntu caused significant impairment for any duration and severe impairment after just two days. For this study, significant impairment represents moderately serious sublethal impacts like reduced growth rate and reduced habitat size and severe impairment represents serious impacts, including lethal and paralethal effects (those resulting in reduced rate of survival from one life stage to the next even if not causing direct mortality). Turbidity levels as low as 40 ntu have also been shown to reduce foraging success of brook trout by 80% (Schwartz et al. 2008).

Direct effects of suspended sediment on salmonids are only known to occur at relatively high levels, with an impaired ability to capture prey at concentrations of 300 to 400 mg/L and mortality at greater than 20,000 mg/L (MacDonald 1991). Indirect detrimental affects on salmonids, benthic invertebrates and other aquatic life can occur at lower levels. High concentrations of TSS affect aquatic life similarly to high turbidity, namely by: 1) acting directly to kill fish or reduce their growth rate and resistance to disease; 2) preventing successful development of fish eggs and larvae by clogging; 3) modifying natural movements and migrations of fish; and 4) reducing the abundance of food available to fish (USEPA 1986).

Maximum turbidity measurements in the Salmon Creek Watershed ranged from 9.58 to 240 ntu for Gold Ridge RCD and volunteer monitoring sites, and from 218 to 1000 ntu for PCI's storm sampling effort (Appendix A). These levels were high enough to cause significant and severe impairment to fish even if they only persisted for one hour (Newcombe 2003). Because these sites were sampled at one point in time, the duration of turbid conditions is not clear and it is not possible to determine whether levels of turbidity above 150 ntu may have persisted long enough to significantly impair fish.

The North Coast RWQCB mandates that turbidity levels not be increased more than 20% above naturally occurring background levels (NCRWQCB 2007). The national criterion for TSS states that: "Setteleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than ten percent from the seasonally established norm for aquatic life" (USEPA 1986). Natural background levels of turbidity and TSS have not been established for the Salmon Creek Watershed.

Temperature

Water temperature was collected during every site visit and ranged from 4°C to 23.50°C for all sites. The lowest mean and maximum temperatures were recorded at MAR and were 7.72°C and 11.63°C, respectively. The VFFR site had the highest mean temperature of 13.88°C and the highest maximum temperature of 23.50°C (Appendix A).

Stream water temperature is affected by variables such as climate, exposure to solar radiation, stream velocity and depth, inflow of groundwater and tributaries, and turbidity. The primary human activities that affect water temperature include vegetation removal, water withdrawal and discharge, and land use changes that increase sediment input. The optimal temperature range for most salmonid species is around 12-14°C (MacDonald et al. 1991), though this is believed to increase to 18°C for steelhead (Raleigh et al. 1984). Welsh et al. (2001) found that no coho salmon were observed in Mattole River tributaries with maximum weekly maximum temperatures (MWMT) greater than 18°C. Lethal temperatures for adult salmonids depend on variables such as local adaptation, acclimation temperature and duration of increased temperatures but are generally in the range of 20-25°C (MacDonald et al. 1991). McMahon (1983) noted that disease and infection increase markedly for coho salmon at temperatures as low as 12.8°. Spawning adults, eggs and larvae are much more sensitive to high temperatures. Fortunately, these life stages generally occur in the Salmon Creek Watershed between November and May when temperatures are cooler.

There is some speculation that salmonids in California's central coast streams have adapted to warmer water temperatures. UCCE's Russian River Coho Salmon Broodstock Monitoring Program found that, though oversummer survival estimates for coho on Russian River tributaries were negatively correlated with MWMT, survival did not decrease markedly until MWMT reached almost 22°C and there was some survival (>0.10) above 24°C (Obedzinski at al. 2008). Due to the geographic proximity of Salmon Creek to the Russian River, it may be reasonable to expect similar trends in salmonid survival in relation to temperature. Temperature data loggers would need to be utilized to determine MWMT at the Salmon Creek monitoring sites.

Water temperatures exceeded 20°C on a total of nine occasions at the following sites: VFFR (three times), EST (two times), FRB (one time), SCS (one time) and BOD (one time).The warmest temperatures were recorded between June and September.

The North Coast RWQCB mandates that temperatures are not to be increased by more than 5°F above natural receiving water temperature (NCRWQCB 2007). Unfortunately, natural background temperatures are unknown.

Dissolved Oxygen

Dissolved oxygen (DO) refers to the amount of oxygen dissolved in water. DO measurements for the sites sampled ranged from 1.47 to 28.5 mg/L (Appendix A). The lowest DO levels were recorded at TAN, SC2, BOD and FAY.

DO is critical to the survival and growth of aquatic organisms and to the decomposition of organic material. Inputs of organic matter and pollution can decrease DO levels by increasing bacterial consumption of oxygen required to break those substances down. Increases in temperature and salinity also decrease DO. Clogging of gravels with fine sediment inhibits water with higher concentrations of DO from delivering oxygen to fish eggs and alevin.

DO concentrations generally vary between the surface water and that flowing through the alluvial material in the streambed, with intergravel DO concentrations being lower than the well-aerated surface waters. The appropriate DO values for embryo and larval stages of salmonids were obtained by assuming that a difference of 3 mg/L between intergravel and water column DO would adequately maintain DO levels within the gravel (USEPA 1986)

DO levels lower than 3 mg/L are lethal to juvenile and adult salmonids, but the limit to avoid acute mortality in embryo and larval stages is 6 mg/L (Raleigh et al. 1984, McMahon 1983). Moderate production impairment occurs for embryo and larval stages and other life stages at 8 mg/l and 5 mg/L, respectively (EPA 1986). Based on the beneficial use of spawning, reproduction and development, the North Coast RWQCB set criterion in Salmon Creek at 7.0 mg/L, with a minimum limit of 9.0 mg/L during spawning, embryo and larval stages (generally between November and May).

