Willow Creek Water Quality and Habitat Assessment

Prepared for:

Alaska Department of Environmental Conservation

By:

Aquatic Restoration & Research Institute

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List of Acronyms

As	Arsenic
ASCI	Alaska Stream Condition Index-Macroinvertebrate sampling and analytical methods
Al	Aluminum
µg/L	Micrograms per liter, parts per billion
C	Temperature in centigrade or Celsius units
cfs	Units of flow or discharge in cubic feet per second
cfu	Colony forming units
Cu	Copper
DEC	Alaska Department of Environmental Conservation
EPA	U.S. Environmental Protection Agency
Flow or Discharge	Measure of the volume of water in a river moving over time
km	Kilometer
m	Meter
mg	Milligram
µg/g	Mass of metal per mass of sediment
mg/L	Milligrams per liter, parts per million
mm	Millimeter
Ni	Nickel
NTU	Nephelometric turbidity units, measure of turbidity
Pb	Lead
QAPP	Quality Assurance Project Plan
PAH	Polycyclic Aromatic Hydrocarbons
Thalweg	The main channel of a stream or river. Portion of the stream that contains most of the flow
VOC	Volatile Organic Compound; includes petroleum hydrocarbons
WQC	Water quality criterion (parameter specific criteria contained within the WQS)

WQS	Alaska Water Quality Standards 18 AAC 70
Zn	Zinc

1.0 Summary

Increasing development and recreational activity along with continued mining within the Willow Creek watershed has raised concerns over possible water quality degradation and changes to physical habitat resulting in impacts to salmon spawning and rearing habitat. In order to address these concerns, water quality sampling, physical habitat and biotic assessments were conducted in the summer and fall of 2014 and the spring of 2015.

Water samples were collected from 4 Willow Creek sampling locations during the spring, summer, and fall. Samples were analyzed for concentrations dissolved metals, macronutrients, alkalinity, and hardness. Stream water pH, specific conductivity, dissolved oxygen, turbidity and temperature were measured in the field. Data loggers were used to collect water temperature at each location every 30 minutes and measure turbidity at two locations every hour. Sediment samples were collected in September and analyzed for select metals and hydrocarbons (below the Parks Highway). Macroinvertebrates were sampled and habitat assessments conducted using the Alaska Stream Condition Index (ASCI) methods. Juvenile salmon and resident fish were sampled using baited minnow traps. Stream channel width, water depth, substrate size distribution, and back and riparian modification was measured at each sampling location.

Habitat and water quality conditions in Willow Creek remain good even though bank and riparian modifications were apparent at all sampling locations. There was no indication of excessive sediment input as embedded substrate or increases in turbidity during storm events. Dissolved and sediment metal concentrations did not exceed water quality criteria or were at concentrations unlikely to affect fish or invertebrates, with the exception of arsenic which is commonly in high concentration in sediments of Southcentral streams. Stream water temperatures were cooler at the farthest upstream sampling location and increased downstream. Temperatures were often in the optimal range for juvenile salmon rearing at the lower 3 sampling locations. Fecal coliform bacteria exceeded water quality criteria at the two sampling locations below the Parks Highway. Juvenile Chinook and coho salmon were abundant at all sampling locations downstream from the canyon. Resident Dolly Varden were more abundant at the upstream sites and rainbow trout downstream. Macroinvertebrate water quality assessments indicates good to excellent water quality and did not indicate a decrease in water quality since previous samples collected over the past 15 years.

2.0 Introduction

Willow Creek, located in the Susitna River drainage in Southcentral Alaska, supports a popular salmon and rainbow trout fishery. Development, recreation, and resource extraction within the Willow Creek watershed have the potential to disturb riparian areas, contribute to bank erosion and impact water quality within Willow Creek. During rain events runoff from parking lots, roads, yards and fields can contribute sediments, salts and metals to surface streams. All of these factors can affect the overall ecological health of the stream including water quality, physical habitat conditions, aquatic insect diversity and abundance, and the distribution and abundance of rearing juvenile salmon and resident fish. Fine sediments in large quantities can limit the amount of living space for aquatic insects, clog the gills of rearing juvenile salmon and resident fish and can also block oxygen flow to developing salmon eggs. Metal pollutants can be toxic to fish particularly during early incubation and can also alter the odor of a stream affecting migrating salmon’s ability to locate spawning areas.

A combination of different activities within the Willow Creek drainage could potentially influence water quality and fish habitat. Mining within the upper drainage has been occurring for the past ~ 100 years and is ongoing. Currently there are several small scale mechanical placer mines in the Willow Creek area along with recreational mining claims where small scale suction dredging operations (<6 inches, <18 horsepower) are permitted in the upper drainage. There also is one large hard rock exploration program about a half mile from Willow Creek in the Hatcher Pass area. Urban development including home construction, land clearing, and road building has occurred within the watershed and within the river flood-prone area from Shirley-Town Road downstream. Four road and two railroad bridges cross Willow Creek with two of the road bridges (Deneki and Shirley-Town) having been lost to floods within the past 10 years. Flooding, in combination with vegetation clearing, has resulted in rapid rates of bank erosion and lateral channel movement threatening some homes. There has been some forest harvest and road building within the Willer-Kash harvest area on the north side of Willow Creek and in the upper Deception Creek drainage. Recreational impacts include all-terrain-vehicle trails in the upper drainage including Peters Creek, and damage to riparian vegetation in the areas of concentrated use near the confluence with the Susitna River associated with the salmon fisheries.

The extent of development impacts on Willow Creek are yet unknown. A complete analysis of the current ecological condition is needed in order to determine whether Willow Creek displays early indications of impairment due to development and to provide a baseline for future water quality and stream habitat monitoring.

Willow Creek, located in the Matanuska-Susitna Borough is a popular area for recreation and sport fishing. Within the Susitna River Drainage, Willow Creek has ranked in the top seven for the number of Chinook salmon harvested for many years. Upwards of 7,000 fisherman report fishing in the drainage every year for Chinook, coho, sockeye, pink, and chum salmon, as well as rainbow trout and Arctic grayling (ADFG 2014). Easy access to the creek from the Parks Highway and Willow Creek Parkway as well as camping facilities in the Willow Creek State Recreation Area and the nearby town of Willow make it one of the most popular streams for fishing within the Susitna drainage. Due to the high and increasing use of this stream, it will be important to define current stream condition for use in identifying stream degradation or any needed habitat restoration or protection actions.

This study has been developed to address the following objectives:

- Measure stream water and sediment chemical parameters in upstream reference and downstream developed or higher use areas of Willow Creek to determine whether development is resulting in changes in water quality;
- Measure the biotic community to assess stream health along the length of Willow Creek, using macroinvertebrate ASCI scores and juvenile salmon distribution, abundance, and condition values;
- Collect physical habitat measures to determine base line values of riparian vegetation cover, sediment size distribution, large woody debris, and channel width and depth.

3.0 Methods

A quality assurance project plan (QAPP) was developed for this project and approved by the Alaska Department of Environmental Conservation (DEC). The QAPP describes the sampling design, data collection methods and handling, and quality assurance procedures and is provided in Appendix B.

Water quality, physical habitat, and biotic characteristics were measured at four sites along Willow Creek (Figure 1 and Table 1). The farthest upstream site (Willow01), is located above the Willow Fishhook Road crossing. Willow02 is located just upstream of the Deneki Road crossing. Willow03 is located just downstream of the Parks Highway crossing. Willow04 is located approximately 1 mile upstream of the mouth and is the furthest downstream site.

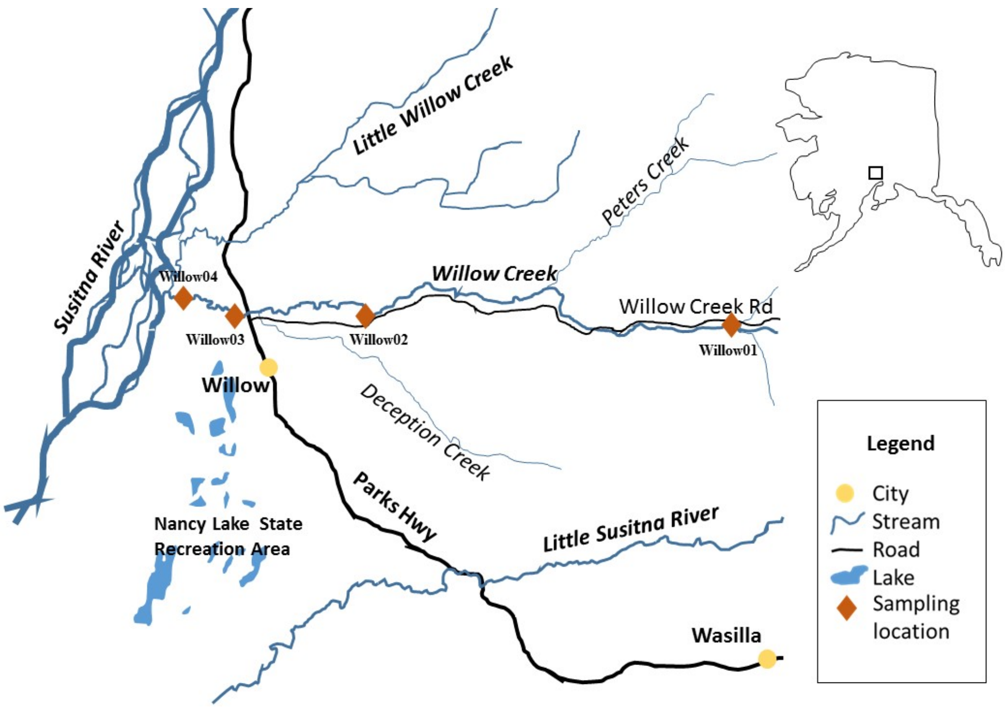

Figure 1. Map of sampling locations on Willow Creek.

Table 1. Sampling locations.

Site	Description	Latitude	Longitude
Willow01	Upstream of Willow Fishhook Rd crossing	N 61.76168	W -149.67406
Willow02	Upstream of Deneki Rd crossing	N 61.77102	W -149.95728
Willow03	Downstream of Parks Hwy crossing	N 61.76687	W -150.07198
Willow04	Upstream of mouth	N 61.77710	W -150.15622

Table 2. Summary of sample timing

Sample Activity	Dates Collected
Water Chemistry - Field Measurements	July 22, 2014, September 5, 2014, September 23, 2014, April 27, 2015
Dissolved Metals and Nutrients	July 28, 2014, September 5, 2014, April 27, 2015
Settleable Solids	July 22, 2014, September 5, 2014, April 27, 2015
Sediment Metals	September 5, 2014
Temperature Loggers	Installed July 22 2014, removed September 23-October 7 2014, Installed May 2015.
Turbidity Loggers	Installed July 22, 2014, removed September 18, 2014
Macroinvertebrates	August 27, 2014
Fish	July 28-30, 2014
Habitat Assessment	August 27, 2014
Fecal Coliform	July 22-August 19, 2014
Bank and Riparian Modification	September 23-24, 2014
Sediment Size Distribution	September 23-24, 2014
Physical Habitat Characteristics	September 23-24, 2014

3.1 Water Quality and Stream Flow

Water quality and stream flow were assessed using *in situ* measurements, laboratory analysis of samples, and data loggers. Water quality was determined from *in situ* measurements of pH, specific conductivity, dissolved oxygen, water temperature and turbidity. Water samples were collected and analyzed for nitrate+nitrite-N, ammonia-N, total phosphorus and total dissolved phosphorus. Water samples were also analyzed for total fecal coliform bacteria. Water temperature and turbidity were measures with data loggers. Field measures of water quality were obtained during summer baseflow (July 22, 2014), during two fall storm events (September 5 and September 23 2014), and during spring runoff (April 27, 2015). Specific conductivity, temperature and pH were measured using a YSI 63 meter and probe. Dissolved oxygen saturation and concentration and temperature were measured using a YSI 550A DO meter. Turbidity was measured on each sampling occasion using a LaMotte TC-3000e meter. Three replicate samples were measured and average turbidity was calculated from these values. Additionally, temperature was recorded every 30 minutes using Onset ProV2 data loggers. Hach Hydrolabs were installed to measure turbidity every 30 minutes at Willow01 and Willow03 from July 22 until September 18. Discharge was obtained from USGS stream gauge 15294005, and precipitation data were obtained from the NOAA National Climatic Data Center station located in Willow (N 61.6995°, W 149.9897°). Settleable solids (mL/L) were measured from 1 liter samples collected in July and September of 2014 and April 2015 using the Imhoff cone method.

