Region II Forest Resources and Practices Act Effectiveness Monitoring

Prepared for: The Department of Natural Resources, Division of Forestry

and the US Fish and Wildlife Service

ARRI

Aquatic Restoration & Research Institute

Jeffrey C. Davis, Gay A. Davis, and Rachel J. Burns
PO Box 923, Talkeetna Alaska 99676
arri@arrialaska.org

May 2016

Cover Photograph. South Fork of Iron Creek (WK1) sampling reach (July 2007).

Acknowledgements. This project was conducted with financial support provided by the U.S. Fish and Wildlife Service, Mat-Su Basin Salmon Habitat Partnership, and the Department of Natural Resources, Division of Forestry. We appreciate the field help and assistance in completing this report that has been provided by multiple ARRI staff, in particular Michelle Briggs and Kay Starzynski.

Table of Contents

Tables

Figures

1.0 Summary

This study was conducted to evaluate whether Alaska statutes and regulations applicable to timber harvest are effectively protecting fish habitat and water quality. The study was conducted in the Willer-Kash State Harvest Area, located in Southcentral Alaska, subject to timber harvest regulations specific to the region. Small-scale harvest of birch and spruce has occurred within the area since the late 1980s to provide firewood and supply local mills.

This study is a continuation of a project initiated in 2006 investigating the water quality, physical habitat, and biotic community of two paired watersheds, one watershed subject to timber harvest (treatment) and one without (reference). Water quality and habitat characteristics were measured at the downstream end of streams draining these watersheds, just upstream from their confluence. An additional site was established downstream of their confluence and downstream of the primary road crossing. Current and temporal trends in water quality and habitat characteristics were compared between the two streams.

There were some differences in water quality and habitat characteristics between the treatment and reference streams but these differences could not be attributed to timber harvest activities. The concentrations of macronutrients differed between these two streams and total phosphorus in the treatment stream is declining over time. Both streams are becoming warmer over time; however, the rate of change is similar. Turbidity increased during storm events; however, there was no indication of increased turbidity downstream from the road crossing. There was no significant change in channel width, width to depth ratios, substrate size, large wood, or debris dams between the two streams or over time in either stream. There is currently, and has been no significant change in food resources (algal abundance or benthic organic matter) between the two streams. The macroinvertebrate community of the treatment stream have remained relatively consistent over time; however, macroinvertebrate metric scores were lower in the reference stream in 2015 compared to previous measures. Both streams continue to support rearing juvenile coho and Chinook salmon and there has been no significant trend in their relative abundance over time in either stream.

The low level of harvest and road building within the treatment watershed did not provide for a robust evaluation of the effectiveness of the FRPA. The effectiveness of current regulations at protecting water quality and fish habitat should be reevaluated if the level of harvest and road building increases. However, based on personal observation, harvest and road construction within the Willer-Kash Harvest Area is comparable to the level of harvest that has occurred to date on other state and Matanuska-Susitna Borough lands within the Susitna River and Little Susitna River watersheds. Therefore, the results from this study are likely representative of conditions in tributaries within the Petersville, Houston, and Rabideux timber blocks subject to similar levels of timber harvest activity.

2.0 Introduction

The Alaska Forest Resources and Practices Act (FRPA) regulations require the evaluation of the implementation and effectiveness of the act at achieving desired objectives (11 AAC 95.830). The FRPA and accompanying regulations for Region II have defined how harvest activities are to be conducted, or best management practices, adjacent to water bodies in order to protect both water quality and fish habitat.

The management intent of FRPA regulations in riparian areas is to protect fish habitat and water quality from the adverse effects of timber harvest. Preservation of fish habitat is accomplished through the maintenance of "short- and long-term sources of large woody debris, streambank stability, channel morphology, water temperatures, stream flows, water quality, adequate nutrient cycling, food sources, clean spawning gravels, and sunlight" (AS 41.17.115). Thus, the effectiveness monitoring and sampling plan was developed to evaluate these stream and riparian habitat characteristics.

The Department of Natural Resources, Division of Forestry, in cooperation with the Alaska Departments of Environmental Conservation, Fish and Game, and U.S. Fish and Wildlife Service initiated a monitoring plan to evaluate the effectiveness of the FRPA within The Willer-Kash State Harvest Area in 2006. The monitoring plan consisted of the collection of reference data from streams within the study area prior to timber harvest, followed by periodic post-project monitoring. Post-project monitoring would be conducted at intervals following various levels of harvest. Measures of post-harvest water quality and fish habitat characteristics would be compared to pre-harvest conditions in order to determine if there were significant differences or trends over time.

Pre-harvest data was collected on 4 Type IIC streams (small anadromous streams) within the Willer-Kash State Harvest Area from July 2006 through June 2008 (see Davis and Davis 2008). Small-scale harvest activity has continued within the Willer-Kash Harvest Area for firewood and to support local mills since 2008 (ADNR 2014).

This study obtained post-harvest water quality and fish habitat data on two tributaries of Iron Creek. These data were evaluated to determine if there are significant differences in water quality or fish habitat between treatment and reference sites. The study tested for differences in the rate and magnitude of change in water quality, habitat characteristics and the biotic community over time in a watershed with timber harvest activity compared to a watershed without.

This study addressed the following objectives:

- Test for differences between the current stream physical, chemical, and biological characteristics and the pre-harvest characteristics at both locations subject to timber harvest activity and reference locations.
- If differences exist, evaluate potential causes, and determine if differences are related to forest harvest and/or implementation of the FRPA regulations.

3.0 Methods

3.1 Study Area and Sampling Locations

The Willer-Kash State Harvest Area is bounded roughly by the Kashwitna River to the north and Willow Creek to the south (Figure 1). The Willow Mountain Critical Habitat Area lies to the east and western boundary generally is the Range line between 3 and 4 West. Three stream sampling locations were selected on Iron Creek tributaries, a tributary to Little Willow Creek. Sampling sites were based upon similar physical characteristics and historical pre-harvest sites for comparison (Davis and Davis 2008). Two study reaches were located on forks of Iron Creek upstream from the Willer-Kash Road crossing, and one site was located below the confluence of these two forks and downstream from the road crossing.

The WK1 sampling reach is located on the south fork of Iron Creek. The south fork of Iron Creek is a second-order stream that flows from east to west, combines with the north fork of Iron Creek and drains into Little Willow Creek. This sampling reach was selected to represent the reference condition with minimal upstream logging or road influence. The 2015 sampling reach is located downstream from the 2006/2007 sampling reach in order to provide better access and at a similar position in the watershed as the treatment reach on the north fork (Figure 1). Some harvest has occurred within the watershed in the 1990s; however, the harvest units and winter roads are buffered from the stream by approximately 900 ft (~270 m) of mixed undisturbed forest and wetlands. The lower 0.5 miles of the south fork of Iron Creek is paralleled by the Willer-Kash Road. The stream is buffered from the road by a minimum of ~264 feet (80 m) of undisturbed forest. There were no signs of road runoff from The Willer-Kash Road to the south fork of Iron Creek.

The WK2 sampling reach is located on the north fork of Iron Creek. The north fork of Iron Creek is a first order stream and joins with the south fork just upstream from the Willer-Kash road. Multiple harvest units and timber harvest roads are proposed for the north fork Iron Creek drainage (Figure 1 and Table 1). There are three active harvest units within the watershed with temporary road access. There are no road crossings of the north fork of Iron Creek. The lower 0.25 miles of the stream is paralleled by the Willer-Kash Road with a buffer of a minimum of ~200 feet (64 m).

The Iron Creek sampling reach is located on the northern channel of the main fork of Iron Creek downstream from the Willer-Kash Road Bridge (Figure 1 and Table 1). Potential impacts from timber harvest activity include all harvest and road construction within the north and south fork drainages and adjacent timber harvest units. Both the Copper #2 and Tin #3 sales contain harvest units within the Iron Creek drainage; however, very little harvest activity has occurred within these units. The boundary for the Tin #3 unit is well separated from Iron Creek and does not cross the stream slope break. The largest potential impact to water quality and fish habitat is from the Willer-Kash Road crossing. The road approaches slope toward the stream from both directions; however, there are no signs of ditching or direct discharge into Iron Creek. Road activity is minimal consisting entirely of passenger vehicles. No logging trucks were observed on the Willer-Kash Road during the 2015 sampling season.

3.2 Physical Habitat Characteristics

Physical habitat characteristics were measured within all three sampling units and included measures of channel geometry, substrate size, large woody debris, and solar radiation. Table 2 provides a summary of 2015 sampling efforts.

3.2.1 Channel Morphology

Stream channel cross-sections were measured systematically at 5 locations in each sampling reach (every 20 m in WK1 and WK2 and every 40 m in Iron Creek) (Davis et al. 2001). At five transects within each 100 m reach, channel width and flood prone width were measured. Channel width was measured by stringing a meter tape across the channel parallel with the water surface. Channel width was the distance between the right and left bank ordinary high water mark. Channel cross-sectional area was calculated from measures of water depth at ~ 30 cm (1 ft) intervals and average water depth was calculated by dividing the cross-sectional area by channel width. Bank undercut was measured on both banks at each cross section. Water surface and bed slope was measured between each cross-section using a hand level and leveling rod.

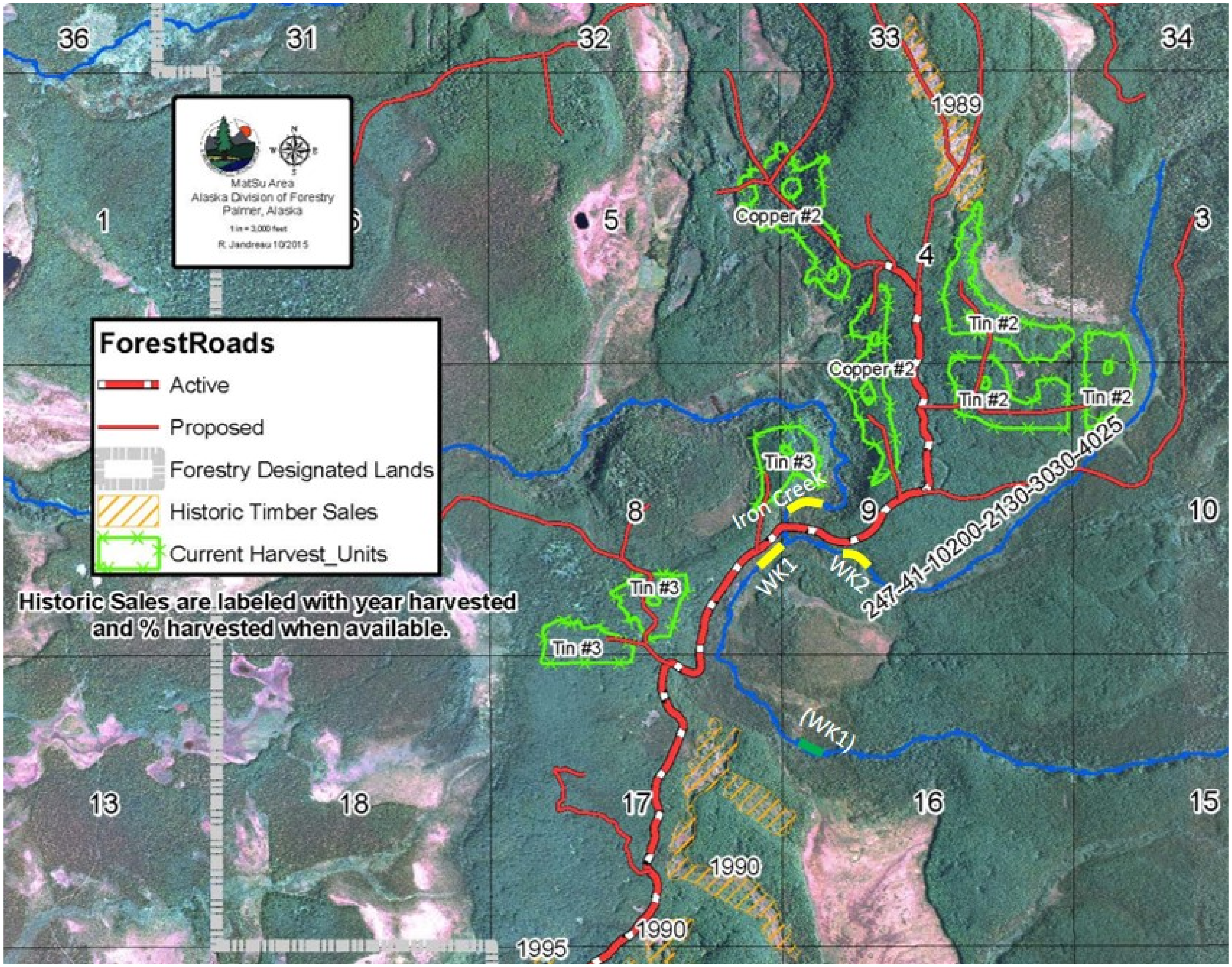

Figure 1. Map of the historic and current harvest units and roads within Willer-Kash State Harvest Area showing streams and sampling reaches (yellow bars). The green bar is the location of the WK1 sampling site used in 2006/2007. Streams are flowing from east to west.

Table 1. 2016 stream sampling locations.