DO concentrations in the Salmon Creek Watershed fell below the lower lethal limit of 3.0 mg/L on seven separate occasions at the following sites: BOD (three times) FAY (one time), TAN (one time), SC2 (one time) and SC4 (one time). All values below 3.0 mg/L were recorded in September and October but only once were they associated with high water temperatures. DO concentrations fell below North Coast RWQCB's criterion of 7.0 mg/L on 123 occasions at 14 of the 17 sites sampled—all sites except for MAR, SCMP, TAN2, which are in the upper mainstem and middle Tannery Creek. These low DO levels occurred during all months and only six times were associated with temperatures above 20°C. SCS and SC4 had the highest number of readings below 7.0 mg/L, with low levels of DO persisting for months on end. Twelve of the 17 sites also had levels below North Coast RWQCB's recommended 9.0 mg/L during the critical spawning and incubation period on a total of 24 occasions.

Nutrients

Nitrate (NO_3) is an inorganic form of nitrogen that is soluble and therefore subject to leaching and biological uptake. Nitrate values at all sites sampled ranged from 0.01 to 5.0 mg/L (Appendix A). The highest measurements were from samples taken at SCS and SC4. Because nitrate as nitrogen cadmium reduction tests conducted with the Hach colorimeter are extremely sensitive to sampling techniques, results from multiple samplers can vary by greater than ten percent (Hach, personal communication 2009).

Phosphate (PO_4) is the primary form of dissolved phosphorous. Phosphate concentrations were measured through the volunteer monitoring program and ranged from zero to 2.55 mg/L (Appendix A). The Gold Ridge RCD tested for total phosphorous (mg/L). One hundred percent of phosphorous concentrations were below the lab detection limit of 0.10 mg/L for all sites sampled except for the EST site, which had a reading of 0.10 and 0.60 mg/L (Appendix A). Although the samples were labeled as “phosphate”, there is some uncertainty as to whether this refers to total phosphate or free phosphate (not bound to other compounds). It does not appear that the predigestor required to acquire total phosphate concentrations was used, which would mean that the phosphate values recorded during this monitoring effort were actually free phosphate concentrations. Method #8167 protocols for tests of both forms of phosphate can be found on the Hach website.

Nitrate-nitrogen, phosphate and phosphorous are not directly toxic to fishes but, where sunlight is available, these chemical nutrients stimulate primary production. Excessive inputs of these nutrients, known as eutrophication, can result in abundant plant growth and decay which depletes dissolved oxygen and can degrade habitat quality. One study indicated that a nitrate concentration of less than 0.3 mg/L would likely prevent eutrophication (Cline 1973). Only one sample at the estuary site had a concentration above 0.3 mg/L.

The national drinking water standard for nitrate-nitrogen is 10 mg/L. This is based links between nitrate concentrations above 10 mg/L and the occurrence of methemo-globinemia, a syndrome which affects human infants (USEPA 1986). The EPA did not establish standards for nitrate in freshwater streams because “concentrations that would exhibit toxic effects on warm or coldwater fish could rarely occur in nature” (USEPA 1986). All sites sampled within the Salmon Creek Watershed had nitrate levels well below drinking water standards.

Although the EPA did not set a freshwater criterion for phosphorous, they set the “desired goal” for the prevention of plant nuisances in streams not discharging directly into lakes at 0.1 mg/L (USEPA 1986). The EST site, which generally was below the detection limit for phosphorous, had one value of 0.60 mg/L on 1/9/2007.

Chlorine

Chlorine is a highly toxic gas that is very reactive and quickly bonds with other compounds in water. It is a common household ingredient in bleach and other cleaners and generally enters the water through runoff and direct discharges from industrial and municipal sources. The volunteer monitoring program sampled for total chlorine at all sites. Total chlorine concentrations ranged from zero to 3.00 mg/L. Fourteen of the 17 sites had zero values on multiple occasions. Concentrations were highest at SCS, FRB, BOD and EST. Chlorine concentrations exceeded 1.0 mg/L one time, on different dates, at each of these four sites.

Volunteers also sampled free chlorine at seven sites. Concentrations ranged from zero to 1.33 mg/L. BOD, FRB, SC2 and SC7.5 had the lowest readings of zero on a total of eight samples on six different dates. The highest reading of 1.33 mg/L was measured at BOD on September 4, 2007. The only other free chlorine concentration above 0.5 mg/L was 0.83 mg/L, measured at SC7.5 on September 5, 2007.

Because the risks associated with chlorine lessen significantly once the chlorine molecules have bonded, free chlorine poses the greatest threat to aquatic life (GRRCD 2007). Thirty-three freshwater species were exposed to total residual chlorine in water and the acute lethal values range from 0.028 to .710 mg/L. Tests of two freshwater invertebrates and one fish species indicate that chronic lethal values for the species tested ranged from .0037 to over .078 mg/L (USEPA 1986).

The EPA set the chronic criteria for chlorine in freshwater at 11 μg/L (0.011 mg/L). That means the four-day average concentration of total residual chlorine is not to exceed 0.011 mg/L more than once every three years on the average. This is the EPA's best scientific estimate of the average amount of time it will take an unstressed system to recover from a pollution event which inputs greater than that amount of chlorine. The EPA's acute criteria is 19 μg/L (0.019 mg/L), meaning that the one-hour average concentration should not exceed this amount more than once every three years on average (USEPA 1986).

Total chlorine concentrations were greater than the EPA's acute criterion of 0.019 mg/L at ten sites on the mainstem, estuary and tributaries on a total of 114 different occasions. Because chlorine sampling was limited to one point in time monthly, there is no way to establish four-day or even one-hour average concentrations. However, both total and free chlorine data are suspected to be inaccurate due to the interference of oxide manganese, which creates the same chemical reaction as a positive chlorine test. Where there is no known source of chlorine in natural waterways, it is likely that all recorded concentrations of chlorine can be attributed to oxidized manganese (Hach representative, personal communication 2009). For each water quality sample collected, samplers must perform the treatment outlined in Hach (2009) to account for the effect of this interference and obtain accurate concentrations of free and total chlorine.

Water Chemistry

pH

pH refers to the concentration of hydrogen ions in water and determines the acidity or alkalinity of water. pH readings at the monitoring sites ranged from 5.60 to 9.58, with a mean range of 7.34 to 8.21 (Appendix A). The highest reading occurred at the estuary site (EST) and the lowest at SC2.