Water samples were collected from all sites in July 2014, September 2014, and April 2015 (Table 2). In July 2014, water samples for nutrients were collected on July 22 and water samples for dissolved metals were collected on July 28. The samples were received by the laboratory on July 30. In September 2014, water samples for nutrients and dissolved metals were collected on September 5 and received by the laboratory on September 9. In April 2015, water samples for nutrients and dissolved metals were collected on April 27 and received by the laboratory on April 30. Samples were laboratory analyzed for nitrate + nitrite-N, ammonia-N, total-P, dissolved organic carbon, alkalinity and hardness, and dissolved metals (aluminum, antimony, arsenic, barium, beryllium, cadmium, copper, lead, chromium, cobalt, magnesium, manganese, molybdenum, nickel, selenium, silver, thallium, vanadium, zinc).

Water samples were collected from Willow03 and Willow04 on five dates during the summer for fecal coliform analyses. Five water samples were collected between July 22 2014 and September 2 2014 and analyzed for total fecal coliforms by Analytica Group, LLC in Anchorage, AK.

Sediment grab samples were collected on September 5, 2014 at each site. The samples were laboratory analyzed for arsenic, cadmium, copper, lead, zinc and mercury. Sediment from Willow03, just downstream of the Parks Highway, also were analyzed for polycyclic aromatic hydrocarbons (PAHs). Sediment samples were received by the laboratory on September 10 2014. Laboratory analysis of both water and sediment samples was performed at AM Test Laboratories located in Kirkland, WA.

3.2 Physical Habitat Characteristics

At each site, physical habitat was assessed over a 100m reach. At five transects within each 100m reach, channel width and flood prone width were measured. The height of the banks was measured, as well as the extent that the bank is undercut. Bank slope was calculated for each of these five transects from cross-section survey data. Dominate riparian vegetation types were measured and classified using the U.S. Forest Service Alaska Vegetation Classification system (Viereck et al 1992). Bank and riparian modifications were measured and photographed, and the cause of modification was recorded. Substrate size distribution was measured within each reach using Wolman pebble counts. One hundred randomly selected particles were measured for median diameter, and percent of embedded in fines was also recorded. Large woody debris (LWD) pieces and dams were counted within each reach. Habitat assessments were conducted at each site using the Alaska Stream Condition Index (ASCI) qualitative assessment methodology (Major and Barbour 2001), which ranks habitat characteristics including substrate, velocity-depth combinations, channel alteration, channel sinuosity, bank stability, and riparian vegetation.

3.3 Biological Characteristics

3.3.1 Macroinvertebrates

All macroinvertebrate samples were collected on August 27th 2014 using standard operating procedures for the Alaska Stream Condition Index (Major and Barbour 2001). Twenty benthic samples were collected in a D net (350 micron mesh). All available habitats were sampled 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 composite 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. 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.

3.3.2 Juvenile Salmon

Juvenile salmon and resident fish were sampled using baited minnow traps in July 2014. Twenty minnow traps (1/4 inch mesh, 1 inch opening) were baited with commercial salmon roe, placed at each site in areas where water depth completely covered the trap opening and in locations with cover provided by woody debris or bank vegetation. The traps were fished for 20-24 hours. All captured fish were identified. Fork length and weight were measured for all salmonids. Catch per unit trap, ratio of salmonids to resident fish, and salmon condition factors were calculated for each site.

4.0 Results

4.1 Water Quality and Stream Flow

4.1.1 Dissolved Oxygen, pH, and Specific Conductivity

Results for in situ water quality measurements are shown in figures 2 through 4. Stream water pH was over 7.0 on all sampling dates. pH was highest for all four sites on September 23, 2014, during the second fall storm event, while the lowest pH was recorded on September 5, 2014, the first storm event. Stream water pH likely varies from the rising to falling limb of the hydrograph through a storm event as soil organic acids are flushed from upland and riparian forests and wetlands. Stream water pH tended to decrease downstream with the lowest values at downstream sites. Specific conductivity generally increased throughout the season, as shown in Figure 3. The lowest specific conductivity was recorded in July 2014 at all four sites, while the highest specific conductivity was recorded at all four sites in April 2015. Dissolved oxygen was near saturation at all sites throughout the study as shown in Figure 4. Willow01 had the lowest percent saturation of dissolved oxygen at 92.2% on April 27, 2015 at Willow01 when ice cover was still present, while the highest percent saturation of dissolved oxygen was at Willow02 on September 23, 2014, at 104.0%.

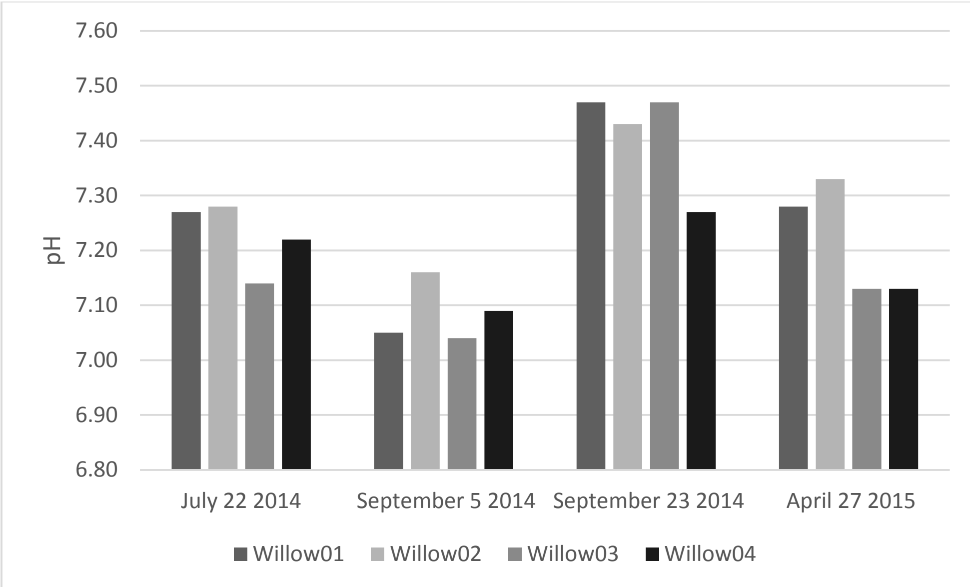

Figure 2. Stream water pH at all sampling locations, measured during summer baseflow (July 22), two fall storm events (Sept 5 and 23), and spring flow.

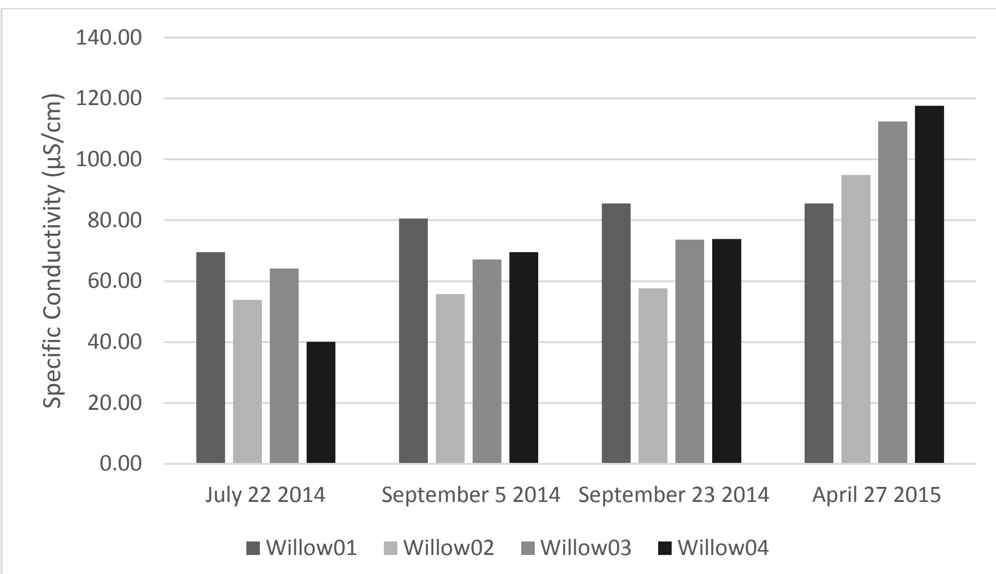

Figure 3. Specific conductivity at all sampling locations, measured during summer baseflow, two fall storm events, and spring flow.

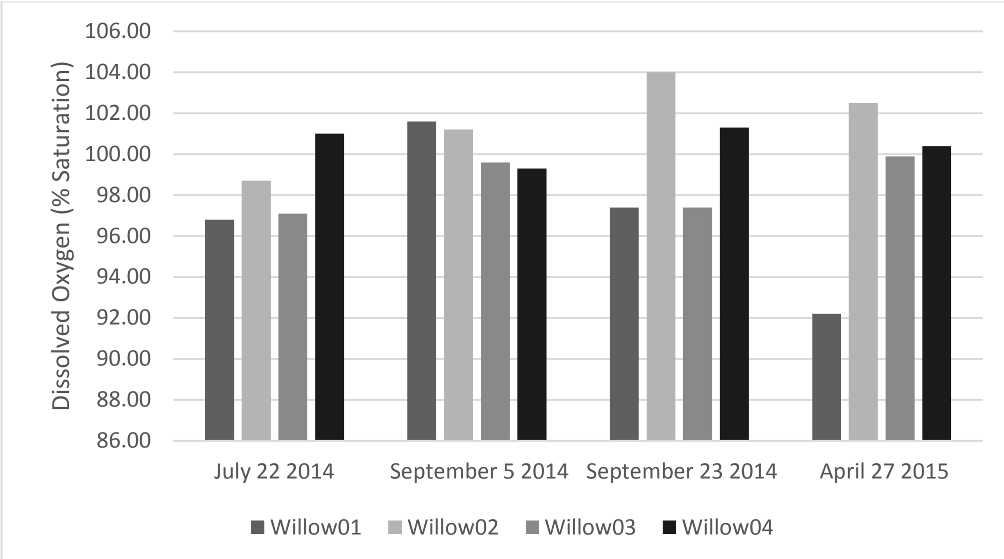

Figure 4. Dissolved oxygen (percent saturation) at all sampling locations, measured during summer baseflow, two fall storm events, and spring flow.

4.1.2 Fecal Coliform Bacteria

Total fecal coliform bacteria at Willow03 and Willow04 for five sampling dates are shown in Table 3. Fecal coliform counts were highest at Willow04, the furthest downstream site; with a geometric mean of 33.61 cfu/100ml. Fecal coliform bacteria exceed 20 cfu/100ml at both sites, which is the state water quality criteria for water use for drinking, culinary, and food processing purposes. Total fecal coliform bacteria did not exceed water quality criteria for other designated water uses. (Alaska DEC 2012).

Table 3. Fecal coliform bacteria (cfu/100 ml) on each sampling date and geometric mean.

Date	Willow03	Willow04
7/22/2014	30.00	65.00
7/28/2014	28.00	25.00
8/4/2014	26.00	24.00
8/12/2014	12.00	44.00
8/19/2014	13.00	25.00
Geometric Mean	**20.25**	**33.61**

4.1.3 Dissolved and Sediment Metals

The Alaska Water Quality Manual for Toxic and Other Deleterious Organic and Inorganic Substances (Alaska DEC 2008) provides water quality criteria for dissolved metals and organic substances in freshwater. The manual presents both acute and chronic criteria for aquatic life in freshwater. Acute criteria are based on a one-hour averages, while chronic criteria are based on a four-day average concentration. This study tested for acute criteria, but measurements could be used to indicate potential exceedances chronic criteria. The Water Quality Manual also outlines criteria for human health consumption for uses of drinking, culinary, food processing, and growth and propagation of aquatic life. Table 4 presents the water quality criteria for some of the dissolved metals that were measured. The criteria for nickel, lead, and copper are hardness dependent. Water quality criteria presented in the table are calculated from average hardness values from summer, fall, and spring samples. Measurements of dissolved metals in water samples are shown in Table 5, while Table 6 displays the maximum measured value of each dissolved metal across all sites and sampling events. All dissolved metals fell below state limits for acute toxicity in freshwater (Alaska DEC 2012). Dissolved aluminum at Willow01 on September 5, 2014, exceeded the state chronic toxicity to aquatic life for freshwater (Alaska DEC 2012) at 99.50 µg/l. Dissolved manganese at Willow04 on April 27 2014 exceeded the chronic criteria for human health for consumption of water and aquatic organisms (Alaska DEC 2012) at 55.20 µg/l.

Table 4. Alaska DEC water quality criteria for dissolved metals. All values are in µg/l.

	Aquatic Life for Freshwater		Human Health Consumption	
Metal	Acute	Chronic	Water and Aquatic Organisms	Aquatic Organisms Only
Aluminum	750	87	NA	NA
Chromium (IV)	16	11	NA	NA
Copper	4.0	3.0	1300	NA
Lead	16	0.61	NA	NA
Manganese	NA	NA	50	100
Nickel	158	30	610	4600
Zinc	42	38	9100	69000

Table 5. Dissolved metals at all four sampling locations, measured during summer baseflow, a fall storm event, and spring flow. ND indicates metals were below detectable levels. All values are in µg/l.

