Matanuska-Susitna Stormwater Assessment

2011-2012

Jeffrey C. Davis, Gay A. Davis, and Leslie R. Jensen
The Aquatic Restoration and Research Institute
Laura Eldred
Alaska Department of Environmental Conservation

December 2013

Acknowledgements:

This project was conducted with support from the Alaska Clean Waters Action Plan, the National Fish Habitat Action Plan, Mat-Su Salmon Partnership, Kenai Watershed Forum, Mat-Su wetland assessment project and prepared by Jeffrey C. Davis, Gay A. Davis, and Leslie R. Jensen under award 44529 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, administered by the Alaska Department of Fish and Game. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration, the U.S. Department of Commerce, or the Alaska Department of Fish and Game. A large portion of the field data collection and laboratory work was conducted by Emma Helverson, Erin Miller, Hannah Ramage and Jenn Woodham.

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1.0 Summary

Stream water physical and chemical characteristics and the biotic community were sampled from three streams in the Matanuska-Susitna (Mat-Su) Borough to assess potential impacts due to urban development and stormwater runoff. Sampling was conducted in Wasilla Creek, Cottonwood Creek, and Meadow Creek. Water samples were collected during spring runoff, summer base flow, and during two fall storm events annually in 2011 and 2012. Water samples were analyzed for turbidity, specific conductivity, dissolved oxygen, pH; ammonia-N, nitrate + nitrite nitrogen, total and total dissolved phosphorus, dissolved organic carbon, settleable solids, total copper, lead, and zinc. Alkalinity and hardness were measured at the farthest downstream site on each sampling date. Polycyclic aromatic hydrocarbons were measured at one site in each stream closest to the Parks Highway. Discharge was measured on each sampling date and discharge pressure rating curves were used to estimate daily discharge from water level/temperature loggers placed at the upper and lower sampling site in each stream. Water and sediment samples were collected from three outfalls during the fall storm events. Macroinvertebrates were sampled from each site in the spring and juvenile and resident fish in July and September. Qualitative habitat assessments were conducted and sediment size distribution measured at each sampling site. Measures of impervious surface area and percent wetlands within the drainages were obtained from previous studies and used to evaluate relationships between water chemistry, biotic communities and land use.

Water chemical and physical characteristics were modified in all streams during storm events. Concentrations of nitrogen and phosphorus do not reflect large increases in stream nutrients commonly observed in urban streams. Total and dissolved Cu, Pb, and Zn were above detection limits but below water quality standard criteria. Total metals increased during storm events, particularly in Wasilla Creek and were associated with increased sediments. The concentrations of metals in stream sediments were generally highest at locations downstream from the Parks Highway and below stormwater outfalls in Cottonwood Creek and Lucile Lake, approaching or exceeding Threshold Effect Levels. Concentrations of nutrients and metals were higher in samples collected in outfalls than in receiving streams.

Stream physical characteristics and qualitative habitat assessments do not reflect patterns observed commonly in urban streams. Changes in stream discharge during storm events caused by concentrated flows may be ameliorated by the undeveloped stormwater system (lack of curb and gutter). Lakes in the Cottonwood and Meadow Creek drainages also may buffer stormwater effects to stream physical characteristics.

The macroinvertebrate and fish communities suggest possible negative responses to urban development. The macroinvertebrate community in Cottonwood and Little Meadow Creeks has shown a consistent decline at sites located below the Parks Highway and in Meadow Creek below Beaver Road. Juvenile salmon are present in all streams but catch rates are low at some Cottonwood and Meadow Creek locations.

The concentration of development within the Wasilla, Cottonwood, and Meadow Creek drainages is still low compared to Anchorage and other urban areas. Water quality and the biotic

communities of these three steams remain good. However, water quality decreases during storm events and concentrations of metals in stream sediments are increasing. The biotic community, particularly in Cottonwood Creek may be showing initial negative response to urban development.

2.0 Introduction

During storm events, sediments, oils and grease, salts, and metals are washed from parking areas, roads, yards, and fields into drainage ditches or storm drains that discharge into surface streams. These pollutants can reach concentrations in streams and rivers that can result in health problems from drinking or recreational exposure. 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 alter the odor of streams affecting the ability of migrating salmon to locate spawning areas.

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 quickly flows off of compacted surfaces (i.e. roads, roofs, parking areas, lawns and other compacted soils) that are impervious to water flow (Paul and Meyer 2001). Tractive force, or the ability of water to suspend and transport sediments and other pollutants, increase with water velocity and depth. Alternatively, vegetation intercepts rainfall, decreasing the energy prior to reaching the ground, slows down surface flows, breaks apart soils and provides a pathway along roots into the soil. In addition, by physically slowing down the delivery of pollutants, soil microbes and plants can metabolize or breakdown toxic chemicals. 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.

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 (Al Bakri et al. 2008, 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 storm events (Mallin et al. 2009). Metals and hydrocarbons often are associated with precipitation events that collect 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).

Copper, lead, zinc, and chromium are commonly measured inorganic chemicals in stormwater studies (Makepeace et al. 2005). Sources of copper include the wearing of brake linings, combustion of lubricating oils, corrosion of building materials, and wear of bearings and bushings (Makepeace et al. 2005). The main sources of lead are from gas-powered vehicles, gasoline additives, and vehicle tires (Makepeace et al. 2005). Sources of zinc include wearing of tires, brake pads, and corrosion of building materials (Makepeace et al. 2005). Chromium is predominately associated with suspended solids, and sources included pesticides, fertilizers, and corrosion of welded metal plating and moving parts in engines (Makepeace et al. 2005). Roads and parking areas have been shown to be a major source of metals (Hoffman et al. 1995, Larkin and Hall 1998). Copper is the major aquatic toxic metal in stormwater and can range from 0.000006 to 1.41 mg/L. Increases in dissolved copper (2.3 to3 µg/L) have been shown to inhibit the olfactory response of juvenile coho salmon (Baldwin et al. 2003). Therefore, increases in copper at concentrations that are not uncommon in stormwater runoff can affect the response of coho salmon to predators and their ability to find their natal streams.

The Mat-Su Borough and core areas of Palmer and Wasilla have been the fastest growing regions in Alaska and among the fastest in the nation. As development increases, the concern for stormwater runoff pollution increases. Development within Wasilla is adjacent to Wasilla, Cottonwood, and Little Meadow Creeks. Cottonwood Creek, once a premier rainbow trout fishery, still supports coho salmon, sockeye salmon, and resident rainbow trout. Cottonwood Creek and Wasilla Lake also are important areas for water related recreation. A seven-mile section of Cottonwood Creek, downstream of the George Parks Highway, is currently listed by DEC as a Category 5 Impaired Waterbody for fecal coliform bacteria. Sources of fecal coliform microbial contamination in Cottonwood Creek have been linked to surface flows during storm events (Davis and Davis 2010). Stormwater sampling conducted more than 20 years ago detected hydrocarbons and metals in stormwater discharging into Wasilla Lake (DEC 1990). However, since that time water sampling has not been conducted to assess potential hydrocarbon and metal pollution of Cottonwood Creek. Biotic assessment of water quality documented a decrease in water quality from 1998 to 2005 (Davis et al. 2006).

Wasilla Creek and Little Meadow Creek have both been identified as high priority waters by the Alaska Clean Waters Actions program ranking for the assessment of potential water quality impacts (DEC 2010). Human settlement of the Palmer-Wasilla area and the Wasilla Creek drainage began with federal experimental farms in the 1930's. Housing development was accelerated further with construction of the George Parks Highway in the early 1970's. Wasilla Creek water quality was investigated in 2001 (Davis and Muhlberg 2002). At that time, most of the land use in the Wasilla Creek drainage was agriculture based. Water quality sampling showed an increase in nitrogen concentrations downstream, which may have been related to livestock grazing, and a decrease in pollution intolerant invertebrates. However, the number of housing subdivisions and commercial development are rapidly increasing within the drainage. In addition, four main roads linking Palmer and Wasilla cross Wasilla Creek.

Little Meadow Creek is located north of Wasilla in the Meadow Lakes area, and residential development within the Meadow Lakes area has been increasing in recent years. Storm runoff from the commercial district of Wasilla discharges to Lucile Lake (also spelled Lucille). Lucile Creek, the outlet stream from Lucile Lake, is a tributary to Little Meadow Creek. Little Meadow Creek and Lucile Creek join to form Meadow Creek, which flows into Big Lake, and then discharges, through Fish Creek to the Knik Arm of Cook Inlet. Meadow and Fish Creeks provide an important salmon and trout fishery, and Big Lake is an important recreational area in the region for boating and fishing. Big Lake has been listed as a Category 5 Impaired Waterbody due to hydrocarbon pollution from boat use. Recent work has been done to document physical habitat conditions in Little Meadow Creek (Curran and Rice 2009); however, water quality sampling for common stormwater pollutants has not been conducted.

Stormwater runoff can have significant and adverse effects to water quality and fish habitat and is related to the degree of impervious surfaces that occur with urban and rural development. Development is increasing in the Wasilla area surrounding streams that support important fisheries and recreation. However, little information is available regarding the concentration of common stormwater pollutants in streams draining the Palmer-Wasilla core area.

This project was conducted to provide measures of water quality, stream physical characteristics, and the biotic community in three urban streams within the core area of the Matanuska-Susitna Borough.

3.0 Methods

The assessment of water quality following stormwater runoff was evaluated in three urban streams: Wasilla Creek, Cottonwood Creek, and Meadow Creek (see maps in Appendix B). Water sample locations, sample collection, analyses, and data management are described in detail in a DEC approved Quality Assurance Project Plan. Water samples were collected at multiple locations that vary in the degree and type of upstream development. Samples were collected in all three streams following spring runoff, summer base flow conditions, and during two storm events in 2011 and 2012. Water and sediment samples also were collected at three stormwater outfall locations during storm events. Samples were analyzed for metals, nutrients, settleable solids, and other pollutants common in stormwater runoff.

3.1 Sampling Locations

Sampling locations in the Cottonwood, Meadow, and Wasilla Creek drainages are shown in Table 1 and Appendix B. Sampling locations are distributed along each stream system and at three known stormwater outfall locations (Figure 1). Sampling sites are located to differentiate between the amount and type of upstream development that could contribute to stormwater inputs.

Table 1. Dates sampling was conducted in 2011 and 2012 for water quality, physical characteristics, and the biotic community.

	2011 Sampling Dates	2012 Sampling Dates
Spring Runoff	April 26	May 4
Summer Base Flow	June 21	July 6
First Storm Event	August 1	August 2
Second Storm Event	August 17	August 23
Macroinvertebrates	June 1	May 3
Fish Summer	July 20 - 27	July 17 - 25
Fish Fall	September 19 - 23	September 12 - 20
Stream Sediment	Not Sampled	August 16
Physical Characteristics	Not Sampled	September 5
Large Woody Debris	Not Samples	September 5
Sediment Size Distribution		September 5
Habitat Assessment		

Table 2. Description of stormwater sampling locations.

Stream	Site	Description	Latitude	Longitude
Cottonwood Creek	CW01	Below Zephyr Road Crossing	61.62443 N	-149.28560 W
	CW02	Above Earl Road Crossing	61.60802 N	-149.29226 W
	CW03	Below Old Matanuska Road Crossing	61.57500 N	-149.40787 W
	CW04	Below Surrey Road Crossing	61.52489 N	-149.52952 W
Wasilla Creek	WA01	Above Crabb Circle	61.66135 N	-149.18846 W
	WA02	Above Bogard Road and Trunk Road Crossing	61.61389 N	-149.24159 W
	WA03	Next to Tributary Road	61.58690 N	-149.25659 W
	WA04	Between Fireweed Road and Railroad Crossing	61.56728 N	-149.31430 W
Little Meadow Creek	MC01	Downstream from Meadow Lakes Loop crossing of Little Meadow Creek	61.59166 N	-149.66658 W
Little Meadow Creek	MC02	Downstream from Parks Highway crossing of Meadow Creek	61.56910 N	-149.67018 W
Meadow Creek	MC03	Downstream from Beaver Lake Road	61.56264 N	-149.82600 W
Lucile Lake Outfall	OF1	Lucile Lake at outfall pipes on NE end of lake	61.50870 N	-149.45543 W
Lower Cottonwood Outfall	OF2	Cottonwood downstream from railroad crossing	61.57456 N	-149.41324 W
Upper Cottonwood Outfall	OF3	Cottonwood upstream from Parks Highway, Shopping Mall Parking Area	61.57577 N	-149.40362 W

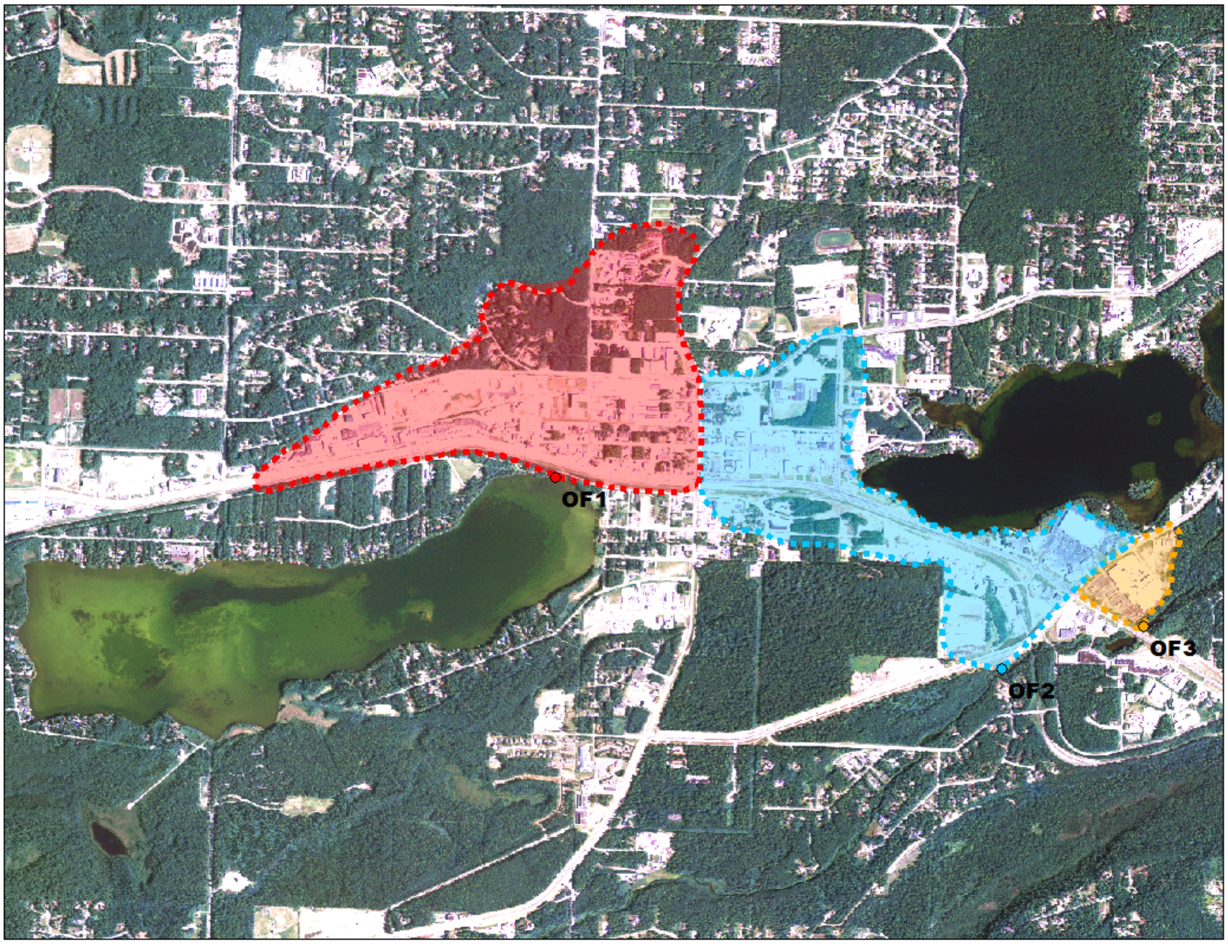


Figure 1. Location and estimated area draining into the 3 outfall sampling locations.

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, 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. Turbidity was measured using a LaMotte 3000 turbidimeter. Three replicate samples were measured and average turbidity calculated from these values. Specific conductivity and pH were measured using YSI 63 meters and probes. 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 some sites during spring sampling due to ice cover. Discharge was measured using a Swoffer 3000 velocity meter. Water level (Onset Corp.) loggers were installed at the upper and lowest sampling location on each stream. The loggers recorded pressure and temperature every 30 minutes. Stream water pressure was obtained by subtracting atmospheric pressure recorded at the ARRI laboratory from pressure values recorded in the streams. Mean daily pressure was calculated from values collected every 30 minutes. Regression was used to determine the relationship between water pressure and discharge and used to calculate daily discharge values. Maximum, minimum, and average daily temperatures were calculated based on the values collected every 30 minutes. Daily averages were compared to state water quality standards criteria for the "growth and propagation of fish, shellfish, other aquatic life, and wildlife" (ADEC). Additionally, monthly degree days were calculated as the sum of average daily temperatures for June-September, 2011-2012. Degree days provide a more biologically significant value for comparing thermal regimes among sites or years than single-day maximum or average temperatures.

Daily precipitation was obtained using rain gauges (Oregon Scientific Model RGR126) monitored by volunteers and from weather stations at the Palmer Municipal Airport (www.ncdc.noaa.gov). Rain gauges were located near the Palmer-Wasilla Highway near Cottonwood Lake in the Wasilla Creek drainage, the DEC Wasilla office on Bogard Road on the North Shore of Wasilla Lake in the Cottonwood Creek drainage, and on Vine Road near Lucile Creek in the Meadow Creek drainage.

Water samples were collected at each sampling location on each sampling date and from outfall discharge during storm events. The concentration of total copper, lead, and zinc, and cadmium (2011) and total and dissolved copper, lead and zinc (2012) 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 collected from the farthest downstream sampling location in each stream 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.

Water samples were collected for measures of petroleum hydrocarbons from one sampling location on each stream located just downstream from the Parks Highway (WA04, CW03, and MC02). In 2011, samples were collected and analyzed for volatile organic carbons (benzene, toluene, ethyl-benzene, and xylene) and polycyclic aromatic hydrocarbons. (PAH). In 2012, samples were collected and analyzed for PAH only. PAH concentrations were also determined from water and sediment samples collected at three outfalls during storm event sampling.

The concentration of metals and PAH in sediments was determined from samples collected downstream from the three outfall locations during each sampling event, with the exception of the first storm in 2011, and from stream sediment samples collected at each site on August 16, 2012.

All 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).

3.2.2 Macroinvertebrates

Macroinvertebrates were sampled at all sampling locations in the spring of 2011 and 2012. Samples were collected using the Alaska Stream Condition Index (ASCI) methodology (Major et al. 2001). Twenty benthic samples were collected in a “D Net” (350 micron mesh). All available habitats were sampled (i.e. streambed, large woody debris, macrophytes) proportional to their occurrence within the sampling reach. The net was placed downstream from the selected habitat and aquatic insects were manually dislodged from the substrate by rubbing the surface. Dislodged insects were transported by stream flow into the net. The cod-end of the sampling net was removed and the insects rinsed into a 5 gallon bucket. This process was repeated until twenty samples within the reach were collected. The entire combined sample from the site was stirred within the bucket to separate the macroinvertebrates from the inorganic substrate. The Macroinvertebrates were then transferred to a 500 ml Nalgene bottle and preserved with 80% alcohol. The sample bottles were labeled with the sampling date, location, and the sampling technicians.

Laboratory processing included sub-sampling, sorting, and species identification. Each site’s aggregate sample was mixed and then subdivided equally into 12 sub-sections. One sub-section was selected randomly and all invertebrates within that sub-section were counted and rough sorted into orders. More sub-sections were randomly selected until 350 or more invertebrates were sorted for identification. Invertebrates were identified to species level where possible; otherwise they were identified to the lowest taxonomic level. Macroinvertebrate metrics, richness, and diversity were calculated to determine the ASCI scores and Cook Inlet Biological Assessment Index (CIBI) scores (Rinella and Bogan 2007) for each site. Individual metrics, as well as ASCI and CIBI scores, were used for regression analyses. ASCI metrics include Trichoptera taxa; percent Ephemeroptera, Plecoptera, and Trichoptera; percent Diptera, percent collectors, Hilsenhoff Biotic Index, and percent scrapers and predators. CIBI metrics include number of Ephemeroptera, Plecoptera, and Trichoptera taxa; number of Ephemeroptera taxa; Shannon’s diversity; percent Ephemeroptera; percent non-insects; and percent scrapers.

Macroinvertebrate ASCI and CIBI scores were compared with previously collected samples. Macroinvertebrates were collected at the downstream Wasilla Creek sampling location (WA04) in May 1998, and at all four sampling locations in June 2000 (Major et al. 2001) and September 2001 (Davis and Muhlberg 2002). A CIBI score for June 2001 at WA04 is published in Rinella and Bogan (2007). Three of the Cottonwood Creek sites were sampled in May 1998 and June 2000 (CW02, CW03, and CW04, Major et al. 2001) and in September 2005 (CW01, CW03, and CW04; Davis et al. 2006). Rinella and Bogan (2007) provide a June 2001 CIBI score for CW04. The Meadow Creek sampling locations below the Parks Highway (MC02) and near Beaver Lake Road (MC03) were sampled in May 1998 and June 2000 (Major et al. 2001) and June 2001 (CIBI score only, Rinella and Bogan 2007).

3.2.3 Juvenile Salmonids

Juvenile salmon and resident fish were sampled using baited minnow traps within the same sampling reaches as delineated for macroinvertebrates. Fish sampling was conducted at each site during July and September of 2011 and 2012. Twenty minnow traps (1/4 inch mesh, 1 inch opening) were used within each 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. All salmonids were measured to fork length and the first 50 salmonids were weighed. All captured fish were released on site after being measured. Growth rates were calculated from the differences in the mode of the length-frequency distribution for age-0 fish between July and September samples divided by days between sampling. Instantaneous growth was calculated as the difference in the log of fork length divided by days between sampling. Average catch per unit trap (CPUT) for total salmonids, salmonid species, and ratios of anadromous to resident fish were calculated for each site and stream and used along with growth rates as dependent variables in correlation and regression analyses with average water chemistry measurements.

3.2.4 Habitat Assessment and Bed Sediments

Habitat assessment and substrate size distribution were determined at each sampling location. 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 walks up the channel diagonally from bank to bank. Every second step a particle of substrate was collected from under the toe of the right foot. The median diameter of this particle was measured with a gravelometer and recorded.

3.2.5 Channel Morphology and Woody Debris

At each site, a study reach of 80 meters was used, with 5 equidistant transects along the reach. A level line was placed across the channel at each transect, and a meter rod was used to measure the distance from the ground surface to the level line. At each transect, survey points were measured at any breaks within the streambed surface, including the thalweg, and extended beyond the wetted channel to include top of bank and floodplain ground shots. Within the wetted channel, depth of water was recorded, as well as any undercut banks. Ordinary high water marks, where different from the water surface elevation at time of surveying, were also recorded.

Where local vegetation and geometry allowed, a laser level was used to obtain relative streambed elevations from one transect to another and were used to calculate streambed and water surface slope over the study reach.

Large Woody Debris (LWD) pieces and dams were counted and rated at each of the study reaches and used to calculate a large woody debris index (LWDI) (Davis et al. 2001). With the exception of the CW03 site, all LWD surveys were conducted over an 80-meter length study reach. The CW03 LWD survey was conducted over a 100-meter reach. LWD pieces are defined as any wood greater than 10cm in diameter at one end and at least 1 meter in length. Debris dams are defined as an assemblage of 3 or more LWD pieces.

Each LWD piece found in the stream was counted and then rated according to seven different parameters. These parameters include the diameter, stability, complexity of structure, percent of bankfull width affected by the LWD, the location, orientation, and the relative influence on morphology and retention of organic matter. The debris dams were rated on such parameters as total length, height, complexity of structure, location, and stability. Each debris dam and LWD piece was rated on a scale of 1-5 for each of the respective parameters. A weighted score was then calculated for debris dams (DDS) and pieces (PS) according to how each piece or dam scored on their corresponding parameters. Collectively the two weighted point scores result in a LWD Index (LWDI) according to the following equation:

$$LWDI = \Sigma PS + 5\Sigma DDS$$

The debris dam score (DDS) is weighted heavier in the equation to account for its increased ability to retard flow and organic matter and provide protection and habitat for macroinvertebrates and fish. To enable the comparison of LWD existing in streams of differing size, the LWD and debris dam counts are divided by the channel width as well as reach length.

3.2.6 Land Use Indices

The percent of impervious surface area, and percent wetland were used as indicators of land use above sampling stations. Percent impervious surface area was obtained from analyses conducted by The Nature Conservancy using satellite data from 2008 (Geist and Smith 2011). The GIS data products were used to calculate the percent impervious surface area upstream of each sampling station and within ½ mile of the stream drainage. Geist and Smith (2011) provide impervious surface coverage in three categories, low, medium, and high. High imperviousness includes large contiguous areas of highways, buildings, parking lots, and compacted soils in gravel pits. Medium level of imperviousness includes roads and large commercial and residential buildings. Low imperviousness is made up of smaller dirt and gravel roads, small buildings and houses, and some driveways. Percent impervious surface was calculated for the area between each sampling station and total cumulative upstream percent imperviousness for all three categories individually and cumulatively.