Sample Site	Description	Latitude	Longitude
WK1	Reference site on the south fork of Iron Creek.	61.83568	-149.84488
WK2	Treatment site on the north fork of Iron Creek.	61.83445	-149.83505
Iron Creek	Main channel downstream from the road crossing.	61.83811	-149.84331

3.2.2 Substrate Size Distribution

Substrate size distribution was determined through Wolman pebble counts, as modified by Bevenger and King (1995). Wolman pebble counts measure the intermediate axis of 100 randomly selected stones within a 100 m long sampling section. The intermediate axis was determined by passing the stone through pre-cut squares representing the different size categories (pebbleometer). Embeddedness was recorded simultaneously, and is a semi-qualitative estimate of the portion of the selected stones that are embedded within fine material.

Table 2. Summary of sample timing, post-harvest.

Sample Activity	Dates Collected
Chemical Characteristics	
Macronutrients Water Samples	May 26, July 29, September 8 2015
Field Measurements	May 26- September 8 2015
Biological Characteristics	
Periphyton Algae	August 4-5. 2015
Macroinvertebrates	May 26 - June 6 2015
Riparian Vegetation/CWD	September 8 2015
Juvenile Fish	July 21-30 2015
Benthic /Dissolved Organic Matter	August 4-5 2015
Physical Characteristics	
Temperature Loggers	Installed May 26 - June 6 2015, removed October
Turbidity Loggers	Installed May 28 - June 6 2015, removed September
Large Woody Debris	July 20-22 2015
Discharge	May 26- September 17 2015
Solar Radiation	July 8- September 17 2015
Sediment Size Distribution	June 22 2015
Physical Habitat Characteristics	August 4-5 2015

3.3.3 Large Woody Debris

All large woody debris (LWD) (>10 cm diameter x >100 cm length) and debris dams (3 or more LWD pieces) were counted within each sampling unit. A woody debris index was calculated based on the size, type, location and influence on the stream system of each piece of LWD and debris dam (Davis et al. 2001).

3.3.4 Solar Radiation

Photosynthetically active radiation (PAR) was measured using a Li-cor sensor and meter. PAR was measured at 10 locations at the stream water surface throughout the sampling reach and at 10 locations unobstructed by trees or topography. Percent light transmission was calculated as the portion of PAR in the open divided by PAR measured at the stream surface.

3.3 Water Quality, Temperature, and Stream Flow

3.3.1 Water Quality

Water samples were collected during spring runoff (WK1 and WK2 only), summer base flow, and in the fall. Water samples were analyzed by a commercial laboratory (AM Test, Inc.) for total and total dissolved phosphorus, nitrate + nitrite nitrogen, ammonia nitrogen, dissolved organic carbon, alkalinity, and hardness.

Dissolved oxygen concentrations were measured in the field using a YSI Pro ODO meter for all samples taken before June 6, 2015. All measurements thereafter were measured using a YSI Model 550A DO meter. Field measures of pH and specific conductivity were measured using a YSI 63 meter and probe. Qualitative observations were made for the presence of foam deposits and any oil sheen.

3.3.2 Water Temperature and Discharge

Water level and water temperature were monitored continuously via Onset level loggers. Loggers were suspended in perforated PVC pipe so that they rested on the streambed. The PVC pipes and loggers were attached to fence posts driven into the streambed. Loggers were placed within a well-mixed portion of each stream sampling site and programmed to record water temperature and pressure every 30 minutes. An additional logger was placed on the stream margin of WK1 to record air temperature and pressure. Water level loggers were checked approximately twice a month.

3.3.3 Discharge

Discharge was measured using a Swoffer Model 3000 Current Velocity Meter. A staff gauge was used to measure water depth. A rating curve was developed using measured discharge average daily water pressure, corrected by air pressure, and used in order to estimate average daily discharge values for each site. Precipitation data was retrieved from NOAA National Climatic Data Center, using the weather station in Willow, located at N 61.6995, W -149.9897.

3.3.4 Turbidity

Stream water turbidity was measured from grab samples collected on each sampling event. Additionally, turbidity was measured every hour using Hydrolab MS5 multimeters at WK1 and Iron Creek downstream from the bridge. Hydrolab multimeters were attached vertically to the fence posts supporting the staff gauges and water level loggers.

3.4 Biological Characteristics

3.4.1 Riparian Vegetation and Coarse Woody Debris

The riparian plant community within the unharvested buffer zone along a representative reach was classified lateral to the channel at each cross-section used to measure channel morphology. Classification followed the methods of Viereck et al. (1992). All coarse woody debris (> 10 cm diameter) on the forest floor within the 100 foot buffer zone was counted along one bank. Coarse wood was recorded by species and in 10 cm diameter, and 5 meter length categories.

3.4.2 Periphyton Algae

Algae was collected from accumulations on natural substrate in mid-summer when algal biomass was near seasonal high. Algae was collected by scraping a known area of 5 randomly selected stones within each sampling reach. The periphyton was collected on Whatman GF-C filters, wrapped in aluminum foil, frozen, and transported to an analytical laboratory (AMTest Inc.) for chlorophyll-*a* and phaeophytin analyses.

3.4.3 Benthic and Dissolved Organic Matter

Benthic organic matter (BOM) was collected on one occasion in mid-summer. BOM was collected at five randomly selected points within the sampling reach by dislodging the bed material and extracting the suspended material in mesh nets. The material was divided into coarse particulate organic matter (CPOM; 1 mm to 16 mm) and fine particulate organic matter (FPOM; 0.05 mm to 1 mm). The amount of organic material was based upon the mass lost upon combustion or the ash free dry mass (AFDM). Five samples were averaged to obtain an AFDM value for each site.

3.4.4 Macroinvertebrates

Macroinvertebrates were collected at all sites in early June according to the technical level Alaska Stream Condition Index (ASCI) methodology (Major 2001). Twenty benthic samples were collected in a D net (350 micron mesh). All available habitats were sampled proportional to their occurrence within each sampling reach and preserved in denatured alcohol. Macroinvertebrate metrics were calculated from a subsample of 300 insects and overall ASCI scores determined.

3.4.5 Juvenile Fish

Juvenile fish were collected in baited minnow traps in the summer and fall. Twenty minnow traps (1 inch opening, ¼ inch mesh) were baited with commercial salmon roe placed in perforated whirl-pak bags and allowed to soak for 20-24 hours. Traps were placed in areas where water depth completely covered the trap opening and in locations with cover provided by woody debris or bank vegetation. Fish were identified to species, fork length was measured, and juvenile salmon were weighed. Fish were inspected for any deformities, eroded fins, or lesions. Catch per unit trap, condition factor, and ratio of resident fish to anadromous fish were calculated for each site.

3.5 Data Analyses

T-tests were used to evaluate differences in water quality, physical habitat characteristics, and measures of the biotic community between the reference reach (WK1) and the treatment reach (WK2) when multiple measures were obtained on a single sampling date in 2015. Paired t-tests were used to evaluate differences in variables between the reference and treatment reaches when multiple measures were available over time. Linear regression analyses were used to test for significant trends in variables over time and t-tests were used to test for significant differences in regression slopes between the reference and treatment reaches. Alpha was set at 0.05 for all tests.

4.0 Results

4.1 Physical Habitat Characteristics

4.1.1 Channel Morphology

Average reach morphological characteristics by site are reported in Table 3. Iron Creek mean width was 5.29 m, with a mean depth of 0.19 m. Iron Creek had the widest and shallowest channel, reporting a width to depth ratio of 28.58. WK1 mean width was 3.30 m, with a mean depth of 0.28m. The width to depth ratio was 11.96. WK2 mean width was 3.05m, with a mean depth of 0.39m. The width to depth ratio was 23.85. Water surface slope was highest in Iron Creek (1.34) and lowest in WK2 (0.591). Undercut banks were present at most cross-sections within all sampling units.

There was not significant change in channel width, width depth ratio, or undercut banks between WK1, the treatment reach, and WK2 the reference reach (Table 4). There was a significant difference in WK1 channel width compared to 2006 and 2007 values (Davis and Davis 2008); however, this is most likely due to the change in sampling location, with the site used in 2015 being slightly steeper, more confined, and with a narrower channel.

Table 3. Stream channel average characteristics (n = 5) and in 2015 with standard deviation in parenthesis.

	WK1	**WK2**	**Iron Creek**
Bank height, m	0.50 (± 0.15)	0.42 (± 0.14)	0.525 (± 0.17)
Width, m	3.30 (± 0.85)	3.05 (± 0.62)	5.29 (± 0.92)
Depth, m	0.28 (± 0.48)	0.39 (± 0.13)	0.19 (± 0.01)
Width to depth ratio	11.96 (± 3.07)	23.85 (± 4.88)	28.58 (± 4.95)
Bank undercut	0.13 (± 0.12)	0.09 (± 0.06)	0.21 (± 0.09)
Wetted perimeter, m	3.34 (± 1.00)	3.36 (± 0.62)	5.57 (± 0.94)
Water surface slope %	1.02 (± 1.27)	0.591 (± 0.36)	1.34 (± 0.50)

4.1.2 Substrate Size Distribution

The substrate size distribution (Figure 2) indicates that median particle diameter was lowest at WK1, with a D50 of 32mm and percent fines 19%. WK2 and Iron Creek both had a D50 of 45mm, however percent fines was 12% at Iron Creek and 4% at WK2. Percent embeddedness was highest at Iron Creek where 50% of particles were embedded more than 20%. At WK1, 46% of particles were embedded more than 20%. At WK2, 34% of particles were embedded more than 20%.

Previous and current measures of substrate size distribution at WK1 and WK2 are shown in Figures 3 and 4. There is no consistent difference in substrate size between the two sites or among years. The WK1 reference site has similar percent fines < 20% and a D50 of 32 mm as in previous years.

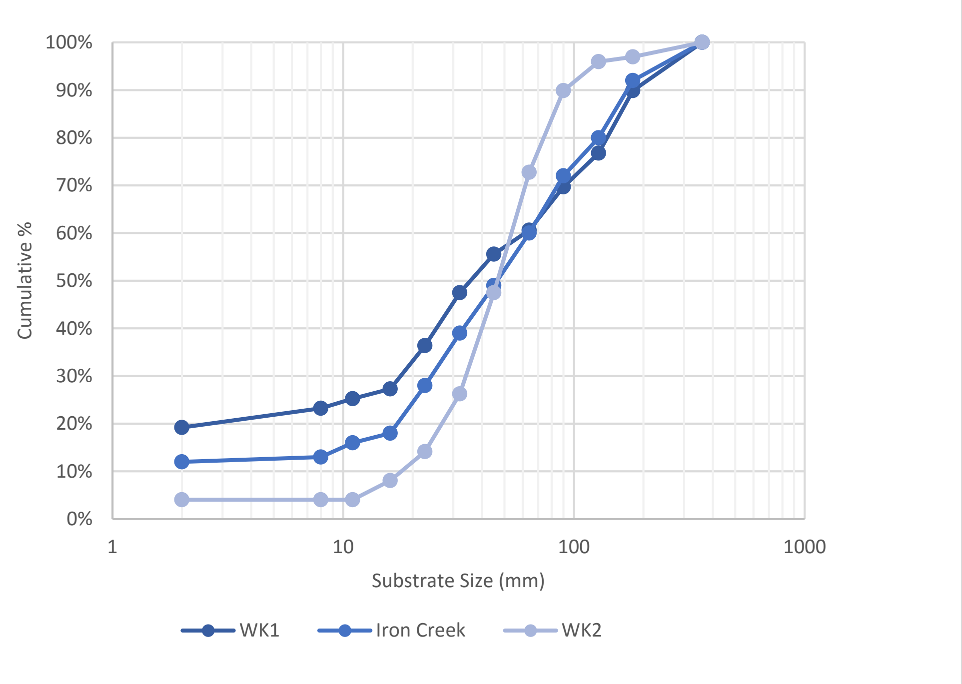

Figure 2. Cumulative substrate size distribution in 2015 at all three sites.

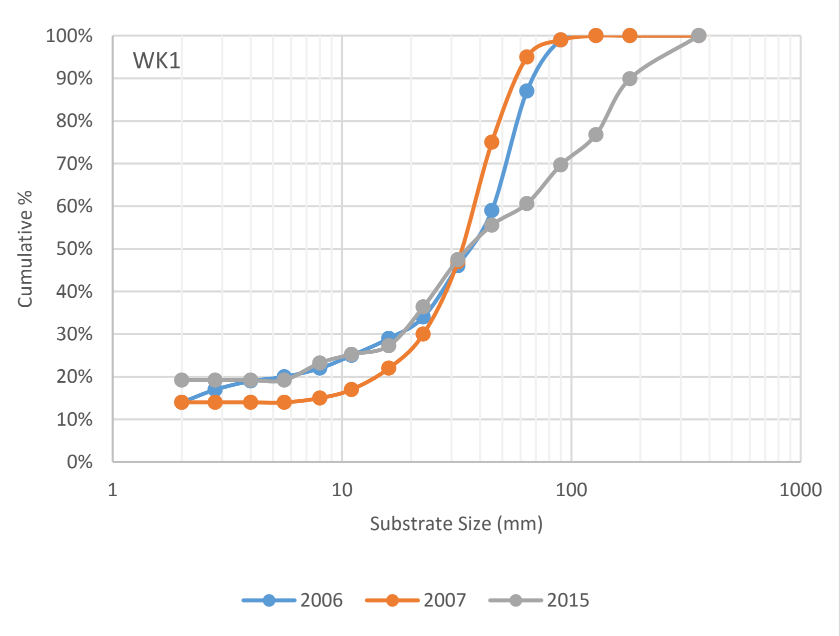

Figure 3. Substrate size distribution at the reference WK1 site comparing previous and current measures.

