Ketchikan Creeks:
Stormwater Quality Assessment

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1.0 Summary

Physical and chemical characteristics and the biotic community were sampled from three streams within the urban boundaries of Ketchikan, Alaska to assess potential impacts to water quality due to urban development and stormwater runoff. Sampling was conducted in Carlanna, Hoadley, and Ketchikan creeks during summer base flow, one fall storm event in 2013, and 2014 spring runoff at upstream reference sites and downstream urban locations. Samples also were collected from one outfall in each drainage during spring 2014. Water samples were analyzed for alkalinity, hardness, ammonia-N, nitrate + nitrite-N, total and total dissolved phosphorus, dissolved organic carbon, settleable solids, and dissolved copper, lead and zinc. Sediment samples at each stream site were collected during base flow and spring flow, and sediment samples at outfall sites were collected during the spring flow sampling event. All sediments were analyzed for metals, and the most downstream sediment sample in each stream was analyzed for polycyclic aromatic hydrocarbons (PAHs). Water samples for total fecal coliform bacteria were collected on six dates from August through September and on four dates in May to create three seasonal 30-day averages, based on four sample dates. Due to mistakes with analytical processing, only six samples were able to be analyzed in August and September, forcing two of the sample results to be used for both the August and September averages.

Field water quality measurements included turbidity, specific conductivity, temperature, dissolved oxygen, and pH. Qualitative habitat assessments and substrate size measurements were conducted at each sampling site. Stream discharge was measured on each sampling date and at each wadeable sampling site. Juvenile salmonids and resident fish were sampled from each stream in September 2013 and benthic macroinvertebrates were collected at each site in May 2014.

Stream surveys were conducted to identify all outfalls discharging into each stream. Outfall locations on each stream were photographed and mapped during a dry period in association with the spring runoff sample. Outfall locations were compared with previously mapped locations completed by the City of Ketchikan. Only two outfalls were located on Carlanna Creek which was consistent with the previous survey. We located 16 total outfalls on Hoadley Creek, six more than those mapped previously by the City of Ketchikan. We also mapped 24 outfalls draining into Ketchikan Creek in addition to those previously surveyed, for a total of 45. The majority of outfalls were constructed of galvanized corrugated metal, a possible source of zinc into these drainages.

Alkalinity and hardness were generally low at all sampling sites, increasing the toxicity of metals in these streams. Dissolved metal concentrations were generally highest during summer base flow conditions, with copper concentrations exceeding acute and chronic toxicities in both Carlanna Creek sites and the lower two Ketchikan Creek sites. The most downstream Ketchikan Creek site had dissolved copper concentrations above acute and chronic toxicity levels during all sampling events. Dissolved lead concentrations exceeded acute and chronic toxicities during base flow at sites in Carlanna and Ketchikan creeks. No dissolved metals analyzed for were above acute or chronic toxicity levels during any sampling event in Hoadley Creek. Daily flux for copper and zinc generally

increased in a downstream direction, excluding the large values observed at the upstream Carlanna Creek site during base flow conditions.

Specific conductivity increased longitudinally in Carlanna and Hoadley creeks, with highest values observed during base flow, but Ketchikan Creek specific conductivity was always highest at the upstream sampling location, with the highest values observed during the storm event. Water clarity was clear during all sampling events, with turbidities less than 5 NTU and no detectable settleable solids at all sampling sites. Dissolved oxygen was near saturation during all sampling events in Carlanna and Hoadley Creeks (>90%) but was on average lower in Ketchikan Creek. (85.6%). Concentrations of ammonia-N and nitrate + nitrite-N tended to be higher in Ketchikan Creek as compared to Carlanna and Hoadley creeks, with daily flux greatest during the storm event. The different trends in water chemistry observed at Ketchikan Creek may be explained by the majority of discharge being diverted away from the stream at Ketchikan Lake and then being reintroduced downstream of the upper Ketchikan Creek site. Nutrients were not picked up as the water flowed through the stream because it was piped, making the downstream Ketchikan Creek sites artificially dilute for nutrients not added directly through urban discharge.

Concentrations of metals in streambed sediments were generally below values that could result in biological effects. However, the most downstream Ketchikan Creek site had sediment copper concentrations above threshold effects levels (TEL) values. Additionally, all three streams and outfalls sampled had sediment cadmium and arsenic concentrations above TEL or PEL values. Sediment PAHs were above the TEL value in the Carlanna and Ketchikan creeks outfalls, but were below toxicity levels or not detected in all of the stream sediment samples.

Water samples collected from the stormwater outfalls had lower dissolved oxygen saturation, higher conductivities and turbidities, and elevated concentrations of nutrients and metals in water and sediment samples as compared to the receiving streams. Both dissolved copper and dissolved zinc concentrations were significantly higher in the outfall samples than in their corresponding stream samples. Additionally, sediment copper and zinc concentrations were generally higher in outfalls than in stream samples.

Total fecal coliform concentrations exceeded the most stringent water quality criteria for two 30-day periods from August through September. During these time periods, the geometric means of total fecal coliform concentrations were 47 and 83 cfu/100 ml in Carlanna Creek, 279 and 106 cfu/100 ml in Hoadley Creek and 63 and 76 cfu/100 ml in Ketchikan Creek. Between 50-100% of the individual samples from each site were greater than 40 cfu/100 ml. The Hoadley Creek site showed the highest concentrations of fecal coliform bacteria with a 4-sample geometric mean from August 21 to September 18 of 279 cfu/100 ml and a single sample of 680 cfu/100 ml. However, during the spring flow sampling period, all of the sites were within the allowable limits.

Biotic sampling revealed decreasing stream health between the upstream and downstream sampling locations in Hoadley and Ketchikan creeks. Macroinvertebrate abundance and richness was generally highest at the upstream sites, with the exception of Carlanna Creek, where the upstream site had a lower biotic index score than the downstream site. Minnow trapping could not be completed at all sites due to high water velocities, so only one site on each stream was sampled for fish. We observed atypical morphology for a number of juvenile coho salmon captured, with irregular parr marks and increased height to length ratios.

2.0 Introduction

During storm events, storm drains and drainage ditches carry sediments, oils and grease, nutrients, and metals from parking areas, roads, yards, and fields into surface streams. Concentrations of these pollutants can reach levels that result in health problems from drinking or recreational exposure or effect the health of biotic communities within the affected watershed. Fine sediments flushed into streams can dominate stream beds blocking the flow of oxygen to developing salmon eggs, clog the gills of rearing juvenile salmon or resident fish, disrupt visual feeding activity, and eliminate the living space for aquatic insects. Pollutants can be toxic to fish and aquatic insects particularly during early incubation. Toxins can indirectly affect aquatic organisms by binding with oxygen or increasing the susceptibility to other diseases. Pollutants can also alter the chemical odor of streams, affecting the ability of migrating salmon to locate spawning areas (e.g. Paul and Meyer 2001, O'Driscoll et al. 2010).

The delivery of pollutants to receiving waters and the effect of stormwater on stream hydrology is controlled by the amount of water flowing on the surface compared to water that is filtered through the ground or vegetation. Water flows quickly off of compacted surfaces (i.e. roads, roofs, and parking areas) that are impervious to water flow, picking up sediments and pollutants as it flows. Alternatively, vegetation decreases the energy of rainfall prior to it reaching the ground, slows down surface flows, breaks apart soils and provides a pathway along roots into the soil. In addition to physically slowing down the delivery of pollutants to water bodies, soil microbes and plants can metabolize toxic chemicals, further reducing pollutant loading. Diversion of stormwater into the soil slows down the rate of delivery to surface streams and ameliorates flood flows. The effects of impervious surfaces to storm flow and the organisms in streams and rivers have been well documented (O'Driscoll et al. 2010).

Common constituents of stormwater pollution include suspended sediments, nitrogen and phosphorus, pH, metals (Cu, Pb, Zn, Cd, Cr) polycyclic aromatic hydrocarbons, and fecal coliform bacteria (Bakri et al. 2010, Erikson et al. 2007, Brown and Peake 2006, Han 2006). The concentration and constituents in stormwater varies with land use within the drainage and often increase with impervious surface area and proximity to highways (Mallin et al. 2009, Van Metre and Mahler 2003). Metals and hydrocarbons often are associated with precipitation events that collected road deposits and particles in the air from combustion of fossil fuels (Hwang and Foster 2005, Hoffman et al. 1985). Biotic indices using fish and aquatic invertebrates have been shown to be an important component of stormwater assessment projects (Walsh 2007, Gresens 2007).

The City of Ketchikan had a population of 7,922 according to the 2000 U.S. census which has recently remained relatively constant. Because access to remaining undeveloped land is difficult, little future development is expected. The population is however dense, as is commercial and industrial development on the waterfront. The concern for stormwater runoff pollution increases with the density of development. Stormwater runoff can have significant and adverse effects to water quality and the biotic community and is related to the degree of impervious surfaces that occur with urban and rural development (e.g. Larkin and Hall 1998, Walsh 2007, Davies et al. 2010).

Stormwater infrastructure in the City of Ketchikan was constructed in the 1960’s and 1970’s. Partly in response to recent events including a stormwater pipeline failure in 2008 that caused a landslide, and other identified pipelines in need of replacement, a stormwater management plan was developed in 2011. The management plan inventoried the City’s infrastructure, identified problems, and developed codes for new management (Tetra Tech 2011). The plan did not however address coastal flooding or flooding on larger creeks including Ketchikan, Hoadley, and Carlanna Creeks. Ketchikan and Carlanna Creeks are the two largest basins, extending beyond the city limits and offering hydroelectric power and public water through their lakes.

Carlanna, Hoadley, and Ketchikan Creeks are classified by the Alaska Department of Environmental Conservation (DEC) Category 3 waterbodies. Category 3 waterbodies are those locations where data or information is insufficient to determine whether the State Water Quality Standards (WQS) for any designated uses are attained. Water sampling is necessary to determine if WQS are exceeded, evaluate stormwater impacts to the biotic community, safety for human use, and to test for relationships between water chemistry and stormwater system design.

The objective of this study was to collect water and sediment samples at multiple locations on each stream to determine the effect of urban area on water quality. Additionally, the biotic community was sampled to provide an index of long-term stream health and to compare with previous study results. In 2002, sites on Hoadley and Ketchikan creeks were sampled for macroinvertebrates and basic water chemistry to create a regional biological assessment index. Our macroinvertebrate data was compared with the 2002 data to analyze for any changes to the macroinvertebrate assemblage.

3.0 Methods

The assessment of water quality following stormwater runoff was evaluated in three urban streams: Carlanna Creek, Hoadley Creek, and Ketchikan Creek (Figure 1, Appendix A). Water sample locations, sample collection, analyses, and data management are described in detail in a DEC approved Quality Assurance Project Plan (QAPP). One deviation from the Project Plan was that HOBO water pressure loggers were proposed to be placed in the stream for measuring daily discharge and water temperature but could not be anchored in place due to flashy flow conditions and bedrock. Sampling sites were selected at multiple locations in each drainage to represent variations in the degree and type of upstream development. Water samples were collected in all three streams during summer base flow conditions and during one storm event in 2013 and spring runoff in

2014, as well as at one outfall location in each drainage during spring runoff in 2014. Sediment samples were collected at all sites during spring flow in 2014 (Table 1). Samples were analyzed for metals, nutrients, settleable solids, and other pollutants common in stormwater runoff.

Figure 1. Location of sampling sites for water quality and biotic measurements.

Table 1. Dates sampling was conducted in 2013 and 2014 for water quality, physical characteristics, and the biotic community.

	Sampling Dates
Summer Base Flow	August 6-7, 2013
Fall Storm Event	September 21-22, 2013
Spring Flow	May 3, 2014
Stream Sediment	August 7, 2013; May 3, 2014
Outfall Samples and Mapping	May 2014
Fish	September 25, 2013
Sediment Size Distribution	September 21-22, 2013
Habitat Assessment	September 21-22, 2013
Macroinvertebrates	May 2014

3.1 Sampling Locations

Sampling locations were distributed along each of Carlanna, Hoadley, and Ketchikan creeks and at one known stormwater outfall location in each drainage (Figure 1, Table 2). Sampling sites are located to differentiate between the quantities of upstream development that could contribute to stormwater inputs. The most upstream sampling site in each stream was selected to be upstream of all or most developmental influence, and the most downstream sites were just above tidal influence to maximize urban drainage area between sampling sites. An additional site was selected in Ketchikan Creek due to increased density of development in this drainage and to account for water chemistry differences that may be associated with flow diversion through the powerhouse.

Table 2. Description of stormwater sampling locations.

Stream	Site	Description	Latitude	Longitude
Carlanna Creek	CA01	Carlanna Lake outlet	55.36840 N	-131.69182 W
	CA02	Upstream of Tongass Avenue	55.35807 N	-131.69534 W
Hoadley Creek	HO01	Upstream of Jackson Street culvert at Jackson Heights	55.35881 N	-131.68045 W
	HO02	Upstream of Tongass Avenue	55.35390 N	-131.68747 W
Ketchikan Creek	KE01	Upstream of powerhouse outflow	55.34450 N	-131.63203 W
	KE02	Upstream of Harris Street Bridge	55.34401 N	-131.63951 W
	KE03	Upstream of Tongass Avenue	55.34292 N	-131.64374 W
Carlanna Creek Outfall	CA-OF	Drains residential area at Garden Lane and Tower Road	55.35984 N	-131.69478 W
Hoadley Creek Outfall	HO-OF	Drains residential area from Baranof Avenue at Thatcher Way	55.35564 N	-131.68428 W
Ketchikan Creek Outfall	KE-OF	Drains residential area at Freeman Street and Park Avenue, just downstream of KE02	55.34368 N	-131.64008 W

3.2 Field Data Collection

3.2.1 Water Physical and Chemical Characteristics

Stream water physical and chemical characteristics were measured in the field and water samples were collected and shipped to an analytical laboratory for further analyses. Specific conductivity, pH, turbidity, true color, dissolved oxygen, and temperature were measured *in situ* at each sampling location and on each sampling date and at the three outfalls during storm event sampling. Specific conductivity and pH were measured using YSI 63 meters and probes. Turbidity and true color were measured using a LaMotte 3000 turbidimeter. Three replicate samples were measured and average turbidity calculated from these values. Dissolved oxygen concentration and percent saturation were measured using YSI 550 meters and probes. Water temperature was measured using the YSI specific conductivity and dissolved oxygen meters. Settleable solids (ml/L) were determined in the ARRI laboratory using the Imhoff cone method from 1 liter samples collected from each sampling location on each sampling date.

Discharge was measured at each sampling location on each sampling date, with the exception of the KE03 site, which was non-wadeable even at low flows. Discharge was measured using either a SonTeck/YSI FlowTracker or a Swoffer 3000 velocity meter. Measured discharge values were compared with daily precipitation data obtained from a weather station at the Ketchikan International Airport (www.ncdc.noaa.gov) to quantify storm size and duration and sample timing in relation to precipitation patterns. Sample timing was used to explain seasonal variations in water chemistry.

Water samples were collected at each sampling location during summer base flow (August 6-7, 2013), during one storm event (September 21-22, 2013), and during spring flow (May 3, 2014). The concentrations of dissolved copper, lead, and zinc were determined from water samples collected from each sampling site on each sampling date in plastic containers (250 ml), acidified with nitric acid (below pH 2). Water samples (250 ml) for hardness and alkalinity were also collected from all sampling sites on each sampling date. Dissolved organic carbon samples were collected in 40 ml glass bottles and preserved with hydrochloric acid. Ammonia-N, nitrate and nitrite-N, total phosphorus, and total dissolved phosphorus concentrations were determined from samples collected in two 250 ml plastic bottles; one bottle was preserved with sulfuric acid. All samples were placed in a cooler with frozen gel-paks immediately following sampling and kept at < 6°C.

Sediment samples were collected during base flow sampling for measures of polycyclic aromatic hydrocarbons (PAH) from one sampling location on each stream located just upstream of tidal influence (CA02, HO02, KE03). The concentrations of total copper, lead, and zinc were also determined from these sediment samples. Sediment samples were again collected during spring flow sampling at all sampling sites, including outfall locations. An ICP scan was performed for concentrations of inorganic nutrients and metals, and samples from the outfalls and most downstream sampling locations were analyzed for PAH concentrations.

All above water and sediment samples were shipped overnight by FedEx to AM Test, Incorporated located in Kirkland, Washington, for chemical analyses. The project QAPP lists the analytical methods and detection limits for each parameter. Sample results less than the method detection limit are reported as not detected (ND).

Average stream concentrations were calculated for each parameter and sampling date. Daily flux was calculated to correct for variations in stream flow among sites and sampling events. Flow conditions prevented measuring discharge at the KE03 site, so discharge at KE02 was used for these calculations, assuming no significant change in flow between the two sampling sites.

Water samples for total fecal coliform analyses were collected in a well-mixed portion of each stream, at the most downstream sampling sites (CA02, HO02, KE03). Samples were collected from mid-water depth by drawing water into a sterile 60 ml syringe and discharging the water from the syringe into a sample bottle with a preservative tablet provided by R&M Engineering-Ketchikan (analytical laboratory). This process was repeated to obtain two 100 ml samples. Syringes were sterilized prior to field sampling by boiling in water for at least 15 minutes. Sample bottles were placed in a cooler with frozen gel-paks and transported to the laboratory for analyses, usually within 1 hour of collection. Samples were analyzed for fecal coliform bacteria using the membrane filtration method (SM 9222D). Sampling was conducted approximately weekly between summer and fall sampling events (for a total of 6 sampling dates) and again in May to provide three four-sample fecal coliform geometric averages within 30-day periods. Sampling was planned for four samples at each site to be collected in August and four in September, but a mistake with analytical processing forced some data to be thrown out and two sampling event results used for both the August and September 30-day geometric means. For individual results below the detection limit, the value of 1.0 was used in the geometric mean to provide a usable number for the calculation.