The percent of wetland upstream from each sampling station was calculated from wetland maps by geomorphic classification type (Gracz 2011). Wetland surveys in these watersheds were conducted in 2009 and 2010. We used ArcGIS attributes tables and wetland maps to sum up the area of wetland by wetland type upstream of each sampling station and total upstream watershed area. Percent wetland between sampling sites and cumulative percent upstream wetland by wetland type, total wetland, and non-lake wetlands were calculated and used in the analyses.

3.3 Data Analyses

Correlation analyses were used to evaluate changes in water chemistry and biotic metrics as a function of percent impervious surface area and wetlands by geomorphic type. Two-factor ANOVAs were performed to test for differences in CPUT among streams, sites, and among sampling events. Tukey post-hoc tests were performed using the program R to determine which streams, sites, or sampling events were significantly different. P values less than 0.05 were considered significant for all tests performed.

4.0 Results

4.1 Water Physical and Chemical Characteristics

4.1.1 Precipitation and Stream Discharge

Water sampling was conducted during spring runoff on April 26, 2011 and April 24, 2012; during summer base flow conditions on June 21, 2011 and July 6, 2012; and following precipitation events on August 1 and 17, 2011 and August 2 and 23, 2012. Cumulative precipitation, as measured at the Palmer Municipal Airport, is shown in Figure 2 in relation to sampling events. Cumulative summer precipitation was 183 mm higher in 2012 than in 2011, with more frequent storm events.

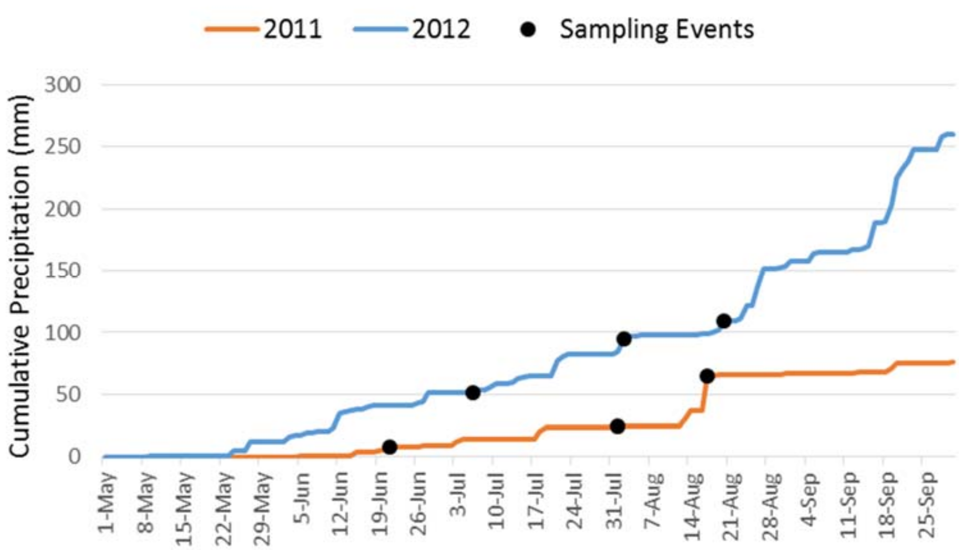


Figure 2. Cumulative precipitation as measured at the Palmer Municipal Airport in relation to base-flow and storm event sampling dates in 2011 and 2012.

Water samples collected in both years for the base flow samples were obtained from all streams during the declining hydrograph following spring snowmelt and represented base flow conditions (Figure 3). Discharge during 2011 spring sampling was 5 cfs higher than on June 21 in Cottonwood Creek, and 18 and 19 cfs higher in Wasilla and Meadow Creeks, respectively. Likewise, discharge during 2012 spring sampling was 20 cfs higher than on July 6 in Cottonwood Creek, and 48 and 32 cfs higher in Wasilla and Meadow Creeks, respectively.

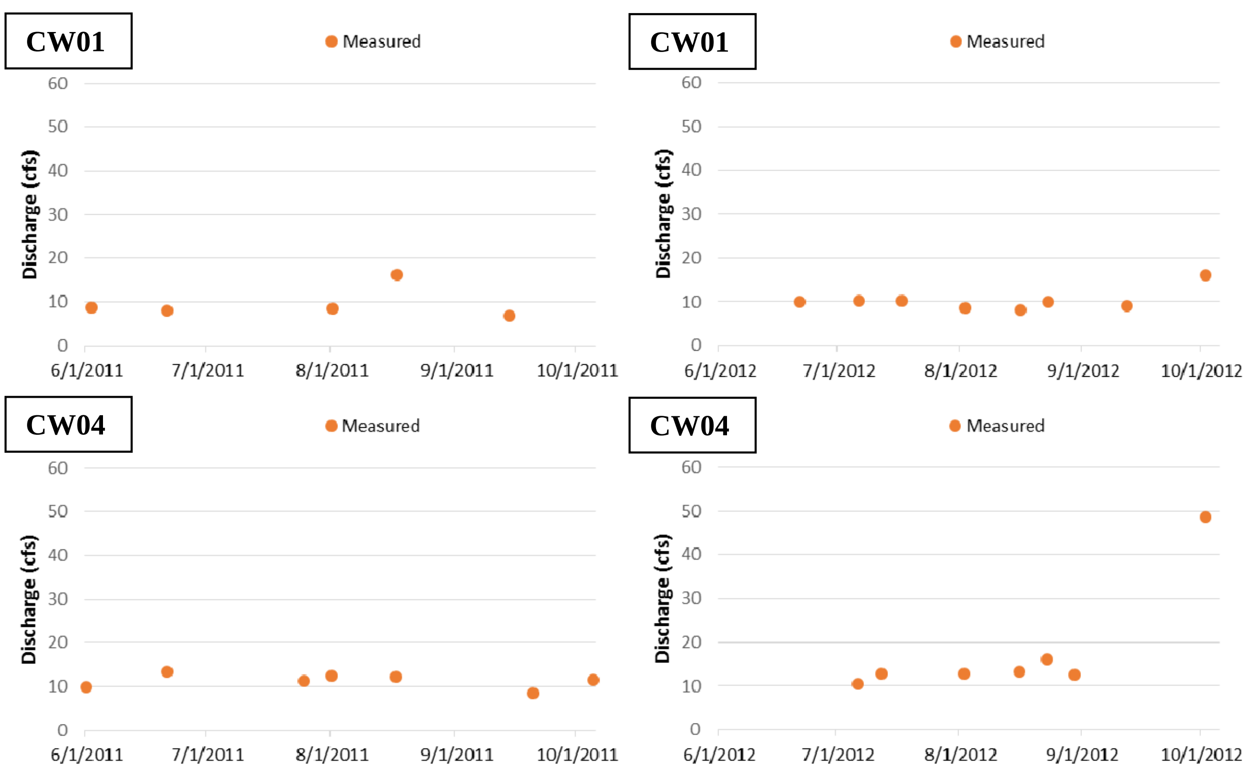
Sampling on August 1, 2011 followed a small storm preceded by a period of up to 4 weeks with very little precipitation resulting in small increases in discharge at most sampling locations. On July 29, 2011 0.4 inches of rain was recorded near Wasilla and Cottonwood Creeks, one day prior to the first stormwater sampling on August 1, 2011. Sampling on August 17, 2011 was during a large precipitation event (Table 3). Three inches of rain had fallen during the 2 weeks before the storm causing an increase in stream flows over this same time. Over 1.1 inches

(Cottonwood Creek) to 1.4 inches (Wasilla Creek) of rain was recorded on August 17. In Wasilla Creek, discharge was 15 to 18 cfs higher on August 1 compared to the base sampling date of June 21.

Sampling on August 2, 2012 followed a small storm preceded by a period of approximately 10 days with very little precipitation. On August 2, 10.4 mm of new rainfall was recorded at the Palmer Municipal Airport. During the fourth storm event sampling on August 23, 2012, 3.0 mm of rain was recorded, followed by an additional 100.5 mm in the four days after sampling (Table 3). Discharge during Storm 4 sampling was lower than all other sampling events in Wasilla Creek, but higher than base flow and Storm 3 in Cottonwood Creek. Meadow Creek had similar measured discharges during both storm events.

Table 3. Precipitation on sample date and cumulative precipitation for day and week prior to sampling storm events, as measured at the Palmer Municipal Airport.

	Precipitation on Sample Date	Precipitation Day Prior	Precipitation Week Prior	Days Since Measurable Precip.
Storm 1	0.0	1.3	1.8	13
Storm 2	27.2	0.0	12.4	3
Storm 3	10.4	2.0	2.3	10
Storm 4	3.0	0.0	11.1	3



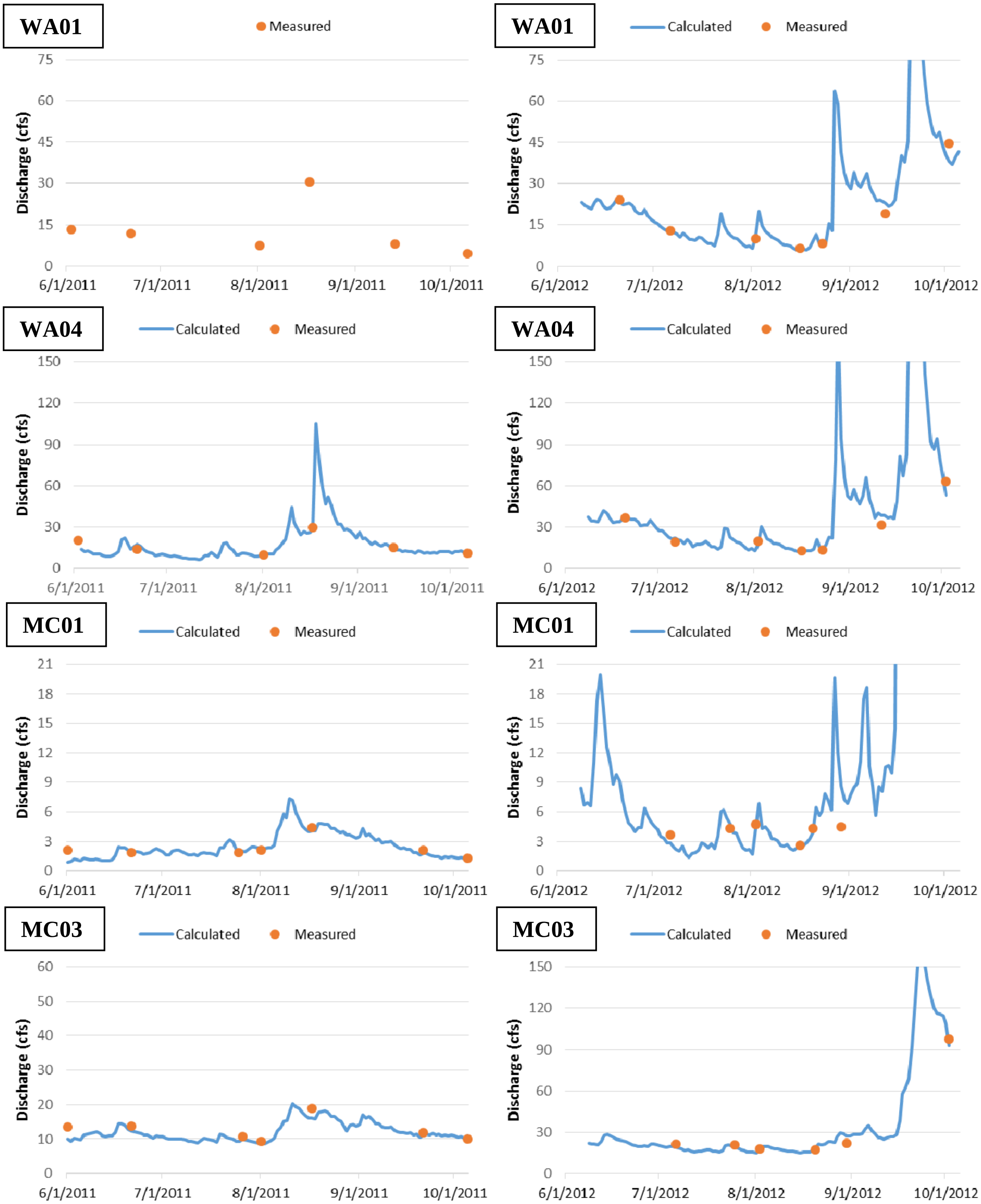


Figure 3. Calculated summer discharge values at Wasilla Creek sites WA01 and WA04 and Meadow Creek sites MC01 and MC03 in 2011 and 2012. Values were calculated based on regression between measured discharge values and average daily water pressure at HOBO water level logger stations at each site. WA01 did not have calculated daily discharge values due to water level logger malfunction and depths at monitoring sites on Cottonwood Creek were too stable to create water level and discharge relationships.

Percent change in discharge during storm events was greatest at the upstream sites, with a muted response downstream of development (Figure 4). The differences between upstream and downstream sites peaked at the height of discharge during storm event 3 on August 3, 2012. On this date, percent change was 46% more at WA01 than WA04 and 205% more at MC01 than MC03. Discharge at MC03 only increased by 27% during this storm event, as compared to pre-storm discharge on July 30, 2012.

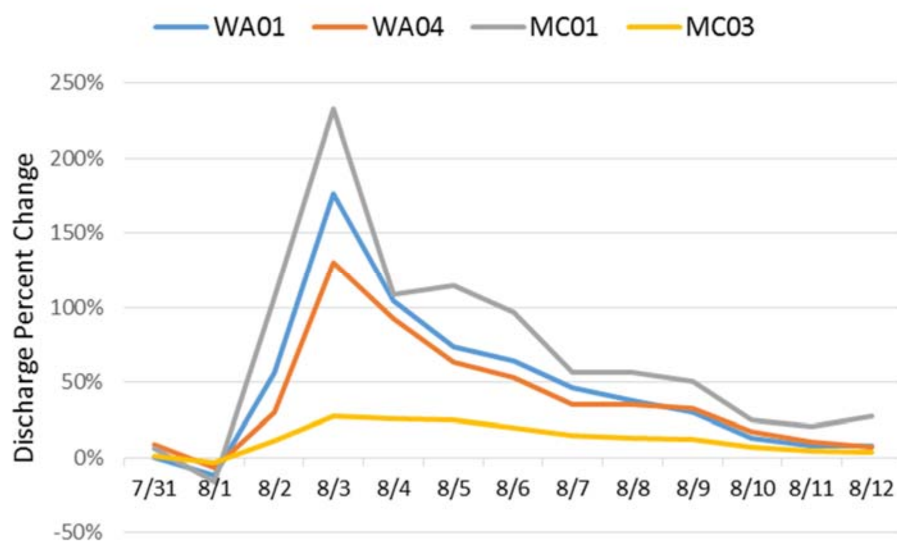


Figure 4. Percent change in discharge during storm event 3 on August 2, 2012. Discharge values were calculated based on average daily water level and compared to pre-storm discharge on July 30, 2012.

4.1.2 Nitrogen and Phosphorus

Stream water nitrogen and phosphorus concentrations for all sampling dates and locations are shown in Tables 4 through 7. Average concentrations for each stream on each sampling date are shown in Figures 5 through 8.

Average ammonia-N concentrations tended to be lower in Cottonwood (0.017 mg/L) and Wasilla Creeks (0.013 mg/L) compared to Meadow Creek (0.05 mg/L), but averages were not significantly different (p=0.10). Ammonia-N concentrations were generally higher during spring runoff and some storm events compared to summer base flow values.

There were no significant differences in ammonia nitrogen concentrations among sites within each stream. The highest average ammonia concentration in Cottonwood Creek was 0.03 mg/L at the CW01 (upstream site) and the lowest average ammonia concentration was 0.01 mg/L at CW02. Average ammonia concentrations ranged from 0.01 mg/L at WA01 at the upper end of the drainage to 0.07 mg/L at WA04 located below the Parks Highway. Average ammonia increased from 0.02 mg/L in Little Meadow Creek at the upstream MC01 site to 0.09 mg/L at MC02.

Cottonwood Creek ammonia concentrations were significantly higher during spring runoff and 3 of the 4 storm events when compared to summer base flow concentrations (Figure 5). Similarly, in Wasilla Creek and Meadow Creek, ammonia concentrations were higher in the spring and during 2 of the 4 sampling dates during storm events.

Average nitrate + nitrite-N concentrations were higher in Wasilla Creek (0.45 mg/L) compared to Cottonwood (0.22 mg/L) and Meadow (0.15 mg/L) Creeks and differences among sites were significant ($p = 0.001$). There were no differences in nitrate-N concentrations between sampling events, with the exception being Wasilla Creek, where concentrations during the spring were higher than during summer base flow (Figure 6).

There were no significant differences in nitrate + nitrite-N concentrations among sites within Cottonwood Creek or Wasilla Creek; however, average concentrations did differ in Meadow Creek. Average nitrate + nitrite-N concentrations increased from 0.04 mg/L at MC01 to 0.24 mg/L at MC02. The highest average concentration in Cottonwood Creek was downstream from Wasilla Lake at 0.49 mg/L and the lowest average nitrate + nitrite-N concentrations was at CW02 at 0.14 mg/L. Average nitrate + nitrite-N concentrations in Wasilla Creek varied from 0.44 to 0.53 mg/L.

There were no significant differences in total or total dissolved phosphorus among the three streams, although average concentrations tended to be lowest in Cottonwood Creek and highest in Wasilla Creek. Average total phosphorus concentrations were 0.024 mg/L in Wasilla Creek, 0.18 mg/L in Meadow Creek, and 0.009 mg/L in Cottonwood Creek. Total dissolved phosphorus ranged from 0.017 mg/L in Meadow Creek, 0.014 mg/L in Wasilla Creek, and 0.007 mg/L in Cottonwood Creek.

Phosphorus tended to differ among sites within Cottonwood Creek and Meadow Creek, but not Wasilla Creek. Average total phosphorus was approximately 0.008 mg/L in the upper three Cottonwood sites and increased to 0.013 mg/L at the downstream site CW04 ($p = 0.08$). However, a similar trend was not observed with Cottonwood Creek dissolved phosphorus concentrations. Total phosphorus increased from 0.007 to 0.023 mg/L between Meadow Creek site MC01 and MC02, and dissolved phosphorus increased from 0.004 to 0.014 mg/L between these two Meadow Creek sites ($p = 0.06$).

Total phosphorus and dissolved phosphorus increased significantly during spring runoff and storm events relative to base flow conditions in Wasilla Creek but not in Cottonwood Creek or Meadow Creek (Figures 7 and 8). For example, total phosphorus (average for the 4 sampling sites) was 0.05 mg/L higher during spring runoff compared to base flow conditions and 0.03 mg/L higher during large storm events, and dissolved phosphorus was 0.03 mg/L higher during spring and 0.01 mg/L during storms.

Table 4. Ammonia-N (mg/L) concentrations for all sampling sites and dates. ND indicates value was below method detection limit of 0.005 mg/L.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	0.065	0.022	0.012	0.007	0.084	0.050	ND	0.031
CW02	0.043	0.031	0.015	ND	0.026	0.008	ND	ND
CW03	0.015	ND	ND	ND	0.022	0.020	ND	0.026
CW04	0.205	0.013	ND	ND	ND	0.005	ND	0.012
WA01	ND	0.001	ND	ND	ND	0.018	ND	ND
WA02	0.191	0.016	ND	ND	ND	ND	0.008	ND
WA03	0.141	0.010	ND	ND	ND	0.020	ND	0.019
WA04	0.060	0.001	0.530	ND	ND	0.015	0.009	ND
MC01	0.055	0.035	ND	ND	0.034	0.023	ND	ND
MC02	0.163	ND	0.010	ND	0.114	0.328	ND	0.119
MC03	0.084	0.010	ND	0.035	ND	0.118	ND	ND

Table 5. Nitrate + nitrite-N concentrations (mg/L) for all sampling locations and sampling dates. ND indicates value was below method detection limit of 0.010 mg/L.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	0.240	0.190	0.029	0.035	0.540	0.180	0.079	0.036
CW02	0.260	0.310	0.120	0.068	0.083	0.081	0.065	0.110
CW03	0.150	3.200	0.450	0.001	0.029	0.046	0.037	0.025
CW04	0.220	0.360	1.100	0.042	0.240	0.120	0.057	0.130
WA01	0.680	0.940	0.360	0.280	0.350	0.300	0.320	0.300
WA02	0.540	0.860	0.460	0.380	0.390	0.330	0.410	0.410
WA03	0.530	0.780	0.420	0.350	0.420	0.340	0.380	0.430
WA04	0.540	0.790	0.450	0.400	0.520	0.380	0.480	0.680
MC01	0.020	ND	0.092	ND	0.100	0.027	0.074	ND
MC02	0.210	0.150	0.660	0.099	0.320	0.220	0.110	0.140
MC03	0.170	0.066	0.430	ND	0.180	0.310	0.071	0.150

Table 6 Total phosphorus concentrations (mg/L) for all sampling locations and sampling dates. ND indicates sample results were below method detection limit of 0.005 mg/L.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	ND	0.011	0.010	0.011	ND	0.009	0.010	0.008
CW02	0.010	0.012	0.009	0.012	0.006	0.013	0.009	0.008
CW03	ND	0.009	0.008	0.009	0.001	0.012	0.016	0.009
CW04	0.018	0.014	0.009	0.012	0.006	0.015	0.013	0.013
WA01	0.031	0.065	ND	0.006	0.013	0.048	0.019	0.008
WA02	0.070	0.056	ND	0.008	0.007	0.034	0.025	0.013
WA03	0.077	0.047	ND	0.006	0.010	0.034	0.024	0.015
WA04	0.036	0.063	0.013	0.007	0.017	0.036	0.028	0.010
MC01	0.013	ND	0.009	ND	ND	0.015	0.008	0.007
MC02	0.010	ND	0.019	0.019	ND	0.063	0.034	0.037
MC03	0.027	0.021	0.022	0.014	ND	0.025	0.019	0.026

Table 7. Total dissolved phosphorus for all sampling locations and all sampling dates. ND indicates value was below method detection limit of 0.005 mg/L.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	ND	0.011	ND	0.011	ND	ND	0.010	0.008
CW02	ND	0.012	ND	0.012	ND	0.012	0.009	0.008
CW03	ND	0.009	ND	0.009	ND	0.005	0.016	0.009
CW04	ND	0.014	ND	0.012	ND	0.006	0.013	0.013
WA01	0.016	0.052	ND	0.006	ND	0.008	0.019	0.008
WA02	0.008	0.049	ND	0.008	ND	0.009	0.025	0.013
WA03	0.007	0.036	ND	0.006	ND	0.006	0.024	0.015
WA04	0.006	0.044	ND	0.007	0.009	0.007	0.028	0.010
MC01	ND	ND	0.008	ND	ND	0.005	0.008	0.007
MC02	ND	ND	ND	0.019	0.081	0.026	0.034	0.037
MC03	ND	0.021	ND	0.014	0.020	0.009	0.019	0.026

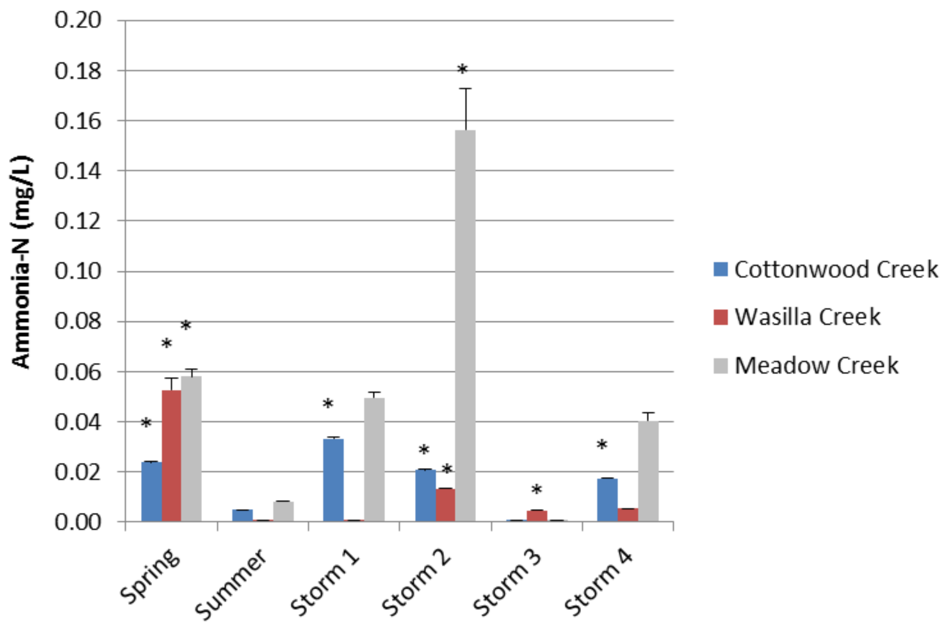


Figure 5. Average ammonia nitrogen concentrations for the 3 streams during spring runoff and storm events. Asterisks indicate significant differences compared to summer base flow concentrations. Error bars are one standard deviation.