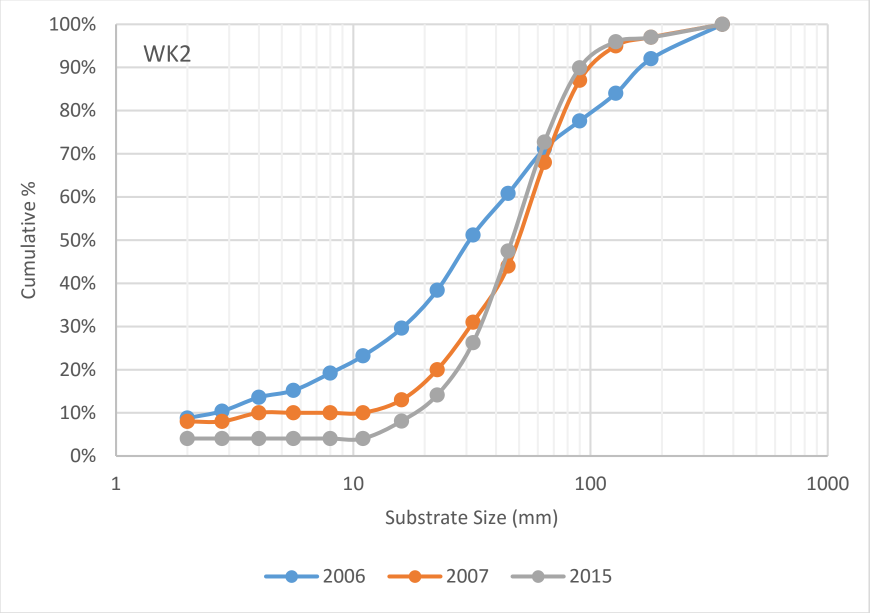

Figure 4. Substrate size distribution at the treatment WK2 site comparing previous and current measures.

There is a slight increase in the portion of cobble (64 to 256 mm) which is consistent with the slightly steeper sampling reach. The substrate size distribution in WK2, the treatment reach, is very similar to previous measures in 2007. Percent fines remained <10% in both years, 8% fines in 2006 and 207 and 4% fined in 2015. The D50 was 45 in 2007 and 2015 and slightly smaller at 32 mm in 2006.

4.1.3 Large Woody Debris

Counts of large woody debris and debris dams within a 100 m sampling reach are summarized by site in Table 4. Large woody debris and debris dams were most abundant at Iron Creek, however the Large Woody Debris Index (LWDI) score was lowest at this site (340.5) due to their lower potential to influence stream morphology, hydrology, and organic matter retention. WK1 had a LWDI score of 546 and WK2 had a score of 415.

There was no change in the amount of large woody debris or debris dams in either the treatment or reference stream reaches since previous sampling in 2006 and 2007 (Figure 5 and 6). The LWDI score at WK2, the treatment site, has remained consistently between 300 and 500 on 4 separate sampling dates. There is no indication of an increase in large wood or debris dams in WK2 due to blowdown, excessive bank erosion, or other potential harvest sources (Figure 6). There also is no indication that changes in hydraulic conditions and large woody debris transport has altered the amount of wood or debris dams within the WK2 sampling reach.

Table 4. Pieces of large woody debris and debris dams per 100 m stream reach and the large woody debris index score.

	WK1	WK2	Iron Creek
LWD piece count	13	11	17
Debris dam count	3	2	3
LWDI score	546	415	340.5

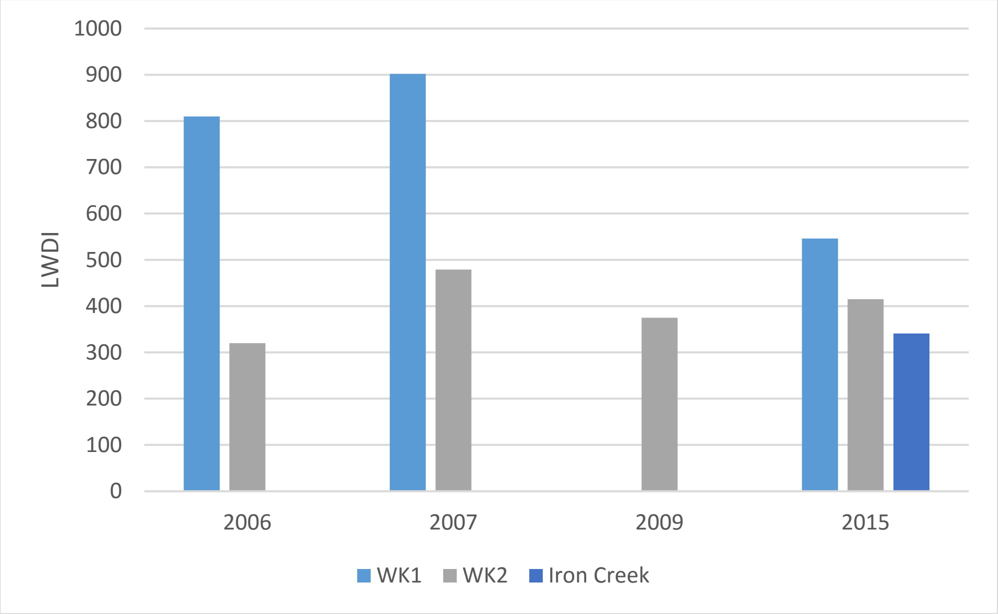

Figure 5. Comparison between current and previous measures of the LWDI in WK1 (reference) and WK2 (treatment) sampling reaches.

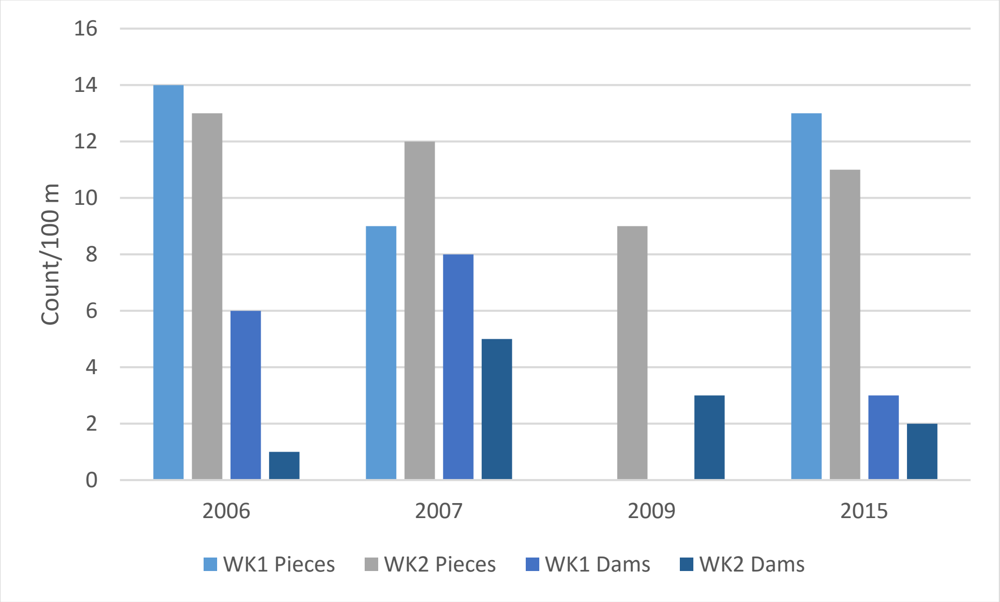

Figure 6. Comparison of large woody debris pieces and debris dams between WK1 (reference) and WK2 (treatment) stream reaches over time.

4.1.4 Solar Radiation

Average percent light transmittance was highest at WK2, with a value of 75.8% and lowest at Iron Creek, with a value of 62.1% although the differences are not significant (Table 5). Percent transmission of solar radiation was higher in 2015 compared with the average of previous measures in 2006 and 2007 (Davis and Davis 2008). The average percent transmission in WK1 increased from 43% to 75%, and in WK2 from 60% to 76%. There was no apparent change in forest composition or density adjacent to these streams. There was a small patch of blown down birch trees near the WK2 sampling reach; however, they were not close enough to influence measurements. Many alder adjacent to these two streams were defoliated (Figure 7), which is the most likely cause of the increase in percent of solar radiation reaching the sampling stream reaches.

Table 5. Percent transmission of photosynthetically active radiation reaching the stream bed on 3 sampling dates.

Date	WK1	WK2	Iron Creek
7/8/2015	43.5%	94.0%	29.9%
7/20/2015	107.2%	54.1%*	72.6%
9/17/2015	74.2%	79.3%	83.9%
Seasonal average	74.9%	75.8%	62.1%

*Measurement taken at WK2 on 7/22/2015, weather: overcast

Figure 7. Photograph of dead and defoliated alder within the WK1 sampling reach (June 23, 2015).

4.2 Water Quality, Temperature, and Stream Flow

4.2.1 Macronutrients and Minerals

Alkalinity and hardness are shown in Figures 8 and 9. Alkalinity ranged from 24 mg/L (WK1 and WK2 July 2015) to 32 mg/L (WK1 September 2015). Hardness ranged from 17 mg/L (WK1 July 2015) to 23 mg/L (WK2 September 2015). Alkalinity and hardness values did not vary significantly between sites or sampling events. Alkalinity values are low indicating low pH buffering capacity. Values are similar to the adjacent Willow Creek where alkalinity ranged from 17 to 30 mg/L $CaCO_3$ and hardness from 22 to 35 mg/L $CaCO_3$ (Davis et al. 2015). Whereas alkalinity in Cottonwood Creek (Wasilla, AK) is near 100 mg/L $CaCO_3$ (Davis and Davis 2005).

Concentrations of total phosphorus, total dissolved phosphorus, nitrate and nitrite nitrogen, and ammonia nitrogen are shown in Table 6.Total phosphorus was invariable throughout sampling, with a maximum detected value of 0.03 mg/L at WK1 in July. Total dissolved phosphorus also remained fairly invariable, with a maximum detected value of 0.0279 mg/L at WK2 in May. Inorganic nitrogen concentrations were fairly low throughout sampling, with the exception of a peak of 0.84 mg/L at WK1 in May. Lower stream nutrient concentration during mid-summer are consistent with other area streams.

Concentrations of total and total dissolved phosphorus in samples collected since 2006 are shown in Figures 10 and 11. Total and total dissolved phosphorus concentrations are significantly higher in WK1 compared to WK2 (paired t-test, $p < 0.05$). Regression analyses shows no trends in total dissolved phosphorus in either stream; however, total phosphorus concentrations are stable in WK1 and declining over time in WK2.

Concentrations of inorganic nitrogen over time at WK1 (reference) and WK2 (treatment) sites are shown in Figures 12 and 13. There was no significant difference in ammonia-N between these two sites and no trends over time. Nitrate + nitrite N was significantly higher in WK2 (paired t-test, $p < 0.001$). There is a significant though low rate of decreasing nitrate + nitrite N concentrations over time in WK2 and a similar low but significant increase over time in WK1.

The higher concentrations of phosphorus and lower concentrations of nitrogen in the reference WK1 site result in molar N:P ratios < 16 on multiple dates suggesting nitrogen limitation of primary production (Redfield 1958, Kahlert 1998). Whereas in WK2, inorganic nitrogen concentrations are higher and phosphorus lower resulting in molar N:P ratios > 16 on most sampling dates suggesting phosphorus limitation of primary production.

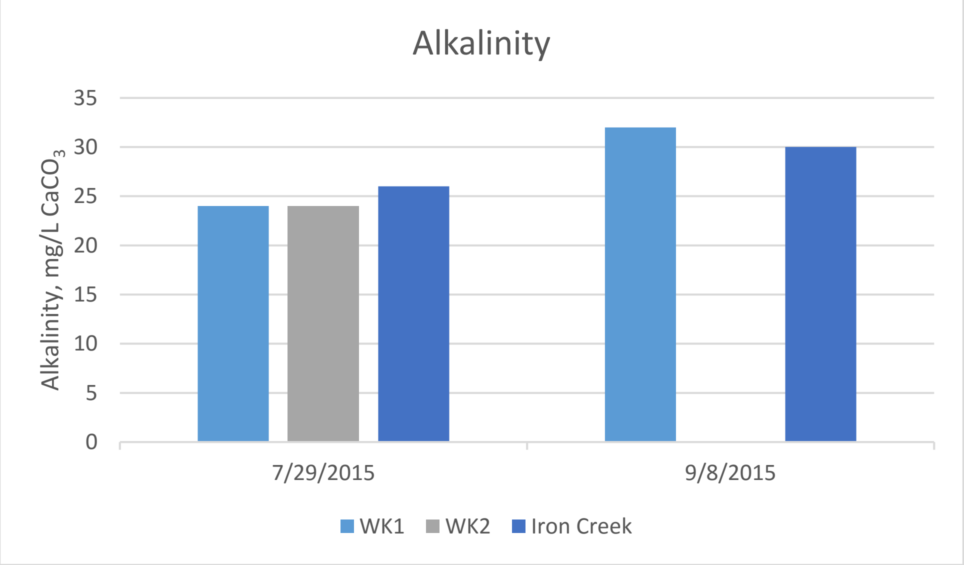

Figure 8. Stream water alkalinity on two sampling dates at the sampling sites.