3.2.2 Macroinvertebrates

Benthic macroinvertebrates were sampled in May 2014 following the Alaska Stream Condition Index (ASCI) methodology of Major and Barbour (2001). We collected macroinvertebrate samples throughout a 100-m reach at each site with a 350-µm-mesh D-frame net. Each sample was a composite of 20 subsamples collected from various instream habitats in proportion to each habitat's abundance within the sampling reach. Sampling at the KE03 site was limited to shallow pools and riffles along the stream margins due to high depth and velocities throughout the majority of the sampling reach. Riffles were the predominant habitat sampled among sites, with pools, large woody debris, emergent vegetation, and undercut streambanks making up a minority of the subsamples. The net was placed immediately downstream of the selected habitat and aquatic insects were manually dislodged from the habitat by disturbing 1.5 ft^2 area of habitat. Each cobble, boulder, and piece of woody debris was rubbed by hand to ensure all macroinvertebrates were dislodged and transported by the stream's current into the net. We preserved all samples in the field with ethanol and returned them to our lab for processing. In the lab, we subsampled each macroinvertebrate sample to a fixed count of 350 organisms or until a subsection was completely picked through to standardize the taxonomic effort across all sites. We identified all insects to genus (or lowest taxon practical) and non-insects to higher taxa using standard taxonomic keys.

Macroinvertebrate metrics were calculated for a biological assessment of each site, using the Rinella et al. (2005) multimetric index method for the Alexander Archipelago. Index metrics included richness, composition, feeding group, habit and tolerance values (Table 3). The resulting values were used to compare biological stream health among sites and streams and to compare scores for Hoadley and Ketchikan creeks to those assessed by Rinella et al. in 2005.

Table 3. Metrics and scoring formulae for the multimetric stream index (Rinella et al. 2003).

Index Metrics	Metric Category	Scoring Formula
Insect Taxa	Richness	100*X/25
Non-Insect % Taxa	Richness	100*(60-X)/55.5
% EPT	Composition	100*X/92
Scraper taxa	Feeding Group	100*X/8
Clinger taxa	Habit	100*X/14
Intolerant % taxa	Tolerance	100*X/75

3.2.3 Juvenile Salmonids

Juvenile salmon and resident fish were sampled at one site in each stream (CA02, HO02, KE02) in September 2013, using baited minnow traps. High water velocities associated with the storm event, prevented fish collection efforts at the other four sampling locations. Twenty minnow traps (1/4 inch mesh, 1 inch opening) were used within each 100-meter sampling reach. Minnow traps were baited with salmon roe placed inside perforated whirl-pak bags suspended from the top of the trap. Traps were placed in eddies or pools at water depths sufficient to submerge the entire trap and under cover provided by overhanging banks or woody debris. The traps were left in place for 20 to 24 hours. All fish within each trap were identified to species, and all salmonids were measured to fork length and weighed. Captured fish were released on site after being measured. Catch per unit trap (CPUT) for total salmonids, salmonid species, and ratios of anadromous to resident fish were calculated for each site.

3.2.4 Habitat Assessment and Bed Sediments

Habitat assessment was determined at each sampling location, and substrate size distribution was determined at each wadeable location (all sites except CA01 and KE03). The KE03 site was not wadeable at any flow level, and the CA01 site was only wadeable at base flows, before substrate size distribution was measured. Habitat assessments were conducted using the ASCI qualitative assessment methodology (Major and Barbour 2001). This methodology ranks physical habitat characteristics including substrate, velocity-depth combinations, channel alteration, channel sinuosity, bank stability and riparian vegetation. The habitat assessment score is calculated as the mean of the scores for the individual physical habitat characteristics. Sediment sampling was conducted using Wolman pebble counts as modified by Bevenger and King (1995). Sediment size distribution was determined through the measurement of the diameter of 100 randomly selected particles within each sampling reach. The investigator walked up the channel diagonally from bank to bank, collecting a particle of substrate under the toe of the right foot every other step. The median diameter of this particle was measured with a gravelometer and recorded.

3.3 Stormwater Outfall Mapping

Carlanna, Hoadley, and Ketchikan creeks were surveyed between sampling sites for outfall locations. Streams were surveyed by foot where possible and GPS coordinates and photographs were collected at each observed outfall location for mapping with ArcGIS. Foot surveys were conducted in conjunction with the spring flow sampling event, during a dry period in which no significant rain had fallen (<1mm) for the previous six days. The outfall pipe material was noted (if applicable) as well as the presence or absence of water flow at the time of the survey. Results were compared with the 2011 stormwater outfall mapping conducted by the City of Ketchikan (Tetra Tech 2011).

3.4 Data Analyses

Precision, a measure of consistency of methods was calculated for every parameter. It was calculated as the relative percent difference between the original and replicate measures (A and B) as follows:

$$\Pr ecision = \frac{(A - B)}{((A + B)/2)} \times 100$$

Water and sediment nutrient, metal, and PAH concentrations were compared with state water quality standards, if applicable. Water chemistry values below detection limits were treated as zeros for all statistical analyses, providing a minimum value for stream averages and daily flux calculations. Biotic assessments were compared with previous study results and among sites to provide a relative ranking of stream health within the Ketchikan urban area and to determine if stream health is declining with continued development and increased population and area use.

Drainage areas and impervious surface areas were calculated with ArcGIS. Impervious surfaces were estimated using aerial imagery and drainage areas upstream of each site were delineated using elevation plots. Concentrations of each water and sediment parameter were compared with absolute and percent impervious surface area upstream. Seasonal water chemistry results were mapped with ArcGIS (Appendix D).

4.0 Results

4.1 Water Physical and Chemical Characteristics

All AM Test laboratory results for all sample duplicates and matrix spike duplicates met the project laboratory precision goal of less than 20% difference. Out of the 130 samples taken that had associated replicates in the field 24.62% did not meet precision goals. Water samples that did not meet precision goals consisted of alkalinity, dissolved organic carbon, hardness and total dissolved phosphorus (Table 4). These values were all relatively low and near detection limits, making any small variation a large percentage difference. The majority (68.75%) of parameters that did not meet precision goals were sediment PAH and metals: benzo(a)anthracene, benzo(a)pyrene, benzo(k)fluoranthene, chrysene, dibenzo(ah)anthracene, fluoranthene, indeno(123-cd)pyrene, phenanthrene, arsenic, beryllium, cadmium, copper, lead, manganese, silicon, sodium, strontium, sulfur, and zinc. Due to extreme natural variability of sediment chemistry through sediment characteristics (e.g. particle size), the observed high percentage differences between samples and replicates were most likely not a reflection of non-standardized methodology (Liaghati et al. 2003, Bathi et al. 2012).

Daily discharge and water temperature measures were proposed but could not be calculated due to flashy flow patterns that washed HOBO water pressure loggers out of the stream. Loggers could not be anchored into the stream sediments because at most of the site locations, the stream flowed over bedrock.

Table 4. Water samples that did not meet precision goals.

Parameter	Sample Date	Value	Replicate	Difference	Precision Value
Alkalinity (mg/l)	8/07/13	4	6	2	40
Alkalinity (mg/l)	9/22/13	4	6	2	40
Dissolved organic carbon (mg/l)	5/03/14	1.3	1.7	0.4	27
Hardness (mg/l)	5/03/14	4.2	7.9	3.7	61
Total dissolved phosphorus (mg/l)	5/03/14	0.0014	0.0022	0.0008	44

4.1.1 Precipitation and Stream Discharge

Cumulative precipitation, as measured at the Ketchikan International Airport, is shown in Figure 2, along with timing of sampling events. Sampling for summer base flow conditions occurred 8/6-8/7/13, during a period with no significant precipitation during the 12 days prior to sampling. Heavy rainfall occurred during the course of the two-day storm event sampling on September 21-22, 2013 (84.1 mm); however, the storm peaked two days prior to sampling with 130mm in a single day. The final sampling event was conducted on May 3, 2014. During this sampling event, no significant rain fell on the sampling date or the two days prior, but 152.9 mm of precipitation fell during the week prior to sampling (Table 5).

The lower Hoadley Creek site had lower discharge values during all sampling periods than the upstream sampling location, indicating some leakage or water use between the two sites (Figure 3). This anomaly was also observed between the Carlanna Creek sites during the storm event, although likely attributably to flow decreases between sampling the two sites. Rapid decreases in water flow occurred immediately following the storm event (see Appendix B). Therefore, not all of the sites were likely sampled at peak flow.

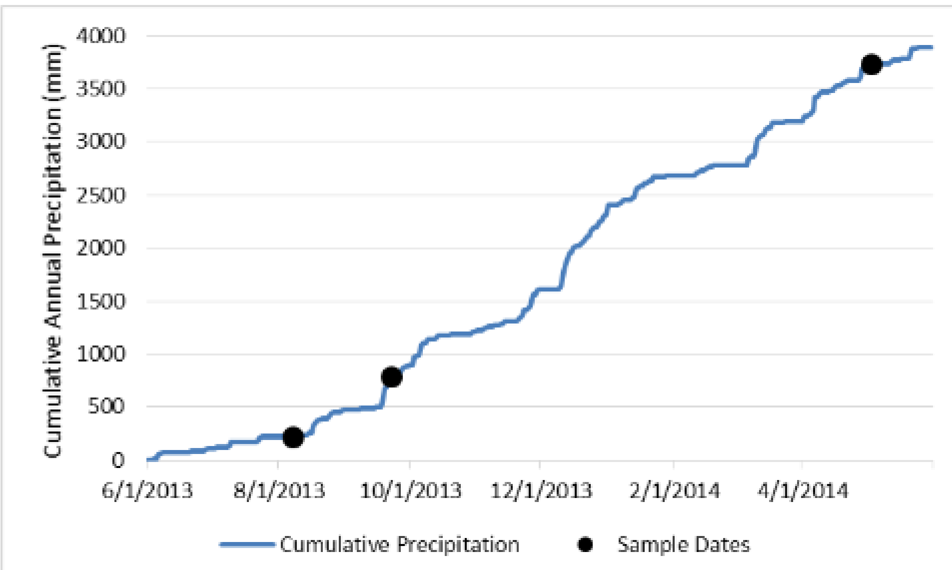

Figure 2. Cumulative annual precipitation (mm) as measured at the Ketchikan International Airport.

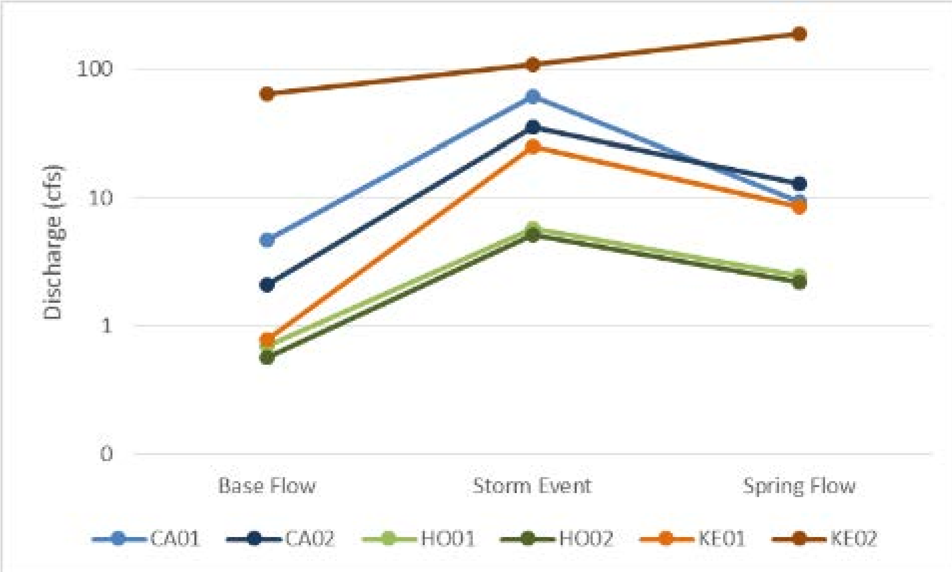

Figure 3. Discharge (ft^3/s) as measured during each sampling event.

Table 5. Precipitation (mm) on sample date and cumulative precipitation for day and week prior to sampling events as measured at the Ketchikan International Airport.

Sample Date	Precipitation on Sample Date	Precipitation Day Prior	Precipitation Week Prior	Days Since >1 mm Precipitation
8/07/2013	0	0	0.3	12
9/22/2013	48	36.1	245.5	0
5/03/14	0	0.3	159.3	3

4.1.2 Specific Conductivity, pH, and Dissolved Oxygen

Specific conductivity for each sampling date and location are shown in Figure 4 and average conductivity for each stream during each sampling event are shown in Table 6. Specific conductivity was highest at the downstream Hoadley Creek site (HO02) during base flow, storm conditions, and spring flow (67, 43.2, and 40.3 µS/cm, respectively). In both Carlanna Creek and Hoadley Creek, the downstream sampling location had higher conductivity than the upstream sampling location, and all storm event samples were comparable with spring flow results, with lower conductivities than base flow measurements. Ketchikan Creek had opposite results, with the highest conductivities found at the upstream sampling site during all sampling events and higher conductivities measured during the storm event as compared to either base flow or spring flow conditions for the KE02 and KE03 sites.

Stream water pH is shown in Figure 5 and average pH for each stream and sampling event is shown in Table 7. The upstream Carlanna Creek site (CA01) was the most acidic site during both the storm event and spring flow sampling periods (pH = 5.95 and 4.53, respectively). Average pH in Carlanna and Hoadley creeks was neutral or higher during the base flow sampling event but tended to be more acidic during the storm event. Ketchikan Creek, however, was slightly acidic during base flow conditions and showed an increase in pH during the storm event.

Figure 6 and Table 8 provide dissolved oxygen values as percent saturation for the three study streams on each sampling event. Average dissolved oxygen was near saturation in Carlanna and Hoadley creeks (>90% saturation), but Ketchikan Creek had lower average dissolved oxygen saturation during base flow conditions (85.6%). The lowest values were measured at the KE02 site during both base flow and storm event sampling dates (73.4% and 87.6%), whereas the KE03 site showed the lowest dissolved oxygen saturation during spring flow (93.8%).

Water temperature was highest during base flow sampling and lowest during spring flow sampling for all sites (Figure 7). Carlanna Creek consistently had the warmest average water temperatures, followed by Ketchikan Creek during base flow sampling and Hoadley Creek during storm event and spring flow samplings (Table 9). Water temperature increased between sampling sites on Hoadley Creek during all sampling periods, but was more variable among sampling events in both Carlanna and Ketchikan Creeks. The temperatures in these two creeks are more influenced by lake processes than by daily weather patterns, with lake drainage occurring upstream of CA01 and KE02. During the storm event, however, flows were dominated by precipitation and runoff, bringing water temperatures to within 1.0°C among all sites, with a consistent downstream increase in temperatures.

The outfalls draining into each stream all had higher specific conductivities and lower dissolved oxygen saturation than the average stream values (Table 10). Conductance was approximately three times higher in the Carlanna Creek outfall than in the stream, approximately six times higher at the Hoadley Creek outfall, and more than 18 times higher at the Ketchikan Creek outfall than average values in Ketchikan Creek. Water temperature in the Carlanna Creek outfall was equal to average stream temperature, but the Hoadley Creeks outfall was 2.5°C higher and the Ketchikan Creek outfall was 0.4°C warmer than the receiving stream.

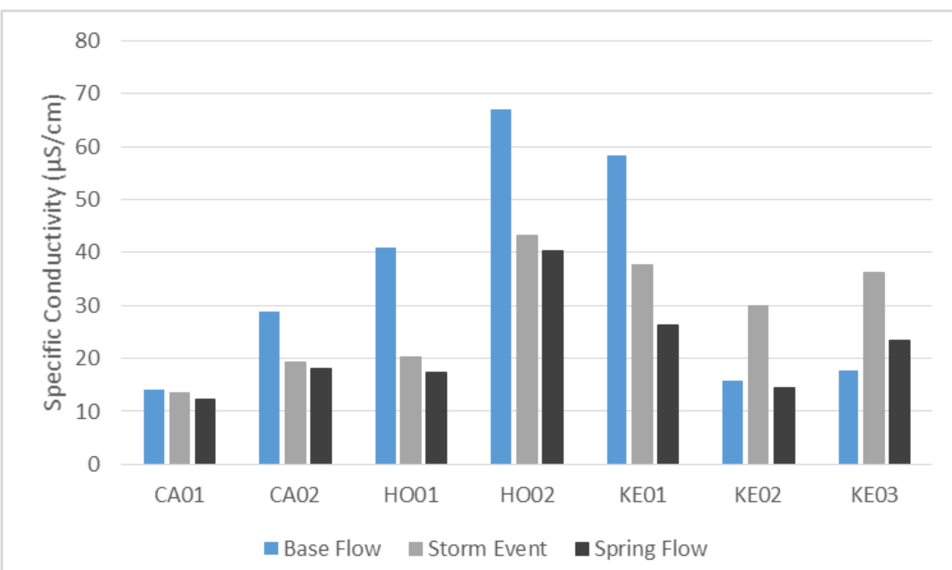

Figure 4. Specific conductivity (µS/cm) for all sampling locations and sampling dates.

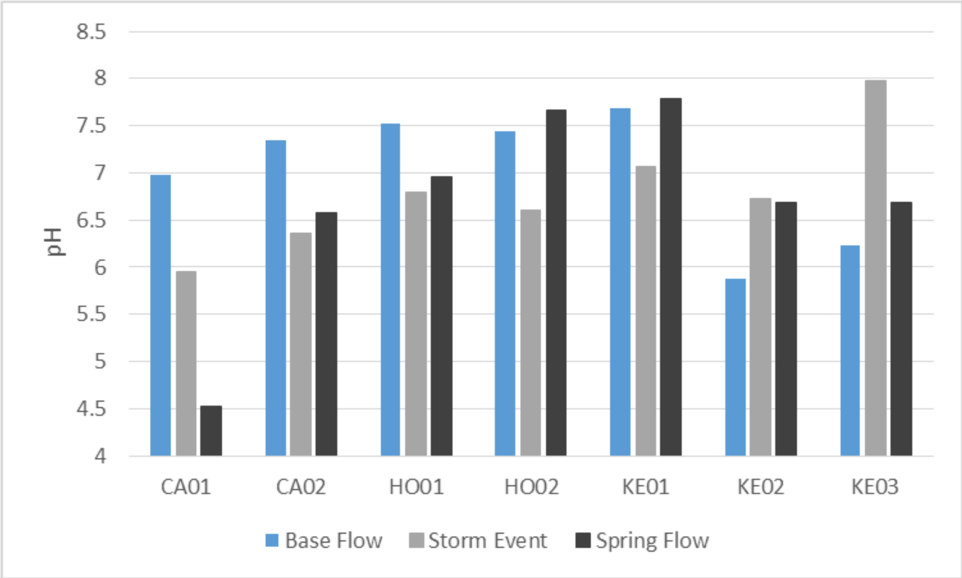

Figure 5. Stream water pH for all sampling locations and sampling dates.