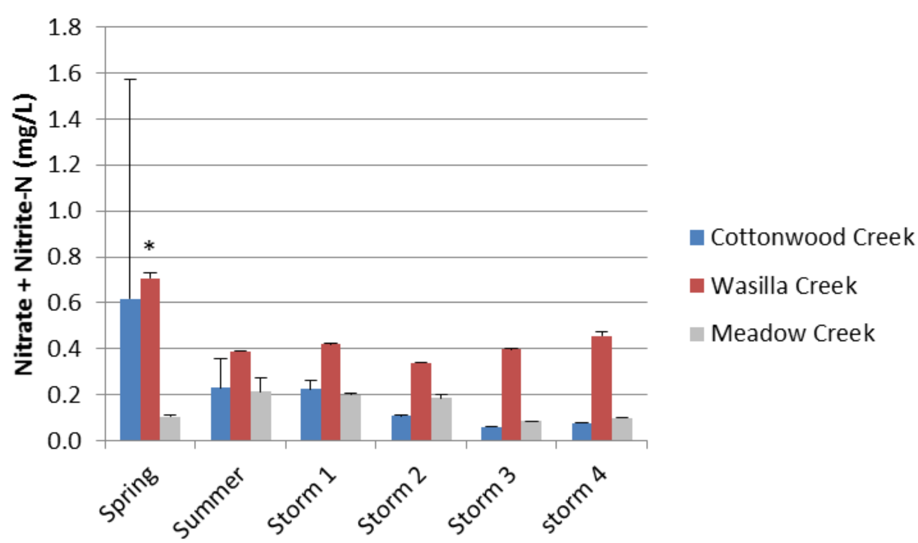


Figure 6. Average nitrate + nitrite nitrogen concentrations for the three streams during spring, summer base flow, and storm events. Asterisk indicated average value significantly different from summer base flow. Error bars are one standard deviation.

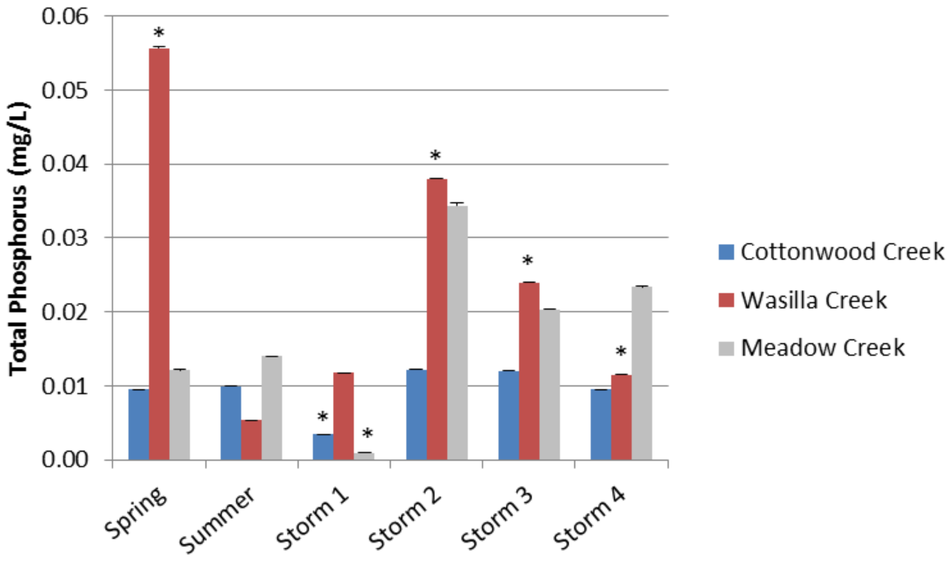


Figure 7. Average total phosphorus concentrations for each stream and sampling event showing significant increases from base-flow conditions (asterisks) in Wasilla Creek.

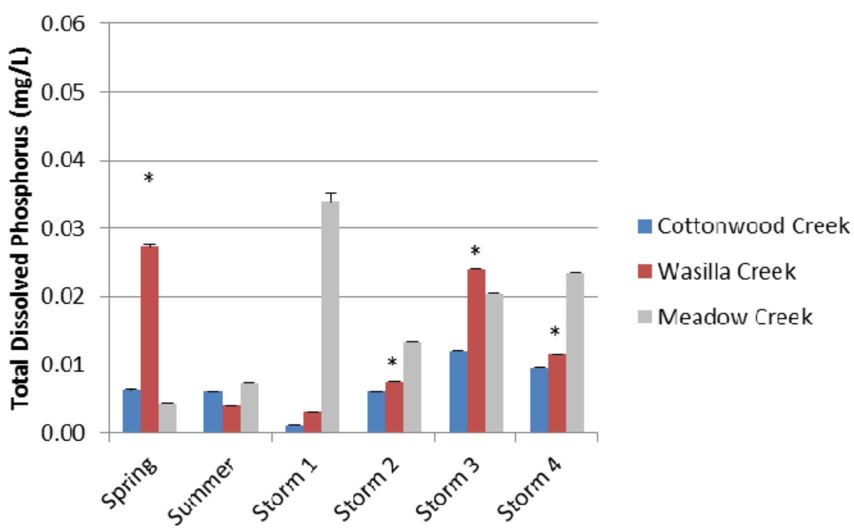


Figure 8. Average total dissolved phosphorus for each stream and sampling event showing signficant increases from base flow conditions (asterisks) in Wasilla Creek.

4.1.3 Specific Conductivity, pH, and Dissolved Oxygen

Specific conductivity for each sampling date and location are shown in Table 8 and average conductivity for each stream during each sampling event are show in Figure 9. Specific conductivity was significantly higher in Cottonwood Creek (204 µS/cm) and Meadow Creek (182 µS/cm) than in Wasilla Creek (138 µS/cm) when comparing average values for each stream on each sampling event, and lower in spring than summer or during storms.

There were no differences in average specific conductivity among sites in Cottonwood Creek. However, average specific conductivity increased from 89 µS/cm at WA01 downstream to 175 µS/cm at WA04. Specific conductivity also increased significantly from 137 µS/cm at the upstream Little Meadow Creek site to 209 µS/cm below the Parks Highway and Blodgett Creek.

There was no significant difference within Cottonwood Creek between specific conductivity in the spring or during storm events and summer base flow. In Wasilla Creek and Meadow Creek, specific conductivity was significantly lower during spring runoff (Figure 9).

Stream water pH is shown in Table 9 and average pH for each stream and sampling event is shown in Figure 10. Average pH in all streams neutral or higher but tended to be more acidic during spring breakup and storm events. Stream pH was significantly lower in Meadow Creek with an average of 7.1 than in Cottonwood Creek or Wasilla Creek with average values over all sampling sites and events of 7.6 and 7.5, respectively. Stream water pH also did not vary significantly among sites within any of the three streams.

Wasilla Creek and Meadow Creek had significant reduction in pH during spring breakup and storms 2, 3, and 4 relative to summer base flow values. Cottonwood Creek pH was significantly lower during the 4th storm event compared to summer base flow but not during any of the other sampling events (Figure 10).

Table 10 and Figure 11 provides dissolved oxygen values as percent saturation for the three study streams on each sampling event. Average dissolved oxygen was near saturation in Wasilla and Cottonwood Creeks, but was significantly lower at an average of 82% in Meadow Creek. Within Meadow Creek, dissolved oxygen was lower at MC01 at 77% on average and increased downstream of Blodgett Creek.

Table 8. Specific conductivity at each sampling site on each sampling date in 2011 and 2012.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	181	223	177	198	195	191	195	196
CW02	163	194	178	207	206	195	205	208
CW03	233	223	242	227	219	177	205	201
CW04	127	220	252	237	222	212	223	219
WA01	38	73	68	104	112	101	105	111
WA02	50	92	92	139	147	127	145	154
WA03	59	105	109	157	169	145	170	178
WA04	73	125	188	199	218	187	215	204
MC01	54	102	145	161	158	131	172	169
MC02	169	156	217	231	223	199	239	240
MC03	78	141	198	206	214	192	204	219

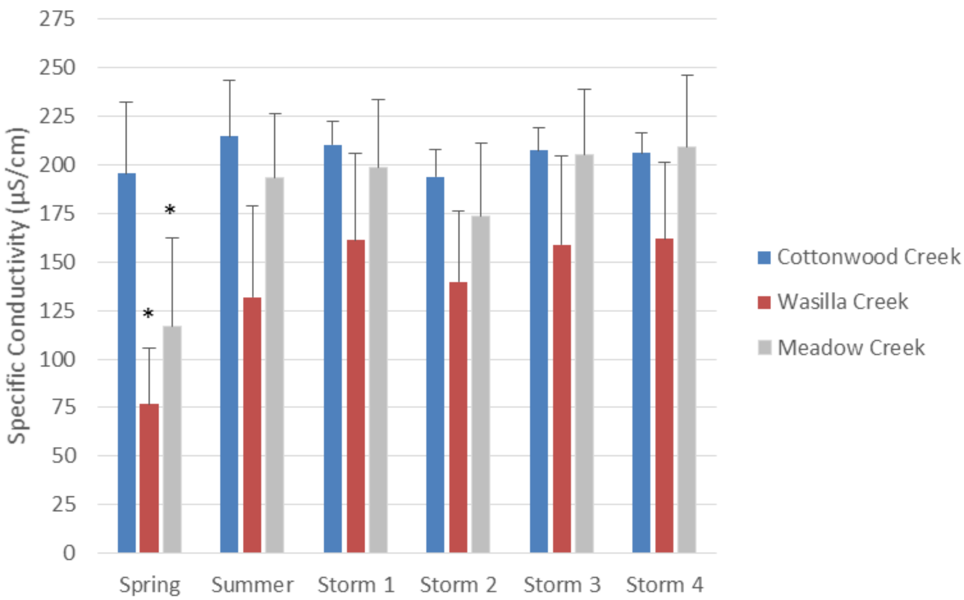


Figure 9. Average specific conductivity for each study stream during each sampling event showing significantly lower values (asterisks) during spring runoff in Wasilla and Meadow Creeks.

Table 9. Stream water pH for each sampling site on each sampling date.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	7.79	8.32	8.04	7.87	7.83	7.45	7.45	5.94
CW02	8.07	8.15	8.12	7.01	7.99	7.58	7.56	6.54
CW03	8.35	8.10	8.09	8.08	7.85	7.41	7.78	7.26
CW04	8.20	7.39	8.15	8.15	7.92	7.75	7.69	7.07
WA01	7.70	7.59	8.02	7.98	7.96	7.61	7.49	7.83
WA02	7.72	7.68	8.09	7.99	7.86	7.79	7.35	7.65
WA03	7.76	7.70	8.06	7.90	7.98	7.70	7.56	7.66
WA04	7.65	7.66	7.69	7.74	7.82	7.57	7.58	7.52
MC01	6.88	7.10	7.33	7.50	7.44	7.41	7.06	6.08
MC02	7.34	7.19	7.53	7.48	7.14	7.16	7.06	6.92
MC03	7.23	7.36	7.60	8.07	7.43	7.57	6.85	6.98

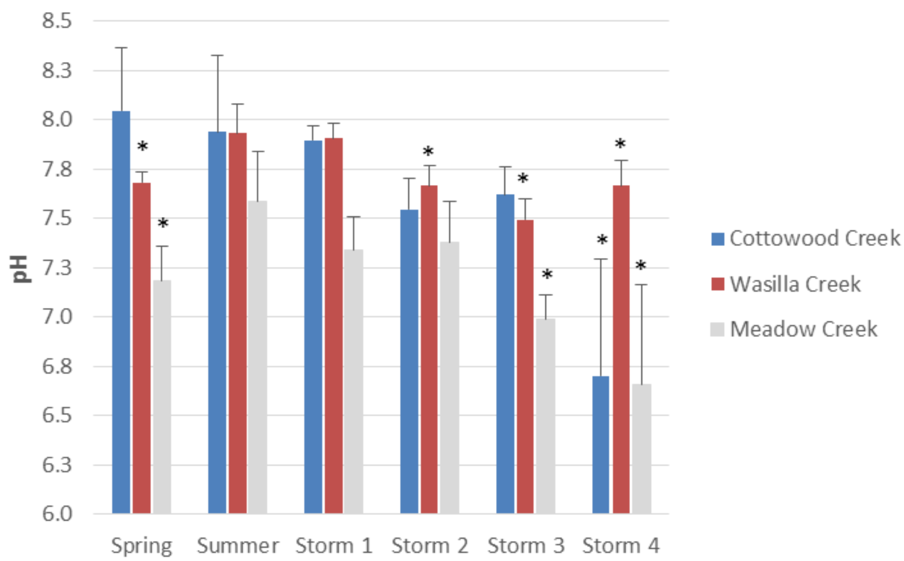


Figure 10. Average pH for each stream on each sampling event showing significant decreases during spring runoff and storm events in Wasilla and Meadow Creeks.

Table 10. Percent saturation of dissolved oxygen for each sampling site on each sampling date.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	87.9	106.8	110.6	108.7	102.9	88.7	89.4	100.5
CW02	93.5	87.9	98.3	92.4	104.7	93.9	94.7	99.1
CW03	106.4	105.6	100.8	111.5	101.5	85.6	93.7	104.6
CW04	97.0	105.1	101.2	91.0	97.1	96.6	97.4	104.8
WA01	95.6	90.0	108.9	111.9	107.0	99.4	98.2	85.7
WA02	96.3	92.6	110.1	106.8	107.0	99.9	99.1	84.6
WA03	96.8	91.7	136.5	103.1	107.0	96.9	99.1	85.4
WA04	98.9	93.8	102.8	101.5	106.4	94.4	96.8	89.4
MC01	63.3	80.0	86.7	76.1	85.4	73.5	75.5	76.5
MC02	90.0	93.6	103.5	82.4	61.2	61.7	81.6	83.3
MC03	77.8	91.3	95.3	109.1	102.1	84.8	87.6	93.6

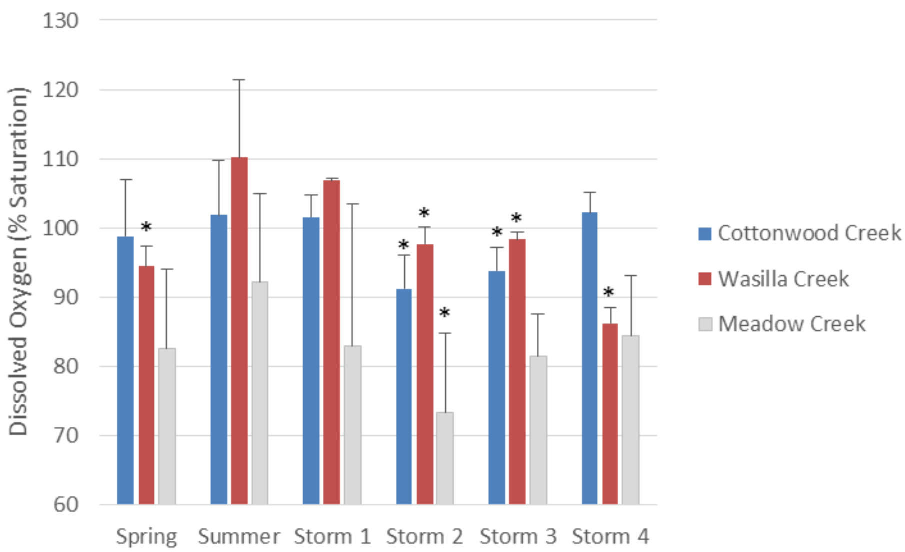


Figure 11. Average dissolved oxygen percent saturation showing significant decrease (asterisks) compared to summer base flow in Wasilla Creek and during the largest storm event in Cottonwood and Meadow Creeks.

Dissolved oxygen tended to decline during storms and during spring runoff. Comparisons of dissolved oxygen between summer base flow and spring runoff or storm events showed significant reductions in Wasilla Creek during spring runoff. Dissolved oxygen was reduced in all of the streams during the second storm event (Figure 11).

4.1.4 Dissolved Organic Carbon, Turbidity, and Settleable Solids

Concentrations of dissolved organic carbon did not vary among or within the study streams but did vary among sampling events. The concentration of dissolved carbon for each sampling site and date is provided in Table 11.

Concentrations of dissolved carbon were less than 5 mg/L in all streams during summer base flow and the storms 2, 3, and 4. Average stream concentrations were significantly higher during spring runoff and the first storm event in 2011 (Figure 12) with average concentrations of approximately 10 mg/L and 20 mg/L, respectively.

Stream water turbidity (Table 12 and Figure 13) was low in all streams during summer base flow conditions at less than 3.2 NTU and less than 2 NTU for most sites. There were no significant differences in turbidity among the three streams, but values tended to be higher in Wasilla Creek. However, even with sampling focused on storm events, average turbidity in Wasilla Creek was only 5.9 NTU, with a maximum of 28 NTU during spring runoff and 17 NTU during the largest storm event (Storm 2).

There were no significant differences in turbidity among sites within each stream. However, turbidity within Cottonwood Creek tended to increase at the lower sites ($p = 0.08$). For example, average turbidity increased from 1.4 NTU at the upper sites (CW01 and CW02) to 2.6 at CW03, downstream from the Parks Highway, and to 3.5 NTU at Surry Road (CW04). During Storm 2, turbidity increased by 1 NTU at CW01 and by 7 NTU at CW03.

Turbidity was significantly higher in Wasilla Creek during spring runoff and Storms 1, 2, and 3. Turbidity in Cottonwood and Meadow Creeks was not higher during spring runoff and increased significantly only during Storm 2.

Settleable solid concentrations were generally low during all sample events, ranging from 0.0-0.8 ml/L, with highest levels recorded at Wasilla Creek during spring breakup and Storm 2 (Table 13). Concentrations were equal to or higher than base flow conditions during all storm events and spring breakup in all three steams sampled. However, there were no significant differences among sampling events or stream sites (Figure 14).

Table 11. Stream water dissolved organic carbon concentrations (mg/L) for each sampling site and for each sampling event.

	Spring 1	Spring 2	Base Flow 1	Base Flow 2	Storm 1	Storm 2	Storm 3	Storm 4
	4/26/2011	5/4/2012	6/21/2011	7/6/2012	8/1/2011	8/17/2011	8/2/2012	8/23/2012
CW01	15	3.6	3.2	4.2	26	2.9	2.6	4.5
CW02	15	3.3	3.2	3.8	27	3.1	2.5	4.0
CW03	18	3.1	3.2	3.7	26	3.7	4.6	5.3
CW04	21	4.3	3.2	4.2	25	3.6	4.9	3.3
WA01	12	7.1	3.1	5.9	17	3.5	2	2.3
WA02	12	6.5	3.1	2.8	20	3.4	2	2.1
WA03	14	6.2	3.1	2.9	22	3.4	2.2	2.1
WA04	15	6.4	3.1	3.5	27	3.7	2.4	2.4
MC01	12	5.0	3.4	5.9	16	6.0	5.9	6.4
MC02	14	4.3	3.4	4.5	25	4.3	4.2	4.1
MC03	13	4.7	3.4	4.6	24	4.1	3.9	3.4

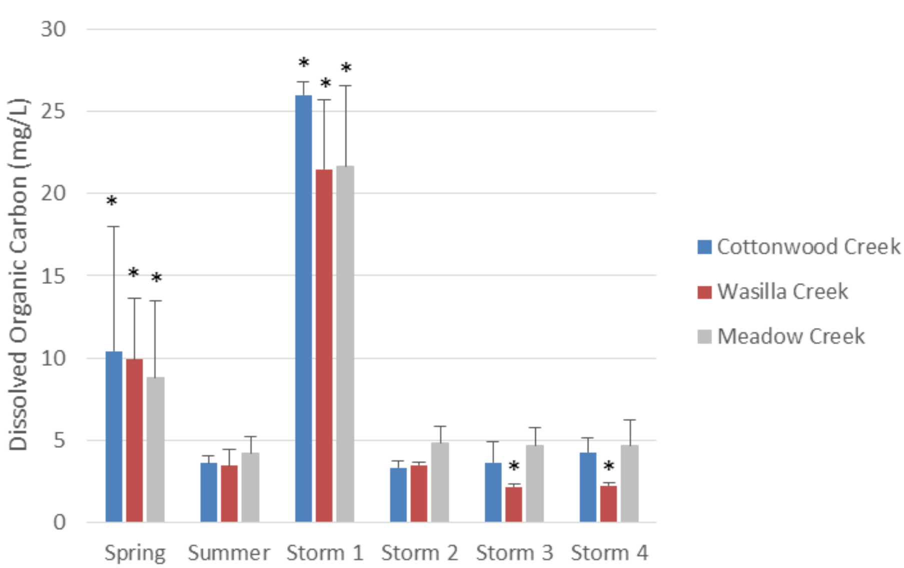


Figure 12. Average dissolved organic carbon concentrations for the three study streams and for each sampling event showing significantly higher concentrations during spring runoff and the first storm event.

Table 12. Stream water turbidity (NTU) measured at each sampling site on each sampling date.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	1.3	1.0	1.4	1.2	1.3	2.5	1.2	1.2
CW02	1.7	1.2	1.1	1.1	0.5	2.3	2.2	1.0
CW03	2.1	1.3	1.7	1.6	2.2	8.7	1.5	1.9
CW04	6.1	1.8	2.7	0.7	2.5	4.2	5.0	2.1
WA01	7.4	6.4	1.0	2.5	3.3	11.0	5.0	1.4
WA02	18.9	7.3	0.9	2.0	2.8	11.2	5.6	2.2
WA03	27.7	2.5	0.8	2.1	2.4	16.5	6.6	2.6
WA04	10.9	9.4	1.2	2.0	2.9	12.8	3.6	1.3
MC01	5.9	1.3	1.8	3.2	2.3	4.5	2.1	4.0
MC02	2.9	0.8	1.7	2.5	8.4	6.1	3.0	1.9
MC03	6.1	1.3	2.0	2.3	4.0	3.8	4.0	2.6

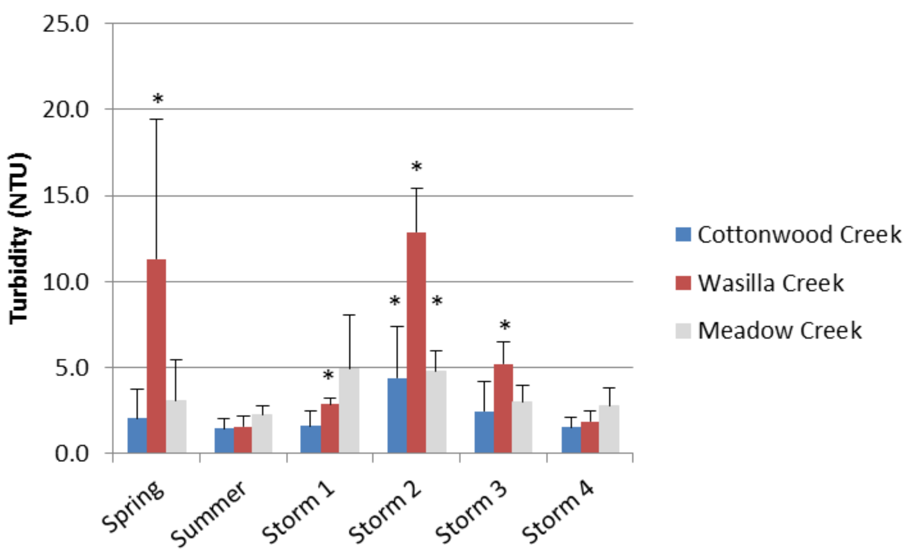


Figure 13. Average stream water turbidity for each study stream for each sampling event showing significant increases (asterisks) from summer base flow during spring and some storm events.

Table 13. Settleable solids (ml/L) measured at each sampling site on each sampling date.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CW02	0.01	0.0	0.0	0.0	0.5	0.0	0.0	0.0
CW03	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
CW04	0.2	0.0	0.2	0.0	0.0	0.05	0.1	0.05
WA01	0.0	0.15	0.0	0.0	0.0	0.2	0.05	0.0
WA02	0.5	0.2	0.0	0.0	0.0	0.2	0.1	0.0
WA03	0.8	0.15	0.0	0.0	0.0	0.2	0.1	0.0
WA04	0.3	0.2	0.0	0.0	0.1	0.2	0.0	0.0
MC01	0.1	0.0	0.0	0.0	0.0	0.25	0.05	0.05
MC02	0.1	0.0	0.0	0.0	0.55	0.2	0.1	0.0
MC03	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0

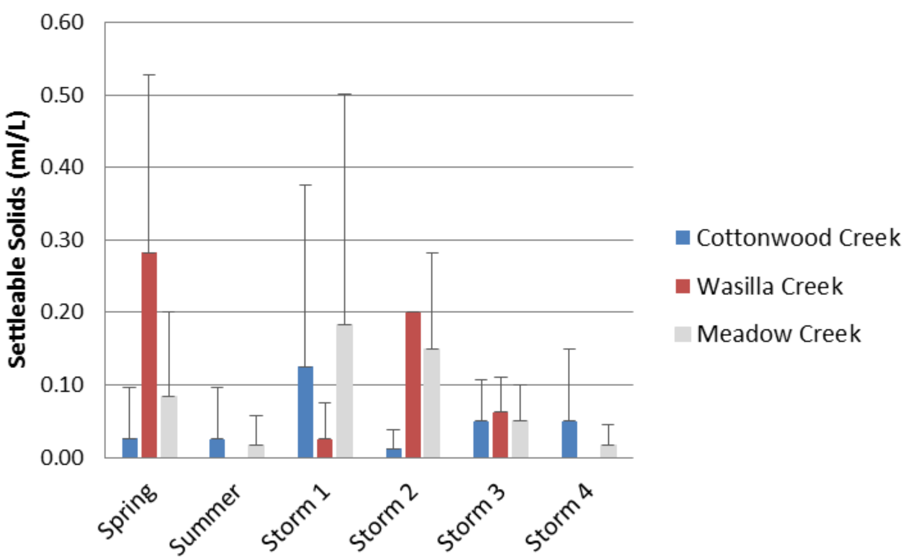


Figure 14. Average settleable solids for each study stream for each sampling event

4.1.5 Metals and PAH

Total and dissolved concentrations of Cu, Pb, and Zn for the study streams during spring runoff, summer base flow and storm events are shown in Tables 14 through 19. Concentrations of cadmium were below detection limits (0.05 µg/L) on all sampling dates in 2011, with one exception. The MC01 Summer sample had a cadmium concentration of 0.07 µg/L. Table 20 are the water quality criteria for dissolved concentrations of these metals calculated based on measures of hardness in each stream (ADEC 2012).