	July 28 2014			
	Willow01	**Willow02**	**Willow03**	**Willow04**
Aluminum	16.80	25.00	52.60	47.90
Antimony	0.04	0.04	0.03	ND
Arsenic	1.52	0.78	1.01	1.07
Barium	12.10	7.47	8.90	8.86
Beryllium	ND	ND	ND	ND
Cadmium	ND	ND	ND	ND
Copper	0.58	0.56	0.75	0.90
Lead	ND	ND	ND	ND
Chromium	0.09	0.07	0.14	0.10
Cobalt	ND	ND	ND	ND
Magnesium	2.50	1.30	1.40	1.50
Manganese	3.35	2.23	10.90	12.60
Molybdenum	0.47	0.61	0.56	0.53
Nickel	0.42	0.26	0.31	0.32
Selenium	ND	ND	ND	ND
Silver	ND	ND	ND	ND

July 28 2014

	Willow01	Willow02	Willow03	Willow04
Thallium	0.13	0.02	0.01	ND
Vanadium	0.10	0.31	0.43	0.41
Zinc	ND	0.75	0.89	ND

September 5 2014

	Willow01	Willow02	Willow03	Willow04
Aluminum	99.50	28.20	57.80	48.30
Antimony	0.10	0.07	ND	ND
Arsenic	1.61	0.72	0.93	1.03
Barium	13.00	7.76	8.76	9.29
Beryllium	ND	ND	ND	ND
Cadmium	ND	ND	ND	ND
Copper	0.72	0.54	0.67	0.67
Lead	ND	ND	ND	ND
Chromium	0.22	0.09	0.24	0.11
Cobalt	ND	ND	ND	ND
Magnesium	2.20	1.30	1.40	1.50
Manganese	14.60	3.36	17.00	18.30
Molybdenum	0.38	0.54	0.44	0.42
Nickel	0.59	0.24	0.32	0.31
Selenium	ND	ND	ND	ND
Silver	ND	ND	ND	ND
Thallium	ND	ND	ND	ND
Vanadium	0.34	0.31	0.43	0.40
Zinc	1.80	1.23	1.68	1.19

April 27 2015

	Willow01	Willow02	Willow03	Willow04
Aluminum	7.04	12.4	12.7	11.2
Antimony	0.03	ND	ND	ND
Arsenic	1.18	0.593	0.691	0.801
Barium	20.8	10.6	11.5	13.8
Beryllium	ND	ND	ND	ND
Cadmium	ND	ND	ND	ND
Copper	1.81	0.98	0.89	0.63
Lead	0.05	ND	ND	ND
Chromium	0.19	0.12	0.12	0.13
Cobalt	ND	ND	ND	ND
Magnesium	NA	NA	NA	NA
Manganese	20.3	8.2	35.7	55.2
Molybdenum	ND	ND	ND	ND

Nickel	0.54	0.26	0.32	0.32
Selenium	0.27	ND	ND	ND
Silver	ND	ND	ND	ND
Thallium	ND	ND	ND	ND
Vanadium	0.094	0.383	0.336	0.33
Zinc	6.96	3.96	3.24	3.39

Table 6. Maximum values of each dissolved metal across all four sites and three sampling events. All values are in µg/l.

	Maximum
Aluminum	99.50
Antimony	0.10
Arsenic	1.61
Barium	20.80
Beryllium	0.00
Cadmium	0.00
Copper	1.81
Lead	0.05
Chromium	0.24
Cobalt	0.00
Magnesium	2.50
Manganese	55.20
Molybdenum	0.61
Nickel	0.59
Selenium	0.27
Silver	0.00
Thallium	0.13
Vanadium	0.43
Zinc	6.96

Metals detected in the sediment grab samples are shown in Table 7. Concentrations of metals in sediments were evaluated using the Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) presented in the National Oceanic and Atmospheric Administration Screening Quick Reference Tables (SQuiRT) (Buchman 2008). TELs indicate the concentrations below which negative effects are unlikely, while PELs indicate the concentrations above which negative effects are likely. All concentrations of metals in the sediment samples except for arsenic (As) fell below both the TEL and PEL criteria. The TEL for As is 5.9 µg/g and the PEL is 17 µg/g with bed sediment values in Willow Creek ranging from 12.2 to 62 µg/g (Table 7). No polycyclic aromatic hydrocarbons were detected in the sediment sample from Willow03.

Table 7. Metals (ppm) in sediment grab samples collected in September 2014. ND indicates values below method detection limits.

	Willow01	Willow02	Willow03	Willow04
Arsenic (µg/g)	21.4	12.2	14.2	62
Cadmium (µg/g)	ND	ND	ND	ND
Copper (µg/g)	18.5	16.2	17.8	22.1
Lead (µg/g)	ND	ND	ND	ND
Zinc (µg/g)	28.7	23.3	24.7	29.3
Mercury (µg/g)	0.0266	0.0405	0.0397	0.103

4.1.4 Nutrient Concentrations

Alkalinity and hardness are shown in Figures 5 and 6, respectively. Alkalinity ranged from 18.00 mg/l (Willow02 in July 2014) to 30.00 mg/l (Willow04 in April 2015). Hardness ranged from 22.00 mg/l (Willow02 in July and September 2014) to 35.00 mg/l (Willow01 in July 2014). Alkalinity and hardness did not display great variation throughout the sampling period. Willow01 and Willow04 had higher alkalinity than Willow02 and Willow03 at each sampling event. Willow01 consistently had the highest hardness value, followed by Willow04. Willow02 consistently had the lowest hardness value. Dissolved organic carbon, shown in Figure 7, tended to increase throughout the sampling period except at Willow01. The low value at Willow01 in April 2015 may have been due to frozen soils in the upper portion of the watershed during spring sampling.

Concentrations of total phosphorus, dissolved phosphorus, nitrate and nitrite nitrogen, and ammonia nitrogen are shown in Table 8. Total phosphorus remained fairly constant throughout sampling, except for a peak at Willow04 in September, at 0.063 mg/l total phosphorus. Dissolved phosphorus increased from July to April for all sites except for Willow01. At Willow01, the highest measurement of dissolved phosphorus was in September. At each sampling event, Willow04 had more dissolved phosphorus than Willow02 and Willow03. Inorganic nitrogen levels were low, and were below detectable levels for most sites in July and September 2014. Nitrogen concentrations were higher in April 2015 prior to leaf out and the onset of terrestrial production and were detected in low levels at most sites[1]. The molar ratio of nitrogen to phosphorus was calculated for sites at which both nitrogen and phosphorus were detected on a single sampling date. The ratio was calculated for four sampling events and ranged from 3.2 to 14.7, which indicates that concentrations nitrogen most likely limit primary production in Willow Creek.

[1] Method detection levels for nitrate and nitrite nitrogen and ammonia nitrogen changed between September 2014 and April 2015. The detection level for ammonia nitrogen decreased from 0.01 mg/l to 0.005 mg/l, while the detection level for nitrate and nitrite increased from 0.02 mg/l to 0.025 mg/l.

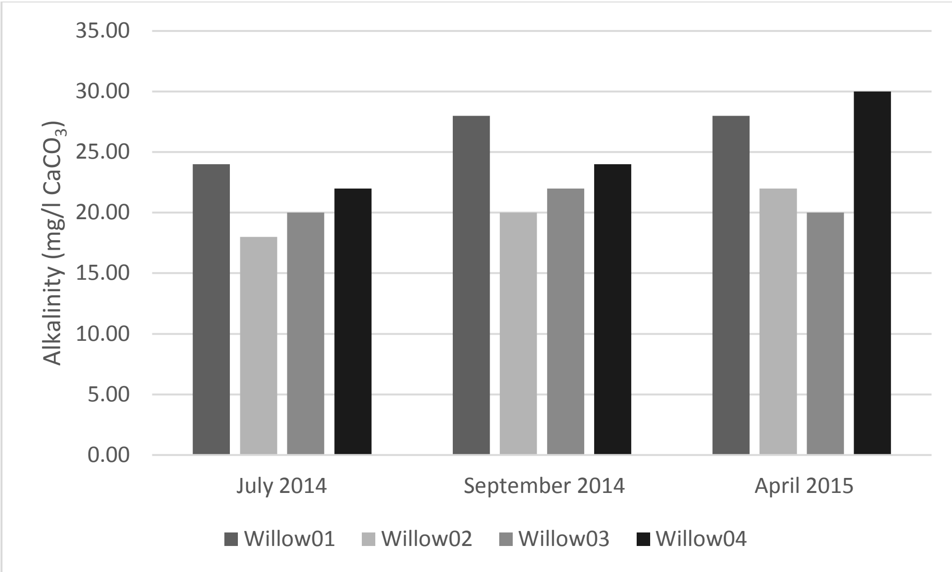

Figure 5. Alkalinity measured at all four sites during summer baseflow, a fall storm event, and spring flow.

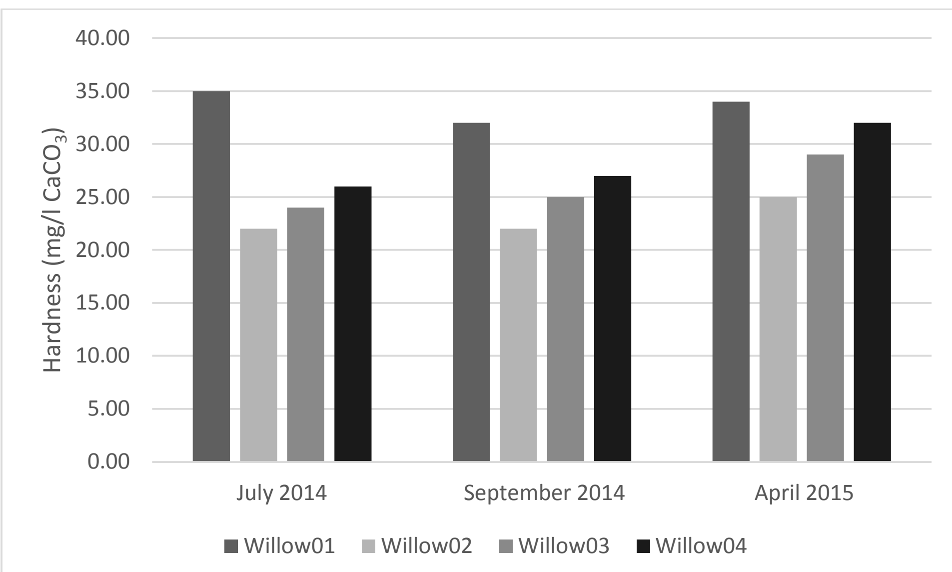

Figure 6. Hardness measured at all four sites during summer baseflow, a fall storm event, and during spring flow.

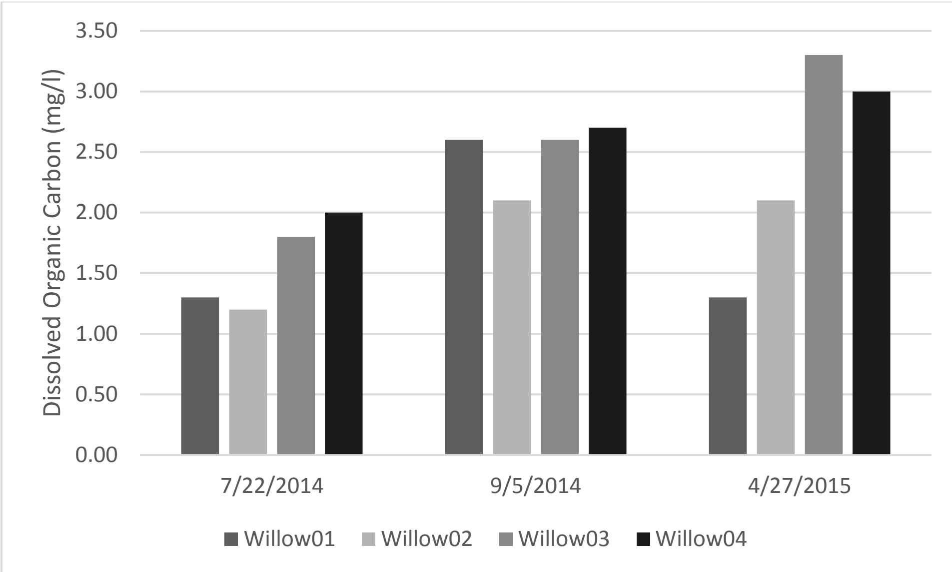

Figure 7. Dissolved organic carbon measured at all four sites during summer baseflow, a fall storm event, and spring flow.