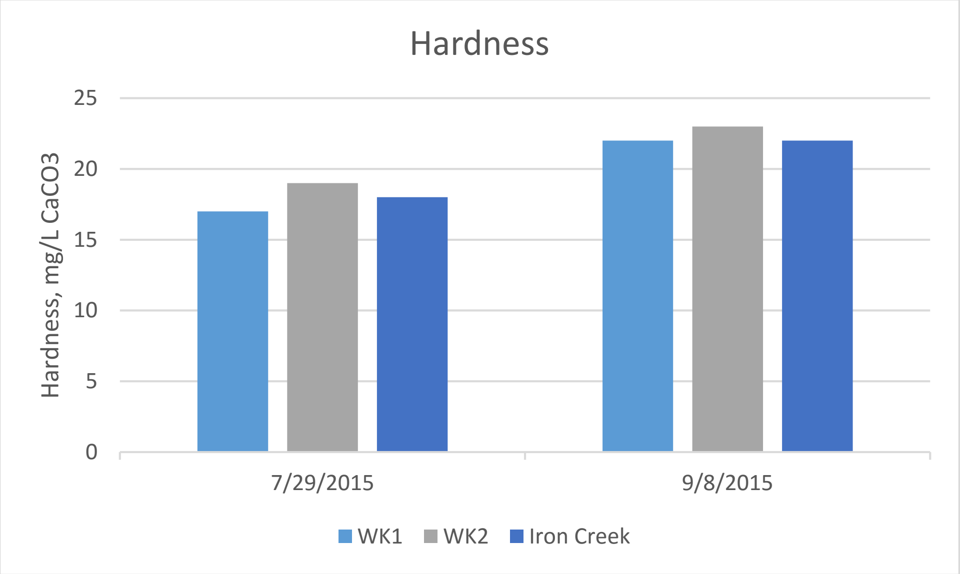

Figure 9. Hardness of water samples collected during summer and fall at the three sampling sites.

Table 6. Concentrations of macronutrients in the three sampling sites during spring, summer, and fall of 2015.

		WK1	WK2	Iron Creek
Total Phosphorus, mg/L	May-15	0.026	0.018	-
	Jul-15	0.030	0.009	0.022
	Sep-15	0.018	0.011	0.015
Dissolved Phosphorus, mg/L	May-15	0.019	0.028	-
	Jul-15	0.008	0.005	0.007
	Sep-15	0.013	0.009	0.011
Nitrate + Nitrite N, mg/L	May-15	0.84	0.086	-
	Jul-15	ND	0.097	0.051
	Sep-15	0.33	0.12	0.091
Ammonia-N, mg/L	May-15	ND	0.016	-
	Jul-15	ND	0.006	ND
	Sep-15	0.021	0.008	ND

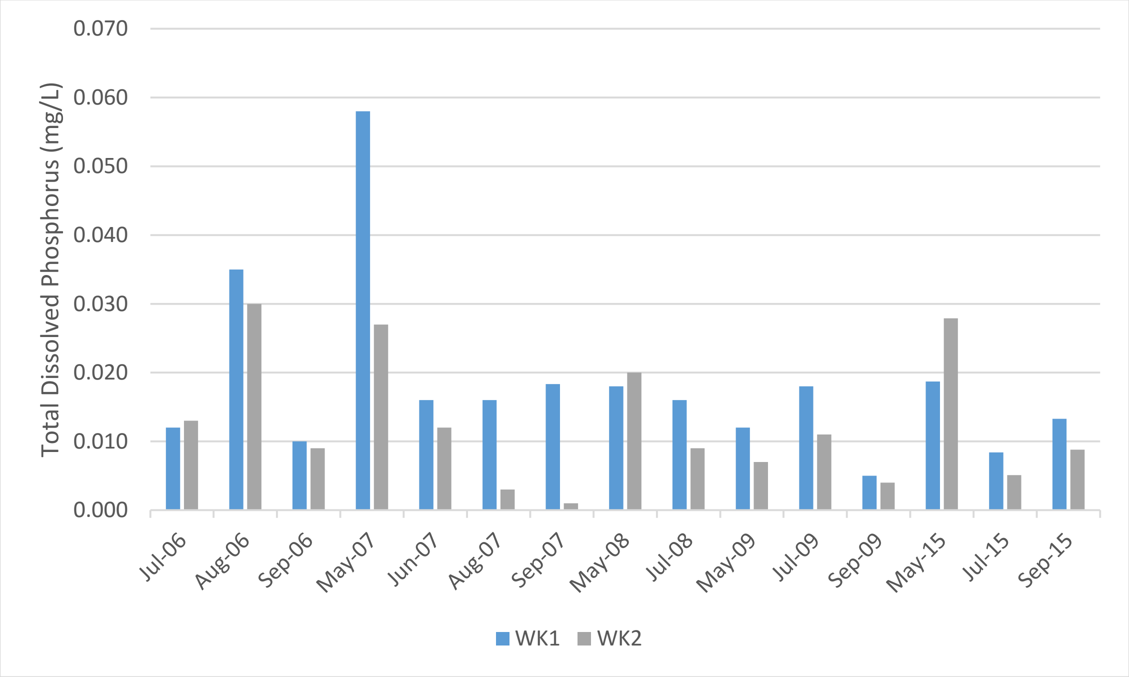

Figure 10. Concentrations of total dissolved phosphorus at WK1 and WK2 on multiple sampling dates from July 2006 through September 2015 showing generally higher concentrations in WK1.

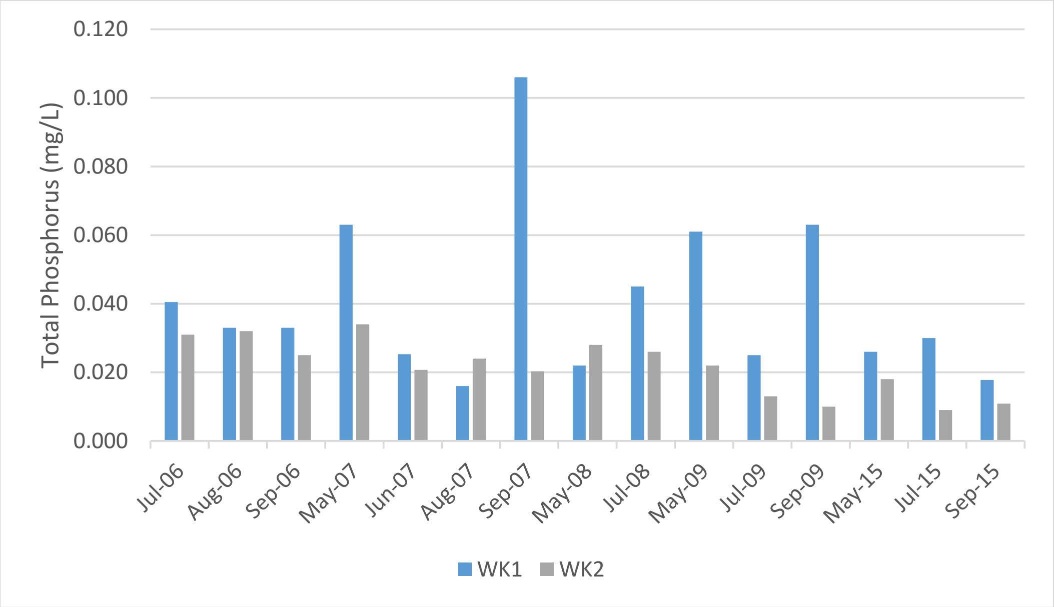

Figure 11. Concentrations of total phosphorus in WK1 and WK2 on multiple sampling dates from July 2006 through September 2015 showing higher values in WK1 and a trend of decreasing concentrations in WK2.

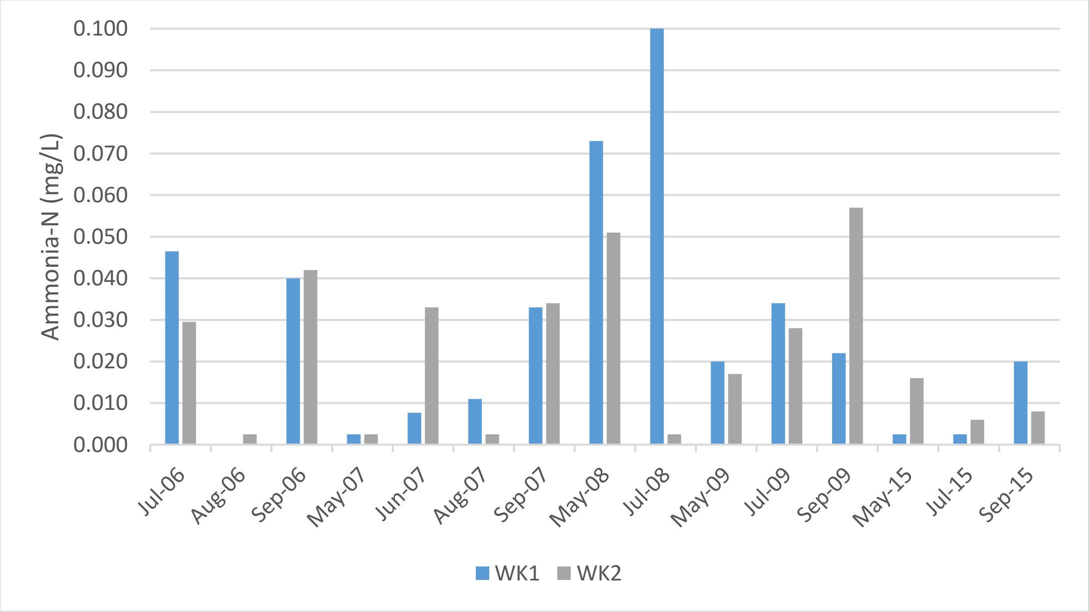

Figure 12. Concentrations of ammonia nitrogen on multiple sampling dates from July 2006 through September 2015 showing no difference between WK1 and WK2.

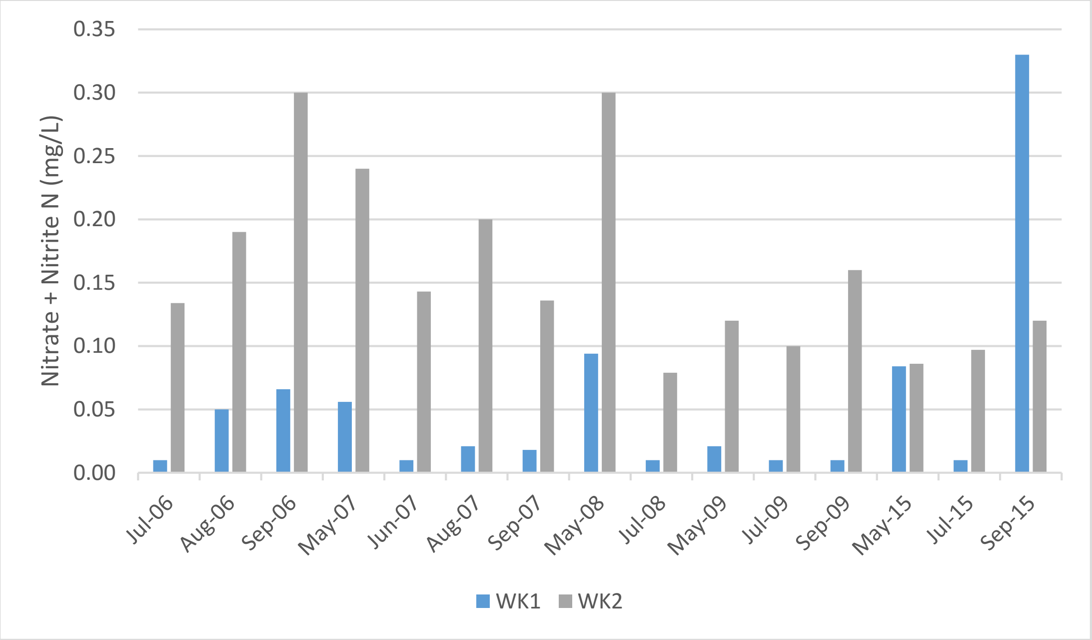

Figure 13. Concentrations of nitrate + nitrite N on multiple sampling dates showing higher values in WK2 compared to WK1.

4.2.2 Dissolved Oxygen, pH, and Specific Conductivity

Dissolved oxygen ranged from 86-109.5% across all dates and sites (Figure 14). The lowest percent saturation was measured at WK1 on August 26, 2015. The highest percent saturation was measured at WK2 on July 29, 2015. Seasonal percent saturation values between sites did not differ significantly.

Dissolved oxygen is consistently near saturation in WK1 and WK2 in samples collected since 2006. There is no difference in dissolved oxygen saturation between these two sites or significant trends over time.

Stream water pH ranged from 6.72-7.45 across all dates and sites (Figure15). The lowest pH value was recorded at WK2 on May 26, 2015. The highest pH value was recorded at Iron Creek on June 23, 2015. Seasonal stream water pH values between sites did not differ significantly. There is no significant trend in pH over time or between WK1 (reference) and WK2 (treatment) sites. Stream water pH tends to be lower during spring runoff and fall storm events (Figure 16).

Specific conductivity generally increased throughout the season, with a slight decline in September (Figure 17). Values ranged from a maximum of 63.6 µS/cm at WK2 on August 26, 2015 and September 8, 2015 to a minimum of 41.5 µS/cm at Iron Creek on September 8, 2015. Seasonal specific conductivity values between sites did not differ significantly. Specific conductivity was slightly higher in 2015 than in previous years (Figure 18). However there is no significant trend over time and specific conductivity averages 48 µS/cm at WK1 and WK2.