Based on samples collected focusing on spring runoff and storms, concentrations of total Cu, Pb, and Zn were significantly higher in Wasilla Creek compared to Cottonwood Creek and Meadow Creek. However, average concentrations of dissolved metals did not differ significantly.

Average total Cu concentrations were 1.5 µg/L in Wasilla Creek, and dissolved concentrations half of this value at 0.74 µg/L. Whereas, in Cottonwood Creek average total Cu concentrations were 0.40 µg/L and in Meadow Creek 0.54 µg/L. Similar differences were observed among steams in average total Pb and Zn.

Average concentrations of total Cu tended to increase in Cottonwood Creek downstream, from 0.3 µg/L at the upper sites to 0.5 µg/L at CW04, the lowest site; however, means were not significantly different among sites. This same trend was present for Pb concentrations in Cottonwood Creek, but not for Zn. Metals did not differ among Wasilla Creek sampling sites. There were significant differences in total Cu among sites in Meadow Creek with an average value of 0.8 µg/L at MC03 below the Parks Highway and Blodgett Creek, and 0.3 µg/L for MC01 and 0.4 µg/L form MC03. Similar differences were not observed among Meadow Creek sites for Pb or Zn.

Concentrations of total metals generally increased during spring runoff and storm events in Wasilla Creek, but only during certain storm events in Cottonwood and Meadow Creeks. Total Cu in Wasilla Creek was significantly higher during spring runoff and all 4 storm events (Figure 15); Pb during spring and storms 1 through 3 (Figure 17) and Zn during spring and storms 1 and 2 (Figure 19) compared to summer base flow concentrations. Total Zn also increased significantly in Cottonwood Creek during the first storm event. Dissolved Cu and Pb were significantly higher during spring runoff in Wasilla Creek but not during any of the storm events and there were no differences in dissolved Cu and Pb among sampling events in Cottonwood Creek or Meadow Creek (Figure 16 and Figure 18). Dissolved Zn, however, did vary among sampling events in these streams with higher values in Meadow Creek during spring runoff and in Cottonwood Creek during Storm 4 (Figure 20).

Concentrations of PAH in stream water were generally below detection limits, except at CW03 in spring 2011 (1.11 µg/L) and at MC02 during Storm 1 (3.48 µg/L).These values were both well below acute or chronic effect levels.

Table 14. Total copper concentration (µg/L) for each study stream and sampling event.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/20/2012
CW01	0.33	0.40	0.34	0.46	0.23	0.25	0.25	0.01
CW02	0.42	0.42	0.36	0.38	0.19	0.51	0.32	0.01
CW03	0.29	0.39	0.32	0.38	0.23	1.30	0.60	0.18
CW04	0.77	0.49	0.62	0.45	0.45	0.72	0.50	0.32
WA01	1.89	2.58	0.93	0.95	1.17	2.58	1.04	0.50
WA02	3.98	2.21	0.71	0.70	1.29	2.26	1.04	0.53
WA03	5.27	2.42	0.74	0.72	2.34	2.63	1.08	0.60
WA04	2.60	2.97	0.67	0.76	1.13	2.50	1.04	0.44
MC01	0.54	0.22	0.24	0.27	0.16	0.64	0.20	0.18
MC02	0.28	0.50	0.42	0.82	2.13	1.26	0.77	0.37
MC03	0.86	0.56	0.44	0.27	0.46	0.37	0.28	0.22

Table 15. Dissolved copper concentrations (µg/L) for each study stream and 2012 sampling events.

	Spring 2 5/4/2012	Base Flow 2 7/6/2012	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	0.44	0.42	0.19	0.28
CW02	0.36	0.40	0.25	0.19
CW03	0.39	0.35	0.49	0.31
CW04	0.40	0.44	0.42	0.28
WA01	1.25	0.68	0.54	0.55
WA02	1.10	0.63	0.79	0.55
WA03	1.25	0.46	0.76	0.45
WA04	1.16	0.59	0.68	0.42
MC01	0.23	0.30	0.22	0.21
MC02	0.43	0.36	0.44	0.34
MC03	0.27	0.38	0.24	0.28

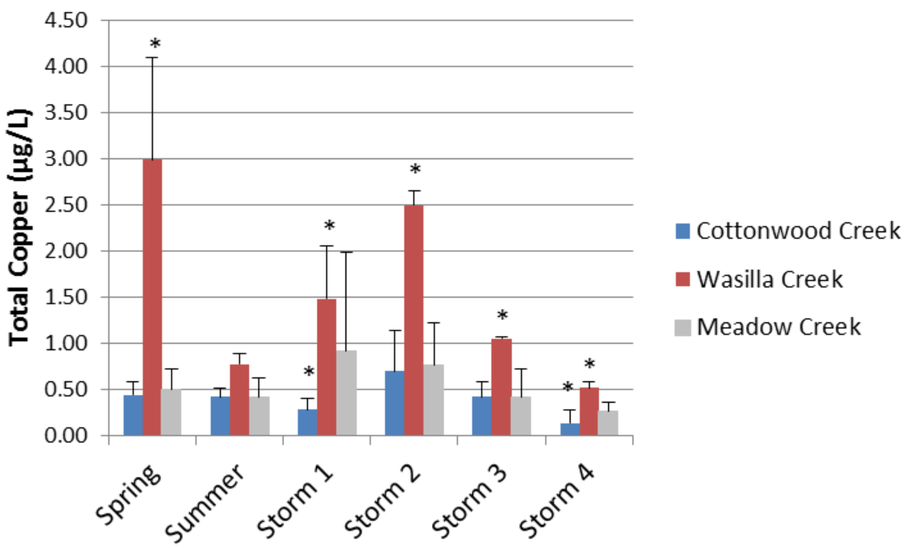


Figure 15. Average total copper concentrations showing those sites where values were significantly different (asterisks) than summer base-flow concentrations.

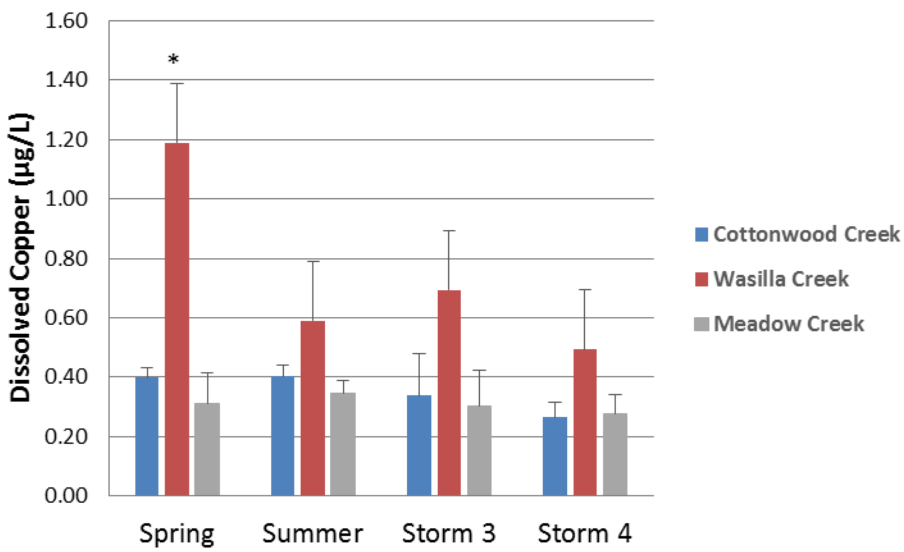


Figure 16. Average dissolved copper concentrations for each study stream on each 2012 sampling event.

Table 16. Total lead concentrations (µg/L) for each study stream and sampling event. ND = concentration below detection limits.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	ND	ND	ND	ND	0.07	ND	0.05	ND
CW02	0.05	ND	ND	ND	ND	0.09	ND	ND
CW03	ND	ND	ND	ND	ND	0.32	0.07	ND
CW04	0.17	0.06	0.11	ND	0.06	0.16	0.09	ND
WA01	0.16	0.45	ND	0.06	0.10	0.46	0.14	ND
WA02	0.81	0.36	ND	0.10	1.87	0.40	0.15	ND
WA03	1.29	0.40	ND	0.07	0.49	0.60	0.17	0.08
WA04	0.48	0.51	ND	0.07	0.17	0.52	0.15	ND
MC01	0.08	ND	0.07	0.07	ND	0.06	ND	ND
MC02	ND	1.74	0.05	0.06	0.37	0.13	0.07	ND
MC03	0.12	0.08	ND	ND	0.05	ND	ND	ND

Table 17. Dissolved lead concentrations (µg/L) for each study stream and sampling event in 2012.

	Spring 2 5/4/2012	Base 2 7/6/2012	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	0.05	ND	ND	0.111
CW02	0.05	ND	ND	ND
CW03	0.06	ND	ND	ND
CW04	0.06	ND	ND	ND
WA01	0.05	ND	ND	ND
WA02	0.17	ND	0.05	ND
WA03	0.09	ND	ND	ND
WA04	0.2	ND	0.05	ND
MC01	ND	ND	ND	ND
MC02	ND	0.05	ND	ND
MC03	ND	ND	0.054	0.062

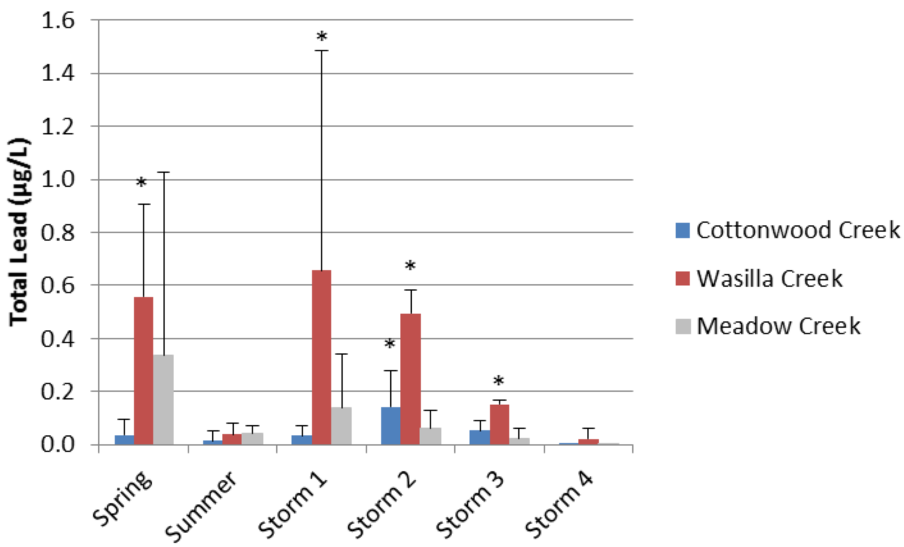


Figure 17. Average total lead concentraions for the study streams and for each sampling event.

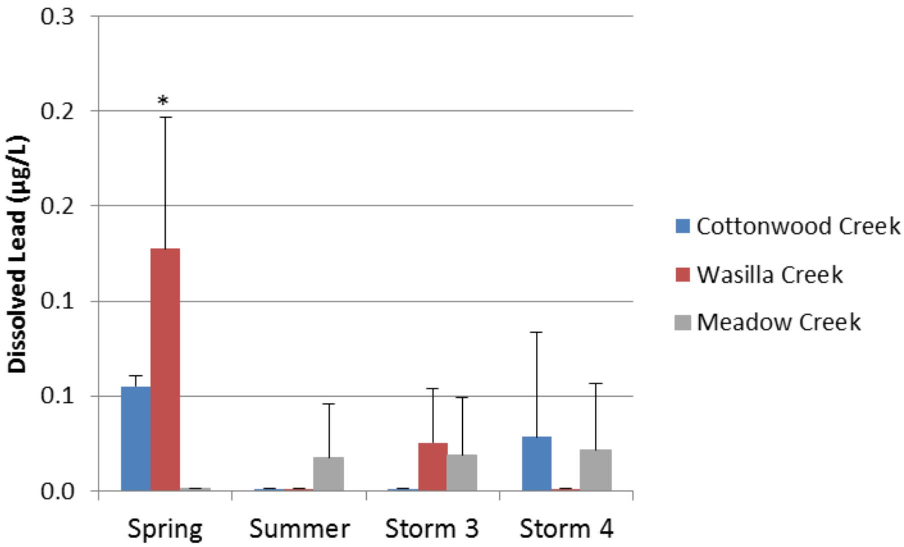


Figure 18. Average dissolved lead concentrations for the study streams and for each sampling event.

Table 18. Total Zinc concentrations.

	Spring 1 4/26/2011	Spring 2 5/4/2012	Base Flow 1 6/21/2011	Base Flow 2 7/6/2012	Storm 1 8/1/2011	Storm 2 8/17/2011	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	4.32	2.40	6.68	3.91	15.30	3.73	1.86	2.44
CW02	2.77	2.65	1.47	2.99	5.13	4.93	2.64	1.82
CW03	5.04	1.89	5.53	2.01	4.86	8.27	3.71	2.28
CW04	5.57	3.17	4.77	2.73	6.45	5.83	3.17	2.48
WA01	5.64	3.97	4.77	2.66	8.60	11.10	2.76	2.00
WA02	14.80	4.04	2.56	3.33	41.00	15.20	4.93	4.37
WA03	15.00	4.09	4.93	3.30	12.50	9.82	4.14	3.33
WA04	6.41	5.58	4.40	2.71	7.04	7.50	3.58	2.79
MC01	3.53	2.66	6.14	2.63	4.15	ND	2.79	2.37
MC02	3.50	2.32	5.29	2.85	6.87	6.31	2.34	2.89
MC03	3.79	3.02	5.73	1.97	5.36	3.96	2.44	2.15

Table 19. Dissolved zinc concentrations.

	Spring 2 5/4/2012	Base Flow 2 7/6/2012	Storm 3 8/2/2012	Storm 4 8/23/2012
CW01	8.94	2.96	2.62	3.46
CW02	2.20	1.80	1.41	1.88
CW03	3.02	ND	3.83	3.04
CW04	2.54	ND	4.00	2.23
WA01	3.95	ND	3.23	8.26
WA02	5.43	3.93	4.66	8.26
WA03	3.43	ND	4.28	6.09
WA04	2.37	2.59	2.26	2.60
MC01	4.26	ND	2.76	2.95
MC02	3.56	2.52	2.35	4.96
MC03	3.35	ND	3.09	2.64

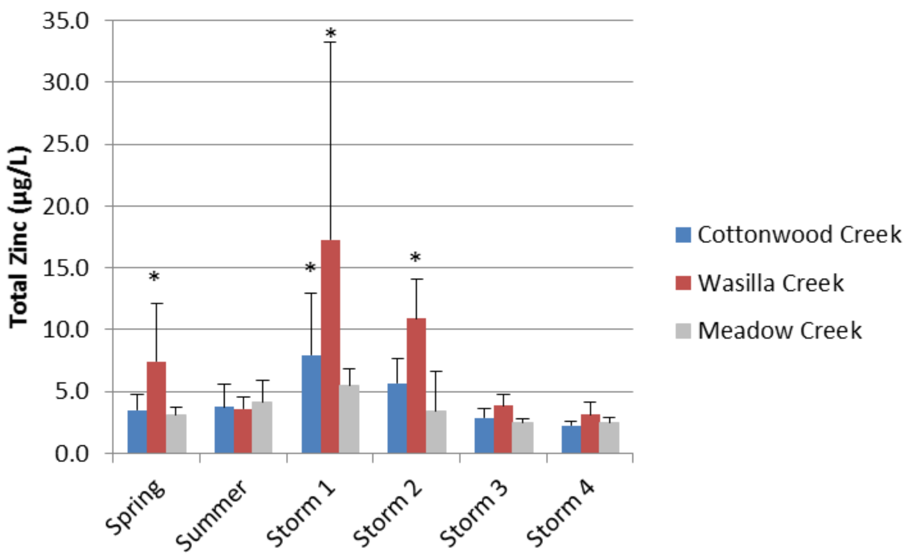


Figure 19. Average total zinc concentrations showing sites with significant increases during spring runoff or storm events.

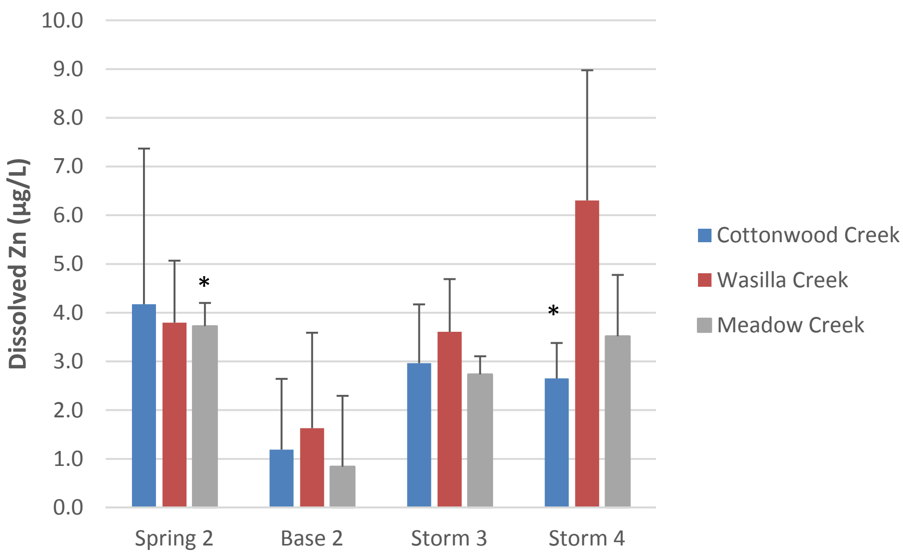


Figure 20. Average dissolved zinc concentrations within each study stream during 2012 spring, base flow, and storm event samples. Significant differences are marked with "*".

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

	Copper (µg/L)		Lead (µg/L)		Zinc (µg/L)	
	Acute	Chronic	Acute	Chronic	Acute	Chronic
Cottonwood	13.1	8.7	79.5	3.9	106.1	107.0
Wasilla	12.7	8.5	76.6	3.8	97.4	98.2
Meadow	13.7	9.1	84.8	4.1	104.4	105.2

4.1.6 Sediment Metal Concentrations

Concentrations of metals in streambed sediments exceeded values that could result in biological effects at one or more sampling sites in all three study streams. Concentrations of metals in sediments were evaluated using NOAA SQuiRT threshold effects levels (TELs) and probable effects levels (PELs). TELs are those concentrations below which biological effects are not observed, and PELs are those levels above which biological effects are likely to occur.

Concentrations of Cu, Pb, and Zn at CW03 all exceeded TEL levels and Cu concentrations were just below the PEL level and Zn concentrations above the PEL level (Figures 21, 22, and 23). Concentrations Cu and Zn also exceeded the TEL level at CW01, the upper site below Zephyr Lake. Cu TEL levels also were exceeded in samples collected at the two upstream Wasilla Creek and Meadow Creek sites and the Zn TEL level at the lower Meadow Creek site (MC03).

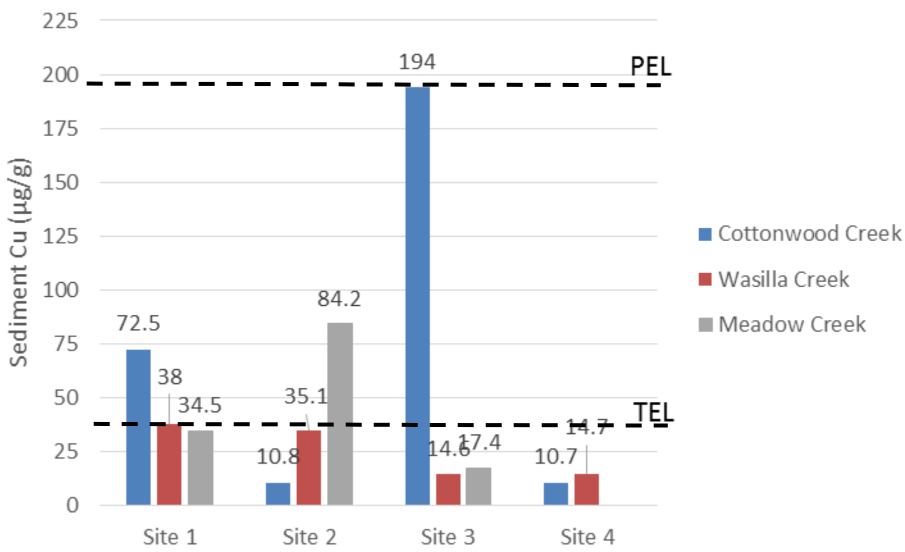


Figure 21. Concentrations of Cu in bed sediment samples collected at each sampling site in the 3 study streams.

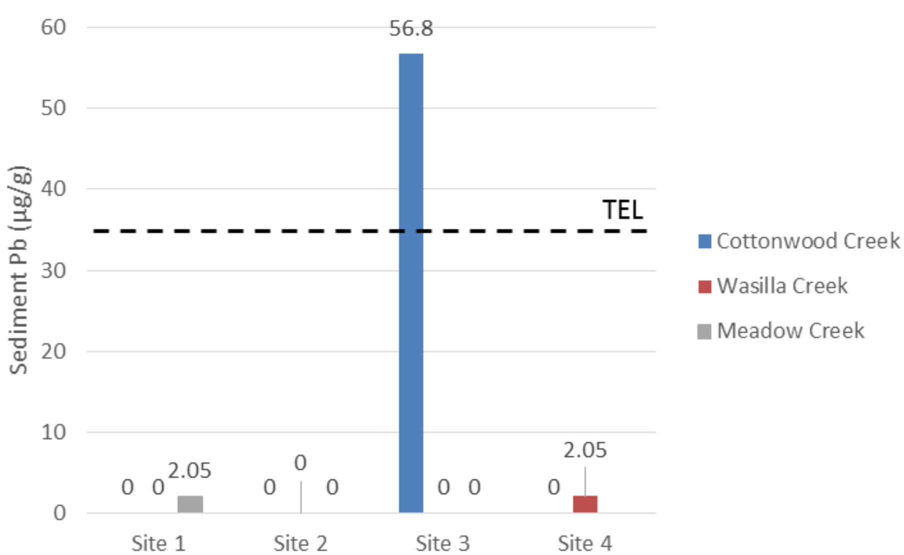


Figure 22. Concentrations of bed sediment Pb concentrations showing the location where concentrations exceeded threshold effect levels.

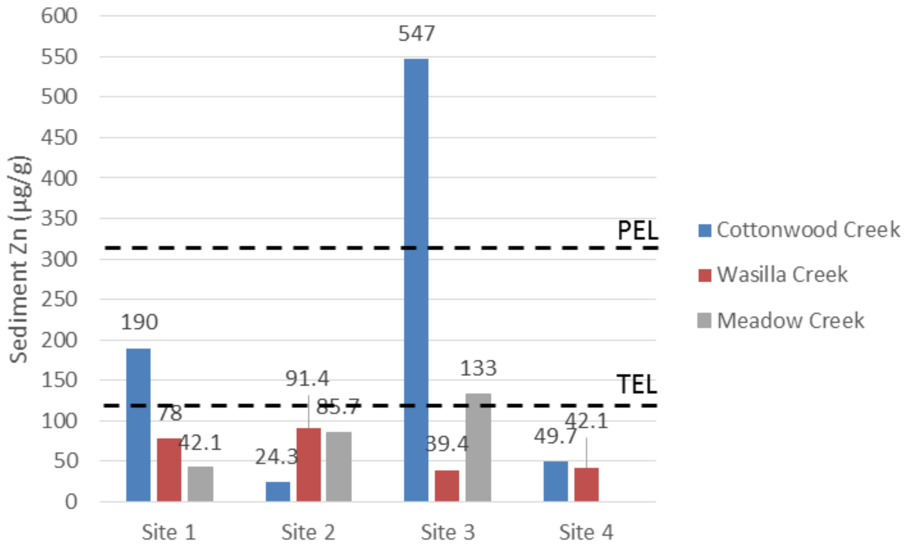


Figure 23. Concentrations of Zn in bed sediments showing those sites where concentrations exceeded threshold and probable effects levels.

4.1.7 Outfall Discharge

4.1.7.1 Water Samples

The chemical and physical characteristics of stormwater outfall discharge varied among outfalls and among storms and differed from receiving streams (Table 21). Concentrations of nutrients, metals, and specific conductivity were generally greater in discharge from OF1 and lowest in OF3 correlating with differences in estimated drainage area. For example, ammonia-N and turbidity increased with drainage area from OF1 to OF3 (Figures 24 and 25). However, ammonia and nitrate+nitrite nitrogen were not significantly different among storms or among outfalls (two-way ANOVA w/o replication $p>0.05$). Total phosphorus discharge was significantly higher during Storm 3 and from OF1 discharging into Lucile Lake. Total dissolved phosphorus discharge was not significantly different among outfalls but was greater during Storm 4 PAHs were below detection limits at all sites and during all storms sampled.