Table 8. Dissolved phosphorus, total phosphorus, inorganic nitrogen (nitrate+nitrite), and ammonia-nitrogen, measured at all four sites during summer baseflow, a fall storm event, and spring flow

		Willow01	**Willow02**	**Willow03**	**Willow04**
Total Phosphorus (µg/l)	Jul-14	5.0	5.0	20.0	14.0
	Sep-14	10.0	5.0	14.0	63.0
	Apr-15	0.0	12.0	14.0	16.0
Dissolved Phosphorus (µg/l)	Jul-14	1.7	3.3	1.8	5.9
	Sep-14	9.2	3.5	3.7	9.0
	Apr-15	3.1	4.6	7.3	16.0
Nitrate + Nitrite N (mg/l)	Jul-14	ND	ND	ND	ND
	Sep-14	ND	ND	ND	ND
	Apr-15	0.101	0.08	0.07	0.042
Ammonia-N(mg/l)	Jul-14	ND	ND	ND	0.02
	Sep-14	ND	ND	ND	ND
	Apr-15	0.015	ND	0.006	0.01

4.1.5 Stream Flow and Precipitation

Discharge peaked for the season on June 26 2014 at 1720.8 cfs, coinciding with a rain event (Figure 8 and 9). Following this peak, discharge tended to decrease until the beginning of September, when rainfall became more frequent.

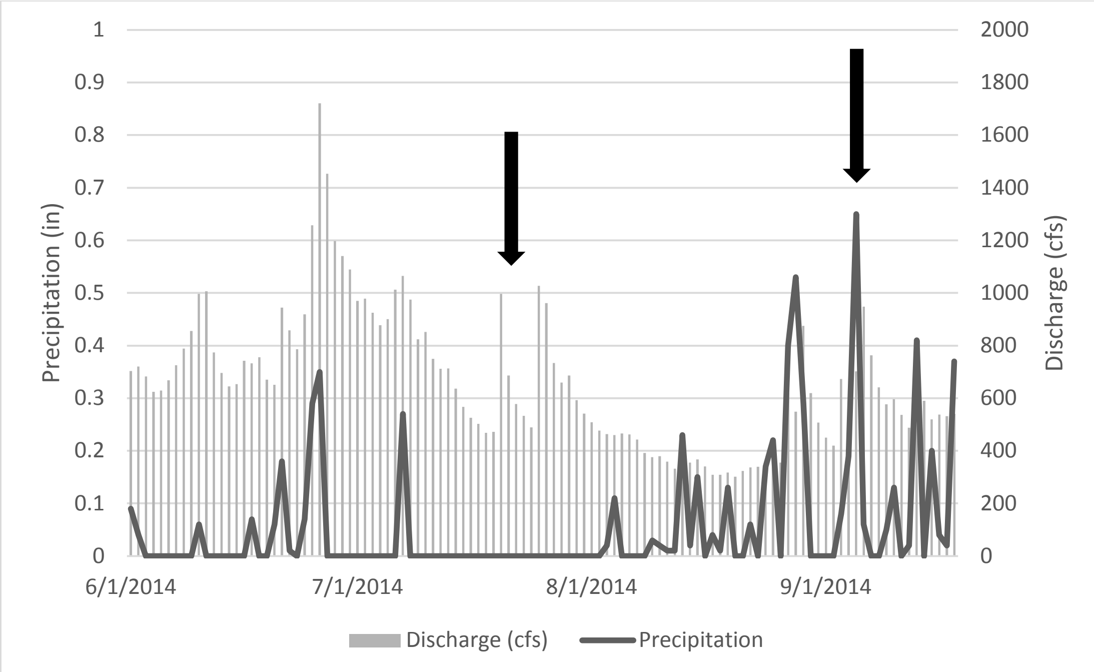

Figure 8. Total daily precipitation and average daily discharge during the open water months of 2014. Arrows indicate water sampling events on July 22 and September 5 2014.

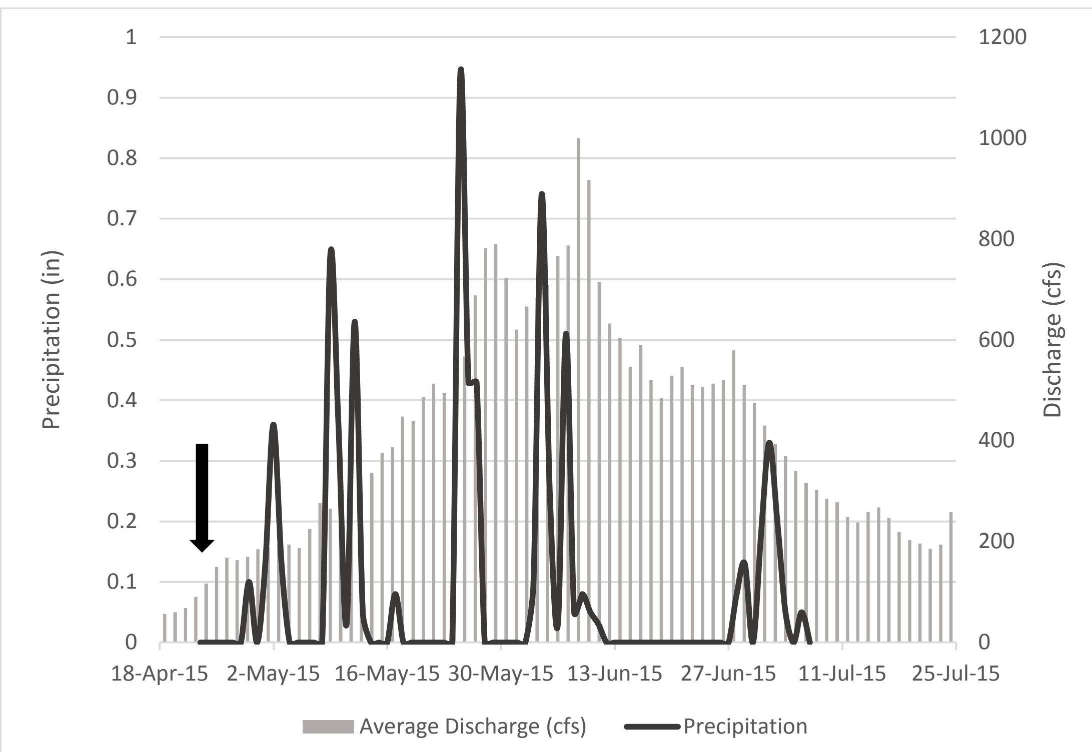

Figure 9. Total daily precipitation and average daily discharge in spring 2015. Arrow indicates the spring water sampling event on April 27 2015.

4.1.6 Turbidity

Throughout most of the season, turbidity was 0 NTU or just above 0 NTU at both the Parks Highway site and the Shirley Town Bridge site (Figure 10). Turbidity spiked on July 25-26, associated with a period of increased discharge. Turbidity also spiked several times in late August and in September, as precipitation increased. Turbidity increases were greater at the Parks Highway compared to measurements upstream at Shirley-Town Bridge. Turbidity always decreased to very low values following rapid increases. Stream flows began to increase in May with the highest value during the study period in June at over 1000 cfs.

Settleable solids were measured in July 2014, September 2014 and April 2015 using the Imhoff cone method. No settleable solids were detectable at any site on any sampling date.

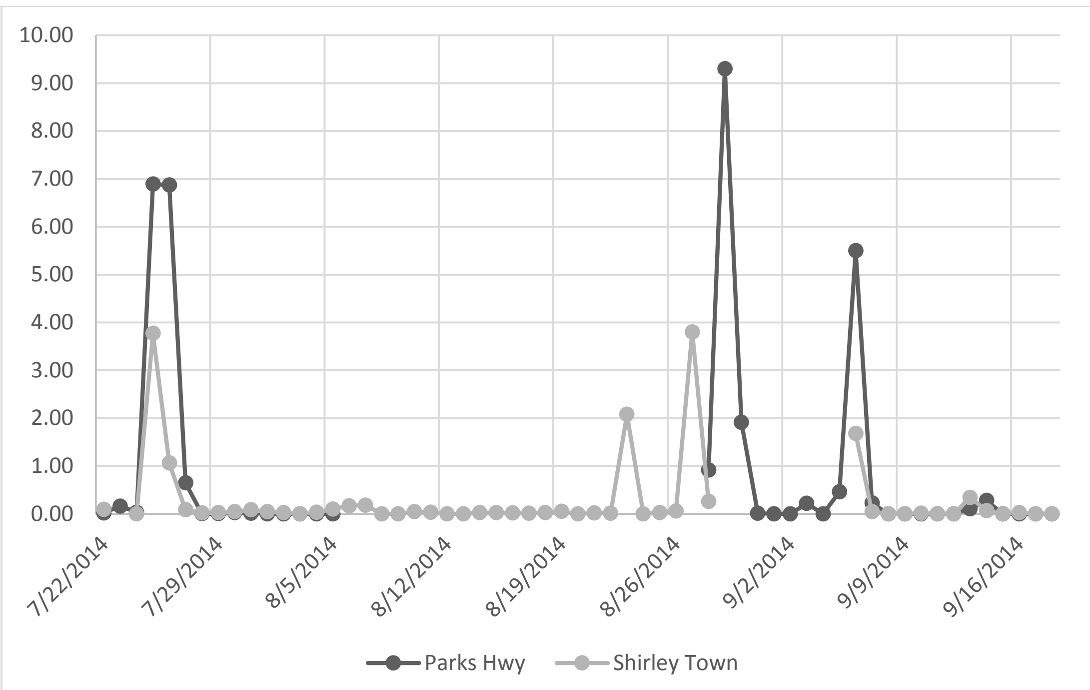

Figure 10. Daily average turbidity measured at the Shirley-Town Bridge and downstream of the Parks Highway crossing.

4.1.7 Water Temperature

Water temperature data are summarized in Table 9, and shown graphically in Figures 11-14. Stream temperatures tended to be warmer in 2015 than in 2014. Willow01, the furthest upstream site, tended to be the coldest throughout the season. Willow01 reached 13 degrees C on just seventeen days. Willow01 also had the lowest value for cumulative degree days (sum of daily average temperatures) in both August and September. The sites tended to become warmer further downstream, with more days above 13 degrees C, and higher values for cumulative degree days. State water quality standards outline temperature criteria for use by anadromous fish, stating that temperatures should not exceed 13 degrees C for spawning areas and egg and fry incubation, and temperatures should not exceed 15 degrees C for migration and rearing areas (Alaska DEC 2012). All sites exceeded 15 degrees C for at least 7 days and exceeded 13 degrees C for at least 17 days. During warmer years, higher temperatures may make Willow Creek less suitable as salmon habitat. This issue would be more prevalent at downstream sites, which tend to have warmer temperatures.

Table 9. Summary of temperature data for all four sites

Site Name	Willow01	Willow02	Willow03	Willow04
Start Date	7/22/2014	7/22/2014	7/22/2014	7/22/2014
End Date	7/8/2015	7/8/2015	7/8/2015	7/9/2015
Season Maximum	18.129	17.891	18.628	18.628
Max Daily Range	7.797	5.54	6.216	6.219
Total Days	115	150	150	137
Days Max>13	17	34	43	47
Percent of Total	15	23	29	34
Days Max>15	7	12	16	19
Percent of Total	6	8	11	14
August Cumulative Degree Days	286.5	339.6	355.7	364.77
September Cumulative Degree Days	181.1	213.4	224.7	
May Cumulative Degree Days		192.1	215.4	226.8
June Cumulative Degree Days	266.0	329.0	343.9	353.4

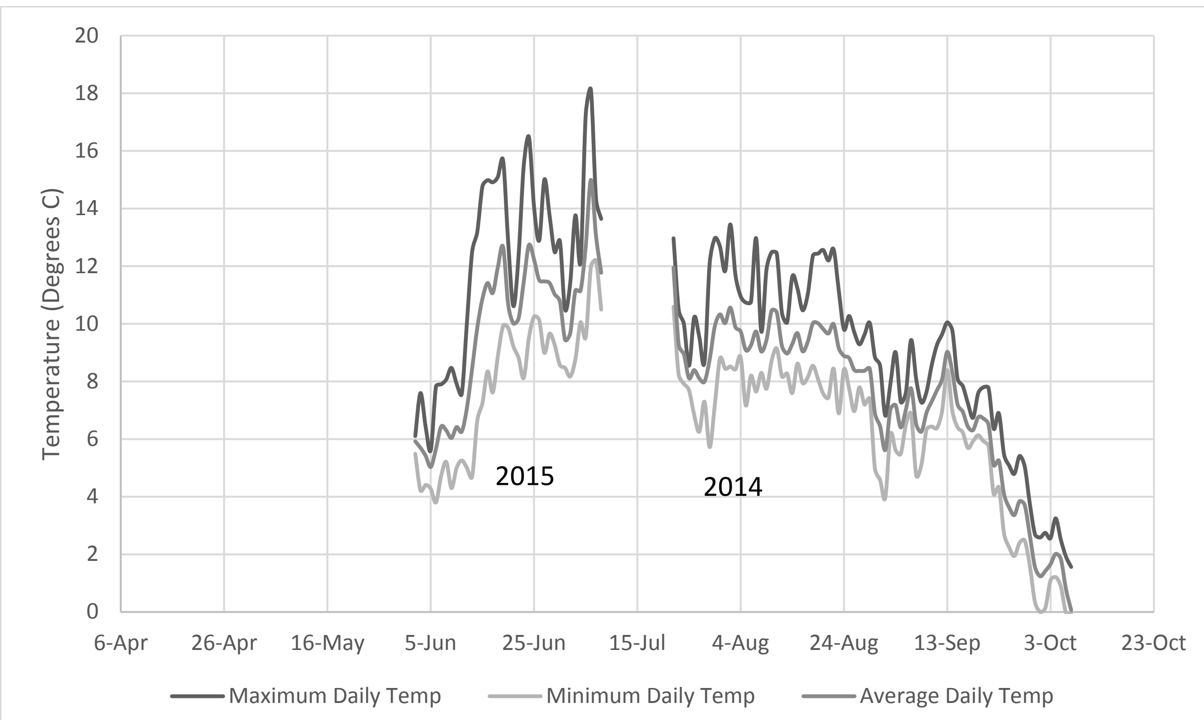

Figure 11. Maximum, minimum, and average daily temperature at Willow01 during open water periods from July 2014-July 2015.