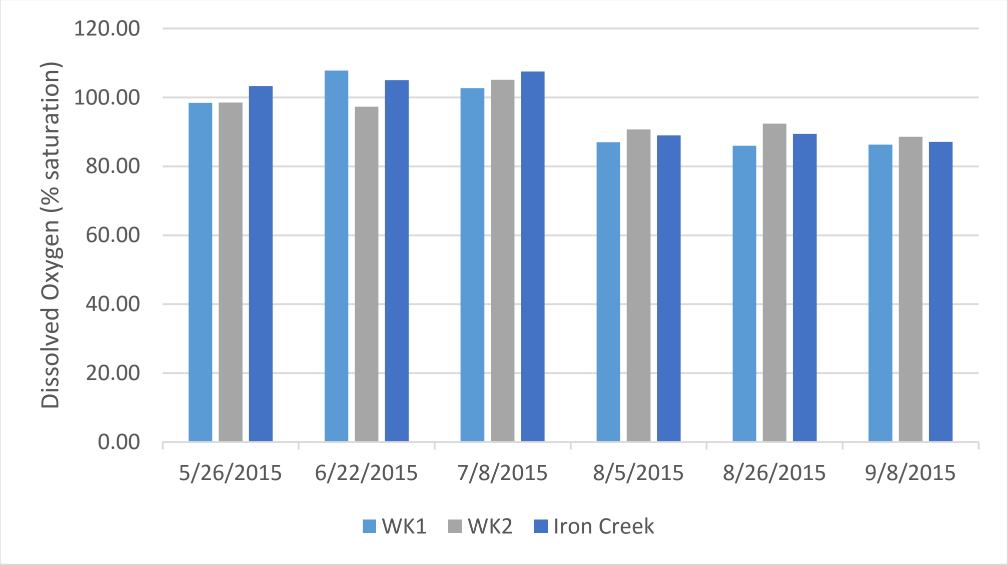

Figure 14. Percent saturation of dissolved oxygen at sampling sites in 2015.

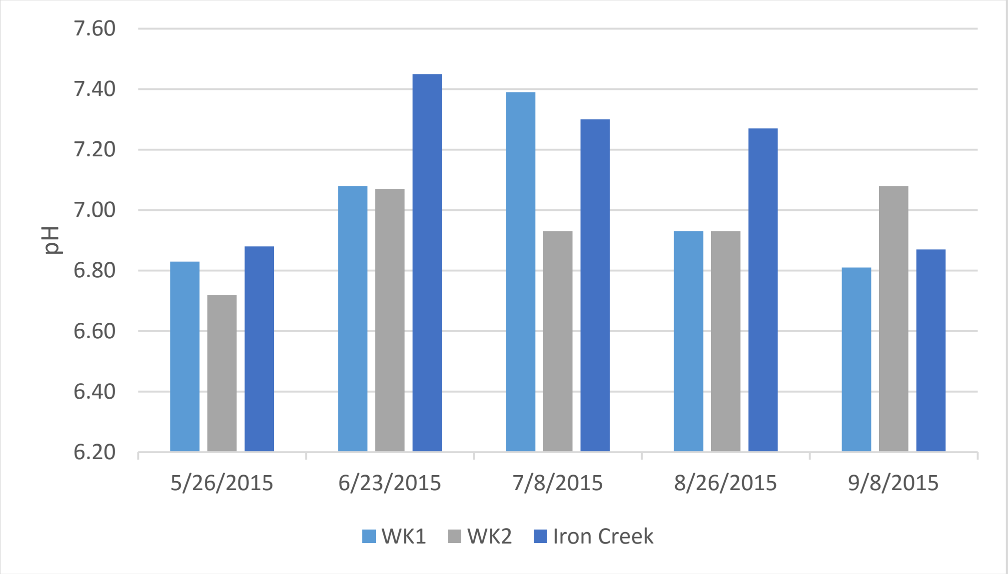

Figure 15. Stream water pH at sampling sites in 2015 showing a general trend of more acidic water during spring runoff and fall storm events.

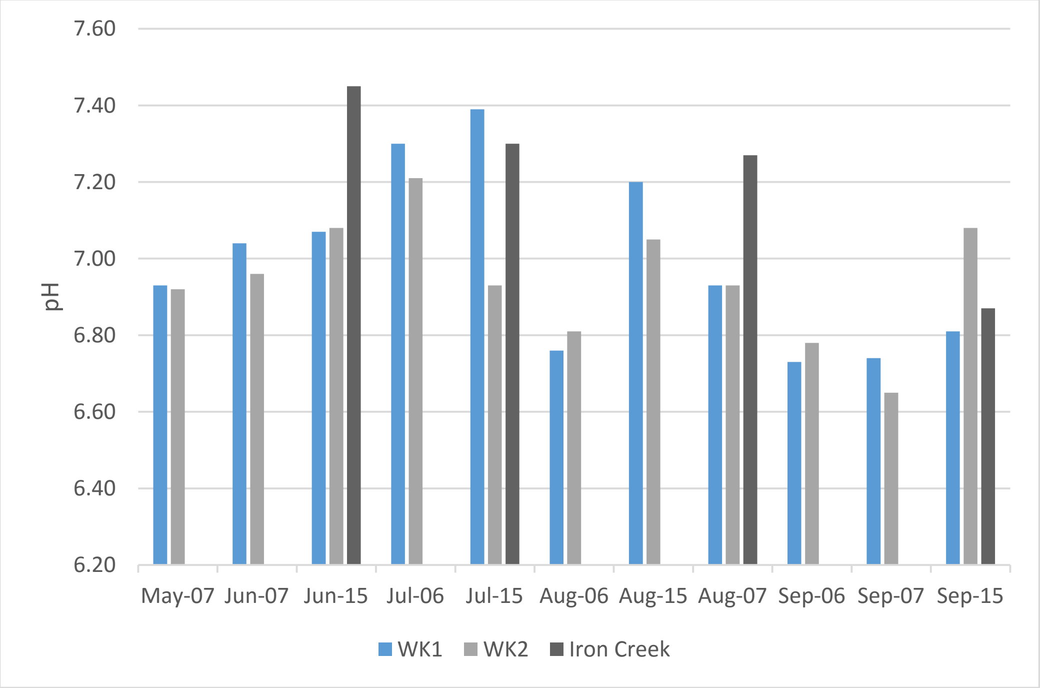

Figure 16. Monthly pH values for 2006, 2007, and 2015 showing a trend toward lower pH in the spring and fall.

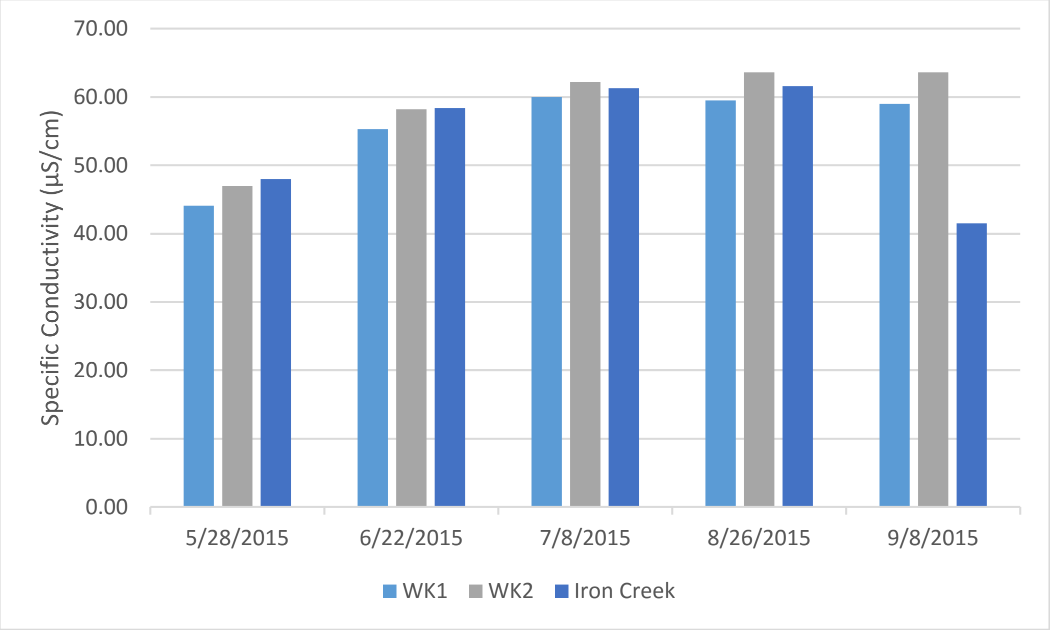

Figure 17. Specific conducitivity at sampling sies in 2014 showing overall low values.

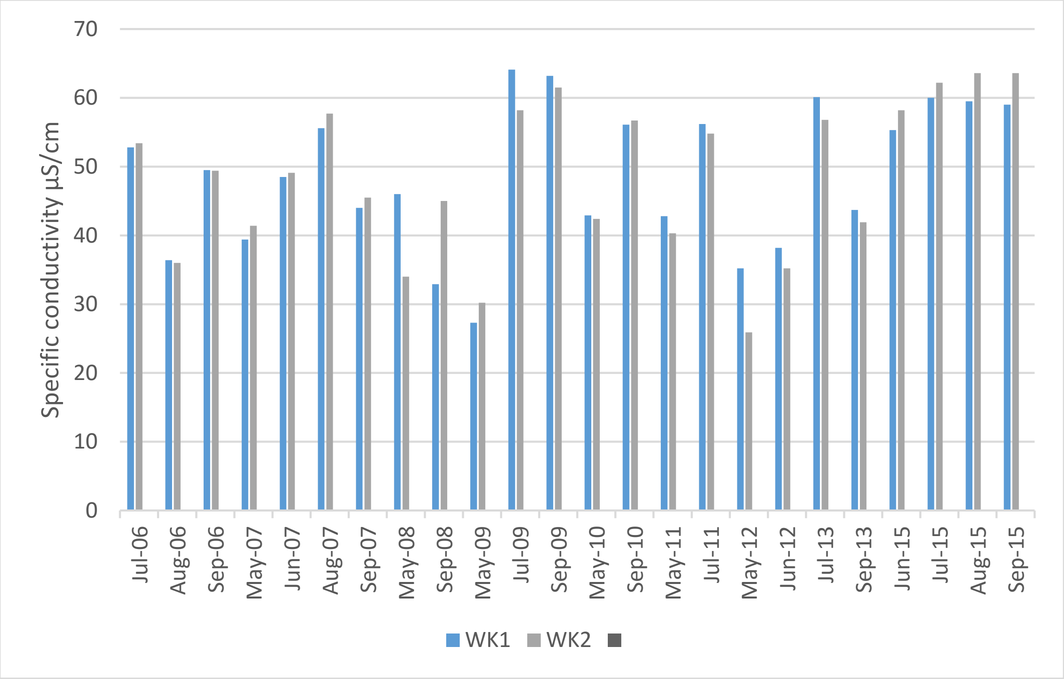

Figure 18. Specific conductivity at the two sampling sites from July 2006 through September 2015 showing no difference between WK1 (reference) and WK2 (treatment) sites.

4.2.3 Foam

Study reaches WK1 and WK2 were examined for the presence of foam, natural or otherwise. Foam from natural causes was observed at WK1 in May and in June. Foam accumulations on logs below areas of aeration (falls or riffles) are natural in area streams that receive runoff with high dissolved organic matter (Davis and Davis 2005).

4.2.4 Water Temperature and Pressure

Water temperature data for all sites are summarized in Table 7 and Figures 19, 20, and 21. Generally, stream temperatures were highest at WK1 and lowest at WK2. WK2 had the lowest value for cumulative degree days (sum of daily average temperatures) in June, July, and August. The seasonal maximum temperature among all sites (17.09 °C) was recorded at WK1 on June 19, 2015. All sites exceeded temperatures of 13 °C for at least two days. WK1 and Iron Creek maximum temperatures exceeded 15 °C on more than five days. At WK1, almost 20% of days reached a temperature greater than 15 °C.

Water temperature data are available for WK1 and WK2 since 2007. Maximum daily water temperature, and monthly degree days (June, July, and August) are significantly higher in WK1 compared to WK2 (Figure 22 and 23). Maximum daily temperature did not increase significantly by year at WK1, but it did at WK2 ($p = 0.03$). July cumulative degrees days have increased significantly at both sites from 2008 through 2015. The rate of annual increase was 6 July degree days/year at the treatment sites (WK2), compared to 10 July degree days/year at the reference site (WK1); however, the slopes were not significantly different ($p = 0.08$).

Table 7. Stream water temperature metrics for the sampling sites in 2015.