Comparisons between discharge from Lower Cottonwood Outfall OF2 and Cottonwood Creek site CW03, located just upstream from the outfall discharge, allowed for comparisons of concentrations of nutrients and metals in stormwater discharge. Average total phosphorus discharge from OF2 (0.078 mg/L) was significantly higher than in Cottonwood Creek just upstream (0.012 mg/L). Similarly, average total dissolved phosphorus discharged from OF2 was 0.023 mg/L and averaged 0.010 mg/L at site CW03 during the same three storm events. Average ammonia-N concentrations were similar in OF2 and CW03 during Storms 2, 3, and 4, but nitrate + nitrite concentrations averaged 0.24 mg/L in discharge from OF2 and 0.036 in Cottonwood Creek at the sampling site just upstream. Specific conductivity was significantly lower in OF2 discharge than in Cottonwood Creek with average values of 79 and 194 µg/L, respectively.

Concentrations of total and dissolved metals for each outfall relative to outfall drainage area are shown in Figures 26 through 28. Concentrations of total metals during storm events tended to increase relative to drainage area and both Cu and Pb were significantly higher in discharge from

OF1 with the largest drainage area during the three storm events. Dissolved Cu and Pb in stormwater discharge presented a different response than total concentrations, with maximum values in discharge from OF2. Total Zn and dissolved Zn also were highest in OF2, during one storm event.

Average total Cu and Pb were significantly higher in outfall discharge (OF22) than in Cottonwood Creek and average total Zn values were much higher, but differences were not significant. Total Cu outfall discharge for Storms 2, 3, and 4, was 7.68 µg/L compared to 0.18 µg/L in the receiving stream. We were unable to test for differences in dissolved concentrations of metals; however, average dissolved Cu was 6.2 µg/L in OF2 discharge and 0.40 µg/L in Cottonwood Creek. Total Pb averaged 1.7 µg/L in outfall discharge and 0.13 µg/L in Cottonwood Creek. Average total Zn concentrations in outfall discharge were extremely high at 245 µg/L and 4.8 µg/L in Cottonwood Creek.

4.1.7.2 Sediment Samples

Sediment samples were collected within the receiving waters below each outfall. Therefore, OF1 sediment samples were collected in Lake Lucile, OF2 samples were collected in Cottonwood Creek approximately 100 m downstream from the ARRC Bridge, and OF3 sediment samples were collected just upstream from the Parks Highway. Concentrations of Cu, Pb, and Zn in bed sediments were highest in Lake Lucile below OF1. Concentrations of all three metals exceeded TELs, and Pb and Zn exceeded PELs on at least one sampling event (Figures 29, 30, and 31). Concentration of PAH in Lake Lucile also exceeded TEls on 2 of the three sampling events (Figure 32). Concentrations of Cu, Pb, and Zn in Cottonwood Creek bed sediments were higher below OF3 than OF2 and Cu concentrations exceeded TELs at this location on two of the sampling events. Cottonwood Creek sediment PAH values were highest below OF2 and exceeded TELs during Storm 2.

Table 21. Concentrations of nutrients, pH, and specific conductivity (left panel) and metals (right panel) collected from outfall discharge during storm events.

	OF1	OF2	OF3
Ammonia-N (mg/L)			
Storm 2	0.108	0.018	< DL
Storm 3	0.009	0.011	0.005
Storm 4	0.068	0.052	0.027
Nitrate-N (mg/L)			
Storm 2	0.720	0.520	0.050
Storm 3	0.310	0.050	0.099
Storm 4	0.160	0.150	0.059
Total-P (mg/L)			
Storm 2	0.100	0.061	0.025
Storm 3	0.126	0.089	0.058
Storm 4	0.105	0.083	0.031
Total Dissolved-P			
Storm 2	0.005	0.006	0.007
Storm 3	0.009	0.011	0.005
Storm 4	0.068	0.052	0.027
Specific Conductivity (µS/cm)			
Storm 2	13.02	71.9	9.0
Storm 3	247.6	59.9	18.7
Storm 4	460.8	106.6	17.6
pH			
Storm 2	6.12	5.54	7.26
Storm 3	6.22	6.60	6.75
Storm 4	6.44	6.77	6.72

	OF1	OF2	OF3
Total Cu (µg/L)			
Storm 2	10.3	6.22	2.23
Storm 3	8.16	5.32	3.74
Storm 4	7.46	7.68	3.83
Dissolved Cu (µg/L)			
Storm 2	NA	NA	NA
Storm 3	5.98	5.53	2.06
Storm 4	1.89	6.92	1.78
Total Pb (µg/L)			
Storm 2	4.99	2.14	2.13
Storm 3	3.29	1.21	2.08
Storm 4	2.91	1.88	1.22
Dissolved Pb (µg/L)			
Storm 2	NA	NA	NA
Storm 3	0.112	0.188	0.084
Storm 4	0.145	0.165	0.062
Total Zn (µg/L)			
Storm 2	205	174	27.3
Storm 3	149	95.1	30.2
Storm 4	147	467	17.3
Dissolved Zn (µg/L)			
Storm 2	NA	NA	NA
Storm 3	94.1	71	19.2
Storm 4	88.3	375	19.3

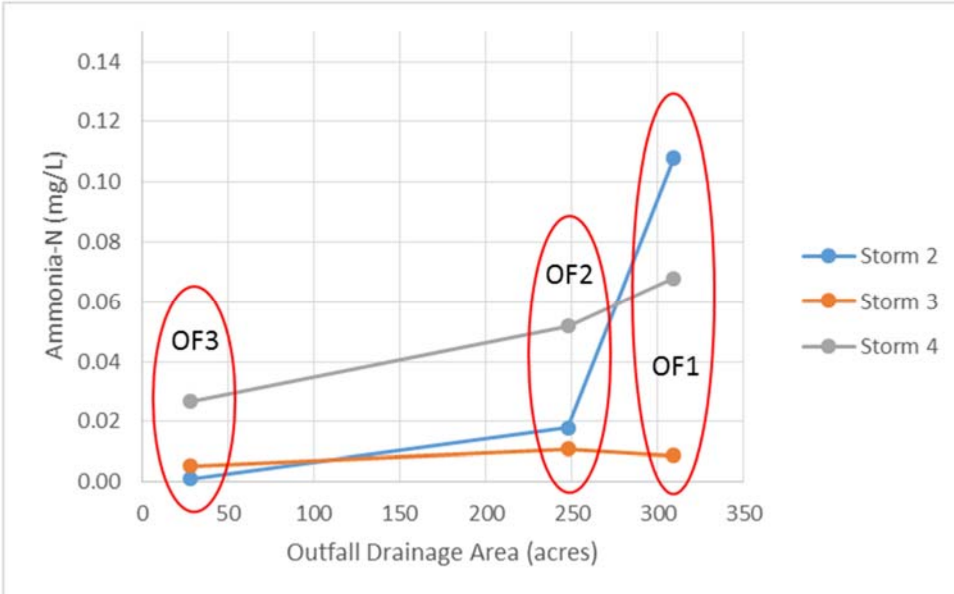


Figure 24. Concentrations of ammonia-N in outfall discharge relative to drainage area for the three outfalls and three storm events.

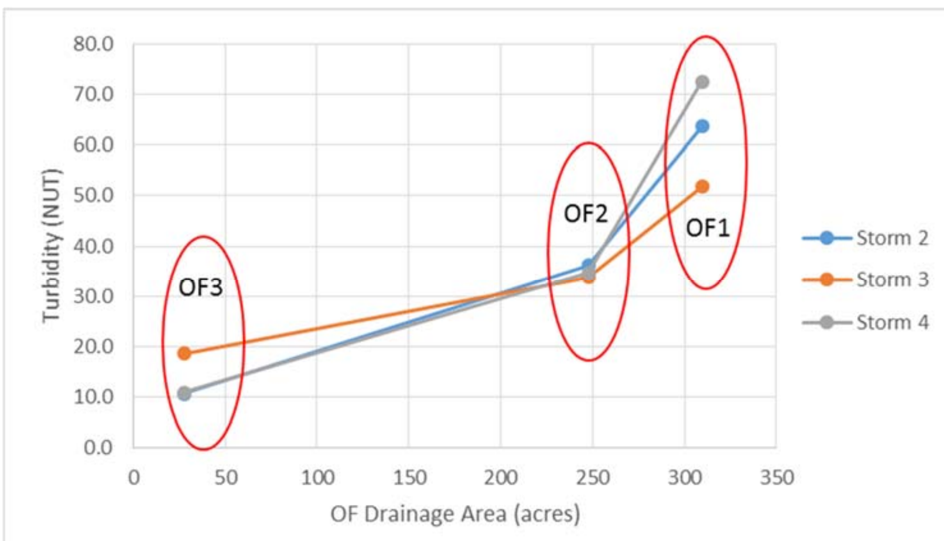


Figure 25. Turbidity of outfall discharge for the three outfalls and storm events showing an increase with outfall drainage area.

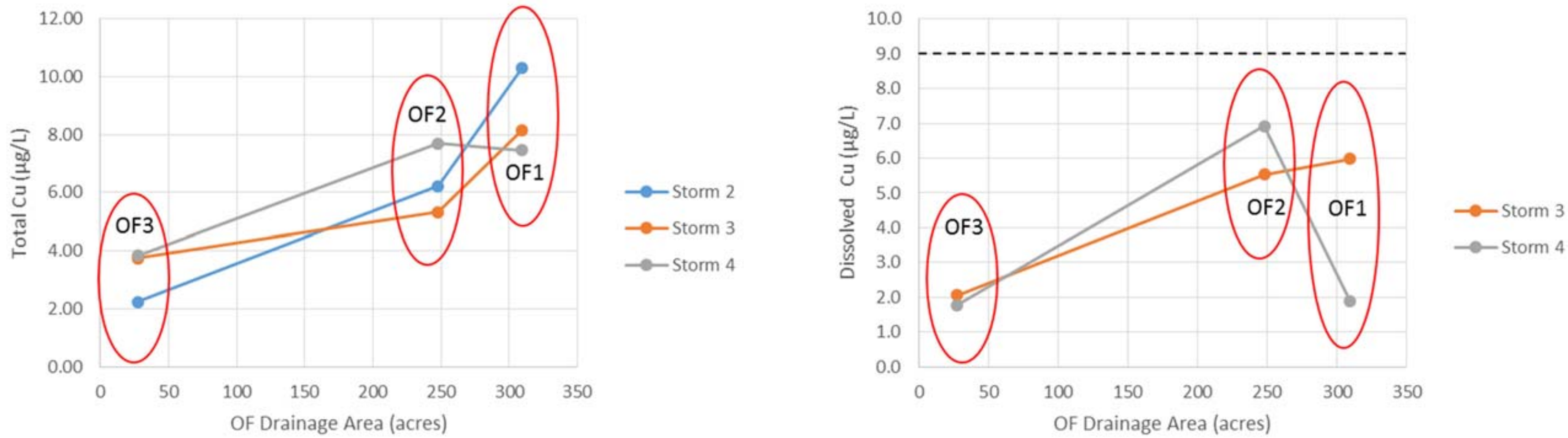


Figure 26. Concentration of total Cu (left) and dissolved Cu (right) for the three outfalls (OF) and storm events. Total Cu increased relative to drainage area whereas dissolved Cu was highest in OF2 during storm 4. Dashed line is chronic water quality criteria for dissolved Cu.

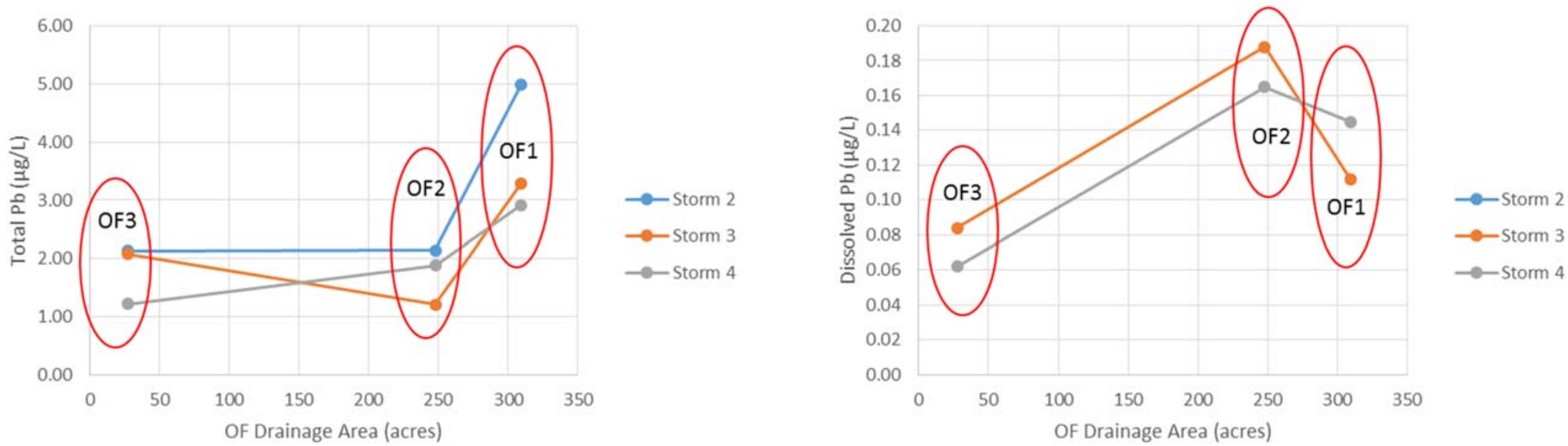


Figure 27. Concentrations of total and dissolved Pb for the three storm events relative to estimated drainage area for the three outfalls. Total Pb concentrations did not increase with change in drainage area from OF3 to OF2, whereas OF1 had the greatest drainage area and greater total Pb concentrations during all three storm events.

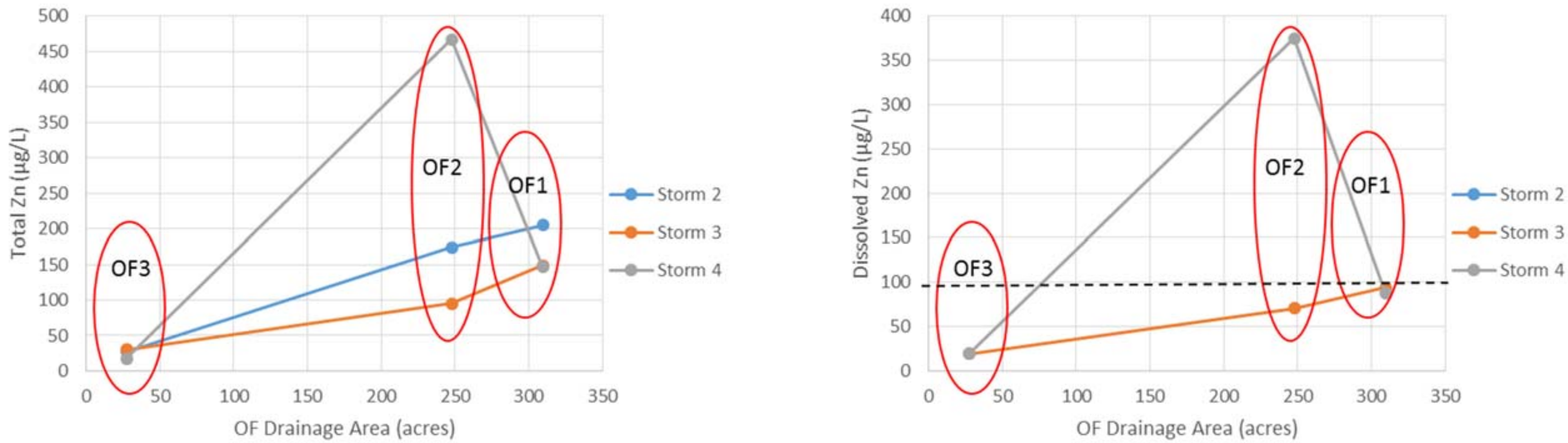


Figure 28. Concentrations of total and dissolved Zn for the three storm events relative to estimated drainage area for the three outfalls. Dashed line is acute water quality criteria for dissolved Zn.

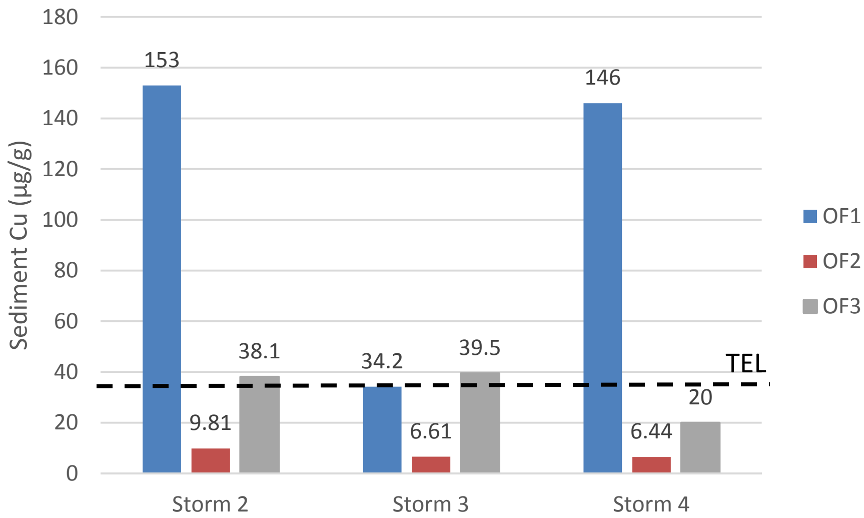


Figure 29. Concentrations of Cu in bed sediments at outfall locations showing those sites that exceed threshold effect levels.

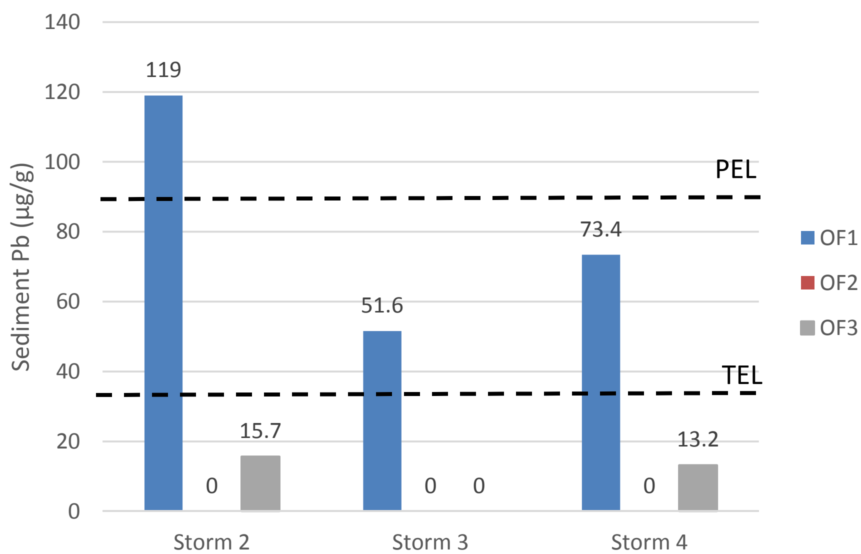


Figure 30. Concentrations of Pb in bed sediments at outfall locations showing those sites that exceed threshold and probable effect levels.

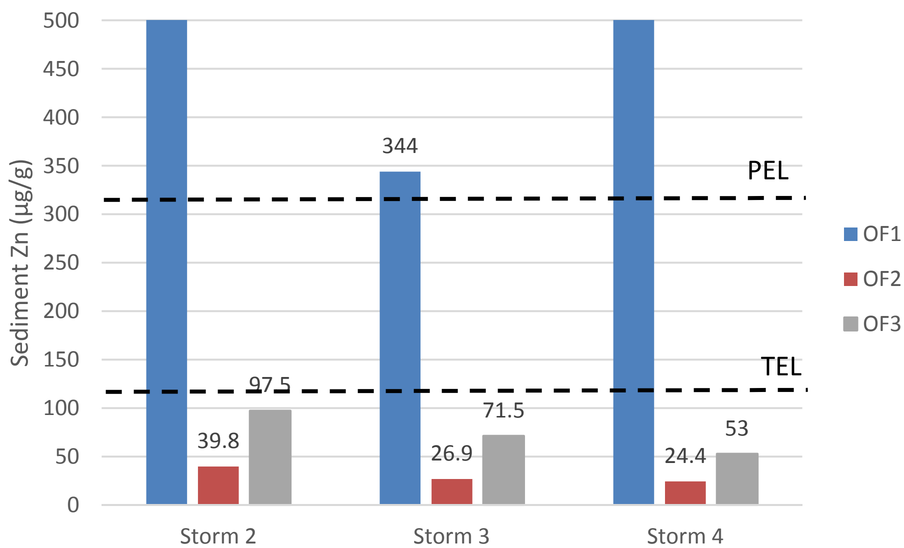


Figure 31. Concentrations of Zn in bed sediments at outfall locations showing those sites that exceed threshold and probable effect levels during storm events. OF1 Storm 2 = 3030 µg/L and Storm 4 = 2460 µg/L.

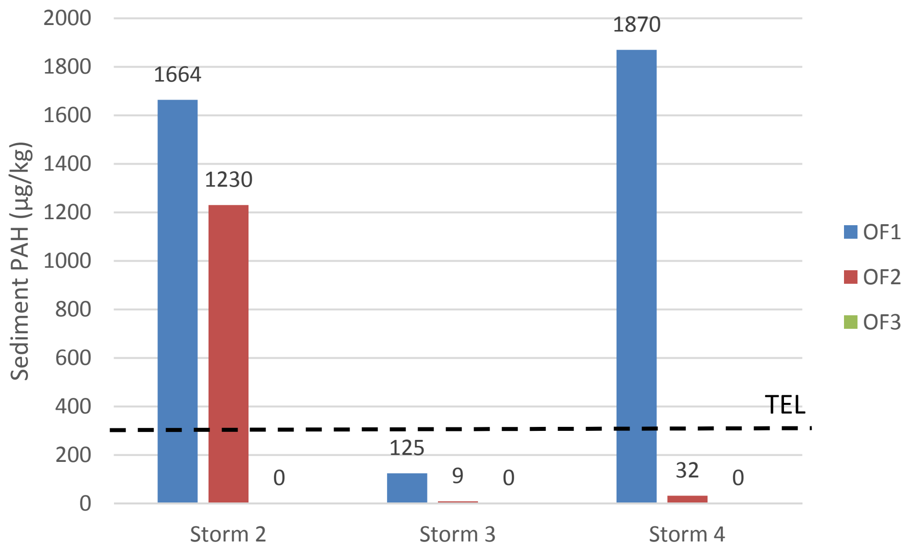


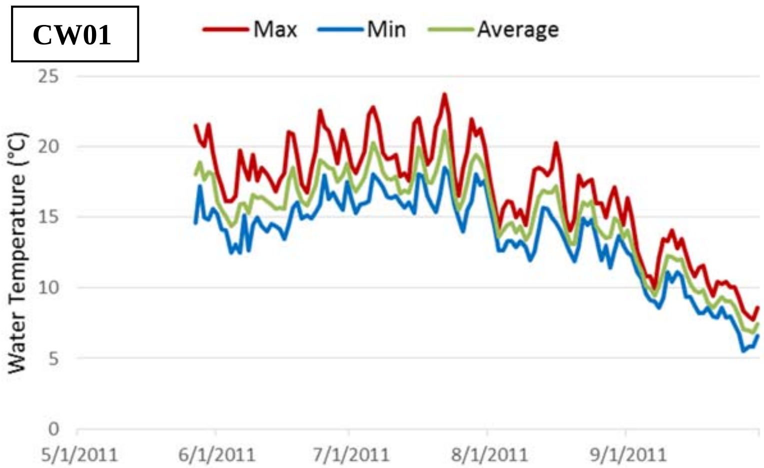
Figure 32. Concentrations of PAH in bed sediments at outfall locations showing those sites that exceed threshold effect levels during storm events.

4.1.8 Water Temperature

Water temperature between upstream and downstream sites were very similar, indicating that there is minimal heat-input from the Wasilla urban areas (Table 22, Figure 33). Both Cottonwood and Meadow Creeks had warmer temperatures measured at the upstream sites than at downstream sites. The Cottonwood Creek site CW01 was the only site with temperatures above 20°C in 2011, whereas all Cottonwood and Meadow Creek sites had temperatures above this threshold in 2012. Wasilla Creek sites stayed below 15°C in both years, and there was a slight longitudinal warming trend in both years, with WA04 having higher cumulative monthly temperatures for all months monitored.

Table 22. Water temperature statistics for the two study years.