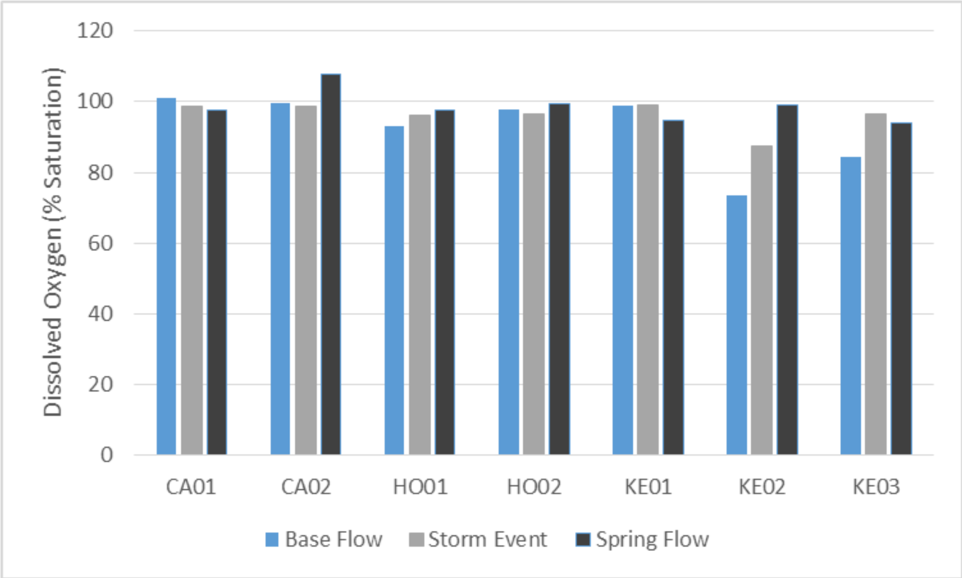

Figure 6. Percent saturation of dissolved oxygen for all sampling locations and sampling dates.

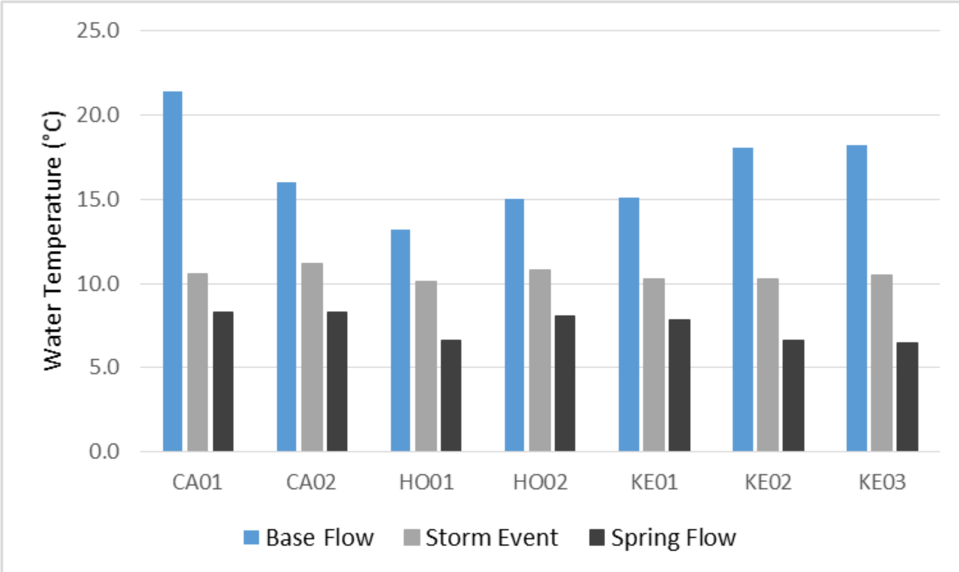

Figure 7. Water Temperature (°C) for all sampling locations and sampling dates.

Table 6. Average stream specific conductivity (µS/cm) for each sampling event.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	21.45	16.35	15.10
Hoadley Creek	53.95	31.70	28.80
Ketchikan Creek	30.53	34.53	21.40

Table 7. Average stream water pH for each sampling event.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	7.17	6.16	5.56
Hoadley Creek	7.48	6.70	7.32
Ketchikan Creek	6.60	7.26	7.05

Table 8. Average stream dissolved oxygen concentration (% saturation) for each sampling event.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	100.25%	98.60%	102.75%
Hoadley Creek	95.45%	96.30%	98.55%
Ketchikan Creek	85.63%	94.43%	95.83%

Table 9. Average stream water temperature (°C) for each sampling event.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	18.7	10.9	8.3
Hoadley Creek	14.1	10.5	7.4
Ketchikan Creek	17.1	10.4	7.0

Table 10. Specific conductivity (µS/cm), pH, and dissolved oxygen saturation from outfalls draining into Carlanna, Hoadley, and Ketchikan creeks during the spring runoff sampling event.

Site	Specific Conductivity (µS/cm)	pH	DO (% Saturation)	Temperature (°C)

CA-OF	45.1	7.59	98.3%	8.3
HO-OF	172.9	7.54	95.3%	9.9
KE-OF	387.6	4.79	86.2%	7.4

4.1.3 Dissolved Organic Carbon, Turbidity, and Settleable Solids

Concentrations of dissolved carbon were less than 5 mg/L in all streams during summer base flow, the storm event, and spring flow. All sites had higher concentrations during the storm event than at base flow conditions, and dissolved organic carbon concentrations were similar between base flow and spring flow (Figure 8, Table 11). Carlanna Creek had the highest average concentration during both 2013 sampling events (3.20 and 4.50 mg/L) and the lowest percent change between sampling events, whereas Hoadley Creek was slightly higher during spring flow (2.70 mg/L, as compared to 2.60 mg/L).

Stream water turbidity (Figure 9, Table 12) was low in all streams during all sampling events at less than 4.5 NTU for all measurements collected. Average turbidity decreased during the storm event, as compared to base flow conditions, for both Carlanna Creek and Ketchikan Creek, and was approximately equal between sampling events in Hoadley Creek (2.94 and 2.97 NTU). All sites had the lowest turbidity values during spring flow, averaging 0.19 NTU among all sites. Turbidities measured in outfalls were higher than in stream sites, averaging 3.22 NTU during the spring runoff sampling event (Table 13).

Settleable solid concentrations were below detection limits (0.1 ml/L) for all sites and sampling events, including the outfalls sampled in each drainage.

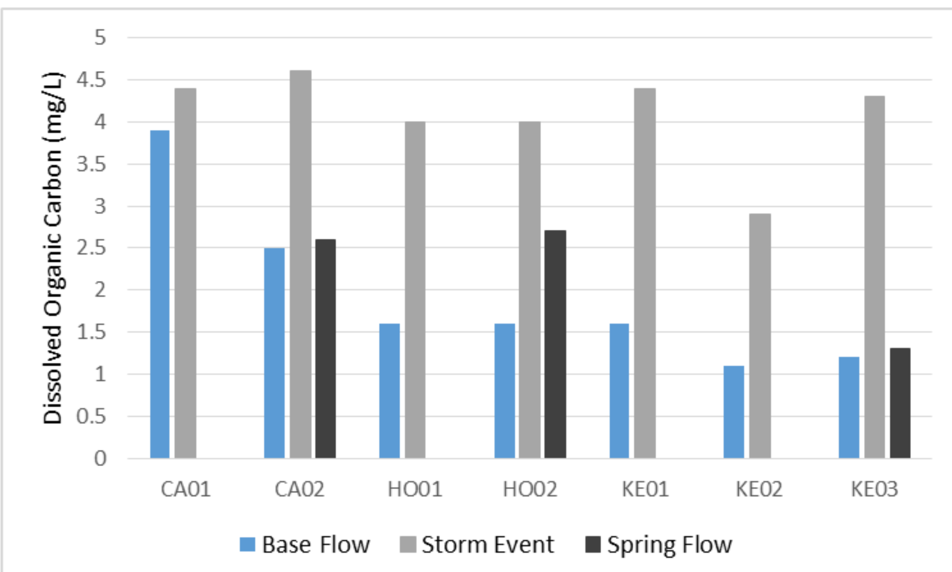

Figure 8. Dissolved organic carbon concentrations for all sampling locations and sampling dates. During the spring flow sampling event, DOC was only measured at the most downstream sampling site on each stream.

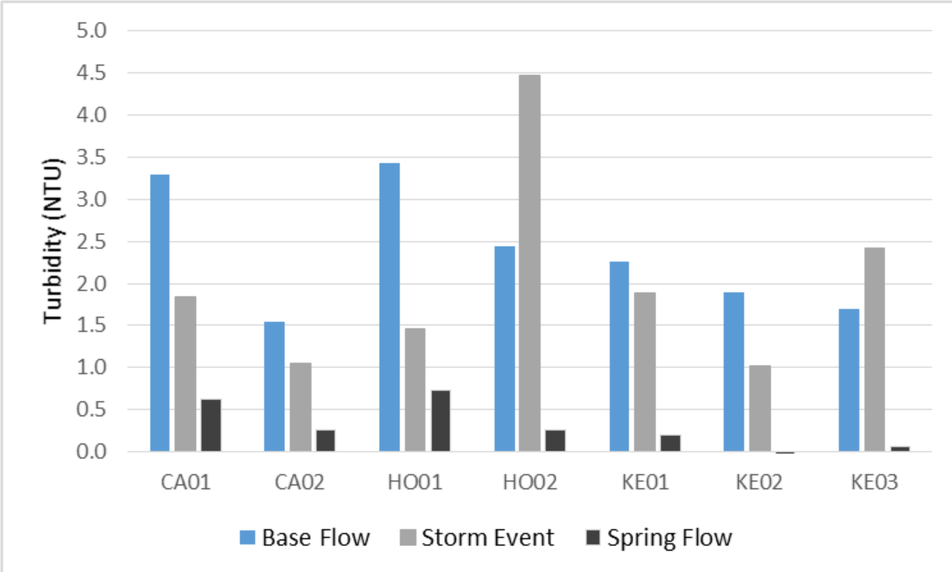

Figure 9. Stream water turbidity (NTU) for all sampling locations and sampling dates.

Table 11. Average stream dissolved organic carbon (mg/L) concentrations for each sampling event.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	3.20	4.50	2.60
Hoadley Creek	1.60	4.00	2.70
Ketchikan Creek	1.30	3.87	1.30

Table 12. Average stream turbidity (NTU) for each sampling event.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	2.42	4.50	0.44
Hoadley Creek	2.94	4.00	0.50
Ketchikan Creek	1.95	3.87	0.09

Table 13. Settleable solid concentrations and turbidity in outfalls sampled in May 2014. ND values were below detection limits of 0.1 ml/l.

Site	Settleable Solids (ml/l)	Turbidity (NTU)
CA-OF	ND	2.47
HO-OF	ND	2.38
KE-OF	ND	4.83

4.1.4 Nitrogen and Phosphorus

Stream water nitrogen and phosphorus concentrations and daily flux for all sampling dates and locations are shown in Figures 10 through 17. Average concentrations for each stream on each sampling date are shown in Tables 15 through 18. For concentrations below the detection limit, a value of 0.0 was used in calculating stream averages.

Average ammonia-N concentrations tended to be higher in Ketchikan Creek (0.064 mg/L) as compared to Carlanna (0.021 mg/L) and Hoadley (0.023 mg/L) creeks. Average nitrate + nitrite-N concentrations also tended to be higher in Ketchikan Creek (0.092 mg/L) as compared to Carlanna (0.063 mg/L) and Hoadley (0.065 mg/L) creeks. Concentrations of nitrate + nitrite-N increased on average within all three streams during the storm event as compared to summer base flow and spring flow conditions. Ammonia-N concentrations did not show a consistent seasonal pattern, but concentrations generally increased in a downstream direction within each drainage. However, all ammonia-N values were well below acute or chronic toxicity values (Table 14).

Daily flux of ammonia-N and nitrate + nitrite-N were generally greatest during the storm event (Figures 11 and 13). During all seasons, the KE02 and KE03 sites had values for both variables orders of magnitude greater than all other sites. There was generally an increase in flux for both parameters from the upstream to downstream sampling sites.

Total and dissolved phosphorus concentrations were below the detection limits for samples collected in Carlanna Creek during both base flow and storm event sampling dates (Figures 14 and 16). Total and total dissolved phosphorus were not detected in Hoadley Creek during base flow. However, all Carlanna Creek and Hoadley Creek sites had trace amounts of phosphorus during spring flow. There was an increasing trend for both total and dissolved phosphorus with distance downstream in Ketchikan Creek during all sampling events, with no phosphorus detected in the most upstream Ketchikan Creek site during any sampling event and trace amounts detected in all KE03 samples.

Daily flux of total phosphorus and total dissolved phosphorus generally increased between upstream and downstream sites (Figures 15 and 17). However, there was a decrease in total dissolved phosphorus in Carlanna Creek during the spring flow sampling event. Flux was relatively high at the KE03 site, with a significant increase in dissolved phosphorus from the KE02 site ($p = 0.033$). The majority of samples analyzed, including the upper Ketchikan Creek sites, were below detection limits for both total and dissolved phosphorus.

The three outfalls sampled all had elevated concentrations of ammonia-N and Nitrate + nitrite-n, as compared to their respective average stream concentrations. Additionally, concentrations of total and dissolved phosphorus were generally higher in the outfall samples, except at the Hoadley Creek outfall that had a dissolved phosphorus concentration lower than that in the stream (Table 18).

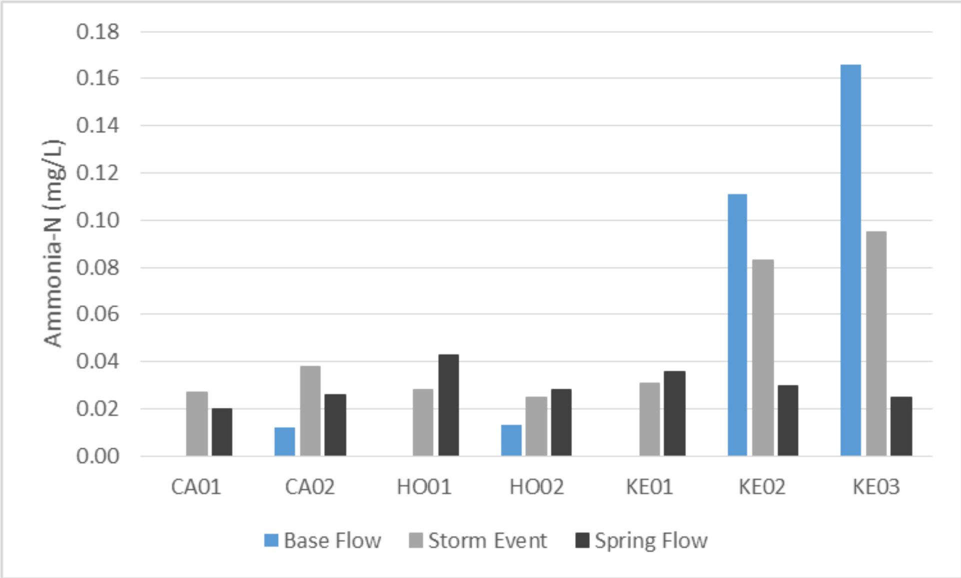

Figure 10. Ammonia-N concentrations (mg/L) for all sampling locations and sampling dates.

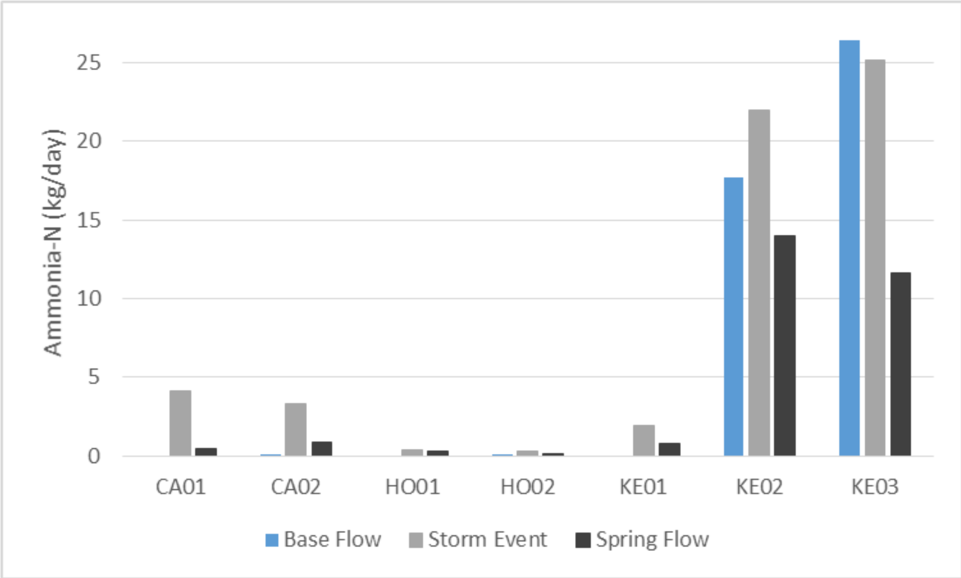

Figure 11. Daily ammonia-N flux (mg/day) for all sampling locations and sampling dates. Flux at KE03 was calculated with discharge values from KE02, assuming no significant change between sampling sites.

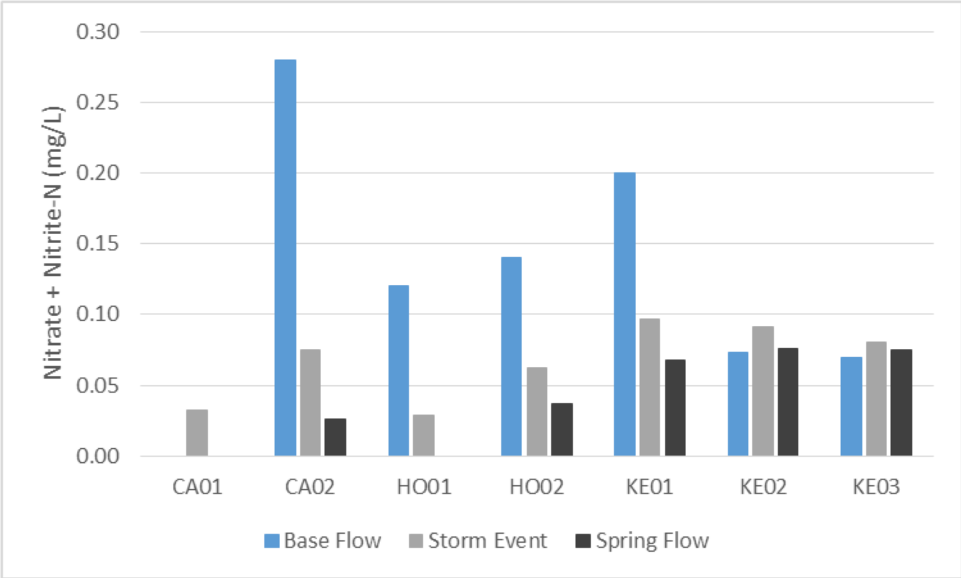

Figure 12. Nitrate + nitrite-N concentrations (mg/L) for all sampling locations and sampling dates.