	WK1	**WK2**	**Iron Creek**
Start Date	5/26/2015	5/26/2015	6/9/2015
End Date	9/17/2015	9/17/2015	9/17/2015
Season Maximum	17.09	13.56	16.05
Max Daily Range	6.70	4.90	6.24
Total Days	115	115	101
Days Max>13	45	2	31
Percent of Total	39.13	1.74	30.69
Days Max>15	21	0	6
Percent of Total	18.26	0	5.94
Days Max>20	0	0	0
Percent of Total	0	0	0
June Cumulative Degree Days	316	280	-
July Cumulative Degree Days	359	312	342
August Cumulative Degree Days	329	280	306

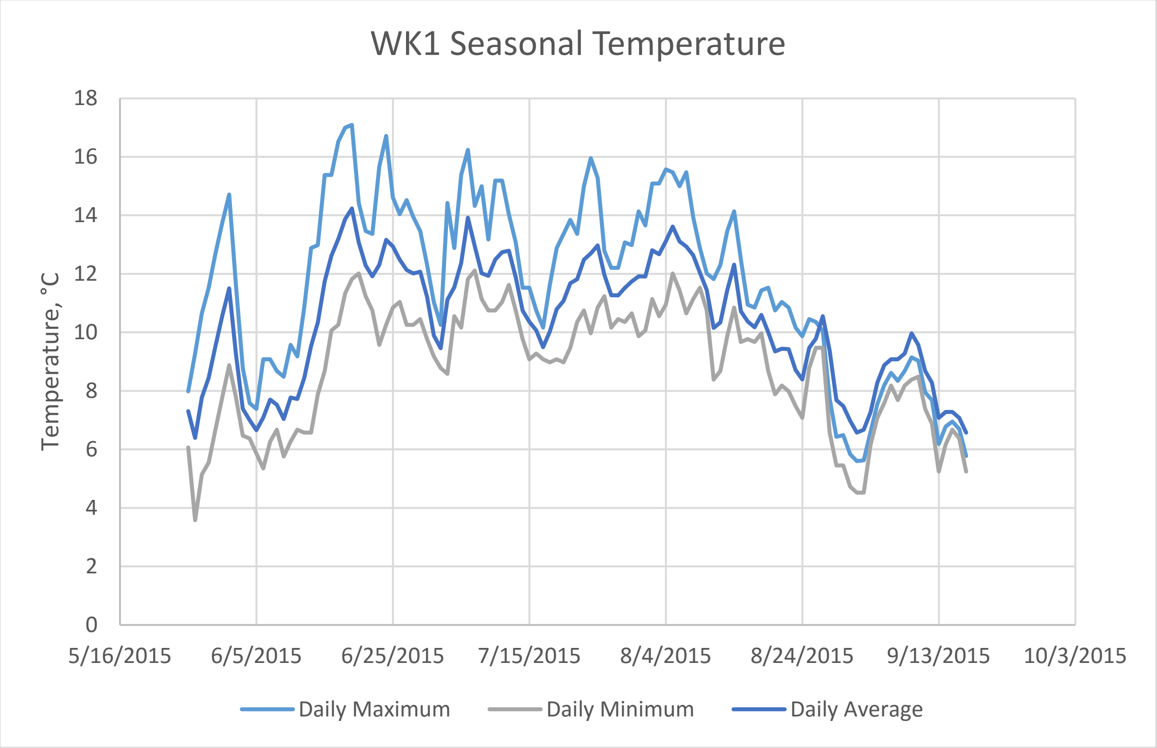

Figure 19. Daily 2015 water temperature in WK1.

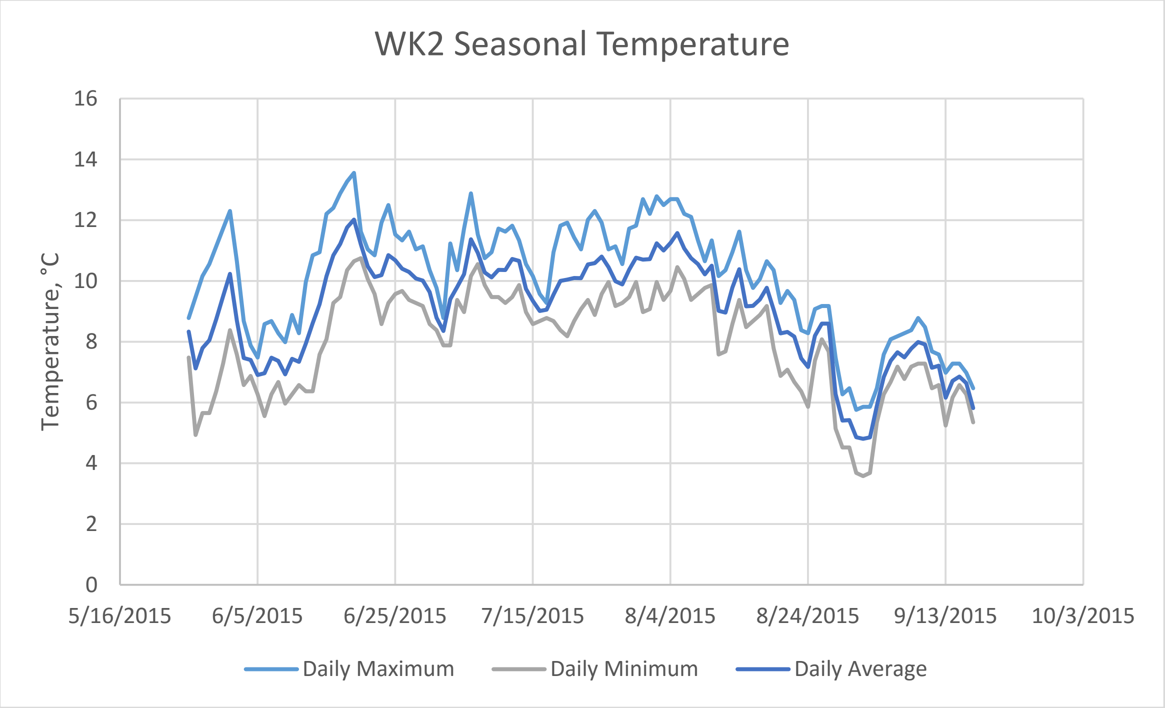

Figure 20. Daily 2015 water temperature in WK2.

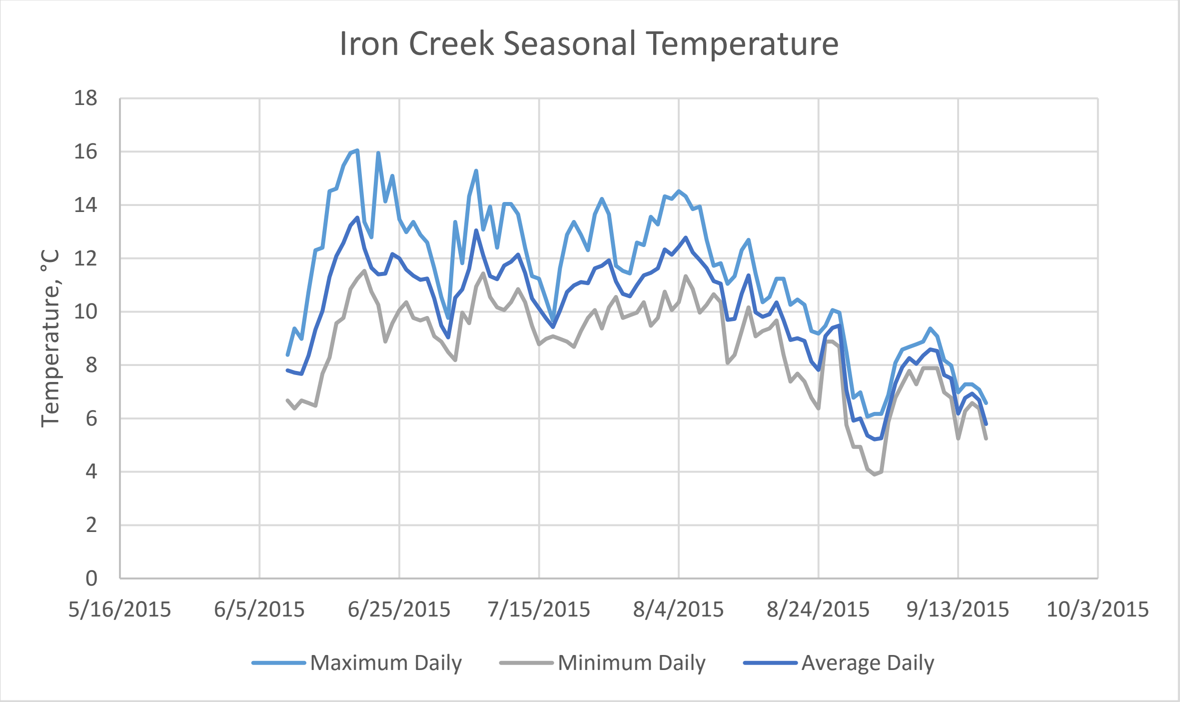

Figure 21. Daily 2015 water temperature in Iron Creek.

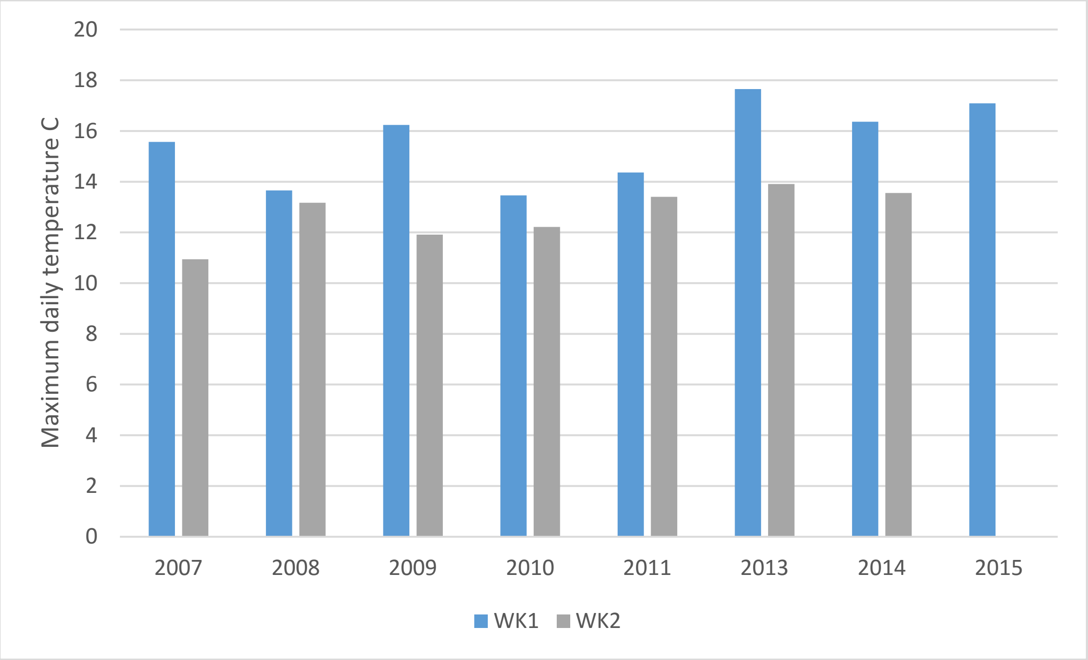

Figure 22. Maximum daily temperature in WK1 (reference) and WK2 (treatment) streams from 2008 through 2015.

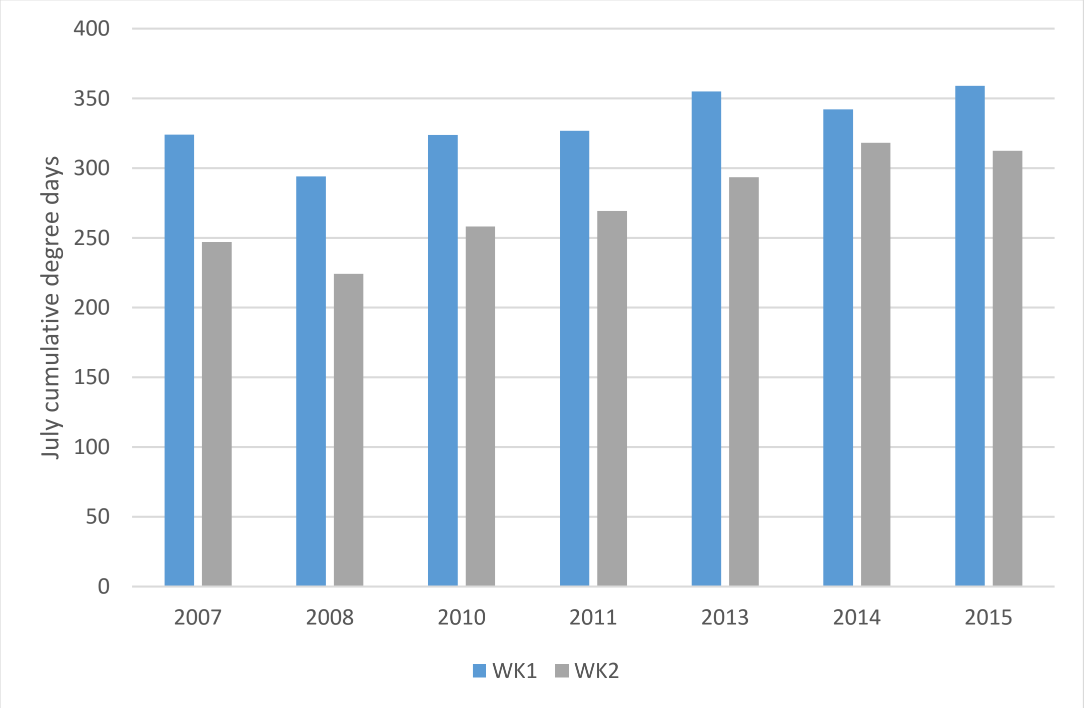

Figure 23. July cumulative degree days (sum of daily means) from 2008 through 2015 showing higher values in WK1 and similar significant annual trends in July degree days.