Site Name	Start Date	End Date	Season Maximum	Max Daily Range	Days Max>13	Percent of Total	Days Max>15	Percent of Total	Days Max>20	Percent of Total	June Cumulative Degree Days	July Cumulative Degree Days	August Cumulative Degree Days	Sept Cumulative Degree Days
CW01	5/26/2011	10/6/2011	23.7	7.3	103	81.1	93	73.2	27	21.3	499	561	460	299
CW01	5/4/2012	10/4/2012	24.6	7.4	109	73.2	89	49.1	20	33.0	470	497	485	274
CW04	6/1/2011	10/5/2011	15.2	2.2	53	43.8	2	1.7	0	0.0	349*	419	385	275
CW04	5/4/2012	10/4/2012	20.9	7.0	97	65.1	49	43.7	2	29.3	418	426	411	266
MC01	5/23/2011	10/5/2011	17.3	8.1	61	48.0	12	9.4	0	0.0	354	399	371	256
MC01	5/9/2012	10/4/2012	21.8	7.4	99	68.8	64	47.7	4	33.2	429	456	436	261
MC03	5/26/2011	10/5/2011	18.7	9.1	78	51.7	48	31.8	0	0.0	399	454	376	254
MC03	5/9/2012	10/4/2012	21.6	6.6	90	62.5	50	43.4	4	30.1	409	441	419	253
WA01	6/2/2011	10/6/2011	11.4	2.9	0	0.0	0	0.0	0	0.0	NA	60*	255	181
WA01	5/4/2012	8/1/2013	13.9	6.0	7	4.7	0	3.2	0	2.1	245	288	282	181
WA04	6/2/2011	10/6/2011	13.1	3.7	1	0.8	0	0.0	0	0.0	270*	319	283	197
WA04	5/4/2012	10/4/2012	13.3	4.0	3	2.0	0	1.4	0	0.9	277	308	299	199


CW01
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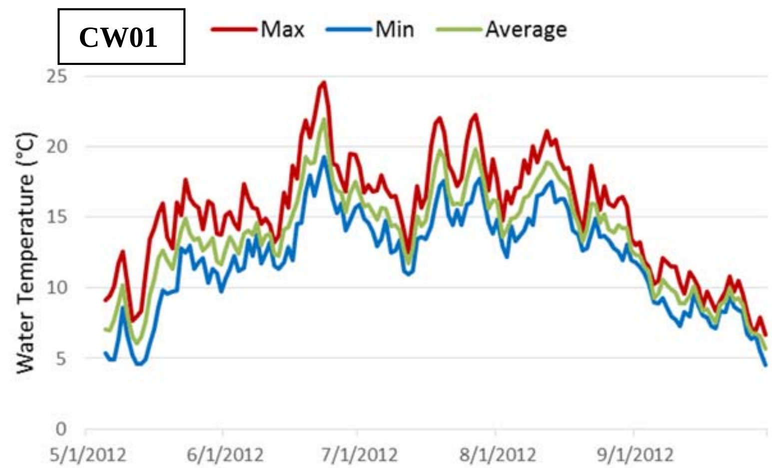
9/1/2011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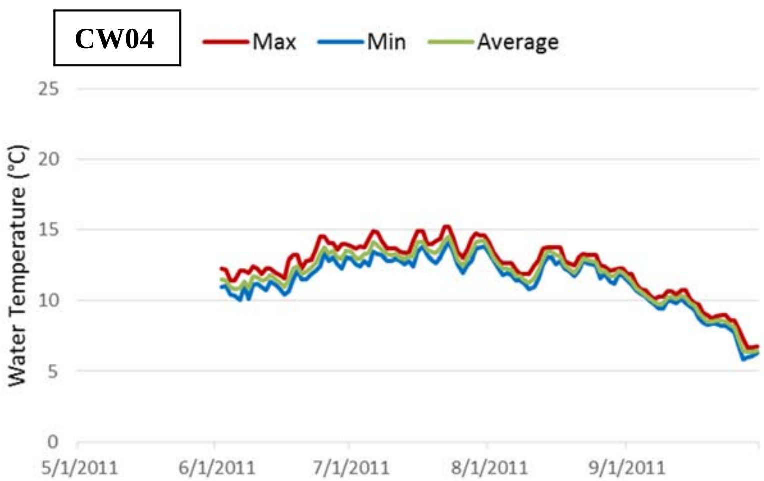
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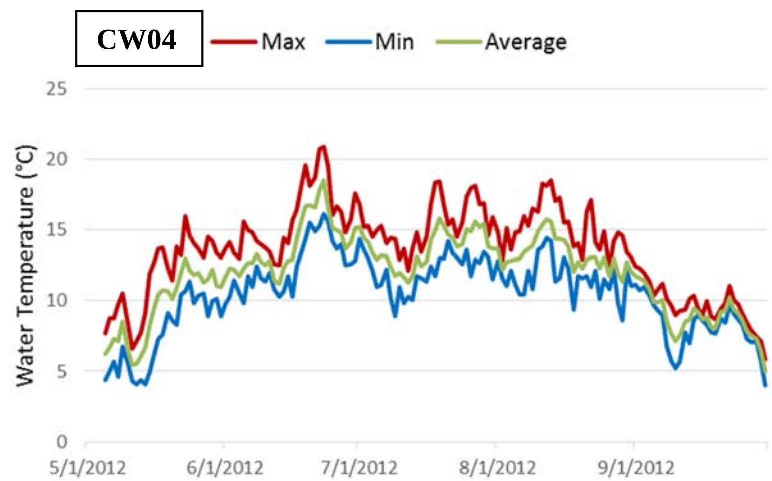
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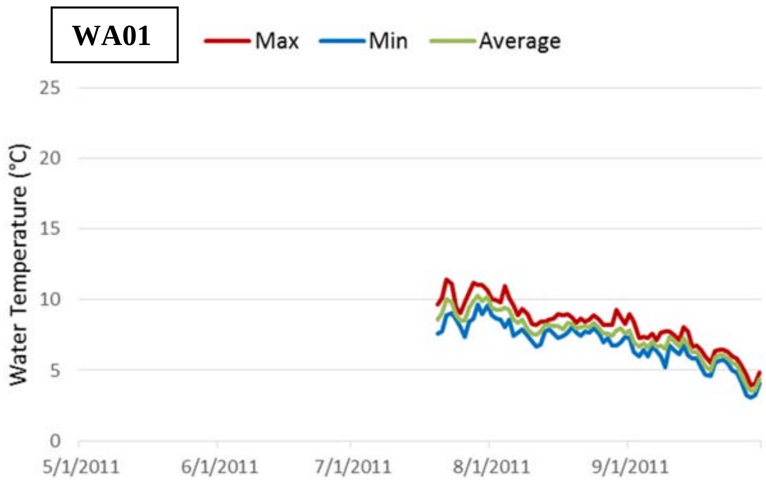
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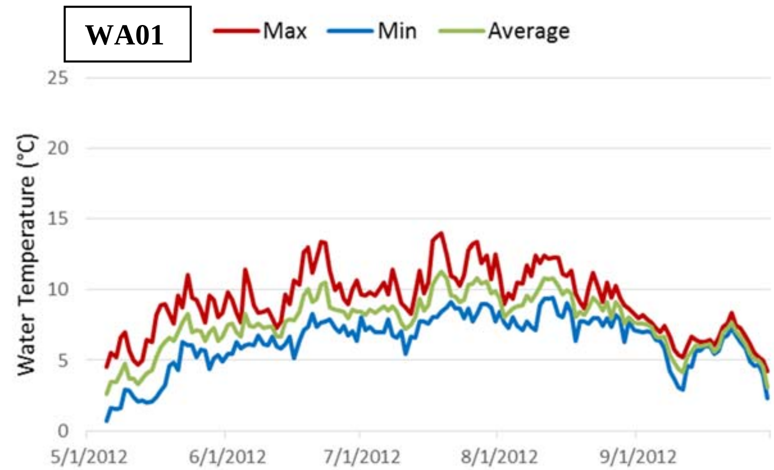
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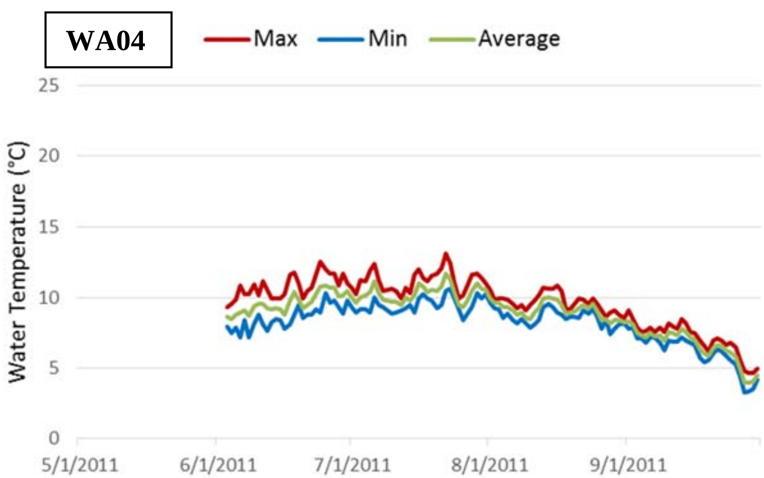
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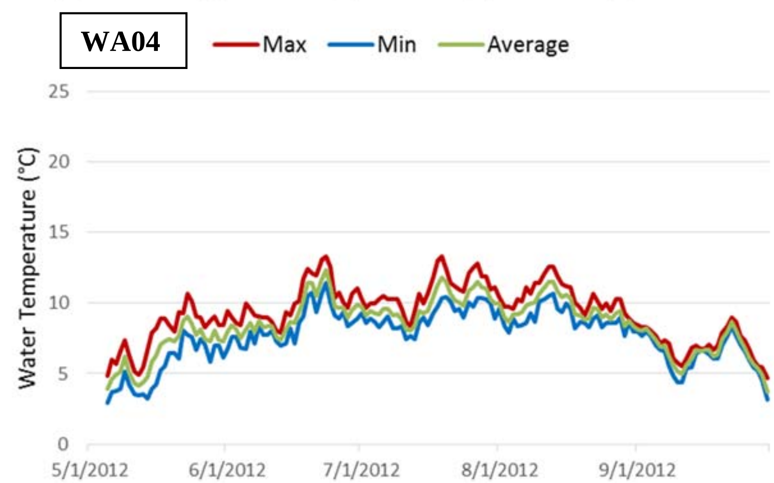
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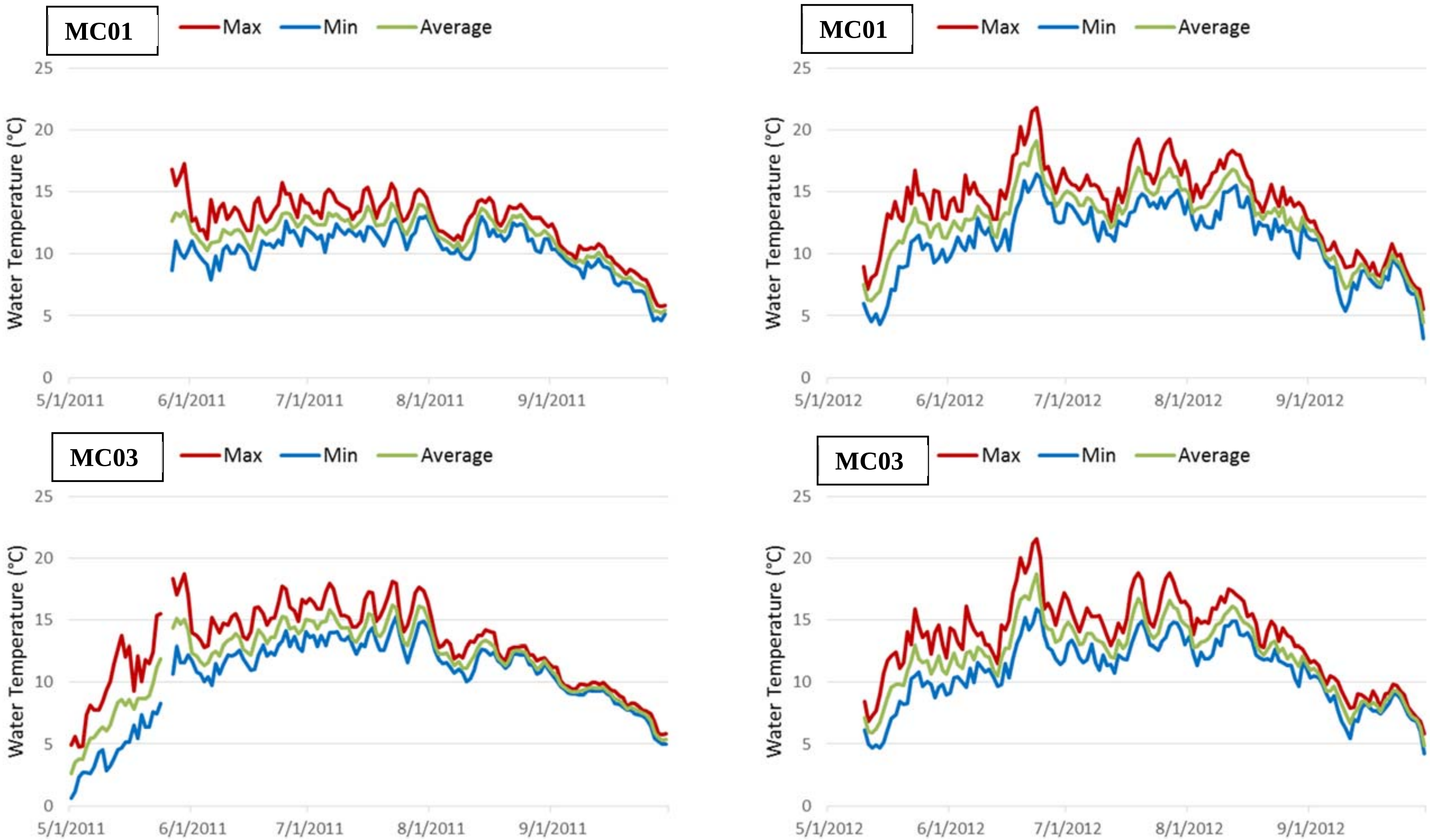

Figure 33. Daily summer water temperature statistics for Cottonwood sites CW01 and CW04, Wasilla Creek sites WA01 and WA04, and Meadow Creek sites MC01 and MC03, as measured in 2011 (left) and 2012 (right).

4.2 Physical Habitat Characteristics

4.2.1 Habitat Assessment and Sediment Size Distribution

Habitat condition in all three streams was suboptimal to optimal based upon qualitative habitat assessment scores (Table 23). 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, optimal habitat conditions were observed at all Wasilla Creek sampling locations except for WA02, near Bogard Road. At the WA02 site, loss of riparian vegetation width, reduced bank vegetation, and substrate embeddedness resulted in a suboptimal score. Suboptimal or marginal individual habitat components at the remaining Wasilla Creek sites were due to sediment deposition and substrate embeddedness. Within Cottonwood Creek, suboptimal habitat conditions were determined for CW02, near the Elks Lodge downstream from Bogard Road and CW03, below the Parks Highway in 2011. The CW03 site had the most variation in scoring between years, with an optimal classification in 2012. Suboptimal conditions at CW02 were due to local bank modification and loss of riparian vegetation and low scores for velocity-depth combinations. The upper Meadow Creek site (MC01, near Meadow Lakes Loop Road) was at the upper end of the suboptimal habitat assessment category in 2011 and the lower end of the optimal category in 2012. Low scores at this site were due to sediment deposition and low variation of water velocity and depth. The lower two Meadow Creek sites were optimal in 2011, while the MC03 site dropped to the upper suboptimal category in 2012. This was due to low scores for epifaunal substrate, embeddedness, and velocity-depth combinations.

The substrate size distribution shows an abundance of fine sediment in Meadow Creek and the lower Wasilla Creek sites (Figure 34). All Wasilla Creek sites, except WA02 had greater than 10% fine substrate (< 2 mm) within the sampling reach during both years of sampling. In 2012, this reach only had 5% fine substrate. The percent fines generally increased downstream in 2011 to 30% at the lower two Wasilla Creek sampling locations. In 2012, the WA01 site had the highest proportion of fines with 40%. Large accumulations of fine sediments also were found in Meadow Creek, with 25% to 50% of the substrate in this size category at MC01 and MC03. Smaller substrate sizes dominated at the Cottonwood Creek sites, where 50% to 98% of the particles were less than 22.6 mm in 2012. In 2011, larger size fractions occurred within Cottonwood Creek at CW03 and CW04. Mean substrate embeddedness was greatest at Wasilla Creek (27.29%), but a greater portion of substrate was at least 20% embedded in Cottonwood Creek (89.66%) (Table 24).

Table 23. Qualitative habitat assessment scores for sampling sites located in Wasilla Creek, Cottonwood Creek, and Meadow Creek, comparing scores from 2011 and 2012 sampling efforts.

Site ID	Year	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
CW01	2011	20	16	13	16	20	20	18	20	20	20	18.3
CW01	2012	19	18	18	19	19	17	19	18	19	19	18.5
CW02	2011	20	19	10	16	15	20	15	20	10	10	15.5
CW02	2012	17	16	13	17	18	15	17	13	12	12	15.1
CW03	2011	9	13	3	9	18	20	9	20	20	13	13.4
CW03	2012	19	17	19	17	19	13	17	14	15	15	16.6
CW04	2011	19	19	14	19	17	20	20	20	20	20	18.8
CW04	2012	17	15	18	15	19	17	19	18	18	18	17.3
WA01	2011	20	12	19	14	20	20	20	17	19	20	18.1
WA01	2012	17	14	14	15	19	19	19	16	18	19	16.9
WA02	2011	16.5	10.5	15	15	19	15	16	19.5	14	11	15.2
WA02	2012	17	12	9	14	19	8	15	16	10	8	12.8
WA03	2011	20	9	20	8	19	18	19	14	18	20	16.5
WA03	2012	17	14	18	13	18	19	19	17	17	15	16.4
WA04	2011	19	11	19	13	18	19	19	17	18	15	16.8
WA04	2012	19	18	20	16	18	19	19	18	16	17	17.8
MC01	2011	14	13	8	9	15	20	19	20	20	20	15.8
MC01	2012	19	18	15	17	19	19	18	18	15	18	17.6
MC02	2011	14.5	16.5	12	15	20	18	14	20	20	20	17.0
MC02	2012	14	16	15	17	20	18	18	18	14	14	16.4
MC03	2011	11	15	10	18	20	20	20	20	20	19	17.3
MC03	2012	14	14	12	13	19	19	18	17	16	16	15.8

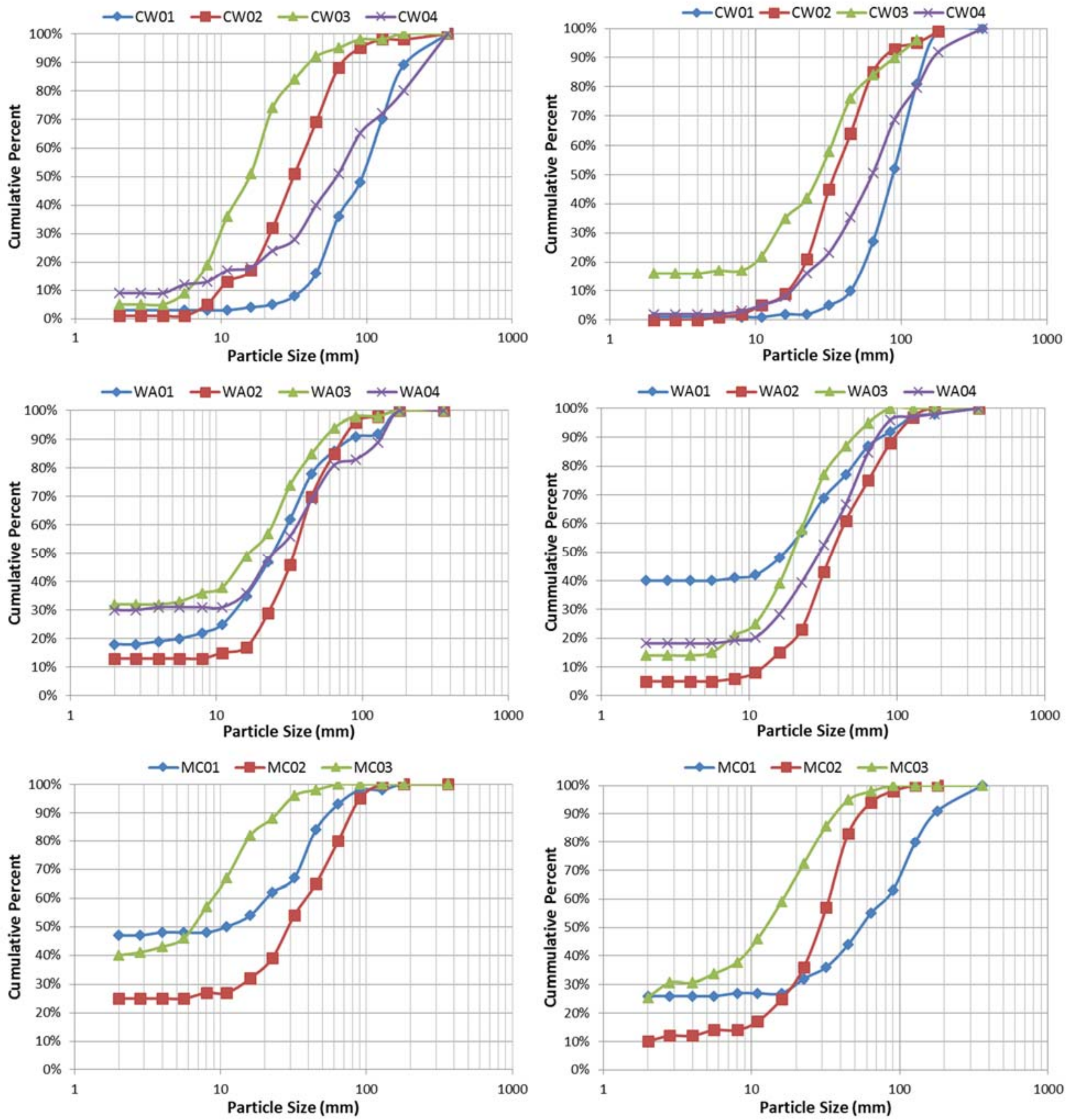

Figure 34. Substrate size distribution within the sampling reaches, as measured in 2011 (left) and 2012 (right).

Table 24. Substrate and embeddedness at the stormwater sites.

	Mean Particle Size (mm)	% Fines <2mm	Mean Embeddedness (%)	D50	D25	% Substrate <20% Embedded
CW01	108.77	1	11.57	90	64	80.00
CW02	53.85	0	23.75	45	32	56.00
CW03	44.69	16	17.50	32	16	80.00
CW04	101.52	2	15.77	64	45	94.00
WA01	36.94	40	37.15	23	2	62.63
WA02	55.31	5	15.47	45	32	70.00
WA03	27.72	14	27.09	23	11	68.00
WA04	46.57	18	29.45	32	16	58.00
MC01	94.57	26	15.68	64	2	76.00
MC02	35.95	10	2.04	32	16	94.00
MC03	19.24	26	1.13	16	2	98.98

4.2.2 Channel Morphology and Woody Debris

Total large woody debris counts were found to be greatest at the Cottonwood Creek survey sites, where total count was 51 pieces and 11 dams over all combined survey reaches. The lowest counts were found at the Meadow Creek sites, particularly Meadow 01. When normalized to the channel width, the LWD piece count was highest at Wasilla 03 (2.125 pieces/width) and lowest at Meadow 01 (0.352 pieces/width). When normalized to channel reach, the LWD piece count was highest at Cottonwood 01 and Cottonwood 04 (both 16.25 pieces/100meters), and lowest at Meadow 01 (1.25 pieces/100meters). The LWD Index was greatest in Cottonwood Creek, with an average LWDI of 519.5 over all study sites (Table 25).

Table 25. LWD Piece Counts, Debris Dam Counts, and Large Wood Debris Index (LWDI) for each stormwater site. *LWD survey was conducted over a 100-meter reach; all other surveys were conducted over 80-meters.

	LWD Piece Count	Piece Count/ Channel Width	Piece/100 Meters	Debris Dam Count	Piece Count/ Channel Width	Dam/100 Meters	LWDI
CW01	13	1.451	16.25	5	0.558	6.25	666
CW02	8	1.336	10.00	3	0.501	3.75	432
CW03*	17	1.669	17.00	3	0.295	3	608
CW04	13	1.632	16.25	1	0.126	1.25	372
WA01	5	1.402	6.25	1	0.280	1.25	171
WA02	4	0.751	5.00	2	0.376	2.5	255
WA03	9	2.125	11.25	1	0.236	1.25	268
WA04	3	0.497	3.75	3	0.497	3.75	353
MC01	1	0.352	1.25	0	0	0	19
MC02	10	1.237	12.50	2	0.247	2.5	306
MC03	5	0.448	6.25	2	0.179	2.5	240

4.3 Macroinvertebrates and Fish

Water quality based on macroinvertebrate ASCI scores ranged from poor to excellent. Water quality assessment using the ASCI methodology ranks water quality into five ratings: “very poor,” “poor,” fair,” “good,” and “excellent.” Scores for ranking vary with stream class: high gradient, low-gradient coarse substrate, and low-gradient fine substrate. Water quality assessment using the revised CIBI scores provided similar results to the ASCI scores (correlation coefficient 0.78 and 0.88 in 2011 and in 2012, respectively). The Wasilla Creek sampling reaches were all classified as low-gradient coarse substrate reaches. In 2011, WA01 and WA03 were ranked as “fair” and WA02 and WA04 were ranked as “good”. Based on the 2012 collection efforts, WA01 was ranked as “excellent” and WA02, WA03, and WA04 were “good”. In Cottonwood Creek, all four sampling reaches were classified as low-gradient coarse substrate reaches. CW01 and CW04 were “fair” in 2011, CW02 was “good” and CW03 was “poor”. In 2012, CW02 improved to “excellent” and CW04 improved from “poor” to “fair”. Meadow Creek sites MC01 and MC03 were classified as low-gradient fine substrate and MC02 was low-gradient coarse substrate. The upper and lower sites were assessed as “fair” water quality in both 2011 and 2012, while the site downstream from the Parks Highway was categorized as “poor” water quality based on the macroinvertebrate community in 2011 and “fair” in 2012. Meadow Creek sites had very low CIBI scores, particularly in 2011 and 2012. Low scores were due to the limited number of Ephemeroptera, Plecoptera, and Trichoptera taxa. The very low values produced by this study for Meadow Creek sites suggests a decreasing trend in water quality within this drainage.