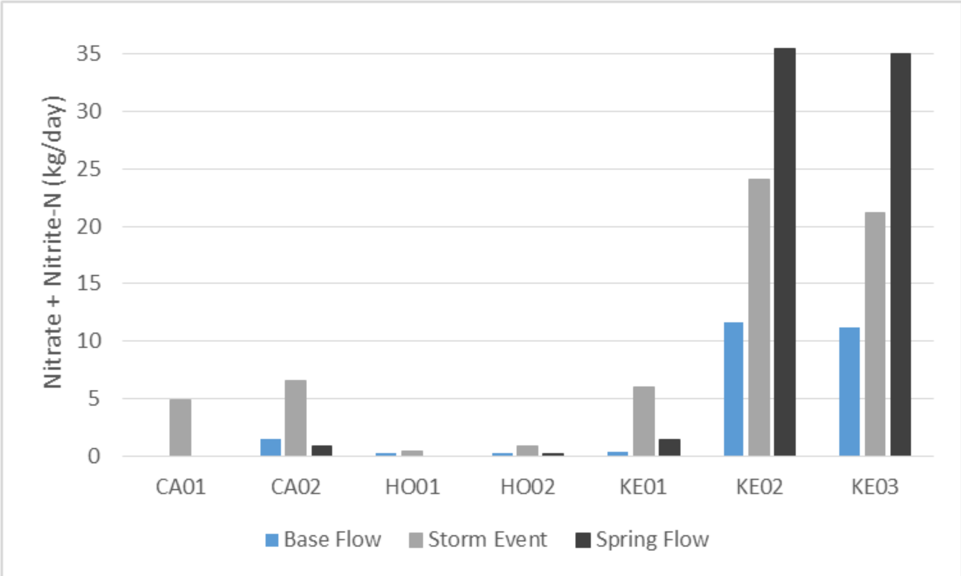

Figure 13. Nitrate + nitrite-N daily flux (mg/day) for all sampling locations and sampling dates. Flux at KE03 was calculated with discharge values from KE02, assuming no significant change between sampling sites.

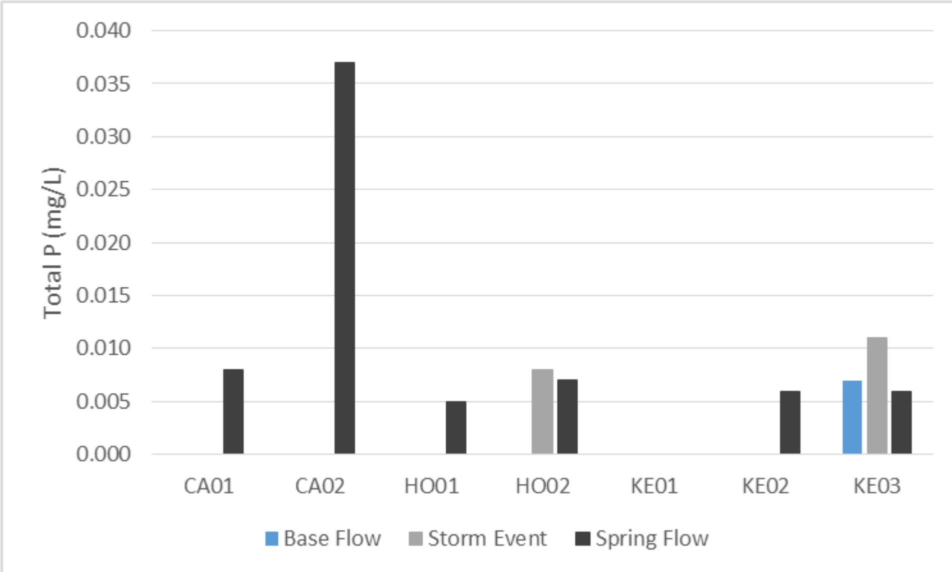

Figure 14. Total phosphorus concentrations (mg/L) for all sampling locations and sampling dates.

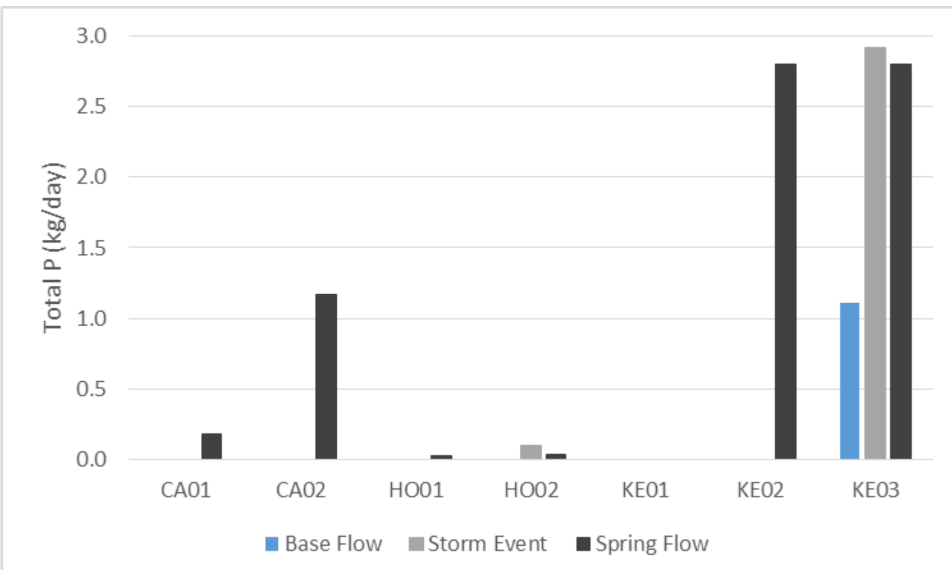

Figure 15. Total phosphorus daily flux (mg/day) for all sampling locations and sampling dates. Flux at KE03 was calculated with discharge values from KE02, assuming no significant change between sampling sites.

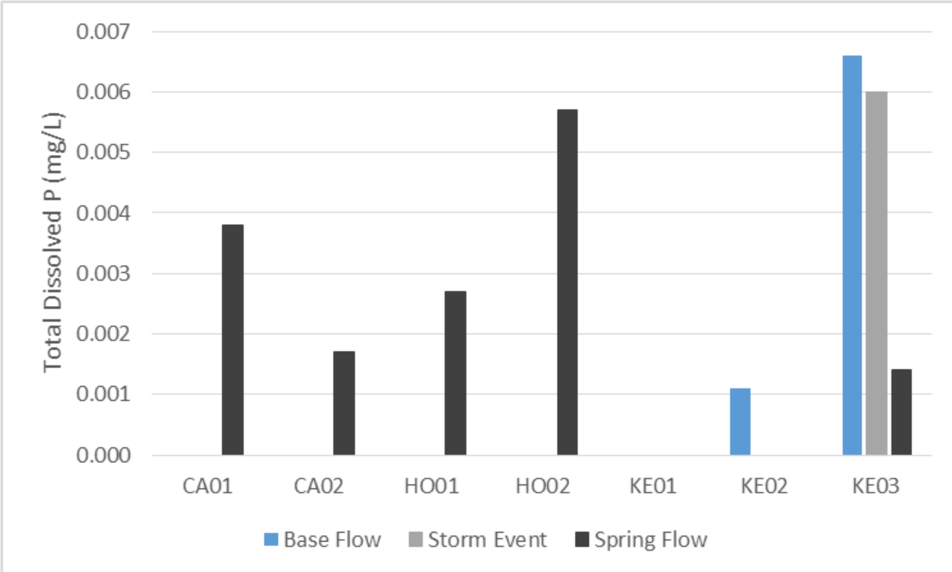

Figure 16. Total dissolved phosphorus concentrations (mg/L) for all sampling locations and sampling dates.

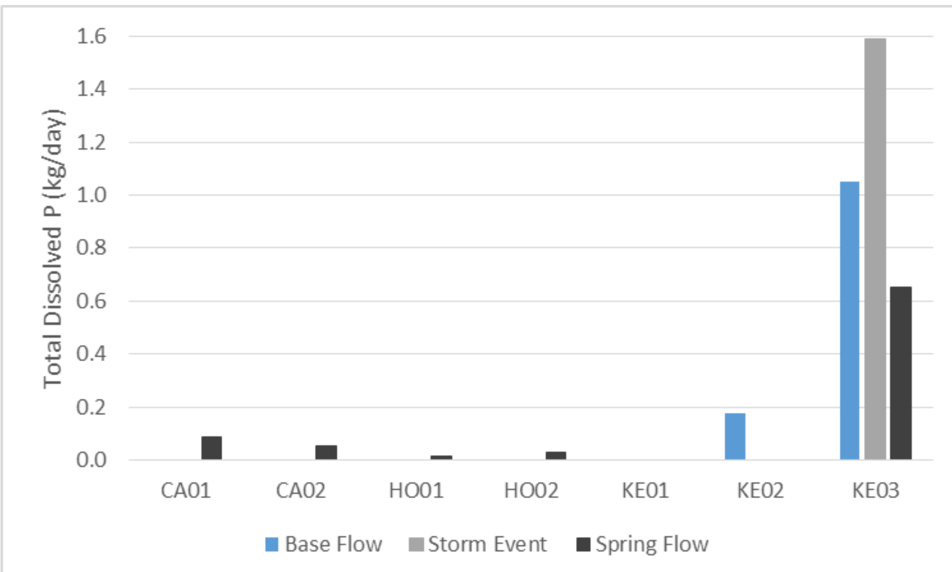

Figure 17. Total dissolved phosphorus daily flux (mg/day) for all sampling locations and sampling dates. Flux at KE03 was calculated with discharge values from KE02, assuming no significant change between sampling sites.

Table 14. Acute and chronic freshwater ammonia criteria. Acute criteria for waters with salmonids present are pH-dependent, and chronic toxicity values are pH- and temperature-dependent.

Stream	Site	Event	Acute	Chronic
Carlanna Creek	CA01	Base Flow	24.5	3.8
Carlanna Creek	CA01	Storm Event	37.0	7.0
Carlanna Creek	CA01	Spring Flow	38.9	7.1
Carlanna Creek	CA02	Base Flow	16.4	4.5
Carlanna Creek	CA02	Storm Event	34.1	6.8
Carlanna Creek	CA02	Spring Flow	31.6	6.6
Hoadley Creek	HO01	Base Flow	12.9	4.3
Hoadley Creek	HO01	Storm Event	28.0	6.3
Hoadley Creek	HO01	Spring Flow	24.9	6.0
Hoadley Creek	HO02	Base Flow	14.5	4.4
Hoadley Creek	HO02	Storm Event	31.3	6.6
Hoadley Creek	HO02	Spring Flow	10.1	3.7
Ketchikan Creek	KE01	Base Flow	10.0	3.5
Ketchikan Creek	KE01	Storm Event	22.8	5.8
Ketchikan Creek	KE01	Spring Flow	8.3	3.2
Ketchikan Creek	KE02	Base Flow	37.2	5.5
Ketchikan Creek	KE02	Storm Event	29.3	6.4
Ketchikan Creek	KE02	Spring Flow	30.1	6.5
Ketchikan Creek	KE03	Base Flow	35.3	5.4
Ketchikan Creek	KE03	Storm Event	5.8	2.5
Ketchikan Creek	KE03	Spring Flow	30.1	6.5
Outfall	CA-OF	Spring Flow	11.6	4.0
Outfall	HO-OF	Spring Flow	12.5	4.2
Outfall	KE-OF	Spring Flow	38.9	7.1

Table 15. Average stream ammonia-N concentrations for each sampling event. The value of 0.0 mg/L was substituted for samples below the detection limit.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	0.006	0.033	0.023
Hoadley Creek	0.007	0.027	0.036
Ketchikan Creek	0.092	0.070	0.030

Table 16. Average stream nitrate + nitrite-N concentrations for each sampling event. The value of 0.0 mg/L was substituted for samples below the detection limit.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	0.036	0.140	0.013
Hoadley Creek	0.046	0.130	0.019
Ketchikan Creek	0.089	0.114	0.073

Table 17. Average stream total phosphorus concentrations for each sampling event. The value of 0.0 mg/L was substituted for samples below the detection limit.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	0.0000	0.0000	0.0225
Hoadley Creek	0.0000	0.0040	0.0060
Ketchikan Creek	0.0023	0.0037	0.0040

Table 18. Average stream total dissolved phosphorus concentrations for each sampling event. The value of 0.0 mg/L was substituted for samples below the detection limit.

	Base Flow	Storm Event	Spring Flow
Carlanna Creek	0.0010	0.0000	0.0028
Hoadley Creek	0.0010	0.0000	0.0042
Ketchikan Creek	0.0029	0.0020	0.0005

Table 19. Concentrations of nitrogen as ammonia and nitrate+nitrite and total and dissolved phosphorus concentrations in outfalls sampled within Carlanna, Hoadley, and Ketchikan creeks drainages in May 2014.

	Ammonia-N (mg/L)	Nitrate+nitrite-N (mg/L)	Total Phosphorus (mg/L)	Dissolved Phosphorus (mg/L)
CA-OF	0.125	0.290	0.040	0.0572
HO-OF	0.120	0.280	0.006	0.0024
KE-OF	0.038	0.530	0.008	0.0027

4.1.5 Alkalinity, Hardness and Dissolved Metals

Alkalinity and hardness (as $CaCO_3$) both were generally low and comparable among sampling events but varied significantly among sampling sites (Figures 18 and 19). Both parameters increased longitudinally in Carlanna and Hoadley Creeks, but were drastically higher in KE01 as compared to all other sites, including the lower Ketchikan Creek sites.

Total dissolved concentrations of metals (Cu, Pb, and Zn) for all study sites and sampling events are shown in Figures 20, 22, and 24. Water Quality criteria for dissolved concentrations of these metals, based on water hardness, are shown in Table 20 for all sampling sites and dates. Low hardness values increase metal toxicities.

Dissolved metal concentrations, in general, were higher during summer base flow conditions than during either the fall storm event or spring flow. Copper concentrations exceeded acute and chronic toxicities during base flows in both Carlanna Creek sites and at the lower two Ketchikan Creek sites (KE02 and KE03). Only the most downstream Ketchikan Creek site (KE03) exceeded toxicity concentrations during the storm event and spring runoff. This site exceeded copper acute and chronic toxicity concentrations during all three sampling events. Dissolved lead concentrations exceeded acute and chronic toxicities during base flow conditions at CA01 and KE03 and chronic toxicities at KE02. No samples collected from Hoadley Creek exceeded acute or chronic toxicity levels for dissolved copper, lead, or zinc concentrations.

Both dissolved copper and dissolved zinc concentrations were significantly higher in the outfall samples than in the corresponding stream samples (Table 21). Dissolved copper concentrations were more than ten times greater than stream values at both Hoadley and Ketchikan creeks. Zinc concentrations were even more elevated compared to stream values, with nearly twenty times greater concentrations in the Carlanna and Hoadley creeks outfalls and over 200 times greater concentrations in the Ketchikan Creek outfall.

Daily flux of dissolved copper generally increased in a downstream direction, excluding the comparatively large value observed at CA01 during base flow sampling (Figure 21). Dissolved lead daily flux was generally greatest during base flow, although there were no obvious and consistent trends among sites or sampling events (Figure 23). Dissolved zinc daily flux generally increased in a downstream direction, except within Carlanna Creek during base flow and the fall storm event (Figure 25). None of the dissolved metals consistently increased among sites during the storm event as compared to either base flow or spring flow conditions. There were large increases in flux of all three dissolved metals analyzed between the KE02 and KE03 sampling sites, especially dissolved copper. Dissolved copper increased approximately six-fold between the two sites during base flow and spring flow conditions, and there was a more than 13 times increase between sites during the storm event.

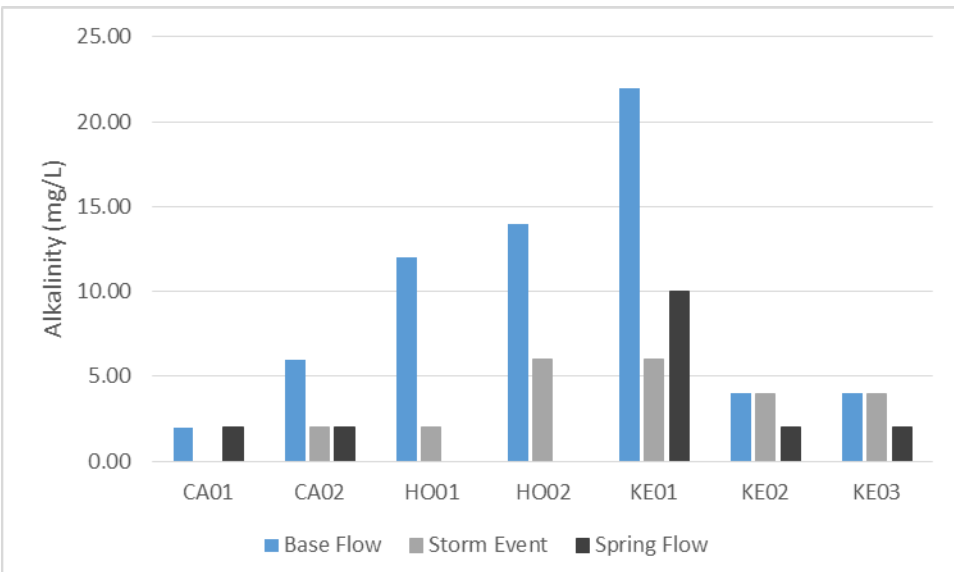

Figure 18. Alkalinity as $CaCO_3$ (mg/L) for all stream sampling locations and sampling dates.