4.2.5 Stream Flow and Precipitation

Daily discharge values were calculated for each site based on the relationship between water level and measured discharge (Figures 24, 25, and 26). At WK1, daily discharge peaked at 44.2 cfs on September 14, 2015 (Figure 24). This peak coincided with a storm event which totaled 47.1 mm precipitation from September 12 to September 14. Seasonal low discharge was 2.44 cfs and seasonal average discharge was 7.93 cfs. At WK2, daily discharge peaked at 27.2 cfs on July 17, 2015 (Figure 25), on which date 13 mm of precipitation was recorded. Seasonal low discharge was 2.42 cfs and seasonal average discharge was 5.17 cfs. At Iron Creek, daily discharge peaked at 62.60 cfs on September 16, 2015 (Figure 26), following 20.6 mm of precipitation. Seasonal low discharge was 4.63 cfs and seasonal average discharge was 12.78 cfs.

The cumulative frequency of estimated 2015 flows is shown in Figure 27. The distribution of 2015 flows was in similar between WK1 and WK2. A shift to more frequent high flows in response to increased runoff was not observed in WK2 or Iron Creek downstream from the road crossing.

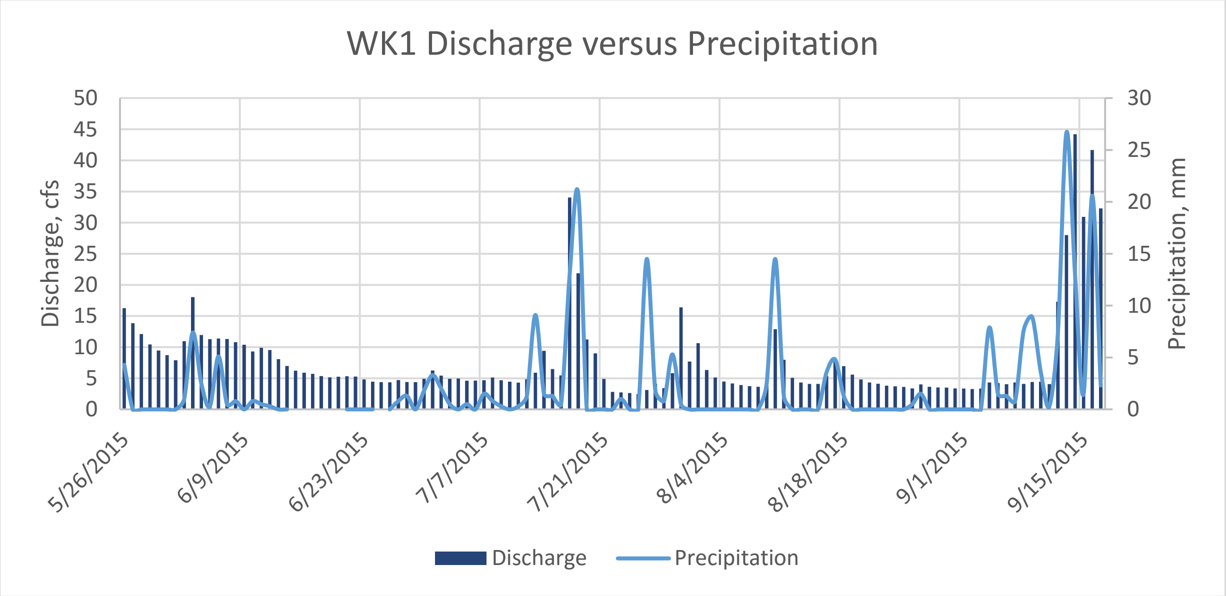

Figure 24. Calculated 2015 discharge and precipitation in WK1.

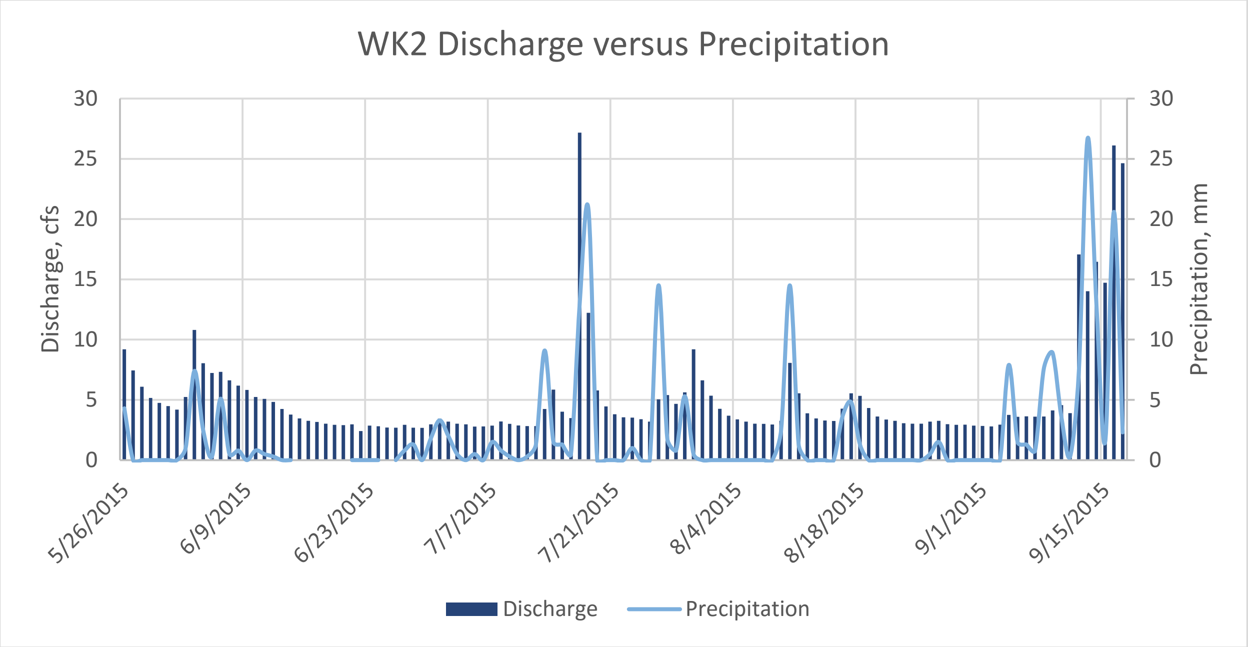

Figure 25. Calculated 2015 discharge and precipitation in WK2.

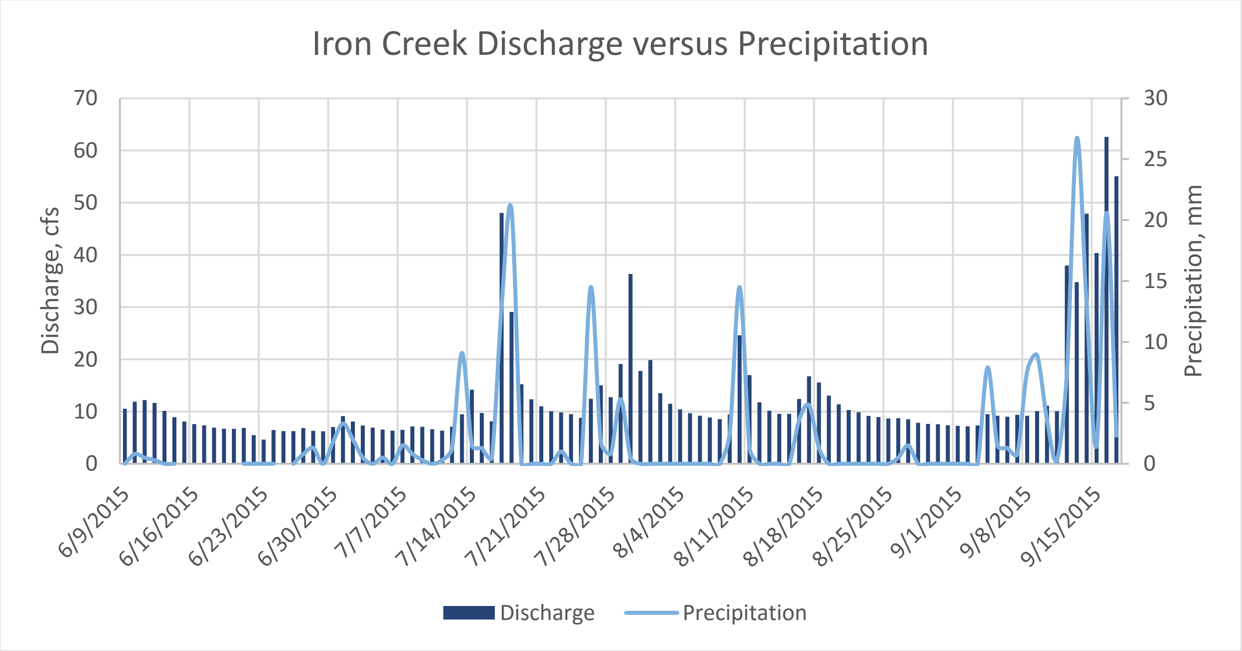

Figure 26. Calculated 2015 discharge and precipitation in Iron Creek.

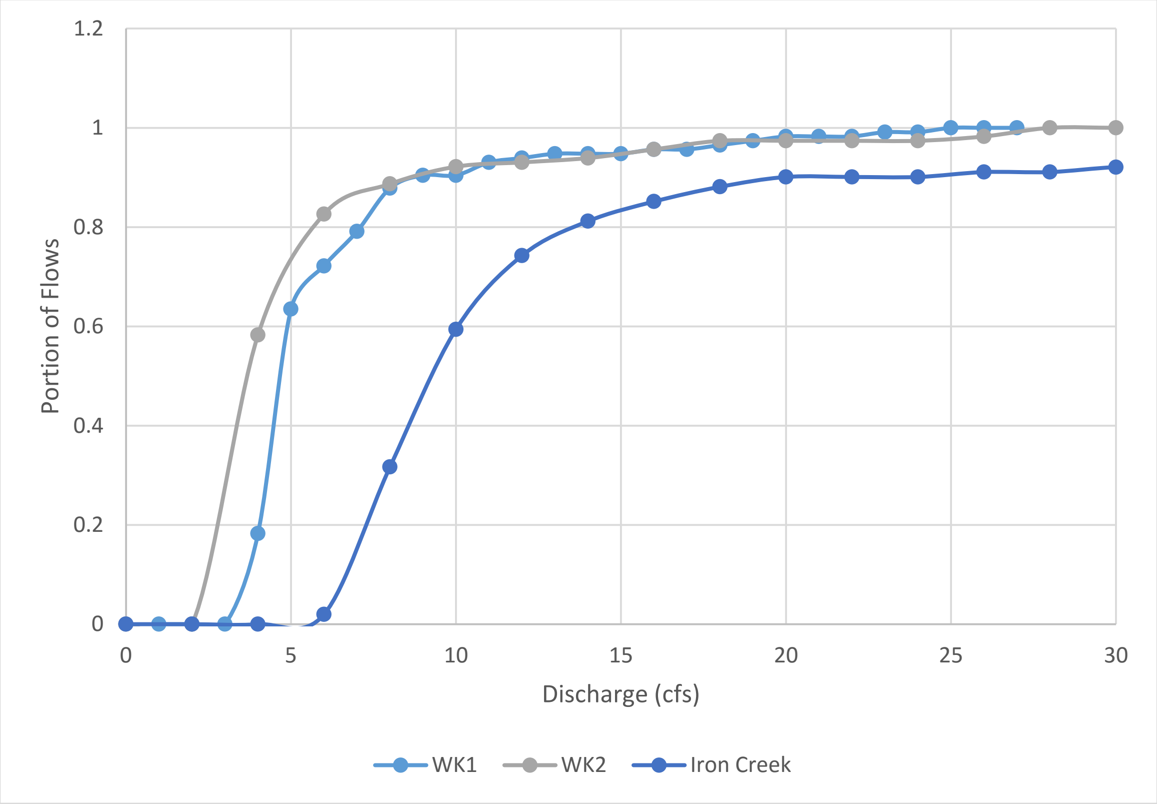

Figure 27. Cumulative frequency distribution of 2015 flows at sampling locations showing similar curves for WK1 (reference) and WK1 (treatment) sites.

4.2.6 Turbidity

Seasonal daily average turbidity values for all sites are displayed in Figure 28. In-situ measures of turbidity were recorded every hour throughout the season at WK1. Measures were recorded at WK2 in the spring, after which the MiniSonde was removed and placed in Iron Creek for the remainder of the season. At WK1, turbidity values ranged from a low of 0 NTU to a high of 87.4 NTU (Figure 98). At WK2, spring turbidity values ranged from 0.1 NTU to 13.1 NTU. At Iron Creek, summer and fall turbidity values ranged from 0 NTU to 53.6 NTU (Figure 30). Over 80% of the flows in WK1 and Iron Creek were < 10 NTU (Figure 31). This is consistent with the cumulative distribution of turbidity in Little Susitna River reference sites (Davis and Davis 2013).

There was no indication of an increase in turbidity due to the Willer-Kash Road Crossing. Daily average turbidity values were slightly higher at WK1 than at Iron Creek. Therefore, discharge from WK2 (treatment site) diluted the higher discharge values in WK1 resulting in a relative decrease in turbidity at Iron Creek. However, the turbidity differences were not significant (paired t-test, p = 0.07).