There were no consistent longitudinal or temporal trends in ASCI or CIBI scores. Most sites showed either relative stability among sampling events or no apparent long-term trend. ASCI scores in Wasilla Creek from samples collected in 2000 and 2001 were similar among sites, with no consistent downstream change in water quality based upon macroinvertebrate ASCI scores. ASCI scores 10 years later were lower at all sites compared to September 2001 samples, but ASCI scores in 2012 were higher at all sites except WA04. The CIBI scores for Wasilla Creek suggest decreasing water quality longitudinally, which was supported with 2012 results; however, 2011 results show large variability among sites and no apparent trend. While the 2011 CIBI score at WA04 was the second lowest value since 2000, the ASCI score in 2011 was the second highest. Similarly in Cottonwood Creek, ASCI and CIBI scores at CW04, the farthest downstream site, decrease over time with the lowest ASCI value in 2011 and the lowest CIBI value in 2012. In 1998 and 2000, ASCI scores at CW04 were the highest recorded among Cottonwood Creek sites. Therefore, 1998 and 2000 were either abnormally high, or conditions at CW04 were much better at that time, and water quality impacts have, over time, extended downstream to this site. Meadow Creek ASCI scores do not confirm declining water quality; however, CIBI scores reflect degenerating water quality conditions in this stream (Figure 35).

The relative abundance and growth rates of juvenile salmon did not reflect declining water quality conditions in these three streams. Juvenile coho and Chinook salmon, Dolly Varden char, rainbow trout, stickleback, and sculpin were captured in Wasilla Creek. July catch per unit trap (CPUT) of coho salmon increased downstream in 2011, with the highest catch rate of over 40 fish per trap at WA04 (Figure 36). Catch rates in September of both years were lower at all Wasilla Creek sites, but still remained the highest at WA04. Chinook salmon were present at all sites in 2011 with higher CPUT at the lower three sampling locations. In 2012, no Chinook salmon were observed at WA01. Coho salmon growth rates were generally low at less than 0.1 mm/d in 2011, but were higher in 2012 with a maximum of 0.164 mm/d at WA04. There was no apparent longitudinal pattern in growth rates within Wasilla Creek (Table 24). Coho condition factors averaged 0.12 in July 2011, 0.11 in July 2012, 0.10 in September 2011 and 0.11 in

September 2012. Ratios of anadromous to resident fish in Wasilla Creek were 23 in July 2011, 7 in July 2012, 13 in September 2011 and 4 in September 2012.

Chinook, coho, and sockeye salmon, Dolly Varden char, rainbow trout, longnose sucker, stickleback, and sculpin were captured in Cottonwood Creek. Very few Chinook salmon were present in this stream in 2011 and none were observed in 2012. In Cottonwood Creek, CPUT of coho salmon was similar among sites at approximately 5 per trap (Figure 36), but growth rates at CW03 were the lowest in 2011 (0.089 mm/d) and the highest in 2012 (0.258 mm/d) (Table 26). Average coho condition factor was 0.12 in July 2011, 0.10 in July 2012, 0.11 in September 2011 and 0.10 in September 2012 (Figure 36). Average ratios of anadromous to resident fish in Cottonwood Creek were 1.7 in July 2011 and 2012, 1.1 in September 2011, and 1.6 in September 2012.

Meadow Creek had fewer species present than the other two streams. Coho salmon, rainbow trout, Arctic lamprey, stickleback, and sculpin were the only species captured within this stream. Coho salmon CPUT was consistently lowest at MC01 and relatively equal at MC02 and MC03. Growth rates increased in a downstream direction, with 2012 MC03 growth rates higher than at any of the other 10 sampling sites (Table 25). Growth rates could not be calculated for MC01 in 2011 due to the low numbers of captured fish. Average Meadow Creek coho condition factors were 0.11 in July 2011, 0.10 in July 2012, 0.10 in September 2011, and 0.10 In September 2012 (Figure 36). Anadromous to resident fish ratios were 0.79 in Meadow Creek in July 2011, 0.10 in July 2012, 0.09 in September 2011 and 0.13 in September 2012.

Coho salmon CPUT was significantly different among sites, streams, and seasons ($P = 0.004$, 0.0007, and 0.010). Specifically, Wasilla Creek CPUT was significantly different than both Cottonwood and Meadow Creeks ($P = < 0.01$) and the summer 2011 CPUT was greater than all other sampling events. This seasonal difference was mostly due to large catch rates in Wasilla Creek in July 2011. Total salmonid CPUT was also significantly different among sites, streams, and seasons ($P = 0.021$, 0.0004, and 0.045). Coho salmon condition factors were different among seasons ($P < 0.01$) but not among sites or streams. Average condition factors in the summer of 2011 were significantly greater than all other seasons sampled.

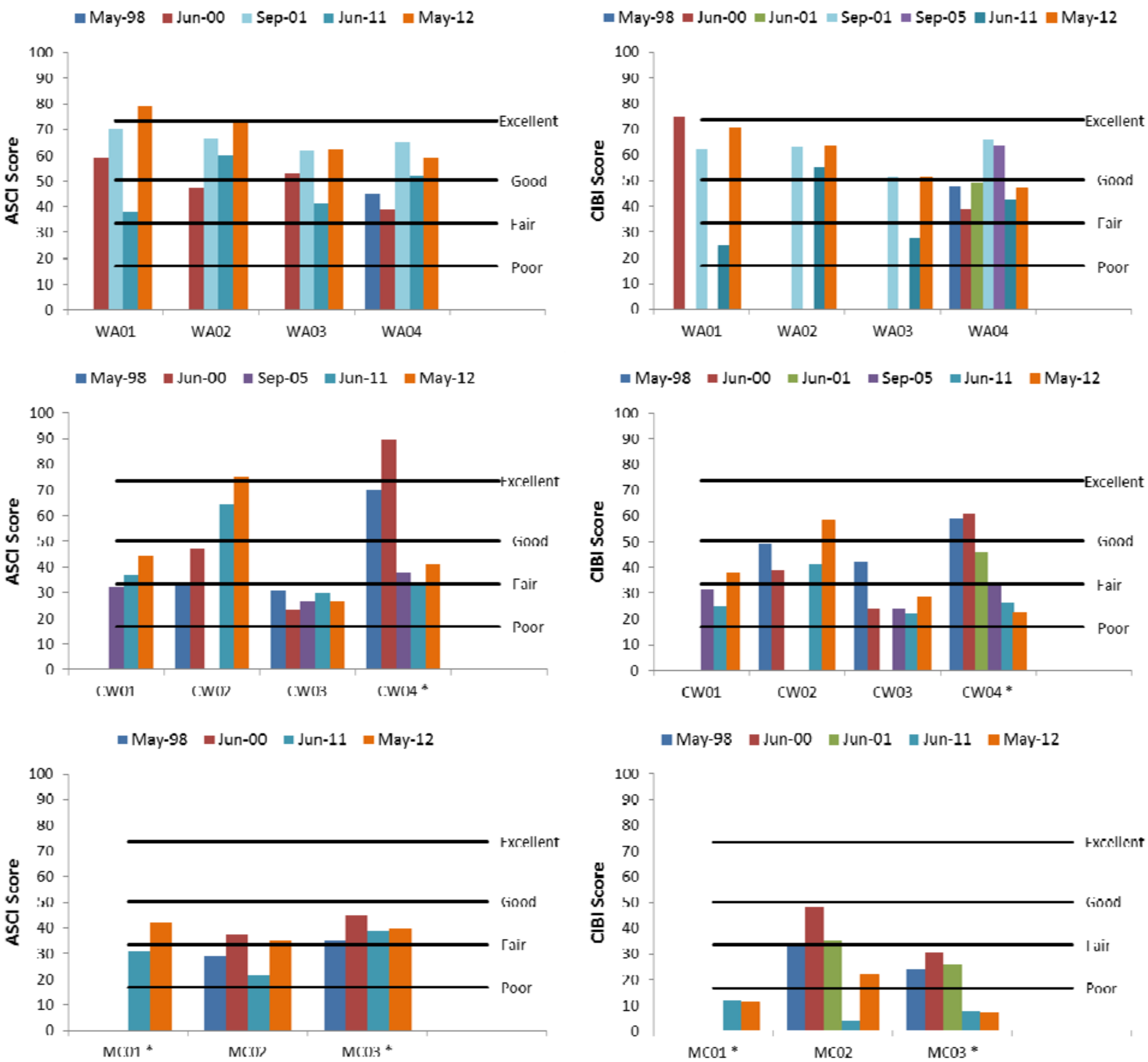

Figure 35. Macroinvertebrate metric ASCI (left) and CIBI (right) scores for samples collected in this study (Jun-11 and May-12) and previous published sampling results. Values for rankings “excellent” “good” “fair” and “poor” were based on ASCI values for low-gradient coarse substrate reach delineations. Sites marked with “*” were classified as low-gradient fine substrate, which has slightly lower values for each category ranking.

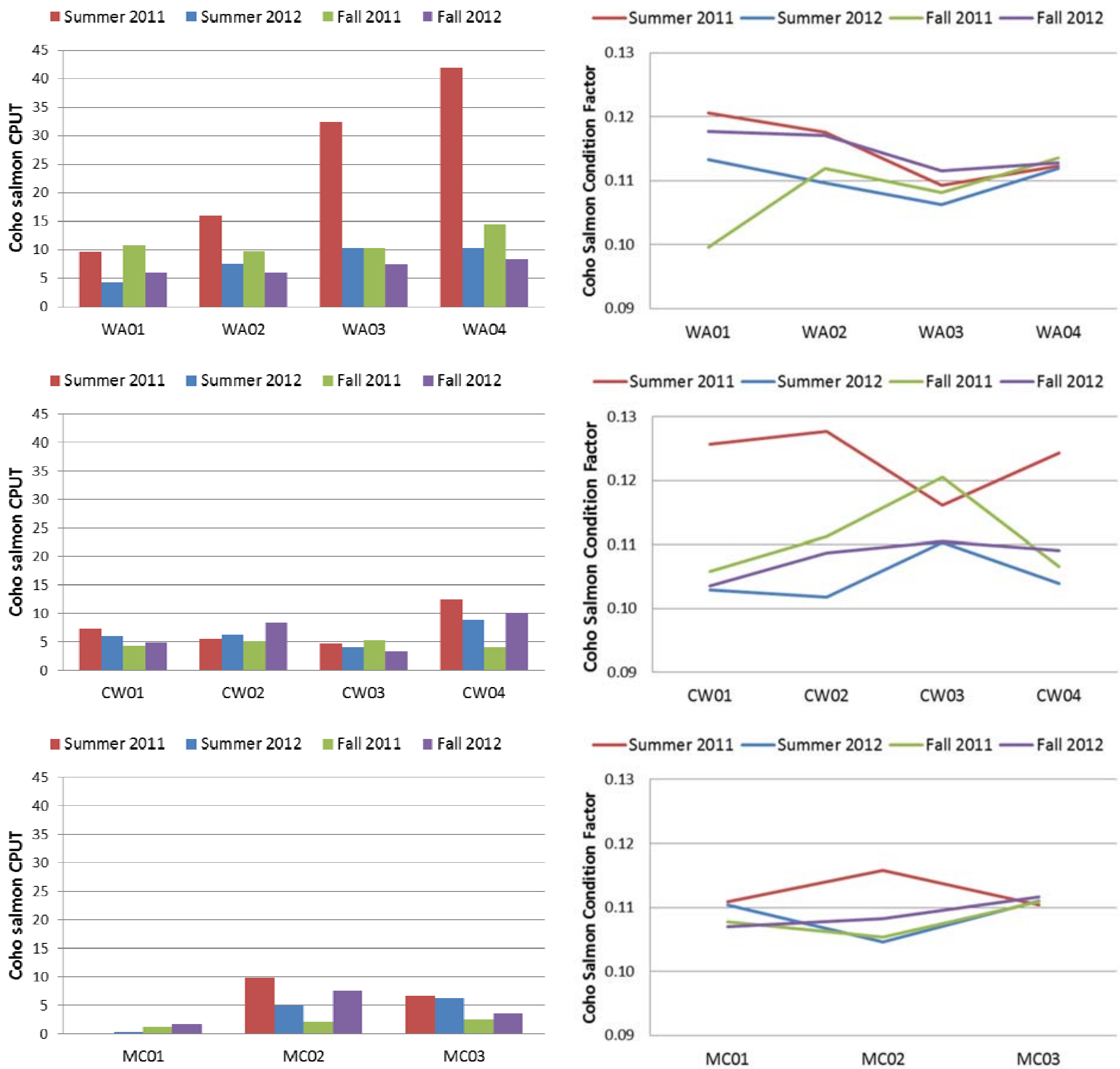

Figure 36. CPUT of coho salmon in July and September 2011 and 2012 (left) and juvenile coho salmon condition factors (right).

Table 26. Growth rates between summer and fall sampling events in 2011 and 2012.

	2011 Growth (mm/d)	2011 Inst. Growth x 100 (g/d)	2012 Growth (mm/d)	2012 Inst. Growth x 100 (g/d)
CW01	0.132	0.259	0.129	0.217
CW02	0.089	0.266	0.161	0.258
CW03	0.089	0.173	0.258	0.428
CW04	0.158	0.266	0.143	0.253
WA01	0.000	0.090	0.070	0.140
WA02	0.088	0.100	0.158	0.307
WA03	0.098	0.102	0.055	0.180
WA04	0.018	0.108	0.164	0.206
MC01	NA	NA	0.194	0.284
MC02	0.053	0.068	0.194	0.333
MC03	0.167	0.150	0.324	0.533

4.4 Impervious Surfaces and Wetlands

The percent of these watersheds that has been converted to an impervious surface is shown in Figure 37. Within Wasilla Creek, the maximum amount of total impervious surface area is 25.8% for the area within ½ mile of the stream channel between WA02 (Bogard Road) and WA03 (Tributary Road). A similar percent impervious area is found between WA03 and WA04 (below the Parks Highway). Considering just the medium and high categories, these values are 10.6% impervious and 10.5% impervious, respectively. Cumulative percent impervious surface upstream from Wasilla Creek sites ranges from 1.1 to 12.5%. However, this range drops to 0.1 to 4.9% when only medium and high categories are used. The Cottonwood Creek drainage has the highest percent of impervious surface, which ranges from 8.4% upstream of CW01 (Zephyr Road) to 23.6% between CW02 (Bogard Road) and CW03 (below the Parks Highway). Cumulative percent ranges from 8.6 to 18.5% impervious. Considering only medium and high categories, cumulative percent impervious ranges from 1.3% to 6.1%. Within Meadow Creek, cumulative percent impervious between sites ranges from 10.7% to 12.4% or 1.6% to 4.1% when using medium and high categories. Cumulative percent impervious surface upstream of the Meadow Creek sampling sites rages from 10.7% to 11.8% or 1.6% to 3.5% when using the medium and high categories.

There is a narrow range of variability in impervious surface area to evaluate relationships with changes in water quality. Total percent impervious surface within ½ mile of the stream systems between sampling sites ranges from 1.1% at WA01 to 25.8% between WA02 and WA03. Using only the high and medium category values this ranged from 0.1% to 12.6%. Percent high category impervious area within ½ mile of the streams between sites does not exceed 1%. Total cumulative percent upstream of a site, the range of percent impervious is lower; 1.1% at WA01 to 18.5% at CW04. Cumulative percent upstream of each site using the medium and high categories ranged from 0.1% to 6.6% or less than 1% using the high category alone.

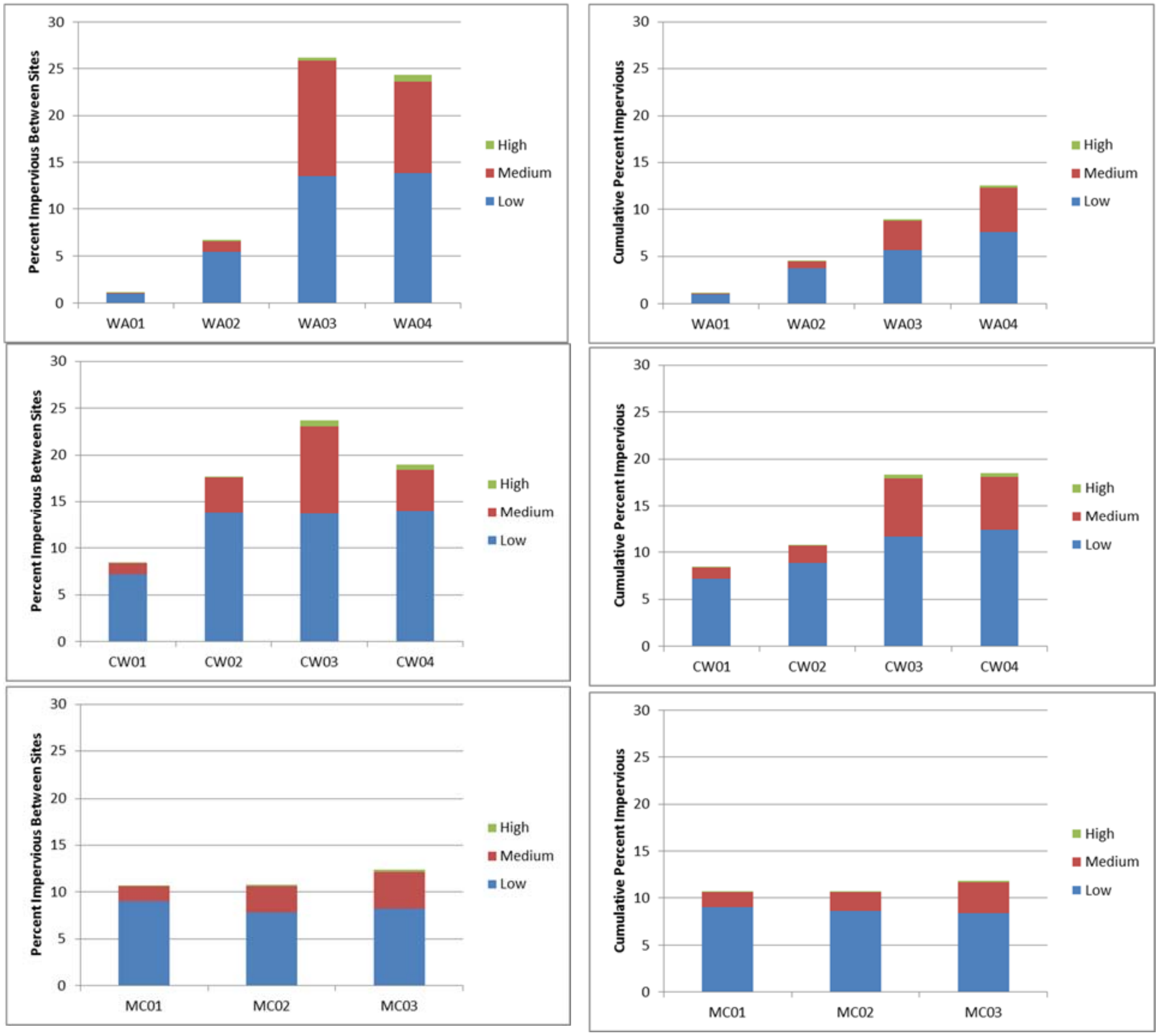

Figure 37. Percent impervious surface area by category within 0.5 miles of the stream channel between sites (left) and cumulative percent upstream (right).

The percent of wetlands within each drainage between sites and cumulative upstream of each sampling site by geomorphic category is shown in Figure 38. The Meadow Creek drainage contained the largest percent wetland, at 31% of the drainage upstream of MC03, and Cottonwood Creek the lowest, at 11.8% wetland upstream from CW01. Cumulative percent wetland upstream from each Wasilla Creek sampling site ranged from 16.7% to 24%. Discharge slope, drainage way, and wetland/upland complexes were the dominant geomorphic wetland types in the Wasilla Creek drainage. Within the Cottonwood Creek drainage, cumulative percent wetland upstream from each sampling site ranged from 8.2% to 11.8%. Lakes were the dominant wetland type, and excluding these, cumulative wetlands accounted for 5.4% to 7.6% of the drainage area. Following lakes, spring fens were the dominant wetland type in the Cottonwood Creek drainage. In Meadow Creek, cumulative wetland area ranged from 27.6% to 31.2%. Lakes were also the dominant wetland type and excluding this category, cumulative percent wetland ranged from 20.8% to 23.8%. Considering all sampling sites, cumulative percent non-lake wetlands ranged from 5.4% at CW03 (below Parks Highway) to 23.8% at MC03 (below Beaver Lake Road).

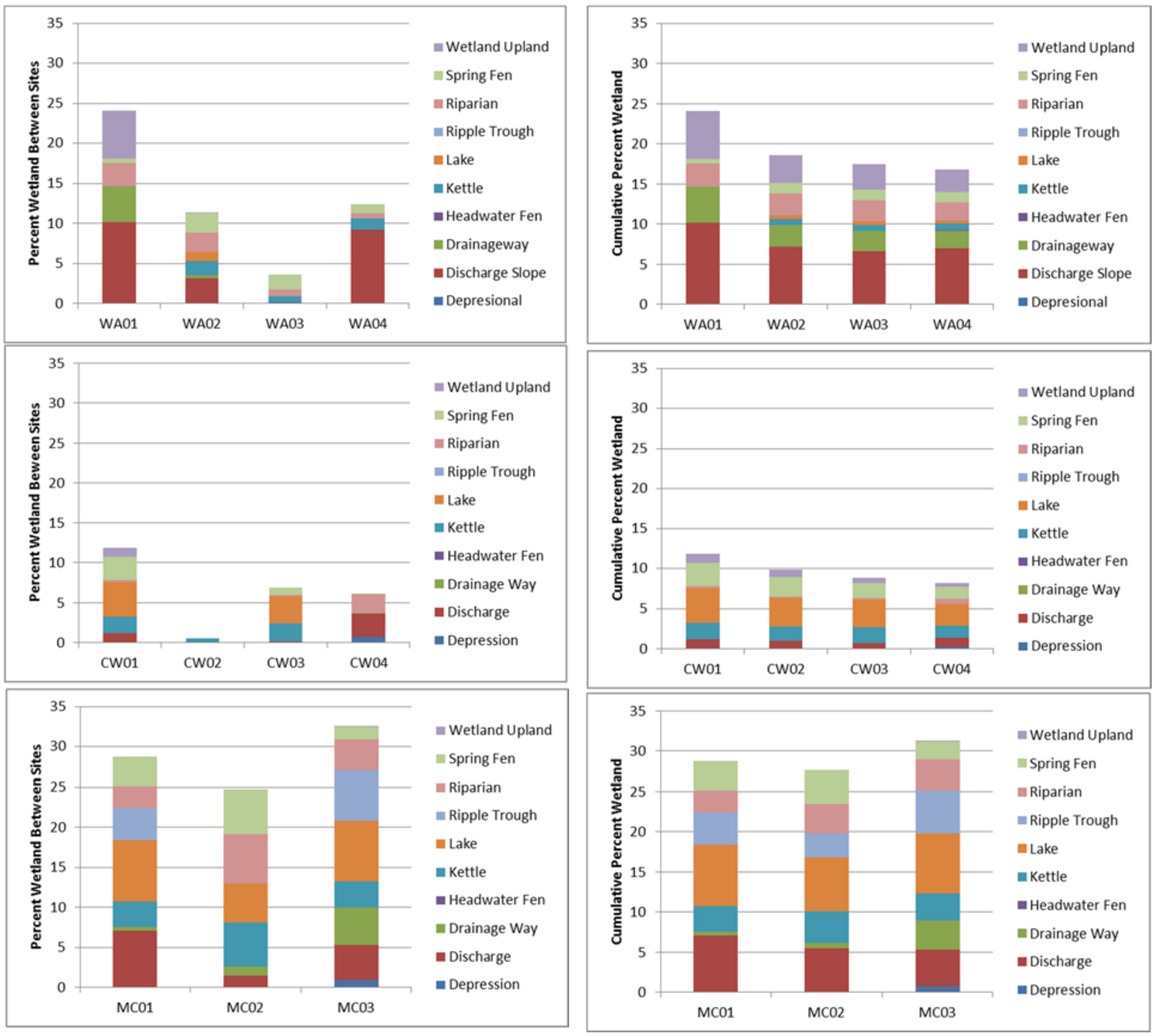

Figure 38. Percent of wetlands by wetland type between sampling sites (left) and cumulative percent upstream (right).

4.5 Relationships between Impervious Surface Area and Water Chemistry

There was no apparent relationship between change in ammonia concentrations during storm events and percent impervious surfaces. However, change in nitrate concentrations was negatively correlated with percent impervious surfaces upstream of the sampling site ($P = 0.013$). There was no significant relationship between total dissolved phosphorous and percent impervious surfaces, but total phosphorous was negatively correlated with percent upstream impervious surfaces ($P = 0.022$).

There were no significant correlations between change in total or dissolved metals during storm events and percent upstream impervious surfaces. However, change in total zinc concentration was nearly significant, with a negative relationship to percent impervious surfaces (r = -0.275, P = 0.07).

4.6 Relationships between Percent Wetlands and Water Chemistry

There were no significant correlations between change in ammonia or nitrate during storm events and cumulative percent wetlands upstream of the sampling site. Changes in total phosphorous and total dissolved phosphorous from base flow conditions were positively correlated with cumulative percent wetlands upstream (P = 0.009 and 0.011, respectively).