Natural pH levels are affected by geology vegetation and soil types in the streambed and surrounding the stream, and the availability of carbon dioxide. Algae increases pH, while decomposing organic matter and root respiration decreases pH. A pH range of 5-9 is not directly toxic to fishes, but a decline from 6.5 to 5.0 resulted in a progressive reduction of salmonid egg production and hatching success (USEPA 1986). The emergence of benthic macroinvertebrates also declines below a pH of 6.5. Changes in pH can also have critical effects on water chemistry. For example, the solubility of many metal compounds changes greatly with pH.

The optimal pH range for salmonids is 6.5-8.0 (Raleigh et al. 1984) and the North Coast RWQCB has set a criterion of 6.5-8.5, with levels not to exceed 0.5 above normal ambient pH levels within this range (NCRWQCB 2007). Background pH levels have not been established for the Salmon Creek Watershed but the estuary clearly has a higher pH than the mainstem or tributary sites, with pH exceeding the North Coast RWQCB criterion on nineteen occasions. A handful of other sites had one or two readings outside of the recommended range but only SC2 and THU had three or more occurrences of this.

Conductivity

Conductivity is a measurement of the number of dissolved ions in water. It is an indicator of possible pollution rather than a primary contaminant. Due to high salinity, specific conductivity was highest in the estuary where it ranged from 133 to 13,150 microsiemens per centimeter. Maximum values at all other sites ranged from 241 to 440 microsiemens (Appendix A).

In a pristine environment, the conductivity of rain water is zero. Soils, geology, rainfall groundwater recharge and evaporation are natural factors affecting conductivity. Sewage discharge, agricultural runoff and inputs of organic compounds like oil and alcohols can cause changes to naturally occurring conductivity. The USEPA did not establish a national criterion due to the relative insensitivity of aquatic biota to conductivity (USEPS 1986). However, the North Coast RWQCB has objectives for conductivity that range in value from 100 to 1,300 microsiemens per centimeter, depending on the water body. There is no numeric objective established for Salmon Creek.

Salinity

Salinity is a measure of salt in water and is related to conductivity because dissolved ions increase salinity as well as conductivity. Salinity data was collected at most sites on the mainstem, tributaries and estuary of Salmon Creek. In this way salinity could be accounted for when considering results for conductivity. Salinity in the estuary ranged from 0.09 to 8.57 ppt. Salinity at all other inland sites ranged from 0.00 to 0.20 ppt (Appendix A).

The average salinity of ocean water is 35 ppt (grams of salt per liter of water). Freshwater salinity is usually les than 0.50 ppt and brackish water, like that in the estuary, generally ranges from 0.5 ppt to 17 ppt (ONR 2009). Rainfall and river runoff can create variations in salinity.

Every organism has a tolerable salinity range. For salmonids, that range varies based on life stage, which determines residence in freshwater or ocean water and timing of smoltification. One study showed that coho salmon fry could survive salinities as high as 29 ppt, provided they had been acclimated to lower salinities for 35 days (Groot and Margolis 1991). Salinity tolerance in coho appears to be a function of size and the threshold for survival in sea water is about seven to eight centimeters (Groot and Margolis 1991). The salinity of Salmon Creek and its tributaries is clearly within the expected range for freshwater, which is suitable for salmonid incubation, rearing and migration.

Subwatershed Analysis

Spatial analysis was conducted to detect differences in water quality between sites and subwatersheds. The limited samples size from each site reduced the statistical power to compare sites so the analysis focused on subwatershed effects. Trends over time were not possible to assess because of changes in data collection methods and annual climatic variation from year to year. However, patterns detected for certain parameters, such as turbidity, will provide adequate baseline data from which to detect future water quality changes in the watershed.

Turbidity and TSS concentration were the result of recent storm events and location in the Salmon Creek watershed. Turbidity concentrations were highly variable depending on the timing of sample collection until storm event factors were statistically accounted for (Figure 2).

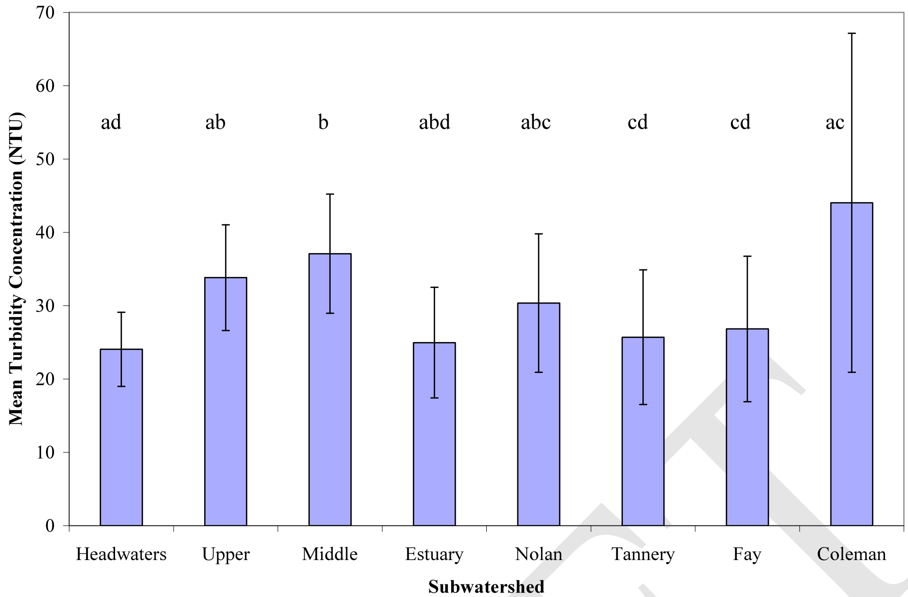

Figure 2: Mean turbidity concentration (Nephelemtric Turbidity Units) by subwatershed with Standard Error bars. Different letters combinations represent significant statistical differences (*P*<0.10) from LME models which controlled for time since storm and amount of precipitation.

Results from our data driven models for the relationship of turbidity and time since precipitation are presented in Figure 3. Though Coleman Creek had the highest single sample value, on average Middle Salmon Creek had greater turbidity for a longer time following storms than Coleman, Tannery, or Fay Creeks (Figure 3). Tannery and Fay Creeks were also lower in turbidity than Upper and Middle Salmon Creek. The biological affect of turbidity on salmon health becomes more of a concern with regard to the duration stream water is turbid and unclear (Newcombe 2003). For the modeled rain event of more than two inches, Middle Salmon Creek turbidity remains over the 20 NTU threshold for three times as long as Tannery and Fay Creeks (Figure 3).