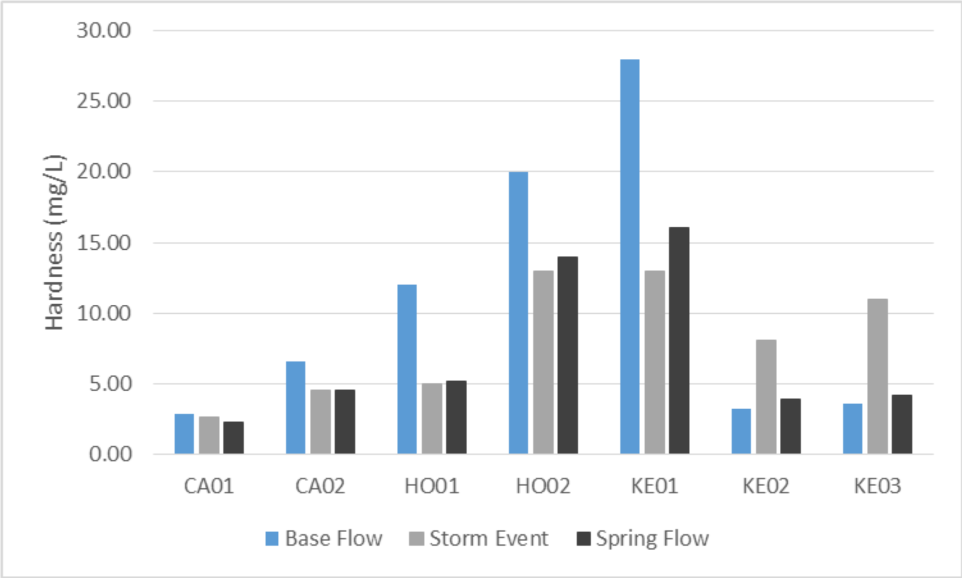

Figure 19. Hardness as $CaCO_3$ (mg/L) for all stream sampling locations and sampling dates.

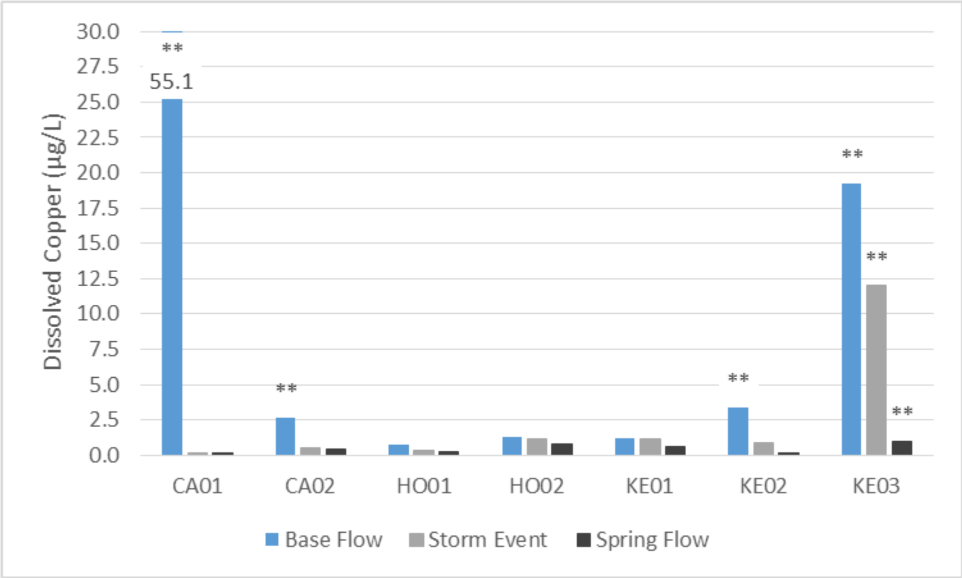

Figure 20. Total dissolved copper concentrations (µg/L) for all sampling locations and sampling dates. "*" indicates values above chronic toxicity levels; "" indicates values above acute and chronic toxicity levels.**

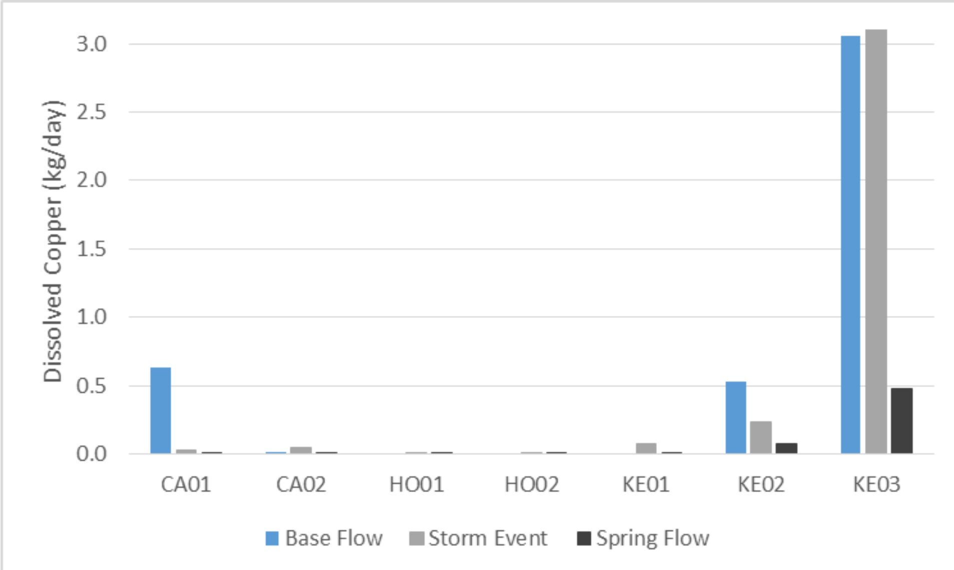

Figure 21. Daily flux of total dissolved copper (µg/day) for all sampling locations and sampling dates. Flux at KE03 was calculated with discharge values from KE02, assuming no significant change between sampling sites.

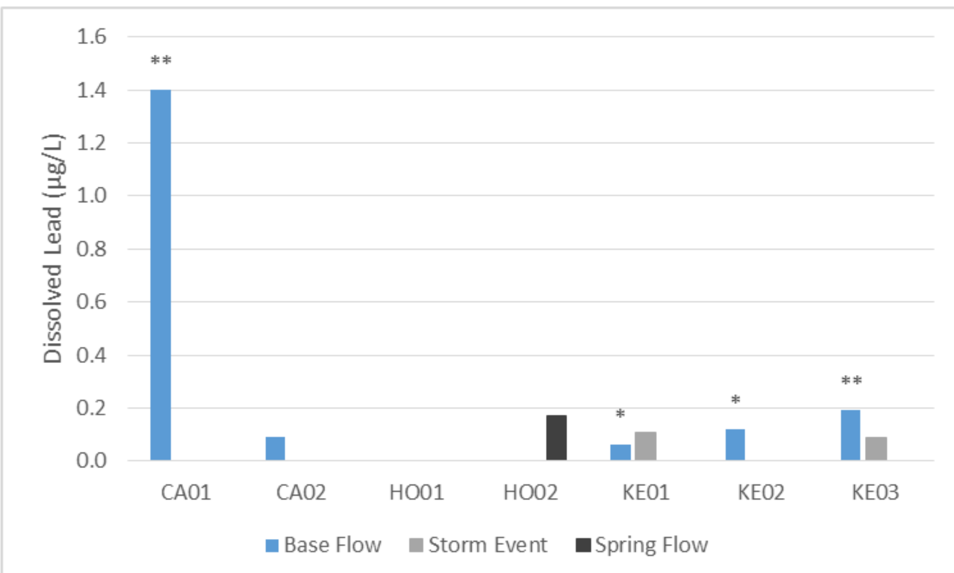

Figure 22. Total dissolved lead concentrations (µg/L) for all sampling locations and sampling dates. "*" indicates values above chronic toxicity levels; "" indicates values above acute and chronic toxicity levels.**

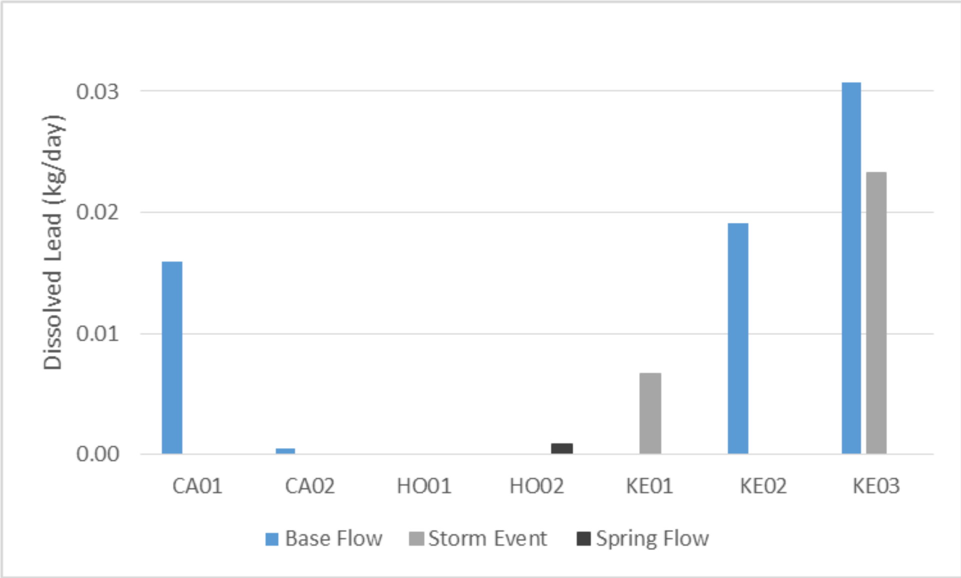

Figure 23. Daily flux of total dissolved lead (µg/day) for all sampling locations and sampling dates. Flux at KE03 was calculated with discharge values from KE02, assuming no significant change between sampling sites.

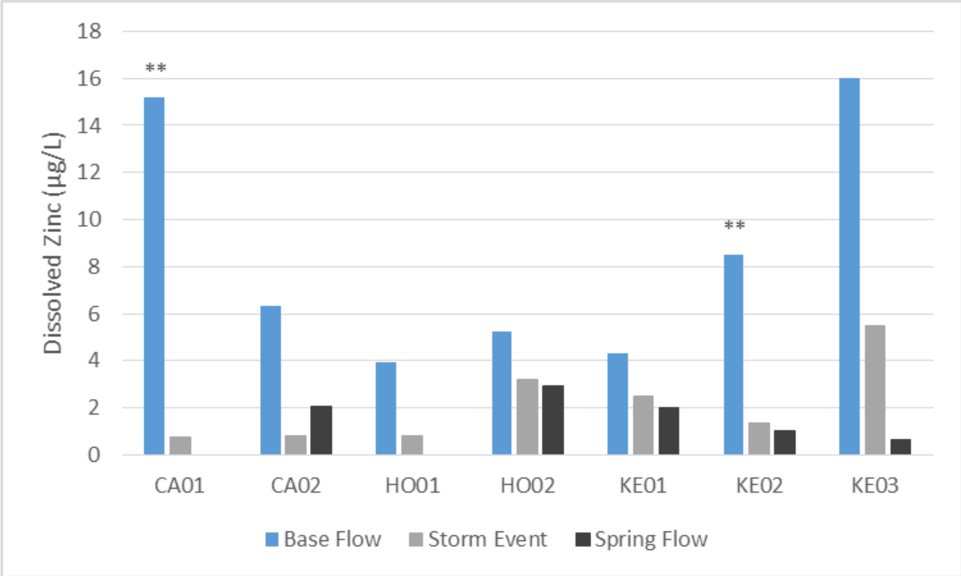

Figure 24. Total dissolved zinc concentrations (µg/L) for all sampling locations and sampling dates. "*" indicates values above chronic toxicity levels; "" indicates values above acute and chronic toxicity levels.**

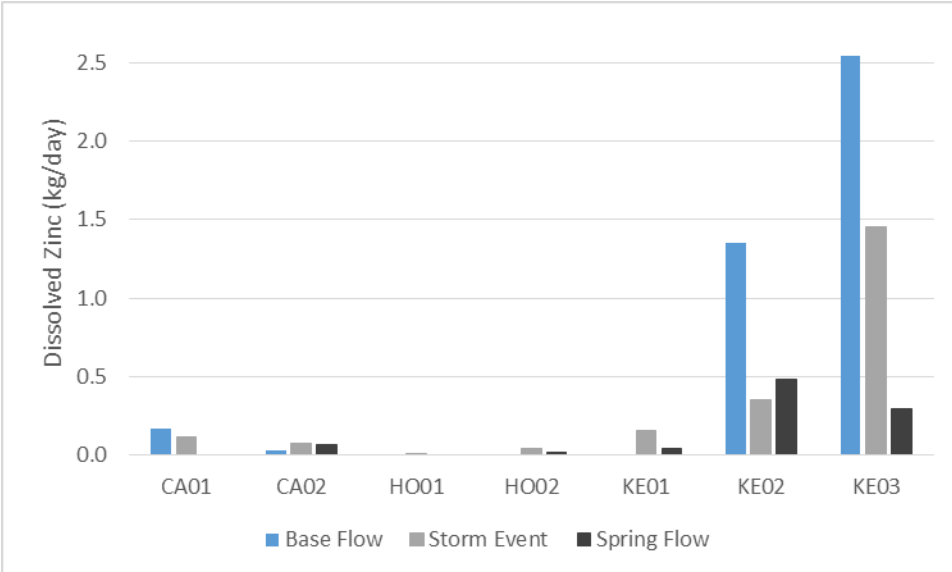

Figure 25. Daily flux of total dissolved zinc (µg/day) for all sampling locations and sampling dates. Flux at KE03 was calculated with discharge values from KE02, assuming no significant change between sampling sites.

Table 20. Acute and chronic hardness-based water quality criteria for dissolved metals for each study site.

Site	Month	Hardness (mg/L)	Copper Acute (µg/L)	Copper Chronic (µg/L)	Lead Acute (µg/L)	Lead Chronic (µg/L)	Zinc Acute (µg/L)	Zinc Chronic (µg/L)
Carlanna								
CA01	Aug	2.9	0.48	0.43	1.18	0.05	5.10	5.14
	Sept	2.6	0.43	0.40	1.04	0.04	4.65	4.69
	May	2.3	0.38	0.36	0.90	0.04	4.19	4.22
CA02	Aug	6.6	1.04	0.88	3.05	0.12	10.23	10.32
	Sept	4.5	0.72	0.63	1.96	0.08	7.40	7.46
	May	4.5	0.72	0.63	1.96	0.08	7.40	7.46
CA-OF	May	44	6.20	4.44	26.14	1.02	51.07	51.48
Hoadley								
HO01	Aug	12	1.82	1.46	6.04	0.24	16.98	17.12
	Sept	5	0.80	0.69	2.21	0.09	8.09	8.15
	May	5.2	0.83	0.72	2.31	0.09	8.36	8.43
HO02	Aug	20	2.95	2.26	10.79	0.42	26.18	26.40
	Sept	13	1.97	1.57	6.62	0.26	18.18	18.32
	May	14	2.11	1.67	7.20	0.28	19.35	19.51
HO-OF	May	140	18.45	11.94	92.97	3.62	136.16	137.27
Ketchikan								
KE01	Aug	28	4.05	3.02	15.77	0.61	34.82	35.10
	Sept	13	1.97	1.57	6.62	0.26	18.18	18.32
	May	16	2.39	1.87	8.38	0.33	21.67	21.85
KE02	Aug	3.2	0.52	0.47	1.32	0.05	5.54	5.59
	Sept	8.1	1.26	1.05	3.85	0.15	12.17	12.27

Site	Month	Hardness	Copper		Lead		Zinc	
			Acute	Chronic	Acute	Chronic	Acute	Chronic
		(mg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
	May	3.9	0.63	0.56	1.66	0.06	5.55	6.61
KE03	Aug	3.6	0.59	0.52	1.51	0.06	6.12	6.17
	Sept	11	1.68	1.36	5.47	0.21	15.78	15.91
	May	4.2	0.68	0.60	1.81	0.07	6.98	7.03
KE-OF	May	340	42.57	25.48	237.54	9.26	288.77	291.13

Table 21. Concentrations of dissolved metals (µg/L) in outfalls sampled in May 2014. ND values were below detection limits.

Site	Copper	Lead	Zinc
CA-OF	1.09	ND	18.7
HO-OF	5.92	ND	19.3
KE-OF	67.1	2.81	277.0

4.1.6 Sediment Metals and PAH

Sediment metal concentrations were evaluated using NOAA SQuiRT threshold effects levels (TELs) and probable effects levels (PELs), shown in Table 22 (Buchman 2008). TELs are those concentrations below which biological effects are not observed, and PELs are those levels above which biological effects are likely to occur. Total concentrations of metals (Cu, Pb, and Zn) and polyaromatic hydrocarbons (PAH) in sediment samples from each downstream sampling site (CA02, HO02, KE03) are shown in Figure 26.

Concentrations of metals in streambed sediments were generally below values that could result in biological effects. All samples had lead and zinc concentrations below TELs, and only the KE03 base flow sample exceeded the copper TEL (37.0 µg/g). All of the outfall sediment samples had copper concentrations above TEL values, and zinc concentrations in Carlanna and Ketchikan outfall samples were elevated as compared to their receiving streams. Copper sediment concentrations were highly correlated with total area of upstream impervious surface area ($r = 0.892$, $p = 0.0009$).

Concentrations of PAH in stream sediments were below detection limits in Carlanna and Hoadley Creeks during base flow conditions. Ketchikan Creek sediments contained measurable PAH levels during both base flow and spring flow sampling events that were well below TEL concentrations (0.0975 µg/g and 0.03185 µg/g). Hoadley Creek sediments also contained low levels of PAH in the spring flow sample (0.02071 µg/g). Both Carlanna Creek outfall and Ketchikan Creek outfall sediment samples had PAH concentrations above the TEL (0.5206 µg/g and 0.3548 µg/g), whereas sediment PAHs were not detected in the Hoadley Creek outfall.

Additional sediment nutrient and metal concentrations from samples collected in May 2014 are listed in Table 23. Arsenic levels were elevated above either the TEL or PEL values in all outfall sites sampled, and were at concentrations nearly twice the PEL of 17 µg/g in KE03 with a value of 33.4 µg/g. Additionally, the concentration of cadmium in all stream site sediment samples were elevated above the TEL as well as in sediment samples from the outfalls draining into Carlanna and Ketchikan creeks. Nickel concentrations were highly correlated with total impervious surface area upstream ($r = 0.929$, $p = 0.001$).