There were no apparent relationships between change in total or dissolved metals during storm events and percent wetlands upstream of sampling sites.

4.7 Biotic Relationships

Using fall salmonid CPUT, there appeared to be a negative relationship with cumulative percent impervious surface area. However, this relationship was not statistically significant. Additionally, there was a nearly significant positive relationship between fall salmonid CPUT and percent wetland area upstream, but only within Wasilla and Cottonwood creeks (Figure 39; r = 0.436, P = 0.092).

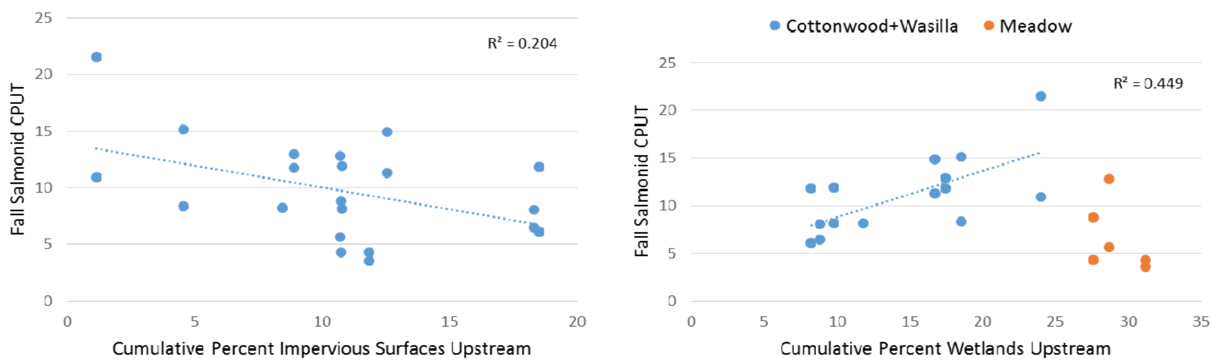

Figure 39. Relationship between average fall coho salmon CPUT and cumulative percent impervious surface upstream of sampling site (left) and cumulative percent wetland area upstream (right). Both values are based on percentages of area within ½ mile of stream.

5.0 Discussion

Comparison of changes in discharge during storm events show that the upstream sampling sites increase by greater percentages than downstream sites. This indicates that the majority of the stormwater input is coming in upstream of the developed area. The riparian areas around these streams in the urban reaches are functionally filtering the stormwater runoff and slowing the peak water input during storm events. This is especially apparent in the Meadow Creek drainage, where surrounding wetlands and lakes absorb some of the excess water, resulting in relatively low changes in discharge at the downstream sampling site during storm events.

Water temperatures between upstream and downstream sites were also very similar, with both Cottonwood and Meadow Creeks having warmer temperatures measured at the upstream sites than at downstream sites. Most of the heat input is likely naturally occurring, and riparian cover appears to have generally been maintained between sampling locations to provide shade from solar radiation.

Ammonia nitrogen concentrations were significantly higher during spring runoff and some storm events, especially in Cottonwood Creek. The highest average ammonia concentration was in Meadow Creek during Storm 2, which had the greatest single-day precipitation on the sampling date. The range of values observed among sampling events in Cottonwood Creek are within the ranges observed during monthly spring and summer sampling events in 2004 and 2005 at the same locations (Davis and Davis 2005; Davis et al. 2006). Inorganic nitrogen values, however, did not have significant changes during storm events but were only higher in Wasilla Creek spring runoff samples. Nitrate + Nitrite-N values observed in Cottonwood Creek in 2011 and 2012 were generally within the ranges observed in previous years, except for some high values at CW03 in spring and base flow samples (Davis and Davis 2005; Davis et al. 2006). This site is the most urbanized reach sampled on Cottonwood Creek, and these high nitrate + nitrite-N values may be a result of increased development and population in recent years. Increases of nutrients in the form of ammonia and nitrate have been related to urbanization, and can result in decreased macroinvertebrate species richness through the loss of pollution sensitive species (Miserendino et al. 2008). There is some evidence that this may be occurring, as ASCI and CIBI scores at Cottonwood Creek site CW04 have decreased during the period of 2000 to 2012, potentially as a result of increased nutrient inputs during this period.

Total phosphorus and dissolved phosphorus increased significantly during spring runoff and storm events in Wasilla Creek but not in Cottonwood or Meadow creeks. Increases in total and dissolved phosphorus have been shown in other studies to be related to urbanization and percent impervious surfaces, as well as cow paths and farmyard runoff (see review by Withers and Jarvie 2008). We did not find a relationship between total or dissolved phosphorous and impervious surfaces. However, the cow grazing land along Wasilla Creek may be a significant input of phosphorous to this stream, especially since the upstream WA01 site tended to have the lowest concentrations of phosphorus among Wasilla Creek sampling sites. All Wasilla Creek sites showed some increases in phosphorous during storm events, suggesting that the natural sources in wetland areas are also contributing to the phosphorous concentrations in spring and storm runoff. Cottonwood Creek total and dissolved phosphorous concentrations were within ranges observed in 2004-2005, suggesting that increased population along this stream has not significantly impacted phosphorous inputs (Davis and Davis 2005; Davis et al. 2006).

Sediment Cu, Pb, and Zn concentrations all exceeded threshold effect levels, Zn exceeded the probable effect level, and Cu was just below the probable effect level at Cottonwood Creek site CW03. This site is located just downstream of the George Parks Highway and may be receiving large inputs of metals from highway runoff. Highway runoff can provide the majority of pollutant suspended solids, PAHs, and metals to a stream (up to 80%), even though the highway may only comprise a small proportion of the drainage area (Hoffman et al. 1985). Additionally, heavy metal contents in farming soil are significantly higher than in forest soil due to frequent manure application, meaning that farm soil runoff may be a significant point source of metal concentrations (Xue et al. 2000). This may potentially be the source of increases in trace metal concentrations throughout Wasilla Creek associated with spring and storm event runoff.

However, metal concentrations in Wasilla Creek remain well below threshold effect levels, indicating that this is not a serious threat to the health of this watershed.

Concentrations of PAH in water and sediment samples within each stream were generally below detection limits and in very low concentrations when detected. Sediment PAH concentrations just below outfall locations, however, were orders of magnitude greater than TELs at outfall site 1 (Lake Lucile) for two of three storm events sampled and during one storm event at outfall site 2 (Cottonwood Creek). This suggests that in general PAH concentrations are not a problem, except at outfall locations. These locations appear to be collecting and concentrating pollutants to a single stream location, rather than allowing the riparian area to filter and diffuse pollutants along the stream length. This second scenario appears to be how stormwater near Wasilla Creek is managed, resulting in few longitudinal changes in water chemistry.

Dissolved organic carbon was significantly higher during spring and Storm 1 sampling events. The values in Cottonwood Creek during these periods were also significantly higher than monthly spring and summer samples at the same locations in 2004-2005 (Davis and Davis 2005; Davis et al. 2006). From these observations, we believe that peaks in dissolved organic carbon are quickly washed out of the system after initial runoff. The large values observed during Storm 1 were likely due to timing of sampling. This sampling event was during the smallest storm event and after the longest dry period, resulting in a more concentrated runoff, as compared to the later storm events. Dissolved organic carbon may only peak early in storm runoff and then return to background conditions as the storm progresses.

Specific conductivity decreased during spring runoff in Wasilla and Meadow creeks but was fairly constant among sampling events in Cottonwood Creek. Other studies have found an increase in conductance related to urbanization, but the lack of observed increases in the Palmer-Wasilla area stream conductivities suggests minimal levels of concrete drainage material (Davies et al. 2010) and minimal use of deicers in the winter (Corsi et al. 2010). We observed few outfall drainage areas into these streams other than direct runoff from roads at road crossings. Decreases in conductivity during spring runoff may also be due to large inputs of naturally low-conductance ice and snow melt in the riparian area. However, both pH and dissolved oxygen tended to decrease during spring runoff and storm events. Reduced levels of dissolved oxygen during wet periods may be the result of increased biochemical oxygen demand directly related to urban runoff (Mallin et al. 2009).

Much of the variability in nutrient concentrations and water chemistry between storm events can be attributed to rainfall conditions before storm events, which determine whether road surfaces are cleaned prior to sampling or if pollutants are able to build up on road surfaces (Hoffman et al. 1985). The highway is likely the major source of metal and road debris, with urban and industrial land uses also contributing to the levels of heavy metals and PAHs in stormwater (Brown and Peake 2006). In general, we did not find systematic increases in pollutants immediately downstream of the George Parks Highways. This was only evident in Cottonwood Creek and may be attributed to the multiple outfall locations immediately upstream and downstream of the highway. These outfalls drain the highway and large parking lots nearby directly into the stream, likely resulting in the reduced water quality and biotic metrics observed at this location.

There are some indications that the biotic community is being affected by the current low levels of development within the study area. Cottonwood Creek macroinvertebrate metrics have shown a decreasing trend through time, potentially due to the increased development and highway use in the area. This could be due to the high metal concentrations observed or recent increases in ammonia or nitrate, which can dramatically alter bacterial community structures after only a few days exposure (Ancion et al. 2010; Miserendino et al. 2008). Additionally, biofilms exposed to heavy metals can accumulate and transfer high concentrations of metals to invertebrates and fish grazing on the biofilms, retaining the pollutants in the water column long after initial exposure periods (Ancion et al. 2010). This biomagnification of metals may lead to the changes we have observed in macroinvertebrate community structure, ultimately impacting fish production within this stream.

Biotic community metrics for both fish and macroinvertebrates were higher in Wasilla Creek, as compared to Cottonwood and Meadow creeks. Wasilla Creek is unique among these three streams with runoff coming from the Talkeetna Mountains compared to the low elevation spring origins of Cottonwood and Meadow Creeks, which are separated from the Talkeetna Mountains by the Little Susitna River. Lakes are common within the Cottonwood and Meadow Creek drainage but make up less than 1% of the Wasilla Creek watershed. Habitat assessments documented more flow types, a mix of pools and riffles, in Wasilla Creek compared to the other two streams. Large woody debris, an important component of fish habitat, was relatively abundant in Wasilla Creek. Cottonwood Creek, however, had a higher average large woody debris index value among sites, with both higher piece counts and more debris dams than Wasilla or Meadow creeks. The combined differences in physical habitat quality among the streams are likely influencing the differences in the biotic community.

We did not find any consistent relationships between impervious surface area and total salmonid catch among annual summer and fall sampling events. This is in direct contrast to previous studies that have documented rapid declines in fish community composition at impervious surface area less than 10% of the watershed (Paul and Meyer 2001). Although total percent impervious surfaces were between 10-20% in each of these watersheds, more than half of this was categorized as low level imperviousness. This includes dirt or gravel roads and small homes, which should have less impact on water quality than large parking lots or highways. Excluding the low level impervious surfaces, there was less than 7% imperviousness upstream of all sampling locations. This level of imperviousness may still be too low for significant watershed effects and direct correlations to water quality.

Large woody debris has been found in other studies to be lower in urban streams (Wenger et al. 2009), but our results are generally opposite of expected. Wasilla Creek had both increasing percent impervious surface and LWDI with each site, moving downstream. Cottonwood and Meadow creeks also showed increasing percent impervious surfaces longitudinally, but there was no relationship between imperviousness and LWDI. Based on observations, at least one land owner along Cottonwood Creek physically removed woody debris from the stream, ironically to improve fish habitat. However, it appears that in general, large woody debris availability has not been strongly influenced by the low levels of development along these streams. This allows for maintenance of habitat complexity and bank stability, which is often lost along with large woody debris in an urban stream (Finkenbine et al. 2000).

Based on our results on water quality, biotic and physical habitat metrics within the Palmer-Wasilla core area streams, we find minimal large-scale effects from urbanization. The current level of imperviousness is still relatively low for strong correlations with water quality, and the riparian areas have generally been maintained throughout the core area. The greatest impacts on water quality appear to be related to the use of stormwater outfalls in the Cottonwood Creek drainage, and Lake Lucile, which concentrate pollutants and deliver them directly into the stream, rather than allowing the riparian area to slow stormwater inputs and filter out some of the pollutants. These effects are especially apparent because the outfalls drain the nearby highway, which is likely the major source of heavy metals and PAH inputs.

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Appendices

Appendix A: Site Photographs

Photograph 1. Upper most Cottonwood Creek sampling site (CW01)

Photograph 2. Measuring base flow discharge of Cottonwood Creek

Photograph 3. Macroinvertebrate sampling in Cottonwood Creek

Photograph 4. Juvenile fish sampling in Cottonwood Creek

Photograph 5. Sampling bottles for storm event #1 at lowest Cottonwood Creek site (CW04)

Photograph 6. Adult sockeye salmon in Meadow Creek 8/15/2012

Photograph 7. Lower most Meadow Creek sampling site (MC03)

Photograph 8. Upper most Meadow Creek sampling site (MC01)

Photograph 9. Culvert at Uppermost Wasilla Creek site (WA01) during storm event #1

Photograph 10. Eroded bank caused by cows on Wasilla Creek (WA02)

Photograph 10. Summer baseline stormwater sampling in Wasilla Creek

Photograph 11. Lower most Wasilla Creek sampling site (WA04)

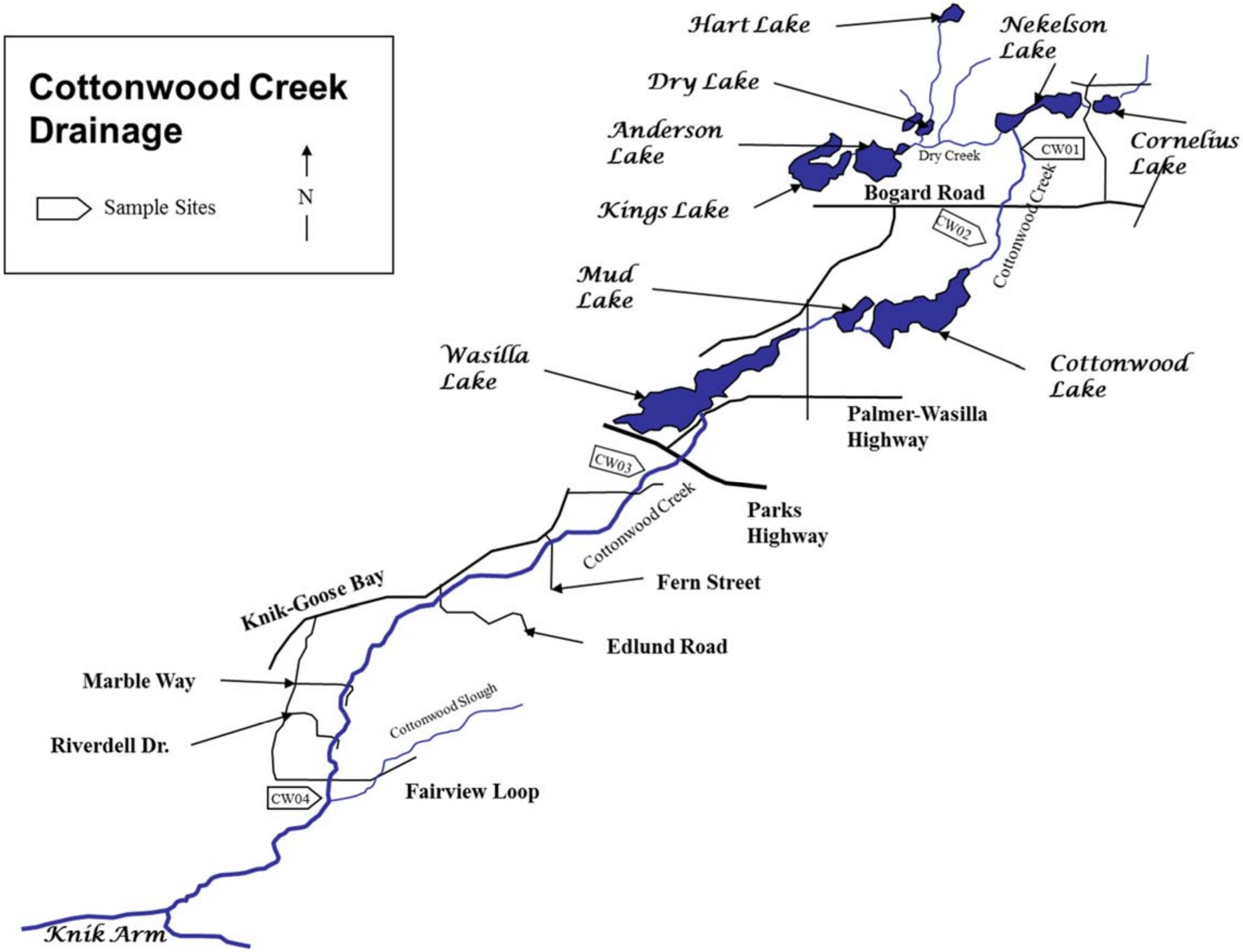
Photograph 12. Stormwater runoff from Hyer Road near Wasilla Creek

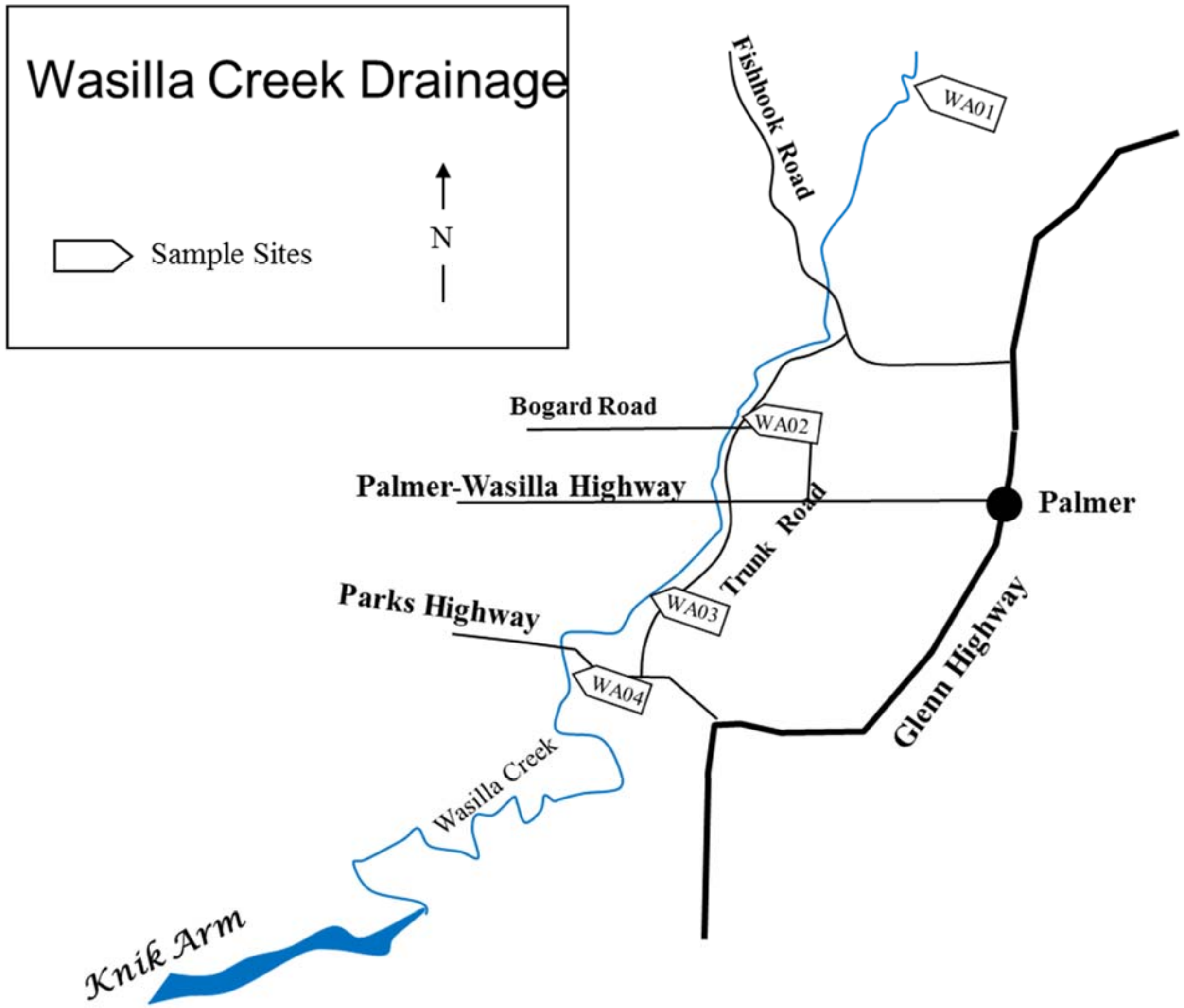
Photograph 13. Outfall 01 (Lucile Lake) during storm event #1

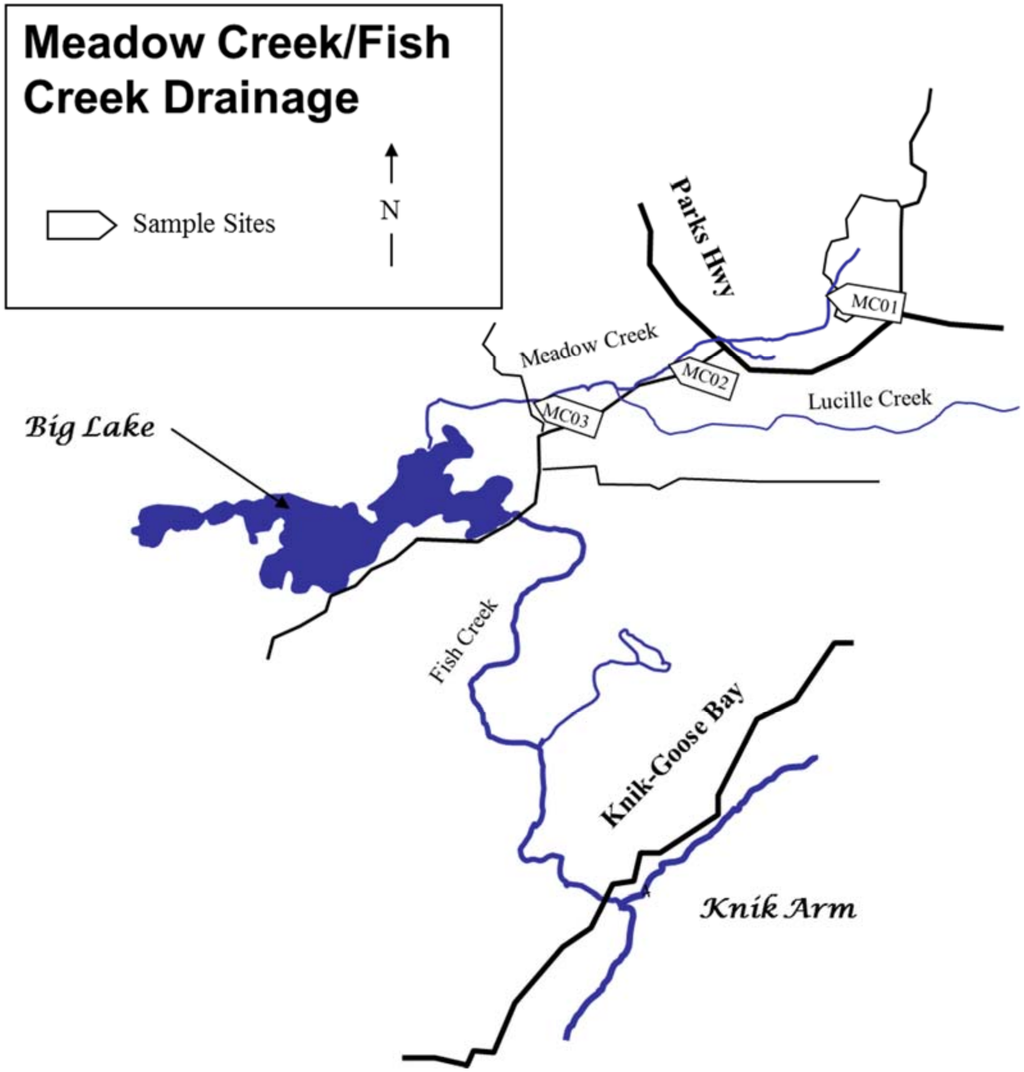
Photograph 14. Sampling at Outfall 01 during storm event #2

Photograph 15. Outfall 03 during storm event #1

Appendix B: Site Location Maps


Cottonwood Creek Drainage
Sample Sites
N
Hart Lake
Nekelson Lake
Dry Lake
Anderson Lake
Kings Lake
Cornelius Lake
Dry Creek
CW01
Bogard Road
CW02
Cottonwood Creek
Mud Lake
Wasilla Lake
Cottonwood Lake
Palmer-Wasilla Highway
CW03
Parks Highway
Cottonwood Creek
Fern Street
Knik-Goose Bay
Edlund Road
Marble Way
Cottonwood Slough
Riverdell Dr.
CW04
Fairview Loop
Knik Arm


Wasilla Creek Drainage
Sample Sites
N
Fishhook Road
WA01
Bogard Road
WA02
Palmer-Wasilla Highway
Palmer
Trunk Road
Parks Highway
WA03
WA04
Glenn Highway
Wasilla Creek
Knik Arm


Meadow Creek/Fish Creek Drainage
Sample Sites
N
Parks Hwy
MC01
Meadow Creek
MC02
MC03
Lucille Creek
Big Lake
Fish Creek
Knik-Goose Bay
Knik Arm