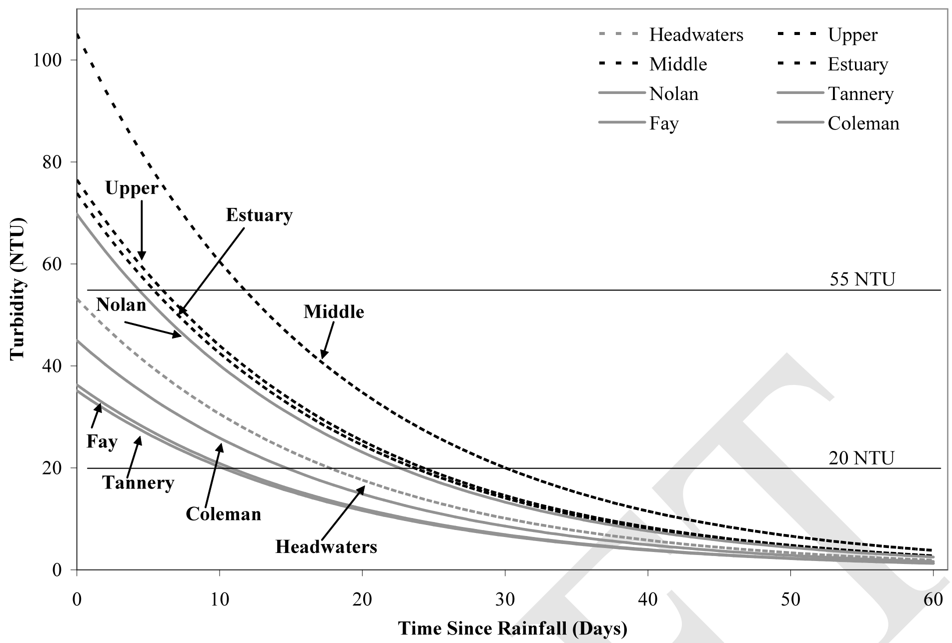

Figure 3: Turbidity concentration as a function of time since rainfall for each subwatershed (dash lines = mainstem Salmon Creek, solid lines = tributary streams) given a storm size over two inches precipitation.

The TSS data was highly variable given the low sample size. As a result, detecting significant differences was difficult and the results should be interpreted cautiously because the time since rainfall was not able to be included in this statistical analysis. The precipitation amount in the previous 24 hours before sample collection provides some confidence in the result that Nolan Creek had higher TSS than the other subwatersheds, except for Middle Salmon Creek (Figure 4). However, more TSS data will be needed to confirm this and strengthen the correlation between TSS and Turbidity (R^2=0.45 currently). All the TSS data from Tannery Creek was below the detection limit (0.15 mg/L). With the existing dataset, TSS will not be useful for baseline trend monitoring of sediment reductions in the Salmon Creek water quality. However, the TSS dataset should be strengthened by continuing to collect TSS and turbidity in conjunction with systematic storm event sampling.

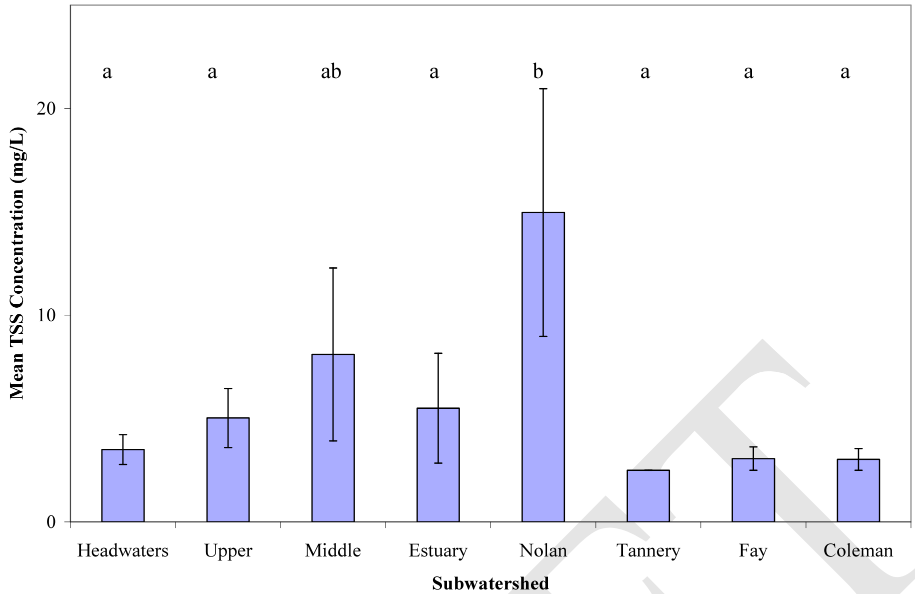

Figure 4: Mean total suspended solid (TSS) concentration by subwatershed with Standard Error bars. Different letters combinations represent significant statistical differences (*P*<0.10) from LME models which controlled for rainfall amount in previous 24 hours.

Water temperature was also highly variable depending on timing and location of water quality sampling. Ambient air temperature was measured when water samples were analyzed which has a large affect on stream temperature. The LME model for water temperature controlled for ambient temperature to detect significant differences between subwatersheds (Figure 5). The estuary was clearly the warmest subwatershed. Interestingly, Salmon Creek significantly cooled from the upper to the middle subwatershed. Nolan Creek was also colder than Headwaters and Upper Salmon Creek. The other tributaries were no different than the mainstem.