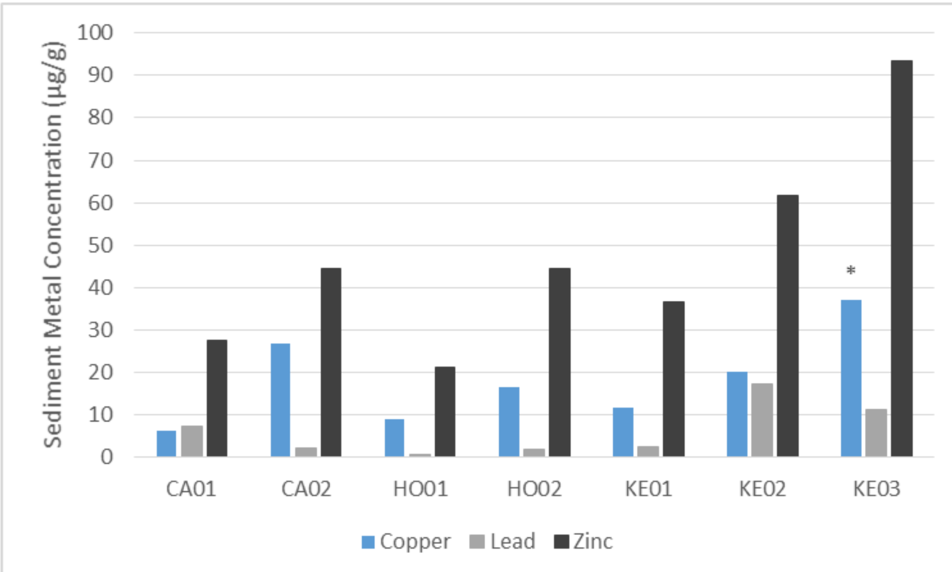

Figure 26. Total metal concentrations (µg/g) for all sampling locations during base flow sampling conditions (8/6/13-8/7/13). "*" indicates values above chronic toxicity levels.

Table 22. Concentrations of metals and PAH TELs and PELs for freshwater sediments. NA is not available for freshwater sediments.

Parameter	TEL (µg/g)	PEL (µg/g)
Copper	35.7	197
Lead	35	91.3
Zinc	123	315
PAH	0.2641	NA

Table 23. Concentrations of sediment nutrients and metals (µg/g) in May 2014. Values for arsenic, cadmium, chromium, mercury, and nickel were compared to NOAA SQuiRT tables for TEL and PEL values. Values exceeding TEL Values are denoted with "*" and values exceeding PEL values are denoted with "".**

Parameter	CA01	CA02	CA-OF	HO01	HO02	HO-OF	KE01	KE02	KE03	KE-OF
Aluminum	13200	16100	10900	77.4	11800	6290	18500	22300	9840	12600
Antimony	<8.18	<11.6	<9.85	<10.3	<9.17	<8.05	<9.87	<9.96	<8.67	<8.7
Arsenic	<2.73	<3.87	**14.7***	<3.42	<3.06	**177****	<3.29	<3.31	**33.4****	**9.28***
Barium	107	66.2	52.3	60.4	48	35.4	156	233	62	53.5
Beryllium	0.19	0.368	0.239	<0.171	0.239	0.146	0.307	0.326	0.201	0.195
Boron	5.36	11.7	7.3	4.31	8.72	9.43	8.16	7.98	7.9	7.72
Cadmium	**0.995***	**1.446***	**0.855***	<0.855	**0.898***	<0.671	**1.279***	**1.418***	**0.941***	**1.003***
Calcium	6600	7800	5200	3500	6600	4000	4600	8200	6300	7200
Chromium	9.11	21.6	13.6	13.2	15.2	13.3	23.9	20.2	13.6	12.7

Parameter	CA01	CA02	CA-OF	HO01	HO02	HO-OF	KE01	KE02	KE03	KE-OF
Cobalt	6	8.71	8.25	5.48	8.91	9.65	8.73	7.14	6.78	8.65
Copper	11.5	20.3	**103***	11.4	25.3	**162***	25.6	32.1	30.2	**51***
Iron	16.7	31700	18900	12200	24.9	21200	22800	22200	21600	17700
Lead	6.97	<3.87	<3.28	<3.42	<3.06	<2.68	11.8	8.39	12	8.91
Lithium	15.8	24.4	8.18	6.81	8.82	5.93	21.4	20.1	8.38	7.99
Magnesium	5200	9100	5800	3400	5600	6100	7200	6600	5900	5400
Manganese	263	412	410	142	251	280	335	306	917	508
Mercury	<2.73	<3.87	<3.28	<3.42	<3.06	<2.68	<3.29	<3.31	<2.89	<2.9
Molybdenum	4.43	9.41	4.63	2.65	5.93	4.09	4.16	4.54	4.22	4.81
Nickel	2.63	4.89	13	5.93	8.23	9.29	8.26	7.92	11.1	7.48
Phosphorus	909	1620	468	526	630	606	590	673	587	539
Potassium	2690	1670	1210	815	886	944	4370	3410	893	1350
Selenium	<5.45	<7.73	<6.57	<6.84	<6.11	<5.37	<6.59	<6.64	<5.78	<5.81
Silicon	477	544	462	377	534	372	428	434	430	408
Silver	<1.36	<1.94	<1.64	<1.71	<1.52	<1.34	<1.65	<1.66	<1.44	<1.45
Sodium	633.9	337	478	570.5	523.9	340.2	588.2	851.9	346.3	671.3
Strontium	28.6	30.3	23.5	45.2	29.1	15.2	38.7	79.3	31.1	34.5
Sulfur	777	127	556	28.3	594	2660	71.9	1510	720	1560
Thallium	<5.45	<7.73	<6.57	<6.84	<6.11	<5.37	<6.59	<6.64	<5.78	<5.81
Tin	<2.73	<3.87	<3.28	<3.42	<3.06	<2.68	<3.29	<3.31	<2.89	<2.9
Titanium	1010	1120	457	574	561	427	1190	950	563	535
Vanadium	46.8	120	37.4	55.4	50.2	62	74.9	74.4	41.9	39.8
Yttrium	4.29	8.41	4.06	2.69	3.2	3.56	2.54	2.67	3.79	3.58
Zinc	37.1	40.4	78.1	14.8	40.2	36.8	52.2	52.2	67.5	86.4

4.1.6 Fecal Coliform

Water samples were collected to determine if total fecal coliform concentrations exceeded Alaska Water Quality Standard Criteria. Water quality criteria for fecal coliforms in freshwater are shown in Table 24. Fecal coliform concentrations for August and September 2013 and May 2014 are shown in Table 25.

All three sites exceeded the most stringent water quality criteria for two 30-day periods from August 21 to September 24. During these time periods, the geometric means of total fecal coliform concentrations were greater than 20 cfu/100 ml and 50-100% of the samples from each site were greater than 40 cfu/100 ml (Tables 25 and 26). The Hoadley Creek site showed the highest concentrations of fecal coliform bacteria with a 4-sample geometric mean from August 21 to September 18 of 279 cfu/100 ml and a single sample of 680 cfu/100 ml. However, during the spring flow sampling period, all of the sites were within the allowable limits. Additionally, no fecal coliform bacteria were detected at the Carlanna Creek site in any of the four samples collected in May 2014.

Table 24. Alaska water quality criteria for fecal coliform bacteria in freshwater (ADEC 2012).

(2) FECAL COLIFORM BACTERIA (FC), FOR FRESH WATER USES	
(A) Water Supply (i) Drinking, culinary, and food processing	In a 30-day period, the geometric mean may not exceed 20 FC/100 ml, and not more than 10% of the samples may exceed 40 FC/100 ml. For groundwater, the FC concentration must be less than 1 FC/100 ml, using the fecal coliform Membrane Filter Technique, or less than 3 FC/100 ml, using the fecal coliform most probable number (MPN) technique.
(A) Water Supply (ii) Agriculture, including irrigation and stock watering	The geometric mean of samples taken in a 30-day period may not exceed 200 FC/100 ml, and not more than 10% of the samples may exceed 400 FC/100 ml. For products not normally cooked and for dairy sanitation of unpasteurized products, the criteria for drinking water supply, (2)(A)(i), apply.
(A) Water Supply (iii) aquaculture	For products normally cooked, the geometric mean of samples taken in a 30-day period may not exceed 200 FC/100 ml, and not more than 10% of the samples may exceed 400 FC/100 ml. For products not normally cooked, the criteria for drinking water supply, (2)(A)(i), apply.
(B) Water Recreation (i) Agriculture, including irrigation and stock watering	In a 30-day period, the geometric mean of samples may not exceed 100 FC/100 ml, and not more than one sample, or more than 10% of the samples if there are more than 10 samples, may exceed 200 FC/100 ml.

Table 25. Total fecal coliform concentrations (cfu/100 ml) on each sample date at Carlanna, Hoadley, and Ketchikan creeks.

Sample Date	CA02	HO02	KE03
8/21/2013	145	680	74
9/3/2013	4	172	8
9/5/2013	36	332	64
9/18/2013	232	156	424
9/23/2013	110	50	30
9/24/2013	52	48	40
5/2/2014	<1	1	4
5/5/2014	<1	2	3
5/6/2014	<1	<1	9
5/7/2014	<1	1	<1

Table 26. Geometric mean fecal coliform concentrations (cfu/100 ml) for time periods with 4 sampling dates and percent of samples with concentrations above 40 cfu/100 ml.

	8/21 - 9/18 2013	9/5 - 9/24 2013	5/2 - 5/7 2014
Carlanna Creek			
Geometric Mean (N = 4)	47	83	1
%>40	50%	75%	0%
Hoadley Creek			
Geometric Mean (N = 4)	279	106	1.19
%>40	100%	100%	0%
Ketchikan Creek			
Geometric Mean (N = 4)	63	76	3.22
%>40	75%	50%	0%

4.2 Physical Habitat Characteristics

Habitat condition in all three streams was suboptimal based upon qualitative habitat assessment scores (Table 27). Habitat assessment ranks conditions on a scale of 1 to 20 and the overall score is an average of scores for individual habitat components. Scores from 1 to 5 are considered to reflect poor habitat, 6 to 10 marginal habitat, 11 to 15 suboptimal, and 16 to 20 optimal habitat conditions. Using these criteria, suboptimal habitat conditions were observed at all sampling locations. The Carlanna Creek sites were suboptimal mostly due to low scores in velocity-depth combinations and epifaunal substrate. Loss of riparian vegetative zone width and channel alteration at the lower Hoadley Creek site combined with low scores in velocity-depth combinations and epifaunal substrate to give Hoadley Creek the lowest stream average assessment score. The loss of riparian vegetation width and low scores in velocity-depth combinations, channel flow status, and epifaunal substrate, and loss of channel sinuosity at the KE02 site, resulted in sub-optimal rankings for all of the Ketchikan Creek sites. All locations on all three streams ranked optimal for the embeddedness, bank stability, and bank vegetative protection individual habitat components.

The substrate size distribution shows an abundance of boulders and bedrock in all of the sampleable sites, except KE02 (Figures 27-29, Table 28). None of the sites had any fine particles sampled (<2mm), but there was some embeddness observed, with a high of 24.5% mean embeddedness at KE01. This site had ≥20% embeddedness for nearly half (40.8%) of all substrate sampled. Just downstream, at the KE02 site, mean particle size was much lower (42.1 mm as compared to 255.1 mm) and embeddedness was mostly nonexistent (0.5%). We were unable to determine if this trend continued downstream to KE03 due to unsafe sampling conditions at that location.

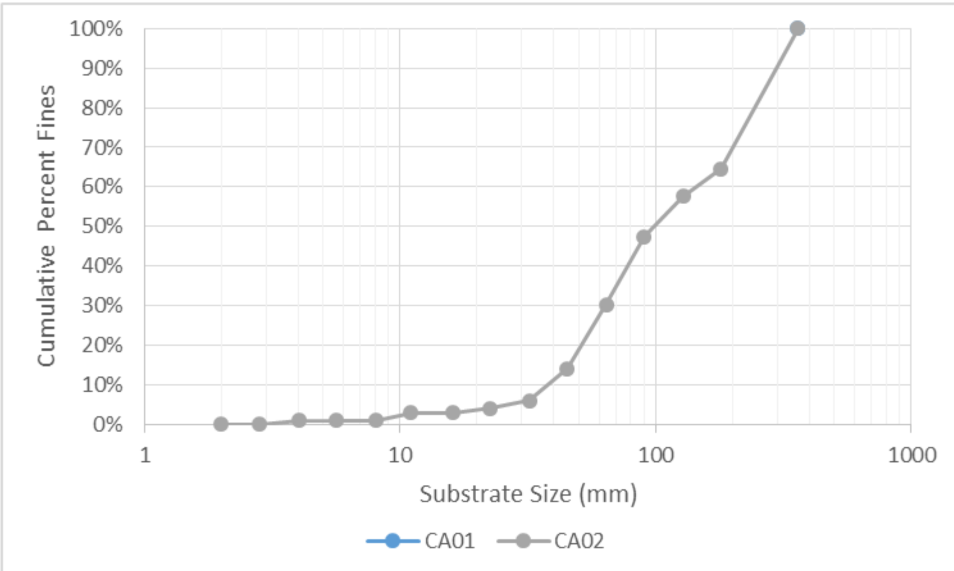

Figure 27. Carlanna Creek substrate size cumulative frequencies based on pebble counts. Substrate measurements were not conducted at CA01 due to safety concerns during the sampling period.

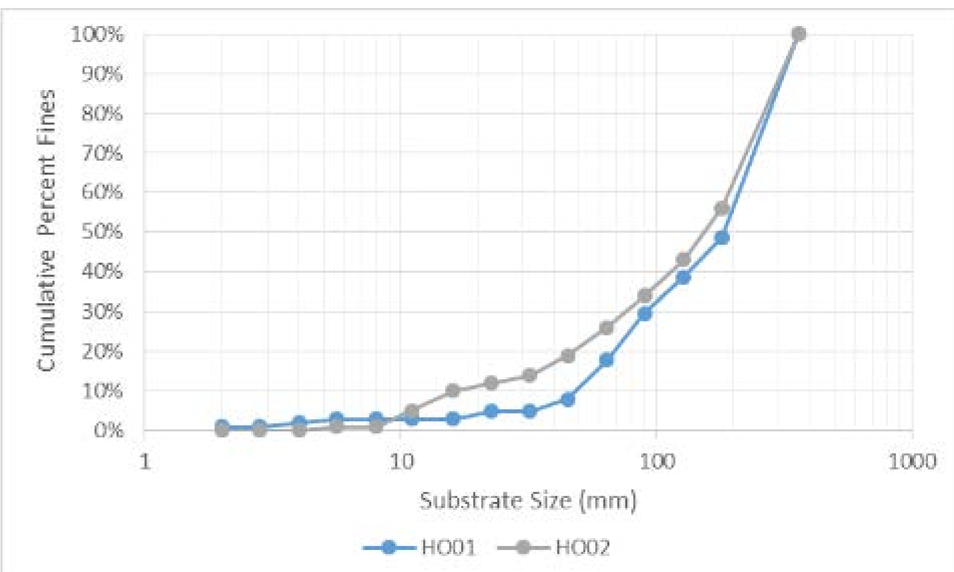

Figure 28. Hoadley Creek substrate size cumulative frequencies based on pebble counts.

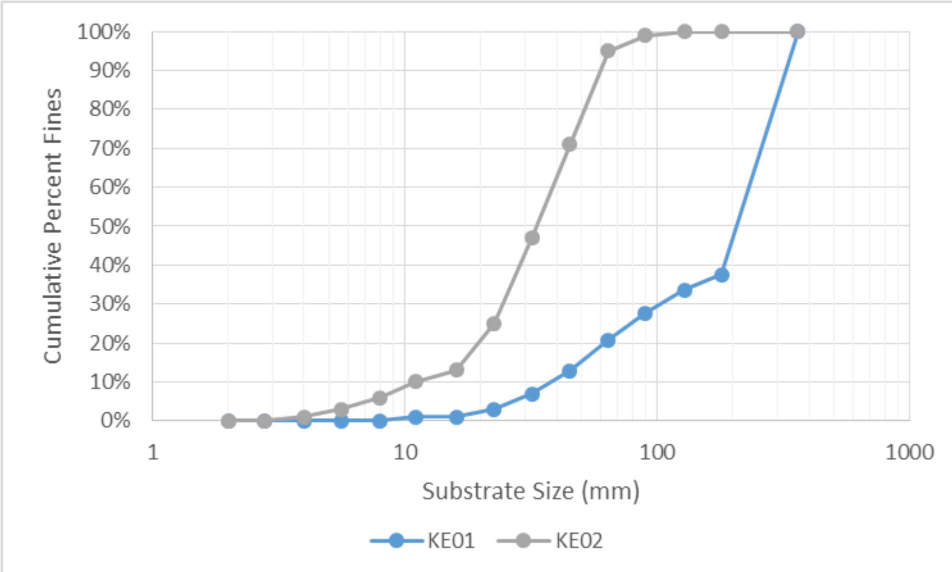

Figure 29. Ketchikan Creek substrate size cumulative frequencies based on pebble counts. Substrate was not sampled at KE03 due to high water depths.

Table 27. Qualitative habitat assessment scores for sampling sites located in Carlanna Creek, Hoadley Creek, and Ketchikan Creek. Assessment was conducted during fall 2013 sampling event.

Site ID	Epifaunal Substrate	Embeddedness	Velocity-Depth Combinations	Sediment Deposition	Channel Flow Status	Channel Alteration	Channel Sinuosity	Bank Stability	Bank Vegetative Protection	Riparian Vegetative Zone Width	Mean
CA01	3	19	2	19	18	16	19	20	20	16	15.2
CA02	7	18	10	18	13	19	18	20	20	10	15.3
HO01	9	18	7	19	13	15	18	18	20	6	14.3
HO02	11	17	11	18	12	9	17	18	20	6	13.9
KE01	12	19	12	18	10	16	18	20	20	14	15.9
KE02	16	16	10	15	10	15	9	18	20	10	13.9
KE03	14	17	4	18	17	11	16	20	20	4	14.1

Table 28. Substrate size distribution and embeddedness at the sampling sites. The CA01 and KE03 sampling sites had too high of depths and velocities to safely sample substrate size.