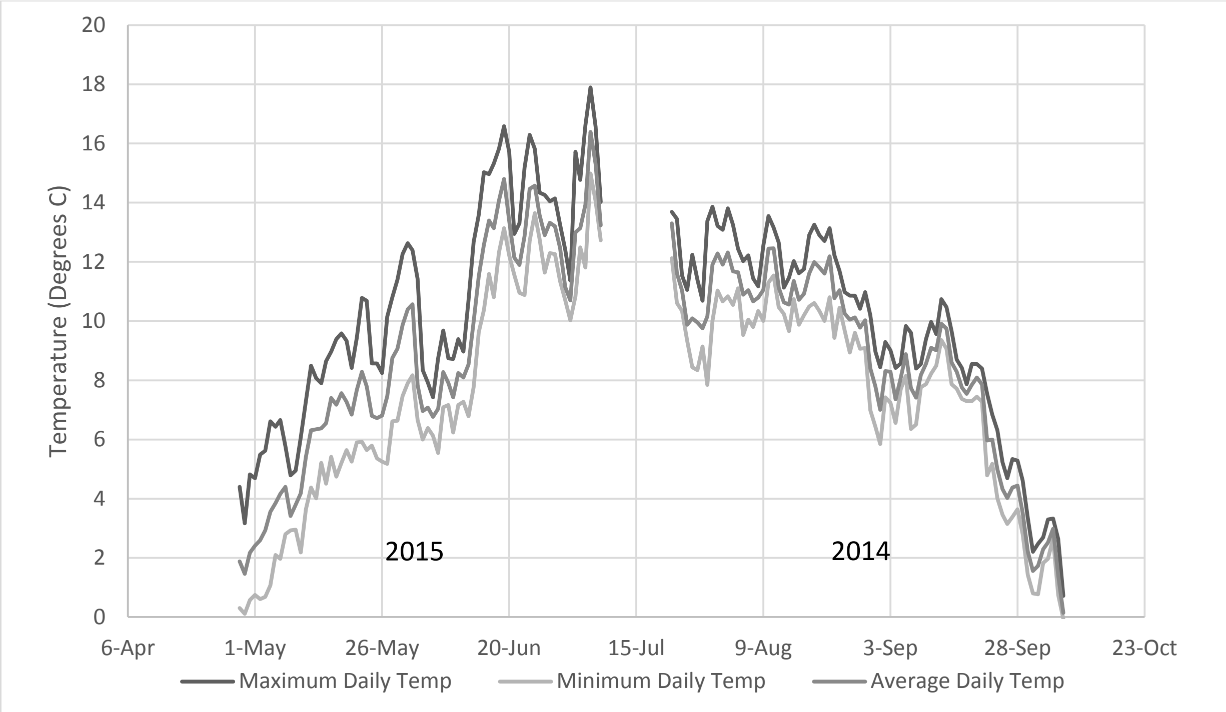

Figure 12. Maximum, minimum, and average daily temperature at Willow02 during periods of open water from July 2014-July 2015.

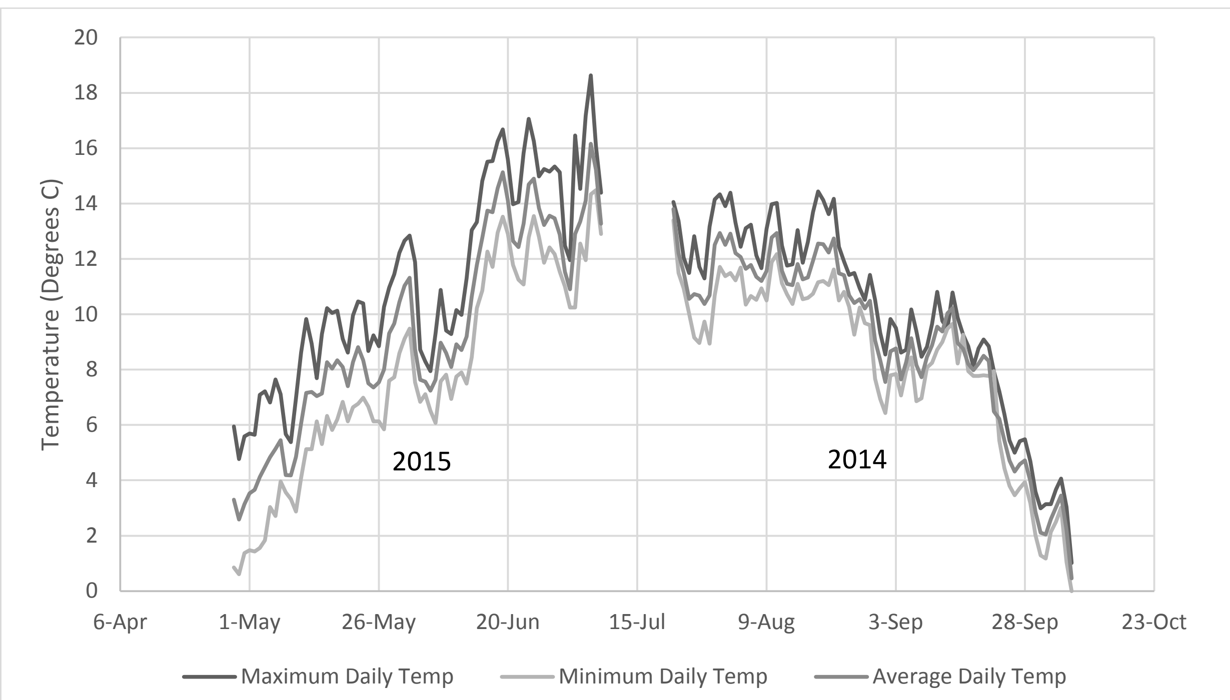

Figure 13. Maximum, minimum, and average daily temperature at Willow03 during periods of open water from July 2014-July 2015.

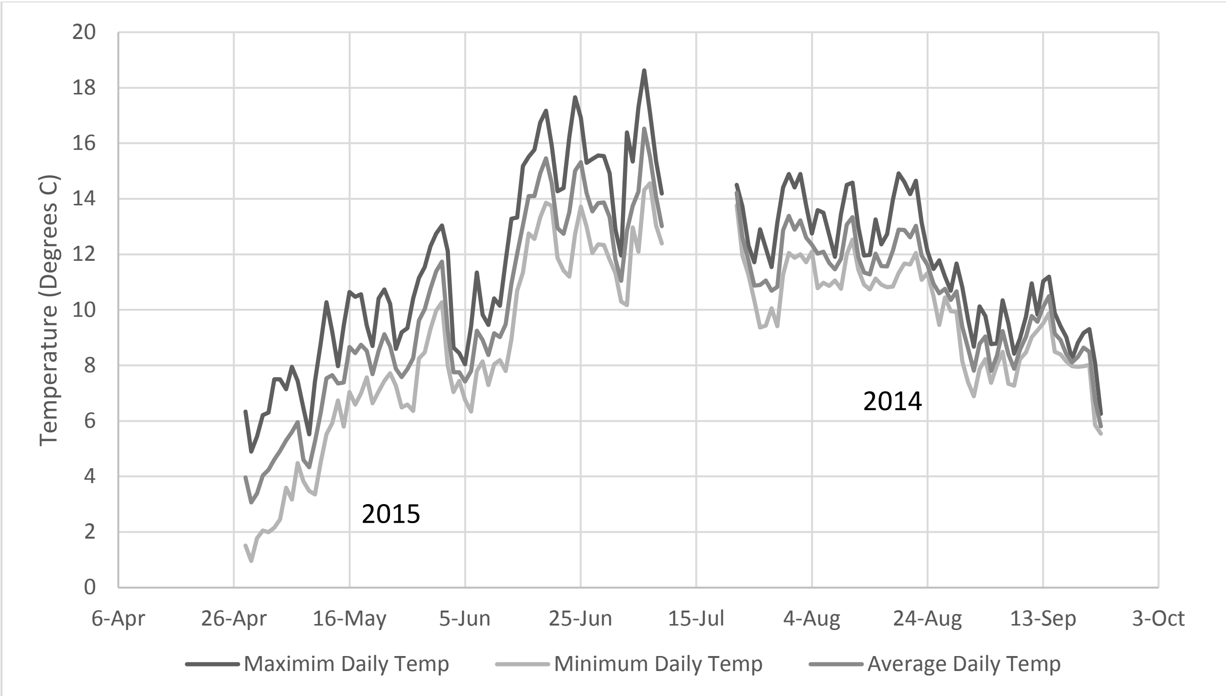

Figure 14. Maximum, minimum, and average daily temperature at Willow04 during periods of open water from July 2014-July 2015.

4.2 Physical Habitat Characteristics

4.2.1 Vegetation Classification

Physical habitat characteristics, including riparian vegetation classification, bank and riparian modification, and substrate size distribution, were measured at each sampling site. At Willow01, the dominate vegetation type within the riparian zone is low closed scrub, which includes willow, alder, shrub birch and devil's club. (IIC1). At one end of the reach the vegetation type changed on the right bank to mesic grasses (IIIA2). The zone of scrub on the left was small (2-5m) giving way to open conifer forest, which includes white spruce and black spruce. The zone of scrub or grass on the right was much larger (65-130m) before transitioning to open conifer forest. At Willow02, the dominant vegetation types are close and open low scrub in a zone 2 to 17m along the shore. Beyond this zone there is either open or closed broadleaf forest on the right bank and open or closed mixed forest on the left. Broadleaf forest mainly consists of birch, cottonwood, and poplar, while mixed forest has both spruce and birch species. There is an island between the two split channels that consists of mesic grasses (IIIA2) and tall open scrub, which is characterized by willow and alder. At Willow03, the dominant vegetation type within the riparian zone is tall open alder scrub (IIB2). Beyond this 6-50m zone there is mixed forest woodland (IC3) on both the right and left and some patches of mesic grass on the left bank (IIIA2). At Willow04, there are a variety of vegetation types present within the riparian zone and each side of the stream is distinctly different. The right side varies among scrub, grasses and forest within the 30 to 80m zone with closed broadleaf forest beyond. The left side has a small 5 to 10m zone of either open tall or low scrub with either mixed, conifer or broadleaf birch forest beyond.

4.2.2 Bank and Riparian Modification

Bank and riparian vegetation modification at all sampling locations was due to ATV trails, residential development, and fishing trails (foot traffic). Riparian modification ranged from 150 to 650 m^2 of 2,000 m^2 total. Bank modification ranged from 0% at Willow02 and Willow03 to a high of 12.7% at Willow04. Riparian and bank modifications at Willow01 also caused by an ATV trail (Table 10). There was a trail from the Willow Fishhook road to a Willow Creek point bar at Willow01. The trail parallel the river upstream (Appendix A Photograph 1 and 2). At Willow02, both the right and left banks had riparian modifications due to residences, creating the largest area of riparian modifications out of the four sites. Willow03 and Willow04 had riparian modifications due to ATVs and fishing trails at Willow03 and foot fishing trails at Willow04. The highest amount of bank modification was measure at Willow04 where bank sloughing was occurring with the break point along the fishing trail (Appendix A Photograph 9).

4.2.3 Large Woody Debris

LWD and debris dams were less abundant at the upper sites (Willow01 and Willow02) where more confined and steeper channels probably resulted in the movement of logs that entered the stream. The amount of large woody debris in the stream tended to increase further downstream, with the highest number of LWD pieces (24) and LWD dams (4) at Willow04.