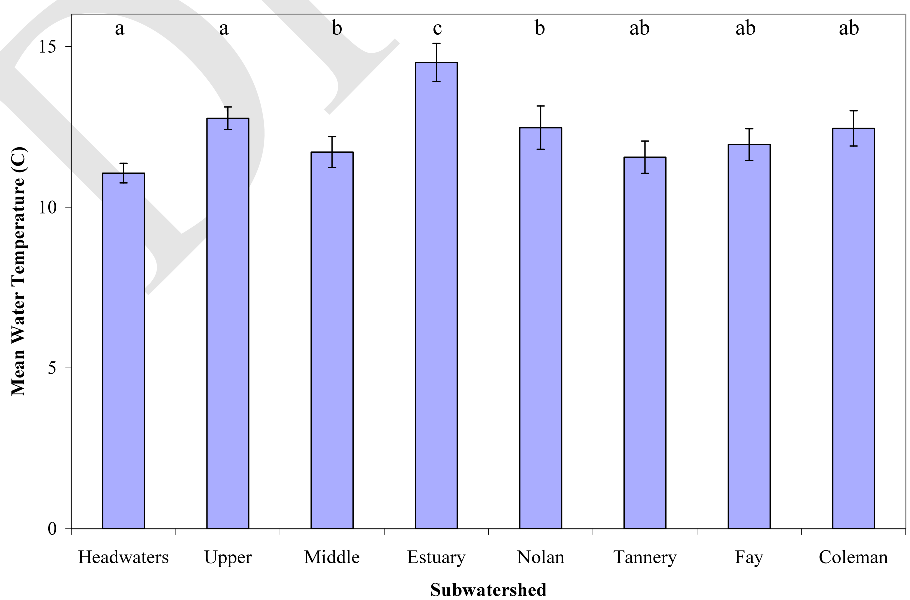

Figure 5: Mean water temperature (Celsius) by subwatershed with Standard Error bars. Different letters combinations represent significant statistical differences ($P<0.10$) from LME models which controlled for ambient temperature.

Dissolved oxygen was also influenced by ambient temperature – dissolved oxygen decreased as air temperature increased. Nolan Creek had the highest dissolved oxygen and all other subwatersheds were not significantly different (Figure 6). This was surprising given the geomorphic variation between subwatersheds. Locations with steeper stream gradients usually have higher dissolved oxygen because of more re-aeration through turbulence.

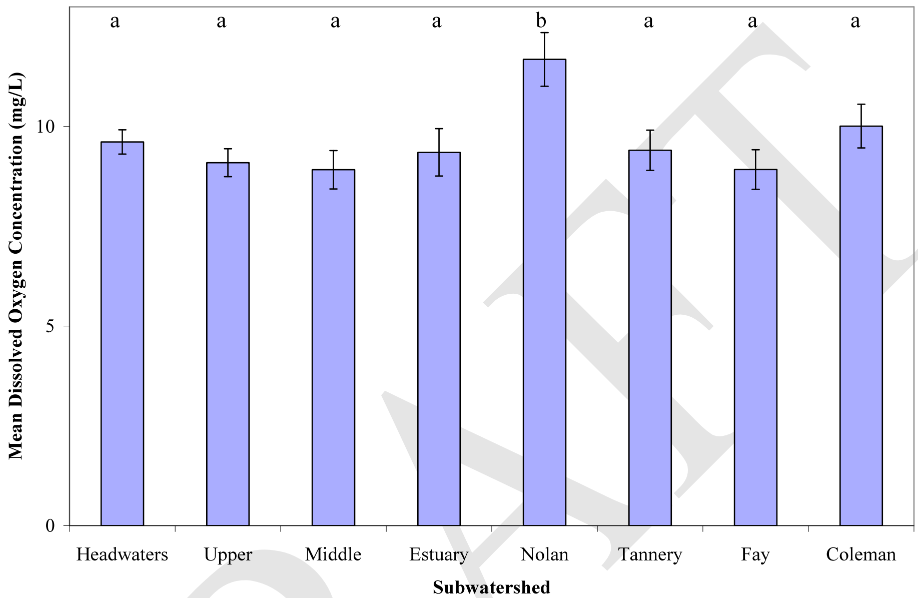

Figure 6: Mean dissolved oxygen (DO) concentration by subwatershed with Standard Error bars. Different letter combinations represent significant statistical differences ($P<0.10$) from LME models which controlled for ambient temperature.

Nutrients were very low on average across subwatersheds. Nitrate was highest in Upper Salmon Creek, but it was only significantly greater than Tannery Creek and not different than the other subwatersheds (Figure 7). Similarly, Tannery Creek was not different than the other subwatersheds and only significantly less than Upper Salmon Creek. Storm event factors and time of year were not useful in statistical analysis of nutrient and chlorine results.

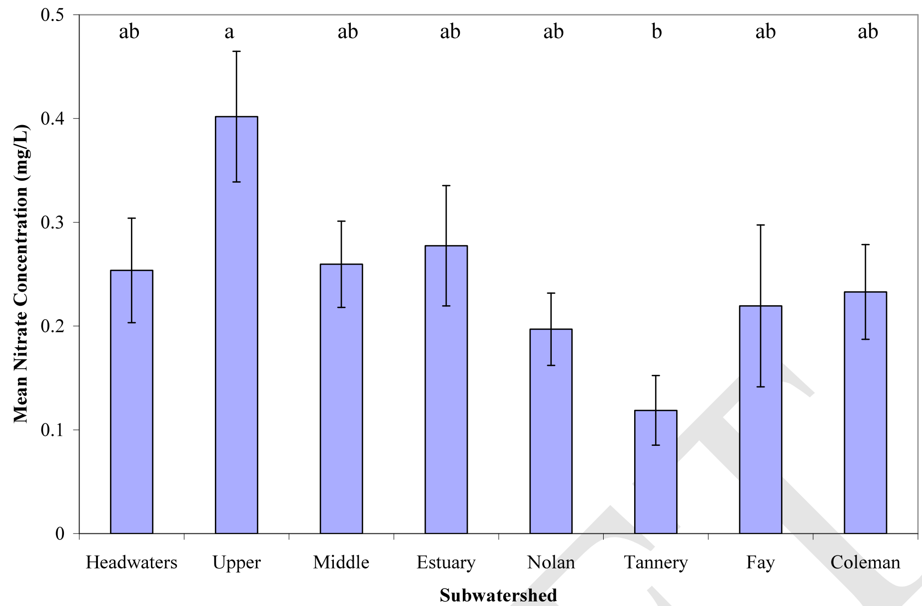

Figure 7: Mean nitrate (NO^3) concentration by subwatershed with Standard Error bars. Different letter combinations represent significant statistical differences ($P<0.10$) from LME model results.