	Mean Particle Size (mm)	% Fines <2 mm	D50	D25	Mean Embeddedness (%)	% Substrate <20% Embedded
CA01	-	-	-	-	-	-
CA02	183.50	0	128	64	5.91	89.90
HO01	229.79	0	180	64	8.29	84.81
HO02	207.39	0	180	64	9.81	79.01
KE01	255.09	0	360	90	24.54	59.21
KE02	42.10	0	45	22.6	0.50	99.00
KE03	-	-	-	-	-	-

4.3 Outfall Mapping

A total of two outfalls draining into Carlanna Creek, 16 outfalls draining into Hoadley Creek, and 45 outfalls draining into Ketchikan Creek were photographed and mapped during the spring flow sampling event (Table 29, Appendix A). This is an additional six outfalls flowing into Hoadley Creek and 24 outfalls flowing into Ketchikan Creek to those mapped by the City of Ketchikan in 2011 (Tetra Tech 2011). Both of the outfalls draining into Carlanna Creek were flowing during the sampling period, seven of the sixteen into Hoadley Creek were wet or flowing, and 25 of the 45 mapped on Ketchikan Creek were wet or flowing, May 6-7, 2014. Of these outfalls, nine draining into Hoadley Creek and 35 draining into Ketchikan Creek were out of corrugated metal pipes. The remaining outfalls were either constructed of plastic or cement or were large natural runoff areas, where there had been no stormwater collection basins. Additionally, there were multiple locations on Hoadley Creek in which the stream was piped through metal culverts under roads or buildings.

Table 29. Outfalls draining into Carlanna, Hoadley, and Ketchikan creeks. Condition is the outfall's flow condition during the mapping period, 5/6-5/7/14, categorized as "dry" "wet" or "flowing." Outfalls were compared with City of Ketchikan surveys to determine if they were previously identified or newly identified (Tetra Tech 2011).

Drainage	Latitude	Longitude	Material	Condition	Previously Identified
Carlanna Creek	55.35849	-131.69516	Plastic	Flowing	Yes
Carlanna Creek	55.35984	-131.69478	Plastic	Flowing	Yes
Hoadley Creek	55.35365	-131.68831	Metal	Wet	No
Hoadley Creek	55.35402	-131.68748	Plastic	Dry	No
Hoadley Creek	55.35407	-131.68648	Metal	Dry	No
Hoadley Creek	55.35426	-131.68648	Runoff	Dry	No
Hoadley Creek	55.35426	-131.68640	Metal	Flowing	No
Hoadley Creek	55.35564	-131.68428	Metal	Flowing	Yes
Hoadley Creek	55.35593	-131.68492	Metal	Dry	Yes
Hoadley Creek	55.35699	-131.68373	Runoff	Dry	Yes
Hoadley Creek	55.35723	-131.68320	Metal	Flowing	Yes
Hoadley Creek	55.35859	-131.68080	Plastic	Dry	Yes
Hoadley Creek	55.35860	-131.68077	Metal	Dry	Yes
Hoadley Creek	55.35880	-131.68036	Plastic	Dry	Yes
Hoadley Creek	55.35883	-131.68036	Metal	Dry	Yes
Hoadley Creek	55.35883	-131.68037	Metal	Flowing	Yes
Hoadley Creek	55.35884	-131.67996	Plastic	Flowing	Yes
Hoadley Creek	55.35899	-131.67989	Runoff	Flowing	No
Ketchikan Creek	55.34442	-131.63216	Metal	Flowing	No
Ketchikan Creek	55.34446	-131.63228	Metal	Flowing	No
Ketchikan Creek	55.34404	-131.63254	Metal	Flowing	No
Ketchikan Creek	55.34376	-131.63251	Metal	Dry	No
Ketchikan Creek	55.34367	-131.63289	Metal	Dry	No

Drainage	Latitude	Longitude	Material	Condition	Previously Identified
Ketchikan Creek	55.34367	-131.63289	Metal	Dry	No
Ketchikan Creek	55.34329	-131.63345	Metal	Flowing	No
Ketchikan Creek	55.34296	-131.63372	Metal	Wet	No
Ketchikan Creek	55.34281	-131.63416	Metal	Flowing	Yes
Ketchikan Creek	55.34279	-131.63509	Plastic	Dry	Yes
Ketchikan Creek	55.34308	-131.63501	Cement	Flowing	No
Ketchikan Creek	55.34284	-131.63481	Metal	Flowing	Yes
Ketchikan Creek	55.34303	-131.63522	Metal	Flowing	No
Ketchikan Creek	55.34305	-131.63538	Plastic	Dry	No
Ketchikan Creek	55.34315	-131.63626	Metal	Dry	No
Ketchikan Creek	55.34326	-131.63675	Metal	Dry	No
Ketchikan Creek	55.34356	-131.63725	Plastic	Dry	No
Ketchikan Creek	55.34393	-131.63727	Metal	Flowing	Yes
Ketchikan Creek	55.34356	-131.63783	Metal	Flowing	Yes
Ketchikan Creek	55.34414	-131.63768	Plastic	Flowing	No
Ketchikan Creek	55.34384	-131.63997	Plastic	Dry	Yes
Ketchikan Creek	55.34376	-131.64005	Metal	Wet	Yes
Ketchikan Creek	55.34375	-131.64009	Metal	Flowing	Yes
Ketchikan Creek	55.34375	-131.64011	Metal	Flowing	Yes
Ketchikan Creek	55.34357	-131.64166	Metal	Flowing	Yes
Ketchikan Creek	55.34358	-131.64172	Metal	Flowing	Yes
Ketchikan Creek	55.34358	-131.64172	Plastic	Dry	No
Ketchikan Creek	55.34367	-131.64206	Metal	Dry	No
Ketchikan Creek	55.34377	-131.64226	Metal	Flowing	No
Ketchikan Creek	55.34391	-131.64195	Metal	Dry	Yes
Ketchikan Creek	55.34391	-131.64195	Plastic	Dry	No
Ketchikan Creek	55.34384	-131.64247	Metal	Dry	Yes
Ketchikan Creek	55.34413	-131.64255	Metal	Dry	No
Ketchikan Creek	55.34388	-131.64262	Metal	Flowing	Yes
Ketchikan Creek	55.34401	-131.64227	Plastic	Dry	No
Ketchikan Creek	55.34425	-131.64296	Metal	Dry	Yes
Ketchikan Creek	55.34381	-131.64359	Metal	Wet	No
Ketchikan Creek	55.34382	-131.64323	Metal	Dry	Yes
Ketchikan Creek	55.34351	-131.64140	Metal	Flowing	No
Ketchikan Creek	55.34381	-131.64099	Metal	Dry	No
Ketchikan Creek	55.34381	-131.64099	Metal	Wet	Yes
Ketchikan Creek	55.34237	-131.64268	Metal	Flowing	Yes
Ketchikan Creek	55.34272	-131.64366	Metal	Dry	Yes
Ketchikan Creek	55.34328	-131.64430	Metal	Flowing	Yes
Ketchikan Creek	55.34328	-131.64406	Plastic	Flowing	Yes

4.4 Macroinvertebrates and Fish

The macroinvertebrate biotic assessment showed a downstream decreasing stream health for both Hoadley and Ketchikan creeks, but a large increase downstream in Carlanna Creek (Figure 30). Richness, as total number of insect taxa, followed the same pattern as the biotic index, whereas total number of macroinvertebrates captured at each site consistently decreased downstream within each drainage. KE03 had the fewest number of insect taxa and the fewest macroinvertebrates captured among all the sites sampled (Table 30).

Juvenile coho salmon, rainbow trout, and sculpin were observed in Carlanna Creek. No coho salmon were collected in Hoadley Creek; only cutthroat trout and Dolly Varden were observed. In Ketchikan Creek, juvenile coho salmon, cutthroat trout, and Dolly Varden were collected during fall sampling.

Average coho salmon and salmonid condition factors were greatest in Carlanna Creek (0.115 and 0.113, respectively), as compared to Ketchikan Creek (0.105 and 0.105) and Hoadley Creek salmonid condition factor (0.095). However, coho salmon CPUT was lowest in Carlanna Creek (0.5 fish/trap) and greatest in Ketchikan Creek (1.7 fish/trap), with only one resident salmonid observed at each site. Hoadley Creek had the lowest coho salmon CPUT (0 fish captured), but the greatest resident salmonid density (1.1 fish per trap) (Figure 31).

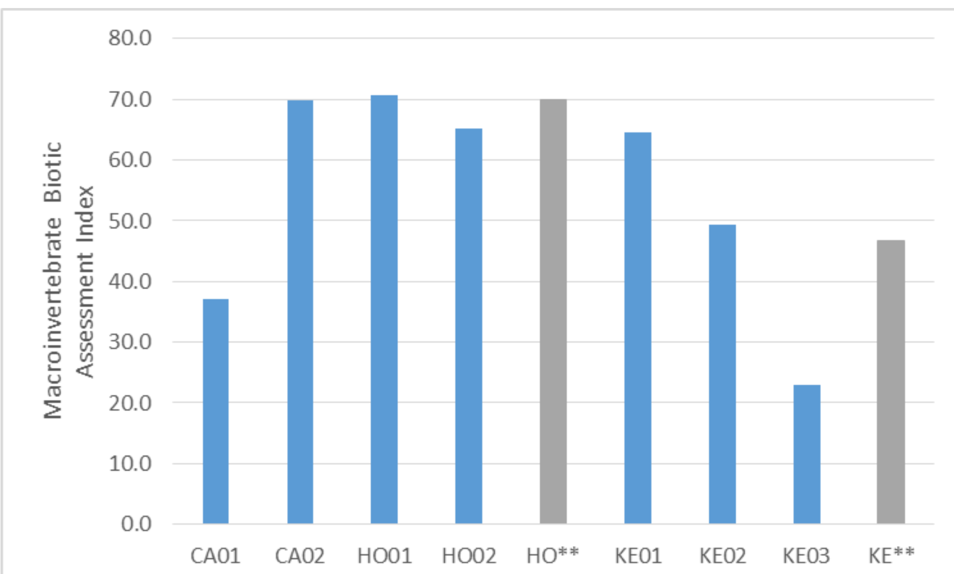

Figure 30. Macroinvertebrate biotic assessment values for each site, calculated using a multimetric index. Site names with "" and were sampled in May 2002 (Rinella et al 2005). HO** was located between sites HO01 and HO02, and KE** was located at approximately the same location as KE02.**

Table 30. Multimetric index and individual metric scores for study sites sampled in May 2014. Site names with "" were sampled in May 2002 (Rinella et al. 2005). HO** was located between sites HO01 and HO02, and KE** was located at approximately the same location as KE02.**

Site	Multimetric Index	Insect Taxa	Non-Insect Taxa (%)	EPT (%)	Scraper Taxa	Clinger Taxa	Intolerant Taxa (%)
CA01	37.1	7	12.5	1.5	0	1	83.3
CA02	69.8	16	11.1	73.0	3	7	87.5
HO01	70.7	16	15.8	92.3	3	6	85.7
HO02	65.2	14	12.5	75.1	2	6	85.7
HO**	69.9	16	5.9	63.7	3	8	70.6
KE01	64.5	13	18.8	95.1	2	5	78.6
KE02	49.4	12	29.4	16.9	4	6	61.5
KE03	22.9	6	45.5	12.3	0	1	50.0
KE**	46.8	12	20.0	41.5	2	4	46.7

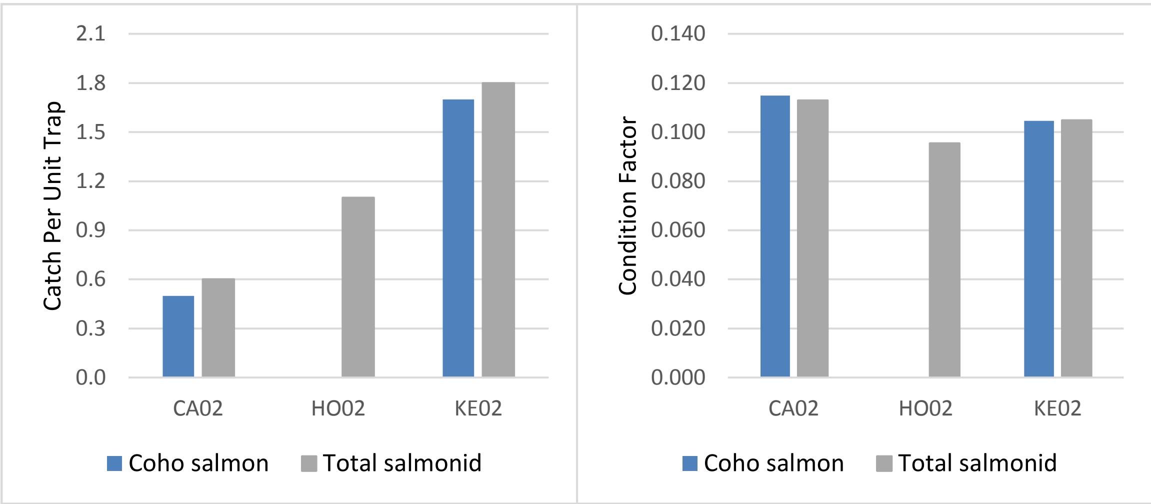

Figure 31. CPUT of juvenile coho salmon and total salmonids in September 2013 (left) and juvenile coho salmon and salmonids condition factors (right).

5.0 Discussion

Specific conductivity was elevated during the storm event and shortly after precipitation in the spring runoff sample. Relatively high specific conductance during spring runoff may be related to deicer used during winter months being washed into the streams following subsequent precipitation (Corsi et al. 2010, Eyles and Meriano 2010). All of the specific conductivity measurements collected in 2013 and 2014 were higher than previous values collected in the same streams in 2002 (Hoadley and Ketchikan creeks) (Rinella et al. 2002). Increasing specific conductivity is commonly associated with landscape disturbances and urban runoff and likely the cause of the increases observed in these streams (Ometo et al. 2002). This is additionally supported by the high conductivity values observed in the three outfalls sampled in this study.

Stream water pH was generally neutral except in sites predominately influenced by lake drainage (CA01, KE02, KE03), which were slightly acidic. Although Ketchikan Lake is upstream of KE01, the majority of stream flow at KE02 is pumped directly from the lake through the powerhouse and returned to Ketchikan Creek between sites KE01 and KE02. This reduces the changes in water chemistry that would have resulted from the water flowing through the stream reach upstream of KE01, such as picking up additional nutrients. Piping water from below the lake's surface also very likely explains the reduction in dissolved oxygen saturation in the downstream Ketchikan Creek sites, as the lower limnion is generally less saturated than surface water. Saturation at KE03 was generally higher than KE02, further supporting the idea that the observed reduction in dissolved oxygen saturation was caused by a point source and could be neutralized with downstream stream distance.

Outfall and storm events did not significantly change water clarity. Turbidity was relatively low in all sampling sites during all sampling periods, with no significant change between base flow and storm event samples. Outfall samples had higher turbidities than stream samples during spring flow, but these values were still approximately clear and within the ranges observed in the receiving streams during summer base flow. Settleable solid concentrations did not increase during storm events or have any detectable concentrations within outfall samples. This is in contrast to multiple studies showing increases in turbidities during storm events related to increases in flow and impervious surface drainage. No decreases in stream clarity may be related to the low percentages of fines at each site that could be mobilized during high stream flows (Deletic and Maksimovic 1998).

Dissolved organic carbon concentrations increased during the storm event, as compared to both base flow and spring flow samples. This shows that there was some flushing of the organic materials in the drainage, although this was not observed through increases in turbidity or settleable solid concentrations. Increases in dissolved organic carbon during storm events have been well-documented in natural and urban settings (Kalscheur et al. 2012).

Nitrogen and phosphorus concentrations and daily flux generally increased between sampling locations in each stream. Inorganic nitrogen concentrations and daily flux increased during the storm event as compared to summer base flow and spring flow sampling events. Anthropogenic sources of this form of nitrogen from fertilizers and fossil fuel emissions can be transported into the streams through precipitation, runoff, and leaching (Camargo and Alonso 2006, Swaney et al. 2012, Huang et al. 2014). Ammonia daily flux also tended to increase during the storm event and concentrations were usually higher at the downstream sampling sites. This may indicate sewer leakage, the single greatest source of ammonia into urban streams (Puckett 1994). Phosphorous concentrations did not increase during the storm event, but were generally highest during spring flow sampling and showed increasing concentrations downstream in Ketchikan Creek during all sampling events. Daily flux of total and total dissolved phosphorus generally increased downstream in each stream sampled, suggesting phosphorus inputs within the urban area. Documented sources of phosphorus in urban streams are largely industrial or municipal wastewater and fertilizer use (Drolc and Koncan 2002). Both nitrogen and phosphorus concentrations tended to be higher in the outfalls as compared to the receiving streams, showing that downstream increases in these nutrients are from human-derived sources or urbanization. However, the values observed were all well below acute or chronic toxicity levels and do not suggest any biological effects from the current levels of nitrogen and phosphorus inputs.

Total fecal coliform concentrations were well above water quality standards in all samples collected between August 21 and September 24. This, combined with high ammonia concentrations in base flow and storm event samples, suggest that there may be some leakage in the city sewers into the streams. However, during the May sampling period, all values were low, with many samples below detection limits. If all contamination were from sewer system leakage, we would expect results to be consistently higher during low flows (base and spring flows), with a reduction in concentrations during peak flow (storm events).Snow melt in the spring raises stream would result in lower concentrations of fecal coliform concentrations, as compared to during storm events, if sources of fecal coliform contamination were related to land area runoff. Low spring fecal coliform concentrations are consistent with patterns in southcentral Alaskan streams (Davis and Davis 2008).

Increasing nutrient concentrations, principally ammonia, and fecal coliform counts during summer and fall above water quality criteria suggest a probable wastewater source. Future sampling should be expanded to include reference samples for fecal coliforms. Future nutrient sampling should focus on stormwater outfalls to isolate potential ammonia source locations.

Alkalinity and hardness were generally low at all sampling sites during all sampling events, with some alkalinity values below detection limits. This is important because, generally, as hardness and alkalinities decrease, the toxicity of metals increase because they become more soluble and fish become more sensitive. (Pascoe et al. 1986, Ebrahimpour et al. 2010). The uptake of Ca and Mg ions reduces cell walls permeability to metal ions (Kim et al. 2001). The low hardness values observed in the Ketchikan streams make dissolved metals in these streams highly toxic to the biotic community, and even low concentrations of metals exceed water quality criteria. For example, in southcentral Alaskan streams, observed hardness values of 94.3 to 102.3 give copper acute toxicity concentrations of 12.7 to 13.7 µg/L, whereas the acute toxicity concentrations at CA01 ranged from 0.38 to 0.48 µg/L among sampling events due to hardness values of 2.3 to 2.9 mg/L (Davis et al. 2013).