4.2.4 Substrate size distribution

The substrate size distribution shows that overall mean particle size decreases downstream. Willow01 and Willow02 had very similar substrate a D50 of 90 to 100mm and <5% fines (Figure 15). Particle size was smaller at Willlow03 with a D50 of 40m and percent fines >10%. The lowest site, Willow04 lacked large cobble and boulders (D50 of 35 mm), highly embedded cobles, and had a high percentage of fines (>30%). Embeddedness measured in Willow01 was due to loose sand in contrast to the downstream sites where embeddedness was due to dense silt.

Table 10. Physical habitat characteristics at all sampling locations.

	Willow01	**Willow02**	**Willow03**	**Willow04**
Undercut (m)	0.14	0	0	0.12
Wetted Width (m)	22.8	33.4	36.2	32.52
Bankful Width (m)	24.28	36.26	39.22	33.14
2X Bankful width (m)	183	∞	∞	∞
Bank Angle (deg)	31.7	6.2	18.2	27.7
Bank Height	1.30	0.82	0.87	1.22
Bank modification (%)	2.5%	0	0	12.7%
Riparian modification (m^2)	250	650	200	150
LWD pieces	2	5	10	24
LWD dams	0	2	0	4

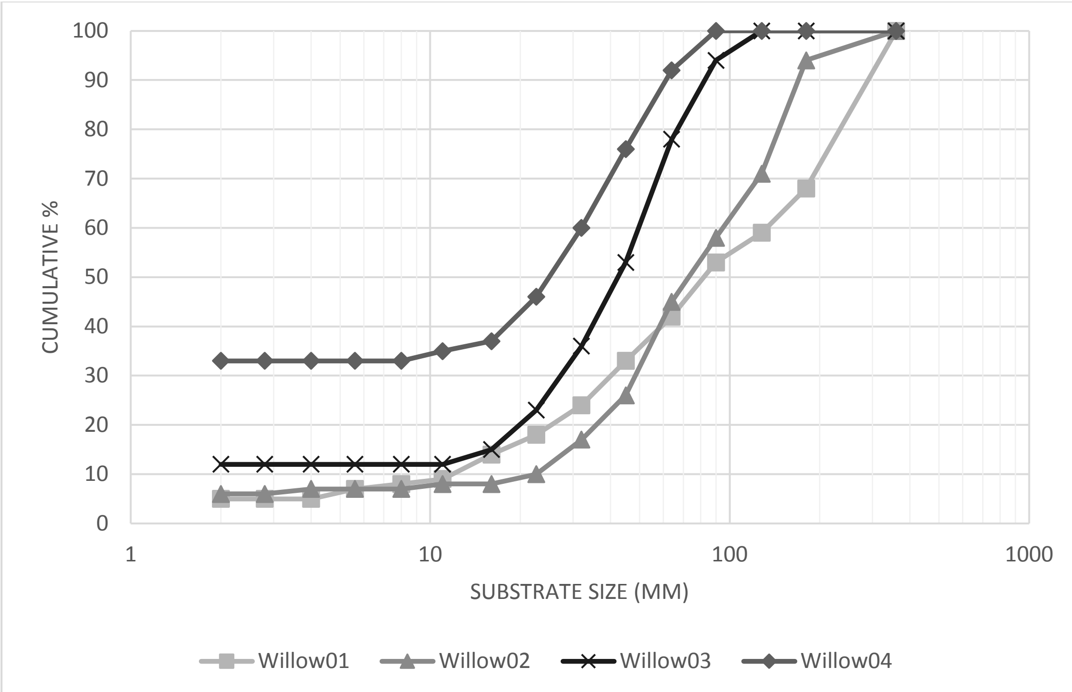

Figure 15. Cumulative substrate size distribution at all four sites.

4.3 Biological Characteristics

4.3.1 Macroinvertebrates

Macroinvertebrate samples were used to compute multimetric scores in order to assess the biological condition of aquatic communities in Willow Creek both longitudinally and over time. Qualitative habitat assessments were conducted along with macroinvertebrate sampling. Metrics for community richness, composition, functional organization and pollution tolerance were calculated as outlined by the Alaska Stream Condition Index (Major et al 2001). The ASCI metric is specific to stream class therefore the four sites sampled were first categorized based on pebble counts and habitat classification results. Willow01, Willow02, and Willow03 were classified as *low gradient-coarse substrate* based on slope (<2%) and abundant clean cobble habitat availability (>40%). Willow04 was classified as *low gradient-fine substrate* based on slope (<2%) and lack of clean cobble habitat availability (<40%).

The ASCI metrics for *low gradient-coarse substrate* include number of Ephemeroptera taxa, percent Ephemeroptera (no Baetids), percent Plecoptera, ratio of Baetidae to Ephemeroptera, percent non-insects, ratio of observed to expected taxa, percent scrapers and Hilsenhoff Biotic Index.The ASCI metrics for *low gradient-fine substrate* include number of Trichoptera taxa, percent Ephemeroptera, Plecoptera and Trichoptera, present Diptera, ratio of observed to expected taxa, percent collectors and Hilsenhoff Biotic Index.

The final ASCI scores (0-100) for each site are shown in Figure 16. Both Willow01 and Willow04 were considered in excellent condition for their stream class. Willow02 and Willow03 were considered in good condition for their stream class. Willow03 had the lowest score of 62. Averaging the scores of all the sites produces a score of 70, an indication of good biological condition of Willow Creek as a whole.

Data collected in previous years at Willow03 (below Parks Highway) for the creation of the ASCI were compared to data collected in 2014 (Figure 17). Water quality, based upon macroinvertebrate metrics does not appear to be declining, with water quality at the “good” to “excellent” level. ASCI scores in 2014 were similar to those measured in 1998; however, lower than those measured in 2000.

Habitat assessment scores are shown in Table 11. Willow01, Willow02, and Willow04 all had high habitat assessment scores, indicating good quality habitat. Willow03 the lowest score, at 12.8, which indicates lower quality habitat. Having the lowest ASCI macroinvertebrate score as well as the lowest habitat assessment score indicates that Willow03 is in poorer overall condition than other areas of Willow Creek.

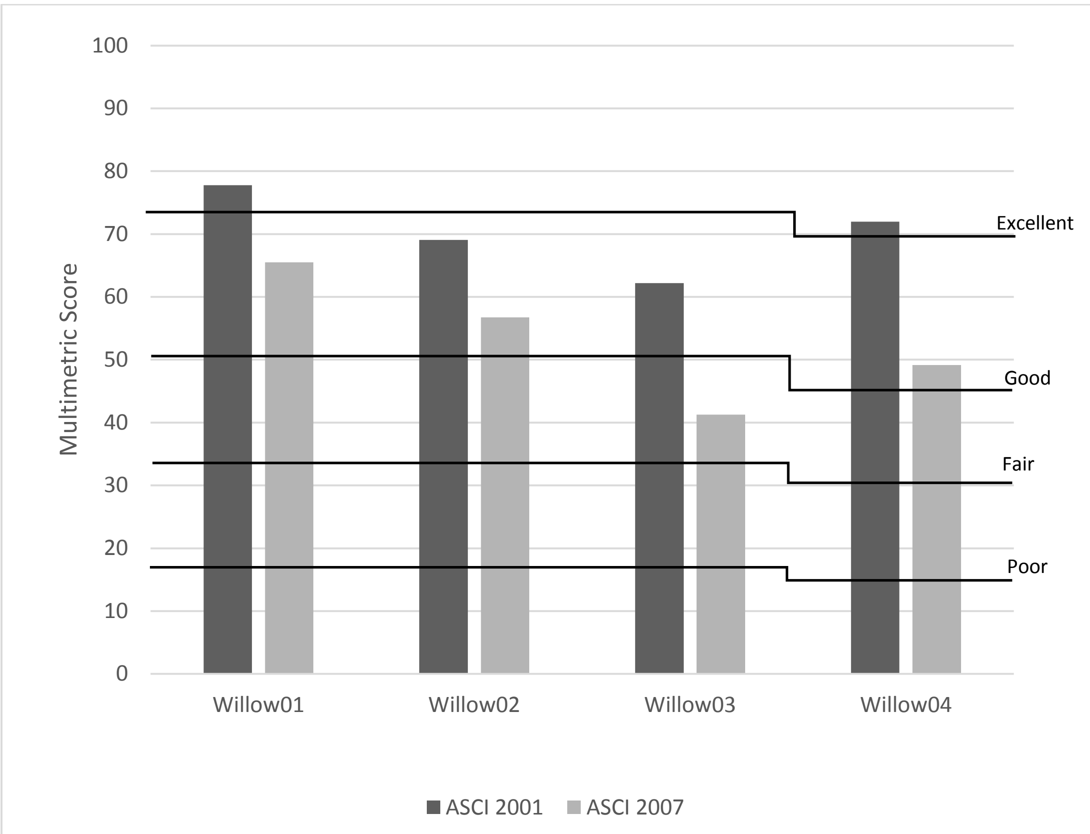

Figure 16. Alaska Stream Condition Index Scores (0-100) for each of the four study sites on Willow Creek in 2014. Lines indicate levels for excellent, good, fair, and poor stream condition for 2001 ASCI scores. Willow01, Willow02, and Willow03 are classified as low-gradient course substrate sites and Willow04 is classified as low-gradient fine substrate sites, giving the sites different thresholds for stream condition.

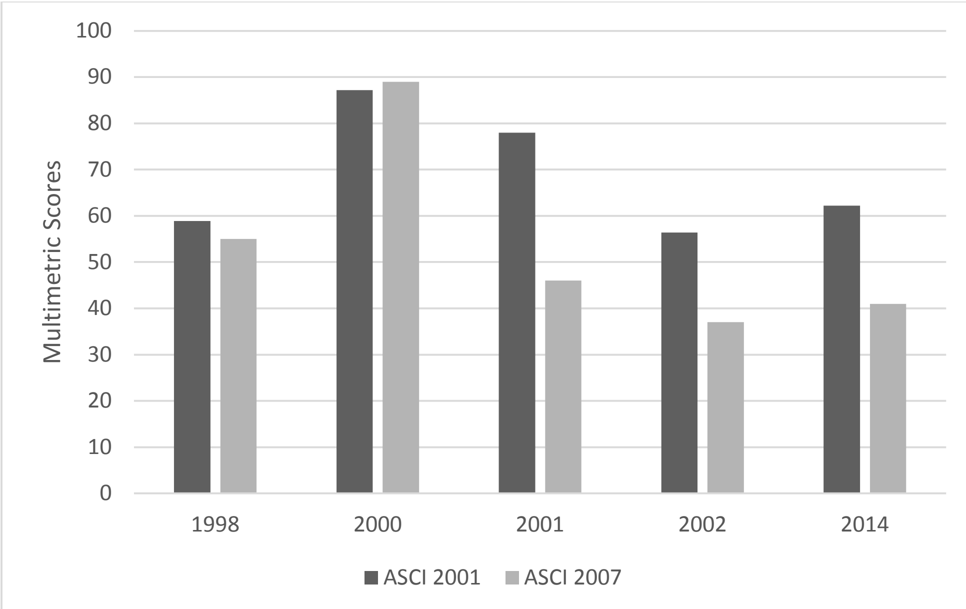

Figure 17. Macroinvertebrate multimetric scores for samples collected below the Parks Highway from 1998 through 2014.

Table 11. Alaska Stream Condition Index habitat assessment scores for all four sites.

	Willow01	Willow02	Willow03	Willow04
Epifaunal Substrate	14.5	18	13	15
Embeddedness	14.5	18	13	10.5
Velocity-Depth Combinations	11.5	16	13.5	16
Sediment Deposition	18	16	12	13.5
Channel Flow Status	17.5	16	11	15.5
Channel Alteration	17.5	19.5	19	20
Channel Sinuosity	11.5	18	12.5	16
Bank Stability	15.5	10	15.5	16
Bank Vegetative Protection	16	14.5	12.5	17.5
Riparian Vegetative Zone Width	13	12	5.5	16.5
Habitat Assessment Score	14.95	15.8	12.75	15.65

4.3.2 Juvenile Salmon

Fish sampling yielded both anadromous and resident fish species. Resident fish included Dolly Varden (*Salvelinus malma*), rainbow trout (*Oncorhynchus mykiss*), and sculpins (*Cottus sp.*) Figure 18 shows the catch per unit trap of resident fish at each site. Upstream sites had higher abundances of Dolly Varden, with the highest CPUT at Willow01. Dolly Varden were also present at Willow02 and Willow03 in lower abundances but were not captured at Willow04. Juvenile rainbow trout and sculpins were not captured at Willow01, upstream from the Willow Creek canyon. Rainbow trout were present at all of the remaining sampling sites in relatively low numbers.