Phosphate was significantly lower in Tannery and Fay Creeks compared to Upper and Middle Salmon Creek and Nolan Creek (Figure 8).

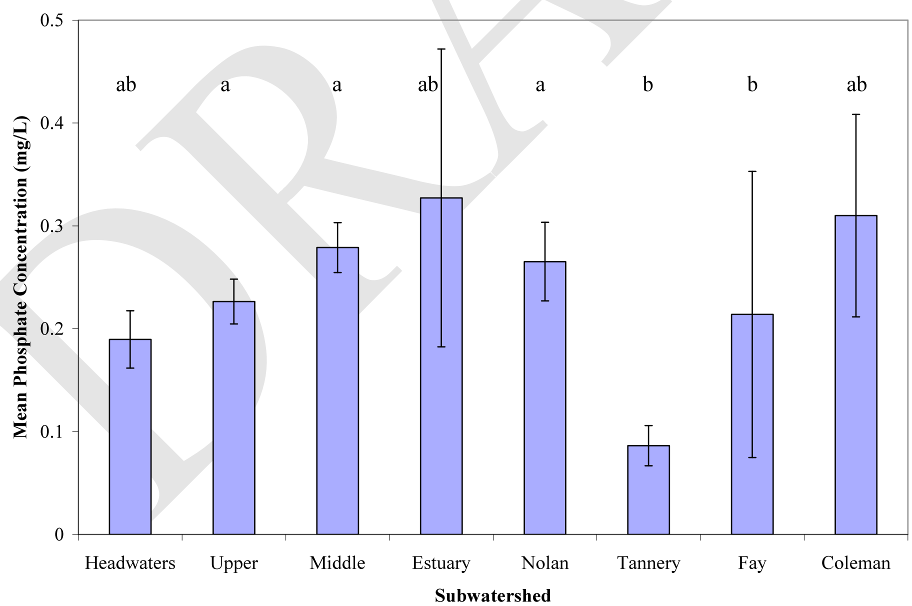

Figure 8: Mean phosphate (PO^4) concentration by subwatershed with Standard Error bars. Different letter combinations represent significant statistical differences ($P<0.10$) from LME model results.

Total phosphorous was not different across subwatersheds (Figure 9).

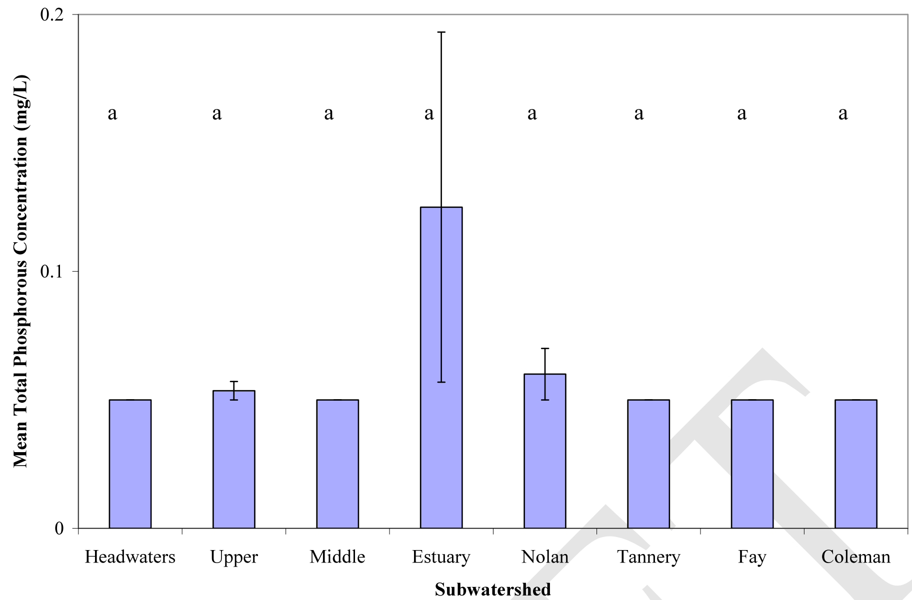

Figure9: Mean total phosphorous concentration by subwatershed with Standard Error bars. Different letter combinations represent significant statistical differences ($P<0.10$) from LME model results.

Free chlorine may be a result of water treatment or minerals leaching from geologic sources. Middle Salmon Creek had significantly greater free chlorine than the estuary.

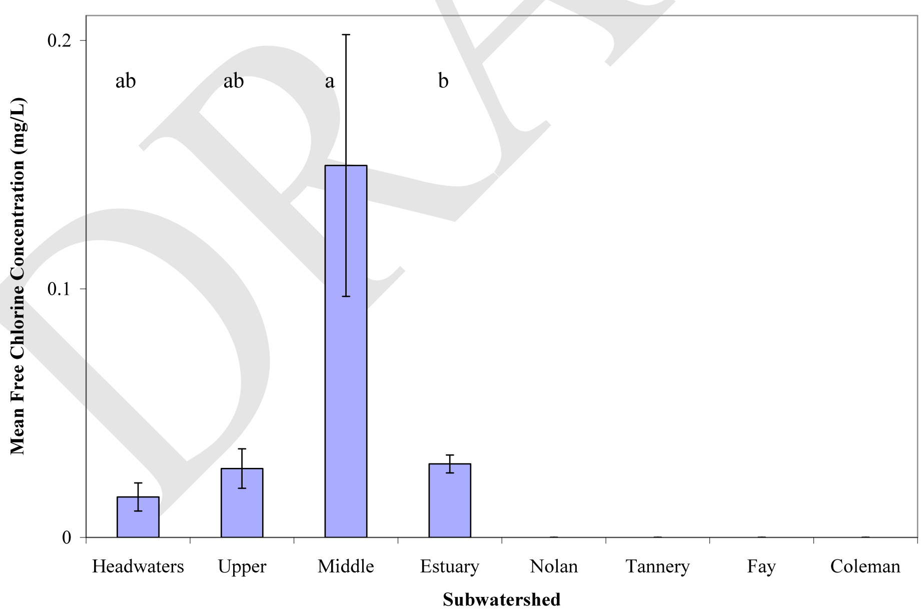

Figure 10: Mean free chlorine concentration by subwatershed with Standard Error bars. Different letter combinations represent significant statistical differences ($P<0.10$) from LME model results.