Dissolved metal concentrations were generally highest during the summer base flow sampling event and showed an increasing trend, longitudinally, in both Hoadley and Ketchikan creeks (the downstream sites had higher metal concentrations). This trend was reversed in Carlanna Creek, where the upstream reference site had high metal concentrations, particularly during base flow sampling. Both Carlanna Creek sites had copper concentrations that exceeded acute and chronic toxicities during base flow, and the upstream site exceeded acute and chronic toxicities for lead and zinc. The lower two Ketchikan Creek sites (KE02 and KE03) exceeded copper acute and chronic toxicity concentrations: KE02 during base flow, and KE03 during all sampling events. Dissolved lead concentrations exceeded acute and chronic toxicities during base flow conditions at CA01 and KE03 and chronic toxicities at KE02.

Concentrations of heavy metals in stream sediments also increased downstream, with cadmium concentrations exceeding the TEL value at most sampling sites and copper concentrations exceeding the TEL value only at the KE03 site. Additionally, zinc concentrations were nearing the TEL value at the KE03 site, suggesting that zinc concentrations may become an issue for water quality in the future if concentrations increase from present values. High concentrations of copper and cadmium in stormwater are strongly correlated to vehicular sources, showing that road use and road drainage streams are major sources of stress for these urban drainages (Harrison and Johnston 1985). The positive relationship observed between nickel concentrations and impervious surfaces, as well as higher nickel concentrations in outfalls than receiving streams may also be related to vehicular exhaust as well industrial land use (OEC 2007). Proximity to roads and highways is also major contributing factor to trace element and PAH loading, through both stormwater runoff and airborne dispersal of contaminated particles (Van Metre and Mahler 2003). Improved vegetative stream buffers along roadways as well as settling basins at outfall sites to reduce contaminated particle inputs to the streams would help to limit PAH contamination within these urban streams.

Potential sources of heavy metal contaminates include metals leached from the large numbers of metal culverts, roof tops, and chain-link fences. Galvanized metal surfaces will leach zinc and other heavy metals into water, as will road runoff, likely explaining the general trend of increasing downstream zinc concentrations in sediment and water samples (Golding 2008, Hoffman et al. 1985). New development using non-metal materials and replacement of older galvanized metal culverts and stormwater pipes will help to reduce anthropogenic inputs of zinc and other metals into these drainages. Additionally, as both PAHs and heavy metals adsorb to sediment particles, the addition of settling basins at outfall locations would help to limit the amount of these toxins being transported into the streams. Future sampling locations could be selected to test for differences in sediment metal concentrations between storm drains with and without sediment basins.

Rinella et al. (2005) determined that in 2002, Ketchikan and Hoadley creeks were disturbed but not yet stressed, using the same habitat assessment methodology as in the current study. All three streams sampled would currently be categorized as “stressed” due to poor velocity-depth combinations and epifaunal substrate in all three streams. Additionally, the lower Hoadley Creek site had loss of riparian vegetative zone width and channel alteration, and Ketchikan Creek had loss of riparian vegetation width and channel sinuosity, as well as low scores in channel flow status. These habitat characteristics could be an indicator of increased anthropogenic impacts to these watersheds in the eleven years between these studies through increases in urbanization and road building within each drainage area. Chronic stress on these habitats through prolonged duration of disturbance could also explain some of the differences between habitat assesssments. One variable that has remained the same between these two habitat assessments was that Hoadley Creek has remained more disturbed than Ketchikan Creek.

Where possible efforts should be directed toward retaining existing riparian areas to provide a filter for stormwater runoff and maintain existing stream habitat characteristics.

Biotic assessments of macroinvertebrate assemblages showed a decreasing stream health trend at downstream locations. Scores were similar to past results on Hoadley and Ketchikan Creeks, suggesting that the biotic community has been minimally impacted over the past eleven years (Rinella et al. 2005), However, the KE03 site, downstream of the 2003 sampling site had a poor stream health index, with a biotic index score of 22.9 out of 100. Additionally, a large portion of juvenile coho salmon captured within each stream showed atypical markings (see Appendix B) or an abnormally deep body shape that appeared to be stunting or a form of deformity. Fish collection efforts, however, were not great enough to attempt to correlate deformities with stream toxicity values. These results suggest that stream toxicities are already effecting the biotic community or that disease is a problem for fish in these streams. Further sampling efforts are recommended to determine whether these changes is fish body shape are a normal variation, and if not, likely causes. Biotic assessments should be continued annually over the next few years, particularly in Ketchikan Creek to determine if results from this study represent an anomaly or a persistent change in the biotic community related to changes in water quality and physical habitat.

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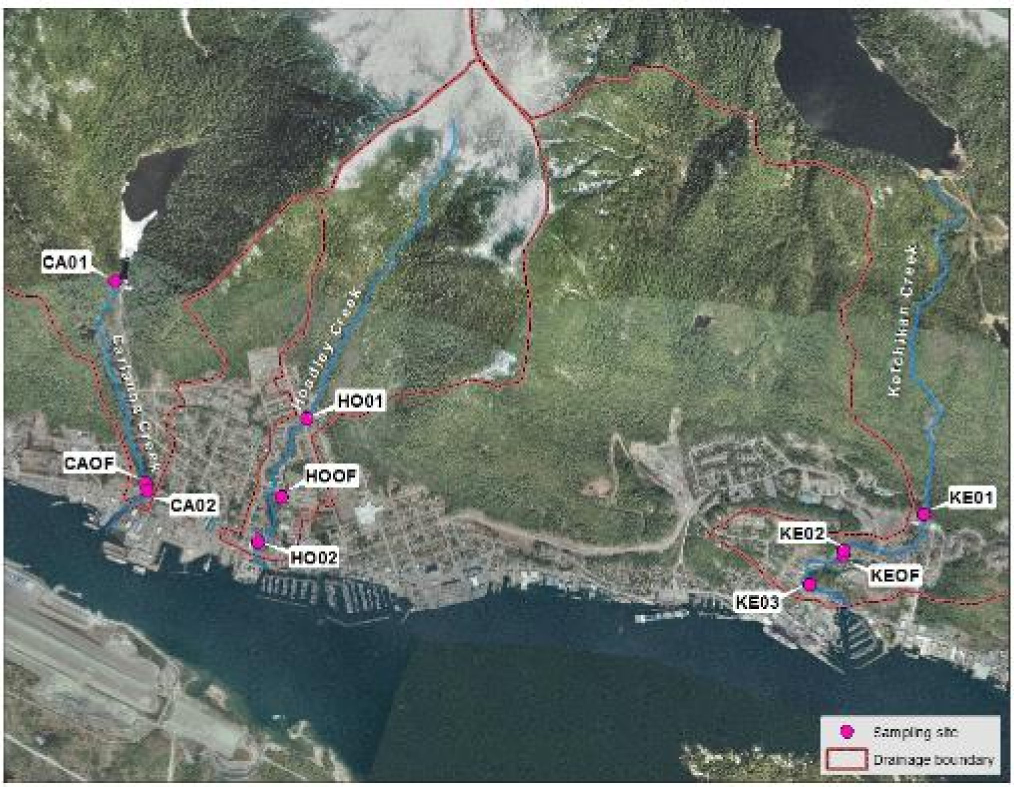
Appendix A: Maps

Carlanna, Hoadley, and Ketchikan creeks drainage areas.



City of Ketchikan and sampling locations.

Carlanna Creek sampling locations.

Outfalls draining into Carlanna Creek.

Hoadley Creek sampling locations.

Outfalls draining into Hoadley Creek.

Ketchikan Creek sampling locations.

Outfalls draining into Ketchikan Creek.

Appendix B: Site Photographs

CA01 looking upstream into Carlanna Lake, September 23, 2013.

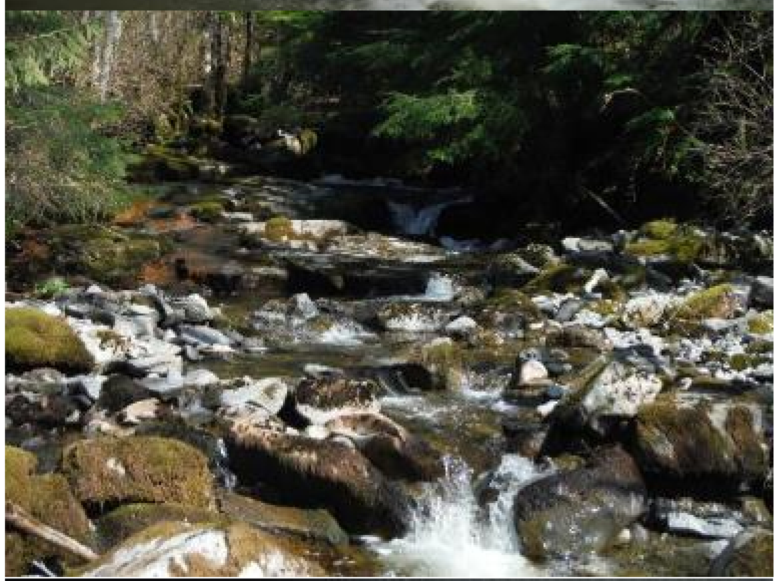
CA01 looking downstream at lake outlet, August 6, 2013.

CA02 at low flow conditions, August 07, 2013.

CA02 during storm event on September 22, 2014

CA02 during spring flow sampling, May 3, 2014.

Benthic macroinvertebrate sampling using a D-net at CA02, May 4, 2014.



HO01 upstream of Jackson Street crossing, May 3, 2014.

HO02 looking upstream into culvert under Peace Health parking lot, May 3, 2014.

HO02 downstream of culvert, August 7, 2013.

KE01 upstream of powerhouse outflow, September 22, 2013.

KE01 downstream showing powerhouse outflow pipe, May 6, 2014.

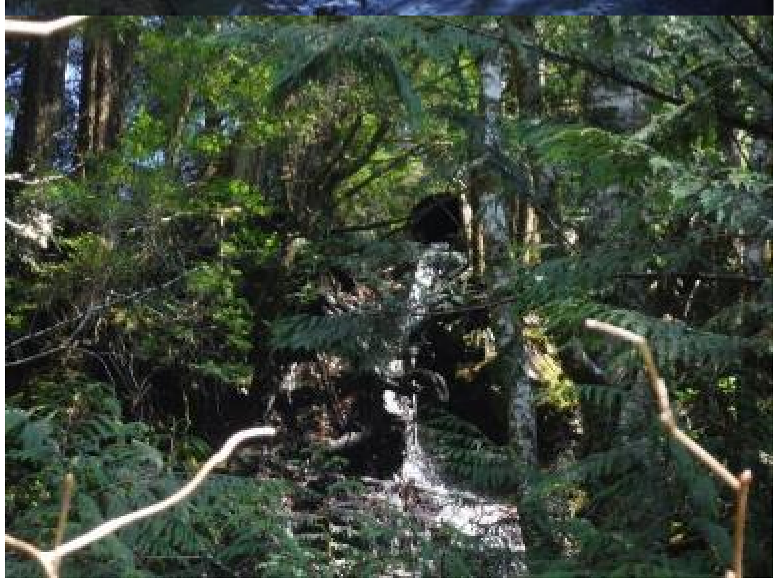
KE02 upstream of Harris Street bridge, May 3, 2014.

Pink salmon adults and carcasses at KE02 September 22, 2013.

Coho salmon captured at KE02 using baited minnow traps. Note the atypical parr marks on the top fish.

KE03 looking upstream at rapids, September 22, 2014.

KE03 looking downstream toward Creek Street, May 3, 2014.



CA-OF at outflow pipe draining residential area. May 3, 2014.

CA-OF at confluence with stream. White color from unknown substance dumped into storm drain on May 4, 2014.

HO-OF outfall draining residential area on Baranof Ave at Thatcher Way, May 3, 2014.

KE-OF outfall draining residential area at Freeman Street and Park Avenue, just downstream of KE02, May 6, 2014.

Appendix C: Water Chemistry Results

Parameter	Event	CA01	CA02	CA-OF	HO01	HO02	HO-OF	KE01	KE02	KE03	KE-OF
Discharge	Base Flow	4.66	2.10	-	0.70	0.57	-	0.79	65.03	-	-
(cfs)	Storm Event	61.96	35.42	-	5.76	5.17	-	25.37	108.25	-	-
	Spring Flow	9.29	12.93	-	2.50	2.19	-	8.53	190.66	-	-
Specific Conductivity	Base Flow	14.0	28.9	-	40.9	67.0	-	58.2	15.7	17.7	-
(µS/cm)	Storm Event	13.5	19.2	-	20.2	43.2	-	37.6	29.9	36.1	-
	Spring Flow	12.2	18.0	130.7	17.3	40.3	163.0	26.2	14.5	23.5	737.0
pH	Base Flow	6.98	7.35	-	7.52	7.44	-	7.68	5.88	6.23	-
	Storm Event	5.95	6.36	-	6.80	6.60	-	7.06	6.73	7.98	-
	Spring Flow	4.53	6.58	7.59	6.96	7.67	7.54	7.79	6.68	6.68	4.79
Dissolved Oxygen	Base Flow	101.0	99.5	-	93.2	97.7	-	99.0	73.4	84.5	-
(% Saturation)	Storm Event	98.5	98.7	-	96.0	96.6	-	99.1	87.6	96.6	-
	Spring Flow	97.7	107.8	98.3	97.7	99.4	95.3	94.5	99.2	93.8	86.2
Dissolved Oxygen	Base Flow	8.93	9.82	-	9.78	9.87	-	9.92	6.93	8.70	-
(mg/l)	Storm Event	10.84	10.84	-	10.79	10.74	-	11.10	9.81	10.63	-
	Spring Flow	11.45	12.48	11.52	11.95	11.60	10.70	11.26	12.13	11.58	10.29
Temperature	Base Flow	21.4	16.0	-	13.2	15.0	-	15.1	18.1	18.2	-
(°C)	Storm Event	10.6	11.2	-	10.1	10.8	-	10.3	10.3	10.5	-
	Spring Flow	8.3	8.3	8.3	6.6	8.1	9.9	7.8	6.6	6.5	7.4
DOC	Base Flow	3.9	2.5	-	1.6	1.6	-	1.6	1.1	1.2	-
(mg/l)	Storm Event	4.4	4.6	-	4.0	4.0	-	4.4	2.9	4.3	-
	Spring Flow	-	2.6	-	-	2.7	-	-	-	1.3	-
Turbidity	Base Flow	3.30	1.55	-	3.43	2.44	-	2.26	1.90	1.69	-
(NTU)	Storm Event	1.84	1.05	-	1.45	4.48	-	1.88	1.02	2.43	-
	Spring Flow	0.63	0.26	2.47	0.74	0.26	2.38	0.20	-0.83	0.06	4.83
Settleable Solids	Base Flow	0.0	0.0	-	0.0	0.0	-	0.0	0.0	0.0	-
(ml/l)	Storm Event	0.0	0.0	-	0.0	0.0	-	0.0	0.0	0.0	-
	Spring Flow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ammonia-N	Base Flow	<0.01	0.012	-	<0.01	0.013	-	<0.01	0.111	0.166	-
(mg/l)	Storm Event	0.027	0.038	-	0.028	0.025	-	0.031	0.083	0.095	-
	Spring Flow	0.020	0.026	0.125	0.043	0.028	0.120	0.036	0.030	0.025	0.038
Nitrate + Nitrite-N	Base Flow	<0.02	0.280	-	0.120	0.140	-	0.200	0.073	0.070	-
(mg/l)	Storm Event	0.032	0.075	-	0.029	0.062	-	0.097	0.091	0.080	-
	Spring Flow	<0.02	0.030	0.290	<0.02	0.037	0.280	0.068	0.076	0.075	0.530
Dissolved Phosphorous	Base Flow	<0.001	<0.001	-	<0.001	<0.001	-	<0.001	0.0011	0.0066	-
(mg/l)	Storm Event	<0.005	<0.005	-	<0.005	<0005	-	<0.005	<0.005	0.0060	-
	Spring Flow	0.0038	0.0017	0.0572	0.0027	0.0057	0.0024	<0.001	<0.001	0.0014	0.0027
Total Phosphorous	Base Flow	<0.005	<0.005	-	<0.005	<0.005	-	<0.005	<0.005	0.007	-
(mg/l)	Storm Event	< 0.005	<0.005	-	<0.005	0.008	-	<0.005	<0.005	0.011	-

Parameter	Event	CA01	CA02	CA-OF	HO01	HO02	HO-OF	KE01	KE02	KE03	KE-OF
	Spring Flow	0.008	0.037	0.040	0.005	0.007	0.006	<0.005	0.006	0.006	0.008
Alkalinity	Base Flow	2	6	-	12	14	-	22	4	4	-
(mg/l)	Storm Event	<1	2	-	2	6	-	6	4	4	-
	Spring Flow	2	2	<1	<1	<1	48	10	2	2	<1
Hardness	Base Flow	2.9	6.6	-	12	20	-	28	3.2	3.6	-
(mg/l)	Storm Event	2.6	4.5	-	5	13	-	13	8.1	11	-
	Spring Flow	2.3	4.5	44	5.2	14	140	16	3.9	4.2	340
Dissolved Copper	Base Flow	55.10	2.62	-	0.71	1.31	-	1.16	3.34	19.20	-
(µg/l)	Storm Event	0.20	0.50	-	0.31	1.12	-	1.14	0.90	12.00	-
	Spring Flow	0.12	0.44	1.09	0.26	0.83	5.92	0.60	0.16	1.02	67.10
Dissolved Lead	Base Flow	1.400	0.093	-	<0.05	<0.05	-	0.064	0.120	0.193	-
(µg/l)	Storm Event	<0.05	<0.05	-	<0.05	<0.05	-	0.107	<0.05	0.088	-
	Spring Flow	<0.05	<0.05	<0.05	<0.05	0.170	<0.05	<0.05	<0.05	<0.05	2.810
Dissolved Zinc	Base Flow	15.20	6.35	-	3.94	5.24	-	4.34	8.51	16.00	-
(µg/l)	Storm Event	0.77	0.84	-	0.79	3.23	-	2.48	1.34	5.49	-
	Spring Flow	<0.5	2.06	18.70	<0.5	2.94	19.30	2.01	1.04	0.64	277.00

Appendix D: Water Chemistry Mapping

See electronic ArcGIS file of water chemistry results.