Juvenile Chinook and coho salmon were found at Willow02, Willow03, and Willow04, but were absent from catches at Willow01 above the canyon. Ratios of resident to anadromous fish are shown in Figure 19. Willow01 had only resident fish, while Willow02, Willow03, and Willow4 had a much greater percentage of juvenile anadromous fish than resident fish minnow trap samples.

Chinook salmon were present in greater numbers than coho salmon at each of the sites where juvenile salmon were present. Willow02 had the highest ratio of Chinook to coho and the highest catch per unit trap of Chinook salmon, with 14.6 Chinook per trap (Figure 19). Chinook salmon tended to be larger at downstream sites. Willow04 had the highest Chinook median fork length (Figure 21) at 65 mm, while Willow02 had the lowest Chinook median fork length at 57 mm. Chinook at Willow02 had the highest median condition factor, while Chinook salmon at Willow03 had the lowest (Figure 22).

Age 0 and Age 1+ coho salmon were present at Willow02, Willow03, and Willow04, and coho showed greater variation in size than Chinook salmon (Figure 23). Age 1+ coho salmon tended to be larger at upstream sites, while Age 0 coho were larger at downstream sites. Willow04 had the highest median fork length for Age 0 coho, but the lowest median fork length for Age1+ coho, as shown in Figure 24. Median condition factor for coho salmon tended to decrease at downstream sites (Figure 25).

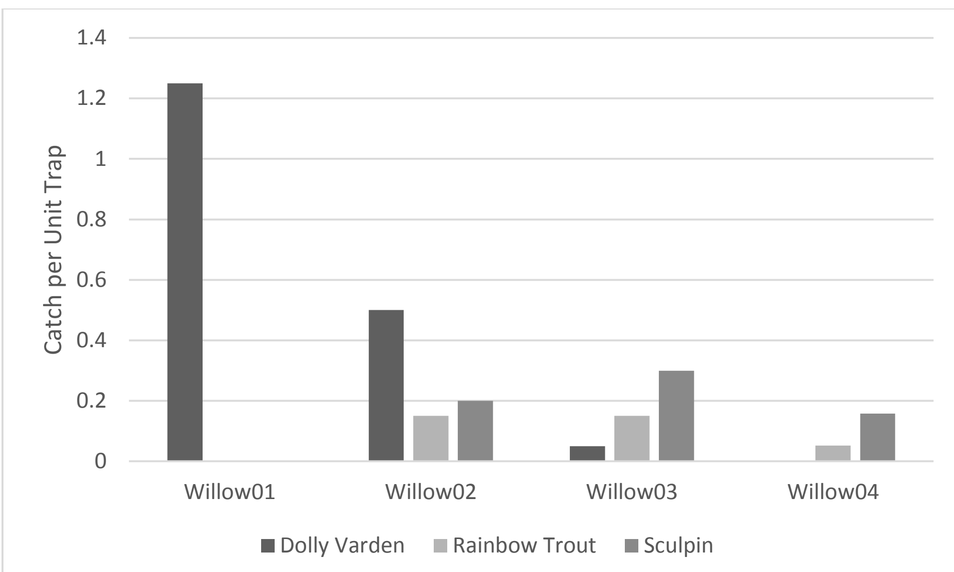

Figure 18. CPUT of juvenile resident fish showing Dolly Varden more abundant in the upper sites and rainbow trout at the lower two sites in samples collected on July 29 and 30, 2014.

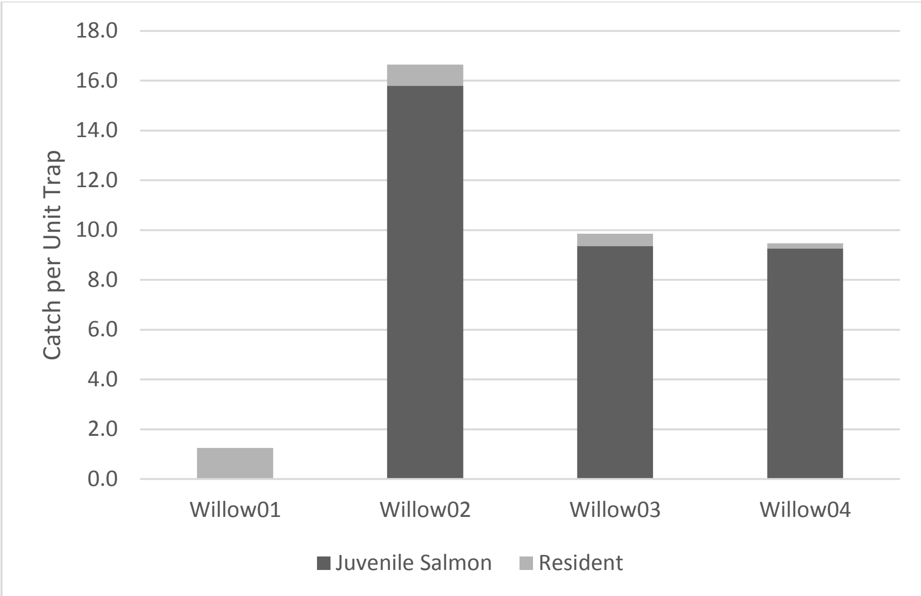

Figure 19. Juvenile salmon were absent from the upper river sampling site, on July 29 and 30, 2014, but dominated catch from Willow02 downstream.

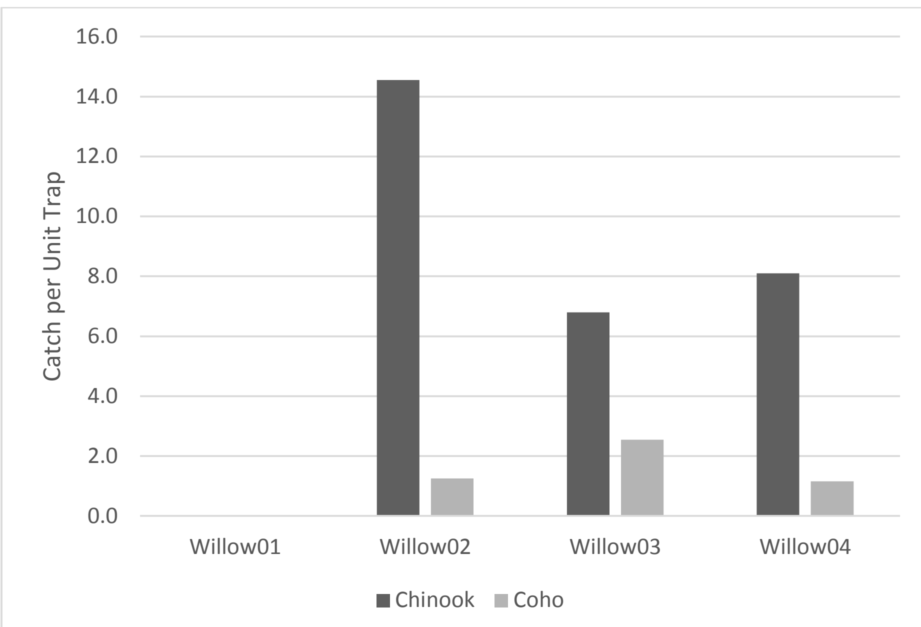

Figure 20. Juvenile Chinook and coho salmon catch per unit trap at each of the four sites on July 29 and 30, 2014, showing the greater abundance of Chinook salmon compared to coho salmon.

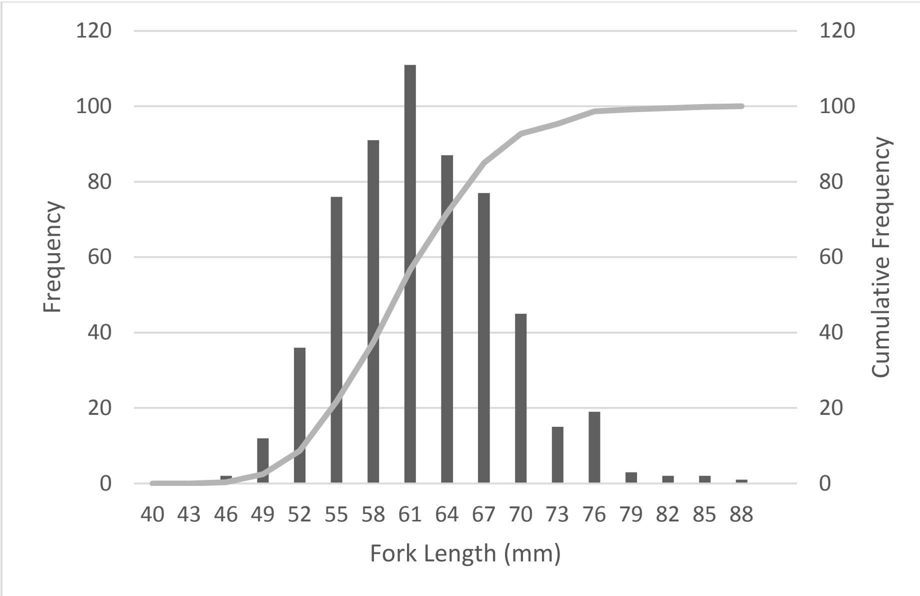

Figure 21. Juvenile Chinook salmon fork length frequency and cumulative frequency across all three sites

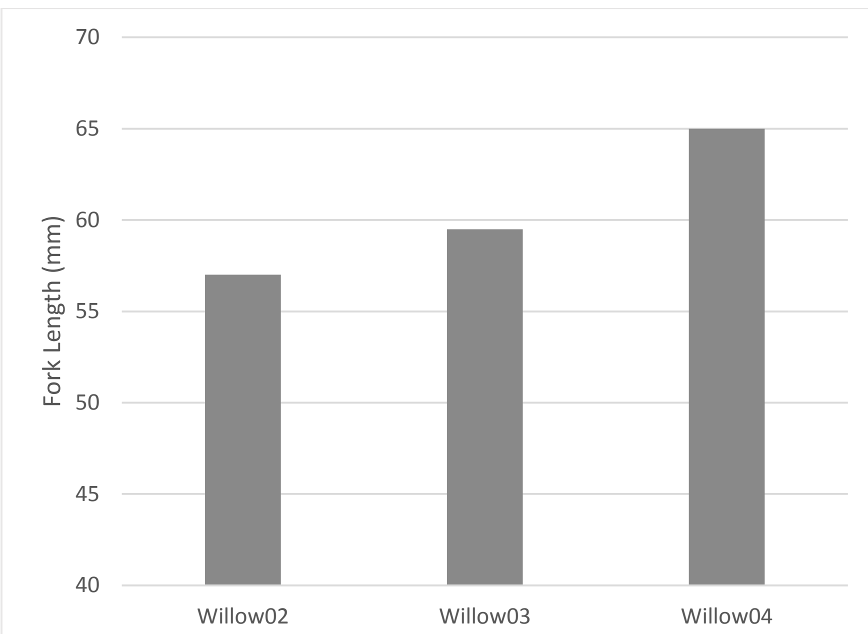

Figure 22. Chinook salmon median fork length at Willow02, Willow03, and Willow04.

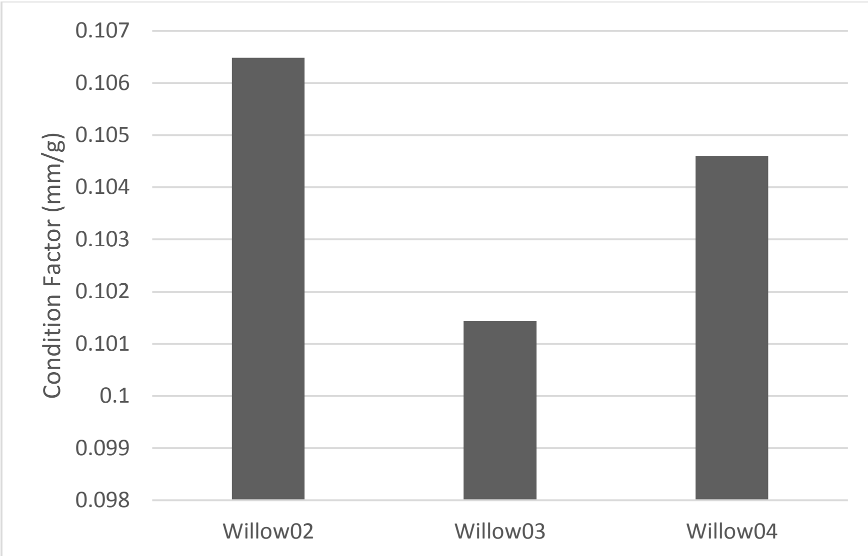

Figure 23. Condition factor for juvenile Chinook salmon.