Total chlorine was not different across subwatersheds (Figure 11).

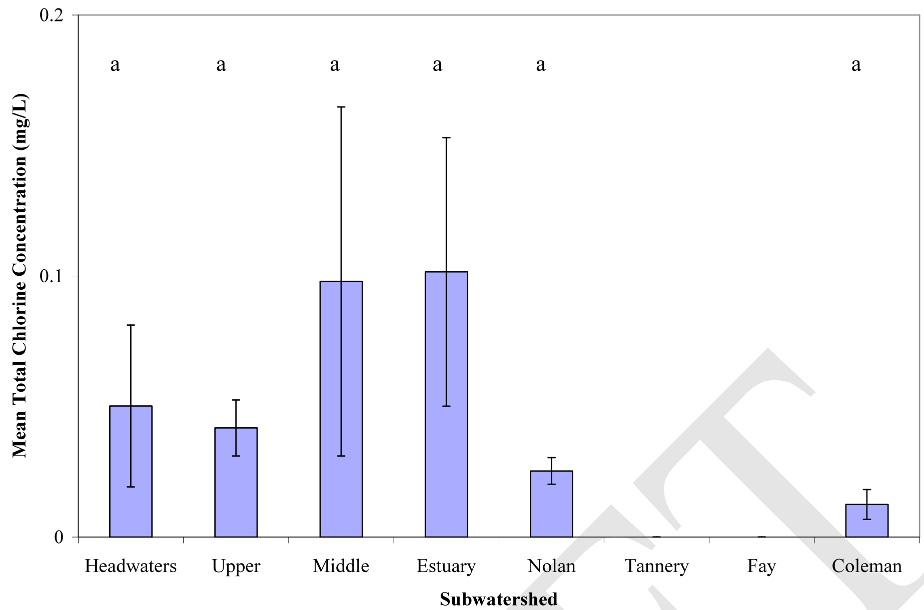

Figure 11: Mean total chlorine concentration by subwatershed with Standard Error bars. Different letter combinations represent significant statistical differences ($P<0.10$) from LME model results.

Specific conductivity was clearly greatest in the estuary by an order of magnitude. Conductivity was affected by ambient temperature and this was controlled for in the LME model – stream conductivity correlated to ambient air temperature. Similarly, conductivity was reduced during storms and increased as the time since rainfall increased, but this relationship had less statistical power. Upper Salmon Creek had significantly greater conductivity than Nolan Creek and these were not different than the other subwatersheds (Figure 12).

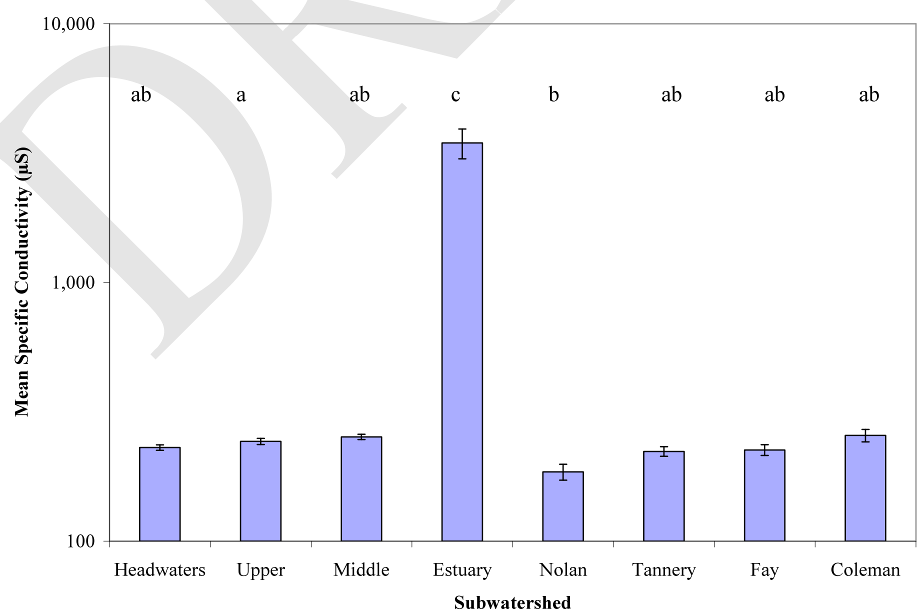

Figure 12: Mean specific conductivity by subwatershed with Standard Error bars. Different letter combinations represent significant statistical differences ($P<0.10$) from LME model which controlled for ambient temperature.

Stream conductivity also correlated to other water quality parameters, as was expected. Turbidity, total phosphorous, and dissolved oxygen significantly decreased as specific conductivity increased. In contrast, salinity, pH, and water temperature significantly increased as conductivity increased. Nitrate, phosphate, and chlorine did not correlate to specific conductivity.

Mean pH results were highly variable across subwatersheds. pH of stream water was also affected by storm events – pH was reduced during storms and increased as the time since rainfall increased. This is likely the result of surface water directly delivering normal more acidic rainfall to streams during rainfall events. The estuary had clearly higher pH than the other subwatersheds, except for Nolan Creek. Middle Salmon Creek had significantly less pH than Headwaters and Upper Salmon Creek as did Tannery and Fay Creeks.

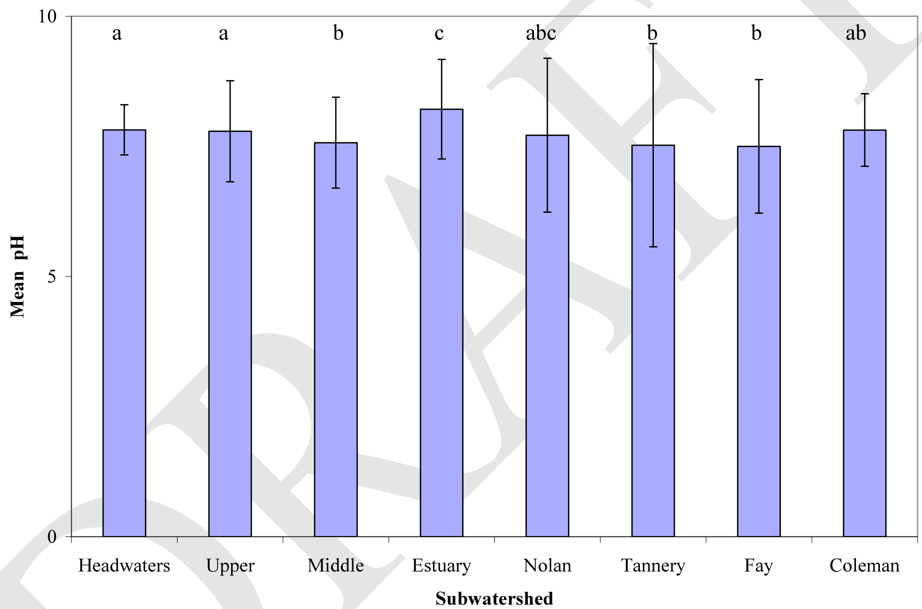

Figure 13: Mean pH by subwatershed with Standard Error bars. Different letters combinations represent significant statistical differences ($P<0.10$) from LME model which controlled for the time since rainfall.

Future Recommendations & Monitoring Objectives

The Salmon Creek Highlanders (SCH) began conducting a citizen water monitoring program at 5 sites in the upper Salmon Creek Watershed in conjunction with the Community Clean Water Institute (CCWI) in June 2002. The sites are in the headwaters of Salmon Creek, Fay Creek, Thurston Creek and Tannery Creek. A sixth site in the middle reach of Salmon Creek was added a year later and monitoring of all sites has been ongoing. We recommend that the Gold Ridge RCD evaluate the data and reports resulting from this water quality monitoring effort. Integrating CCWI's data set with that produced by the volunteer and RCD monitoring programs may allow for enhanced site comparisons and trend evaluation, which could lead to the identification of problem sites and possible remediation projects. CCWI's data may also prove useful in establishing natural background conditions for Salmon Creek, particularly as some of their sites were in the more pristine locations in the upper watershed.

We recommend ongoing systematic sampling of RCD sites at the same approximate time and in relation to storm events. If possible, water quality measurements should be taken over consecutive days following each storm to determine persistence of excessive pollutants over time such as turbidity and nutrients. Ideally, sampling would continue until levels are below thresholds for significant impairment. Plus, flow data should also be collected systematically in the future at all sample sites in order to help interpret water quality results given the importance of hydrologic factors.

The sample size for the TSS data was insufficient to identify trends and enable accurate site or subwatershed comparisons. Where possible, TSS data should be collected routinely to increase the sample size and enable the correlation of turbidity with TSS results for the Salmon Creek watershed.

Because high summer temperatures were recorded at several sites within the watershed, it is recommended that continuous data loggers be deployed at the monitoring sites to provide reliable average and maximum summer temperature data to determine limiting factors to coho and steelhead populations. Similarly, 25% of dissolved oxygen samples were below impairment levels at multiple sites and continuous monitoring should be conducted in conjunction with temperature monitoring.

The methods used to sample for nitrate, phosphate and chlorine should be evaluated to insure the highest level of accuracy possible using the equipment. Nitrate as nitrogen cadmium reduction tests conducted with the Hach colorimeter are extremely sensitive to sampling techniques. Shaking samples at a different angle or even using different hands can produce results that vary by greater than ten percent, even when shaken for the same period of time (Hach, personal communication 2009). Obviously, shaking techniques are difficult to standardize among multiple volunteers but making the best effort to do this will result in more reliable data.

In order to test accurately for total phosphates, rather than free phosphates, volunteers using the Hach colorimeter should be trained to use the predigestor required to acquire total phosphate concentrations. Protocols for this technique can be found on the Hach website. Similarly, for the collection of chlorine data, it is recommended that all samplers be trained to perform the treatment outlined in Hach (2009) to account for the effect of oxidized manganese and obtain accurate concentrations of free and total chlorine.

It would be ideal to compare the water quality results with DFG's biological sampling effort to determine how fish presence/absence data correlates to water quality factors. Analyzing this data with future biological sampling would allow for the evaluation of water quality conditions in relation to the presence and abundance of steelhead. This would help identify limiting factors specific to Salmon Creek and its tributaries.

More samples are needed from the Nolan Creek site to provide accurate baseline data for that location. We recommend continued monitoring of that site to document both conditions in Nolan Creek and possible contributions to conditions at the BOD site downstream of the confluence with Salmon Creek.

SUMMARY

Overall, water quality was fair to good in the Salmon Creek Watershed, with tributary streams exhibiting better conditions than the mainstem given the water quality dataset to date. This was supported by benthic macroinvertabrate samples collected from stream substrate. The resulting index of biological integrity (IBI) rated the watershed health as "fair". However, the percent of pollution intolerant invertebrates were 32, 12, and 20 in Fay Creek, and Upper and Middle Salmon Creek, respectively. Tributaries were similar but not equal in water quality and may be ranked in order. The cleanest subwatershed was Tannery Creek, followed by Fay Creek, then Coleman Creek, and then Nolan Creek.

The water quality results presented in this report indicate that, in general, Salmon Creek has reasonable water quality to support the identified beneficial uses for the watershed. Certain constituents, such as turbidity, temperature, dissolved oxygen, and chlorine values that did not meet water quality criteria beyond thresholds at certain points in time. Further investigation and monitoring is needed to document the duration and running average of these parameters. This type of monitoring will require daily and hourly sampling and analysis through a given storm hydrograph to understand if conditions of risk to aquatic organisms persist. In the case of chlorine, additional training and quality control for sample collection and analyses is required to improve the confidence in the results.

With regard to using these results for restoration planning, results indicate that the tributaries generally have higher water quality than the mainstem. However, tributaries like Tannery and Coleman have TSS and turbidity values that are higher than other locations in the watershed. While trends over time could not be established, the water quality monitoring and results summarized in this chapter are useful as the baseline for future trend development. Water quality monitoring is recommended in conjunction with watershed restoration activities to document long-term restoration project effectiveness. Ideally, ongoing water quality monitoring in the Salmon Creek Watershed will be used to document changes in the system over time as a result of both natural factors and human activities, as well as to support the enhancement of conditions that benefit salmon and steelhead.

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