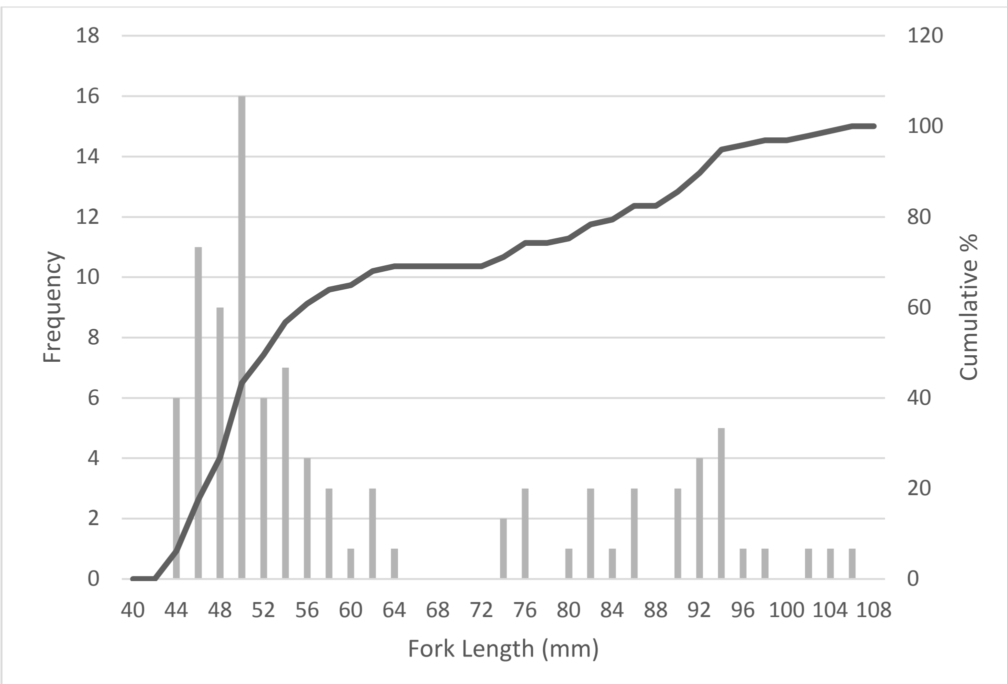

Figure 24. Coho salmon fork length frequency and cumulative frequency across all four sites.

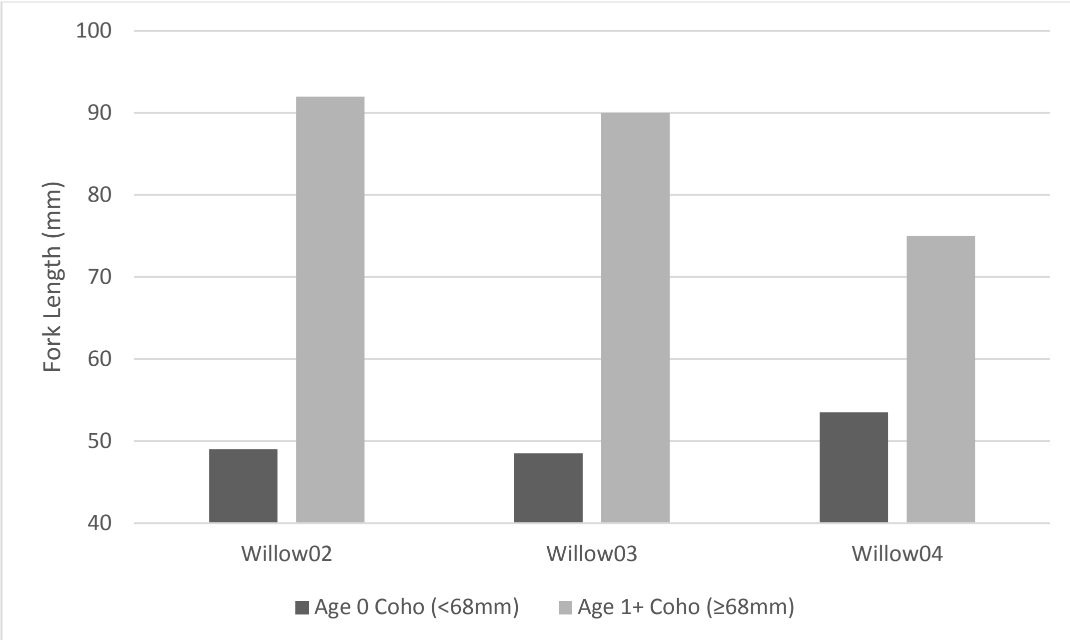

Figure 25. Median coho salmon fork length for Age 0 fish and Age 1+ fish at Willow02, Willow03, and WIllow04.

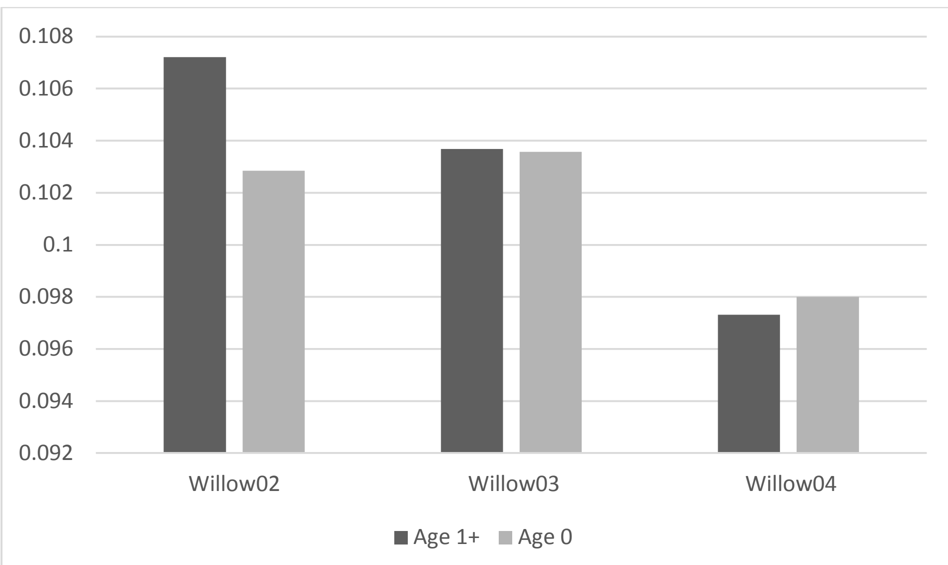

Figure 26. Condition factor for Age 0 and Age 1+ coho salmon.

5.0 Discussion

This study results indicate that water quality and habitat in Willow Creek are generally in good condition, with some areas that may warrant further monitoring. *In situ* measurements of water chemistry were fairly consistent throughout the data collection period. Stream water pH remained between 7.00 and 7.50 on all sampling dates, with lower measurements at the beginning of a storm event and higher measurements after a period of increased precipitation during the month of September. Specific conductivity was highest in April 2015 and increased at downstream sites, which could be due to the use of road salts during the winter. High conductivity during spring sampling has been observed in other streams at higher latitudes (Corsi et al. 2010). Dissolved oxygen was at or near saturation at all sites. The lowest measurement, 92.0% saturation at Willow01 in April 2015, was likely lower due to compete ice cover upstream of the sampling location.

Levels of fecal coliform bacteria exceeded the state criteria for drinking water, and are comparable to levels measured in Montana Creek near the Parks Highway and the Little Susitna River near the Public Use Facility (Davis and Davis 2006, Davis and Davis 2007) and remained consistent throughout the sampling period.

All measured dissolved metals fell below state acute criteria for, indicating that there were no acute metal contamination in Willow Creek. Both aluminum and manganese exceeded chronic criteria for contamination on one date at one site: aluminum at the highest upstream site during a fall storm and manganese at the farthest downstream site during spring runoff. However, results from a single sample cannot be used to evaluate compliance with chronic criteria. Further sampling could determine if these high concentrations are persistent or if 96-hour average concentrations exceed chronic criteria.

Hydrocarbons were not detected in bed sediments from samples collected below the Parks Highway and arsenic was the only metal in sediments to exceed TELs or PELs. Sediment Cu and Zn were lower than values reported for Southcentral streams as reported by the USGS for samples collected between 1998 and 2000 (Frenzel 2002). High As in bed sediments is not unique to Willow Creek as approximately 50% of bed sediment samples analyzed by the USGS in Cook Inlet streams exceeded PELs (Glass and Frenzel 2001). Higher concentrations of As in bed sediments at the downstream Willow04 site are likely due to the higher percentage of fine sediment to which the metal can adsorb (Glass and Frenzel 2001).

Alkalinity and hardness remained consistent throughout the study, and measurements were similar to those in the Little Susitna River (Davis and Davis 2007). Levels of inorganic nitrogen and ammonia nitrogen were low, and nitrogen was detected at only one site in July and September 2014. Levels were slightly higher in April 2015. It is likely that nitrogen is a limiting nutrient in Willow Creek, as molar N:P ratios were low (ranging from 3.15 to 14.74), and nitrogen was not detected in many of the samples. Low stream nitrogen has been observed previously in the Little Susitna River and other area steams during the growing season as nitrogen is taken up by upland and riparian vegetation.

Turbidity was consistently very low, and only increased slightly to approximately 10 NTU during periods of elevated stream flow. Turbidity quickly returned to low levels as discharge decreased. These changes in turbidity during storm events is similar to values in the Little Susitna River below the Parks Highway (Davis and Davis 2013).

Temperature was lowest at upstream sites and increased at downstream sites. Water temperatures were considerably warmer at the lower 3 sites when compared to the upper river sampling locations. Water temperatures at the lower 3 sampling locations were generally optimal for salmon rearing during the summer months. Downstream sites had temperatures above 13 and 15 °C for longer periods of time than upstream sites, which could explain the longer fork lengths of juvenile Chinook at downstream sampling locations. Water temperatures at Willow Creek were unlikely to negatively affect salmon migration and rearing.

Modifications of physical habitat have occurred at all four sites in Willow Creek. Willow01 and Willow04 both have bank modifications, while all four sites have riparian modifications. Modifications are mainly due to residences, ATV trails, and recreational fishing use. No sites had high percentages of bank or riparian modification. Substrate size tended to be larger at the upstream sites, with more fines and higher embeddedness at the downstream sampling sites.

ASCI scores indicated that Willow Creek has a healthy population of macroinvertebrates, with Willow01 and Willow04 rating "excellent" and Willow02 and Willow03 falling into the "good" category. ASCI habitat assessment scores were high for Willow01, Willow02, and Willow04, while Willow03 had a lower habitat assessment score. Willow03 also had the lowest score for macroinvertebrates. This site is just downstream of the Parks Highway crossing and local campgrounds, which may be associated with its lower quality physical habitat.

Juvenile salmon were abundant at the downstream sites, and resident fish were present at all sites. Chinook salmon were more abundant than coho salmon at all sites with anadromous fish and Chinook CPUT was higher than other Mat-Su streams sampled with the exception of the Little Susitna River (Davis et al. 2015, Davis and Davis 2011). Salmon were most abundant, and median condition factor was also highest for both Chinook and coho salmon at Willow02. Additionally, Willow02 had the highest ASCI habitat assessment score and more woody debris than either Willow01 or Willow03.

Habitat and water quality conditions in Willow Creek remain good even though bank and riparian modifications were apparent at all sampling locations. There was no indication of excessive sediment input as embedded substrate or increases in turbidity during storm events. Dissolved and sediment metal concentrations did not exceed water quality criteria or were at concentrations likely to affect fish or invertebrates, with the exception of arsenic which is commonly in high concentration in sediments of Southcentral streams. Fecal coliform bacteria exceeded water quality criteria at the two sampling locations below the Parks Highway. Juvenile Chinook and coho salmon were abundant at all sampling locations downstream from the canyon and macroinvertebrate water quality assessments indicate good to excellent water quality.

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Appendix A. Site Photographs

Photograph 1. Willow01, taken August 27 2014

Photograph 2. Riparian modification at Willow01, taken September 23 2014

Photograph 3. Willow02, taken June 19 2014

Photograph 4. Deneki Road crossing at Willow02, taken June 19 2014

Photograph 5. Residences along the bank at Willow02, taken August 27 2014

Photograph 6. Parks Highway crossing Willow Creek at Willow03, taken June 19 2014

Photograph 7. Measuring substrate size at Willow03, taken September 23 2014

Photograph 8. Willow04, taken June 19 2014

Photograph 9. Riparian modification at Willow04, taken September 23 2014

Photograph 10. Willow Creek in Hatcher Pass, October 2014.

Photograph 11. Eroded road bed in Hatcher Pass, October 2014.

Photograph 12. Willow01 during April 27, 2015, sampling.

Photograph 13. Willow02 during April sampling.

Photograph 14. Willow03 looking upstream towards the Parks Highway, April 27, 2015.

Photograph 15. Willow04 looking upstream, April 27, 2015.

Appendix B. QAPP