Turbidity increases paralleled storm events and subsequent increases in stream discharge. Turbidity (NTU) at WK1 (reference) and Iron Creek (below the road crossing) was significantly related to stream discharge (cfs). The slope of the regression relationship, however, was lower in Iron Creek below the road crossing (0.47) than in WK1 upstream (1.2).

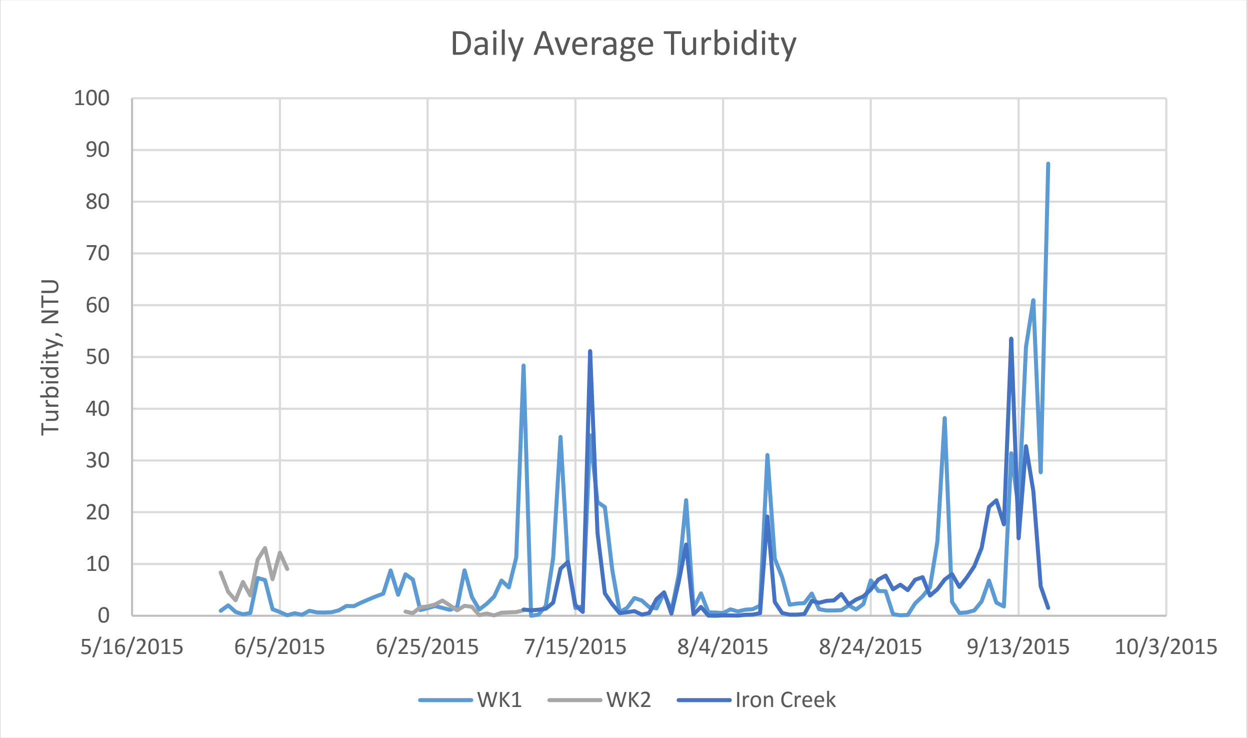

Figure 28. Daily average turbidity at WK1 and WK2 upstream from the road crossing and Iron Creek, downstream from the road crossing.

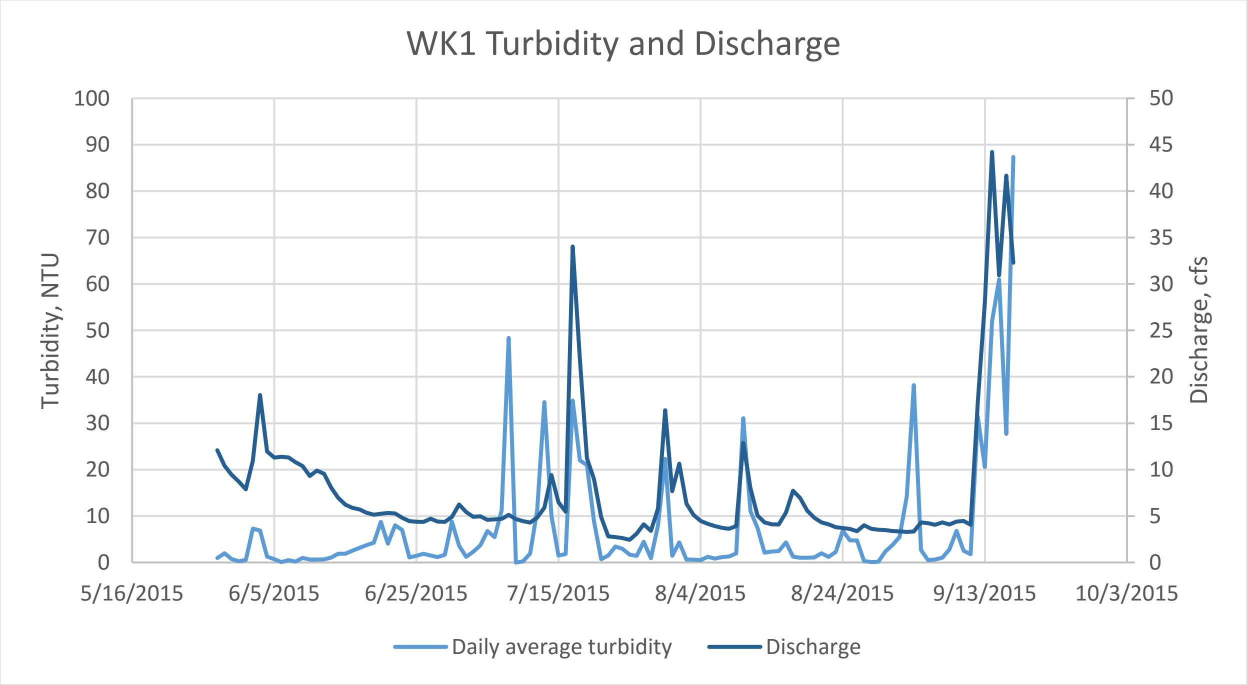

Figure 29. Daily average turbidity and discharge at WK1 (reference).

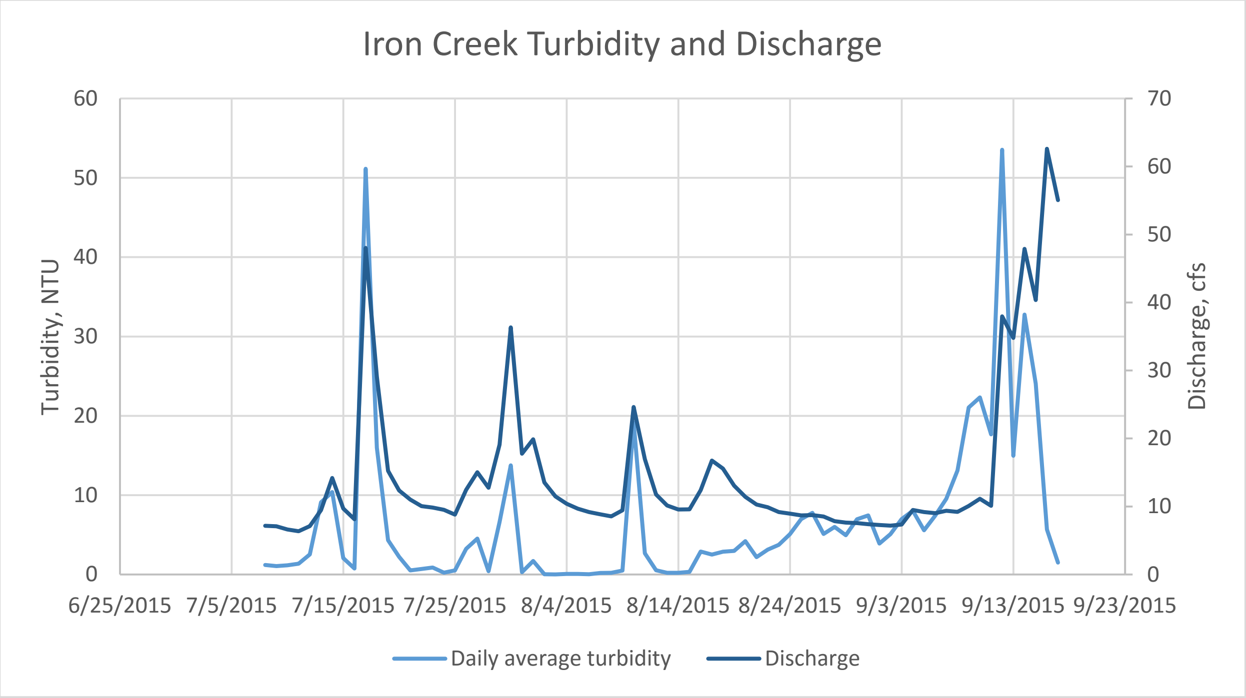

Figure 30. Daily average turbidity and discharge in Iron Creek below the road crossing.

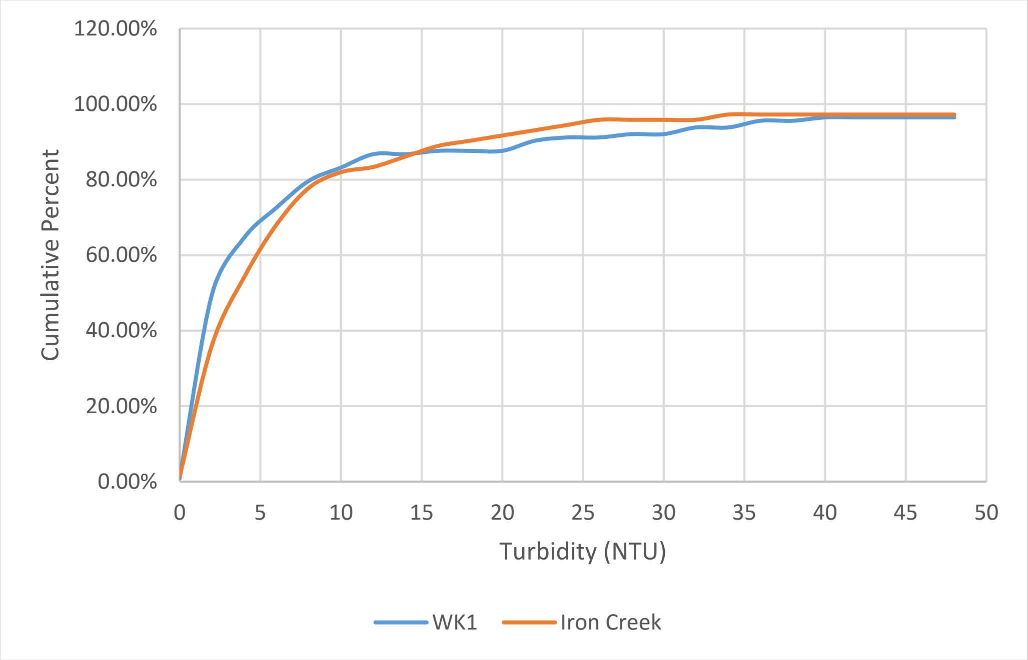

Figure 31. Cumulative frequency distribution of turbidity at WK1 and Iron Creek in 2015 showing that 80% of the values were < 10 NTU at both locations.

4.3 Biological Characteristics

4.3.1 Riparian Vegetation and Coarse Woody Debris

Riparian coarse woody debris is summarized in Table 8. The abundance of coarse wood within the riparian buffer zone was similar between WK1 and Iron Creek, with 20-22 pieces counted in 3,000 m^2. WK2 had a significantly lower abundance of coarse wood in the buffer zone, with only 8 pieces counted in 3,000 m^2. The low wood count in WK2 was due to differences in the riparian plant community, which along the left bank of the study reach consisted of open *Calamagrostis* meadow. There was no indication of timber harvest or blow down within the riparian area adjacent to the sampling reaches.

4.3.2 Periphyton Algae

Measures of algal abundance as chlorophyll-a (mg/m^2) at each site are presented in Figure 32. Mean chlorophyll-a ($n = 5$) was highest at WK2 (1.46 mg/m^2) and lowest in Iron Creek (0.79 mg/m^2); however, values did not differ significantly among sites (ANOVA, $p = 0.70$).

Algal abundance was measured at WK1 and WK2 in 2006, and 2007, and in WK2 in 2008. Chlorophyll-*a* showed no statistically significant temporal trends or differences between WK1 and WK2 (Figure 33). Values peaked in 2008 at WK2 with at 13.28 mg/m^2. Sampling in 2015 produced the lowest algal abundance values for both sites in all sampling events.

Table 8. Riparian coarse woody debris counts.

Diameter	**10-19 cm**	**20-29 cm**	**≥ 30 cm**	**Total**
WK1	16	5	1	22
WK2	5	2	1	8
Iron Creek	17.5	2.5	0.5	20.5
Length	**1-4 m**	**5-9 m**	**≥ 10 m**	**Total**
WK1	7	12	3	22
WK2	4	3	1	8
Iron Creek	5	15.5	0	20.5
Species	**Spruce**	**Birch**	**Alder**	**Total**
WK1	12	8	2	22
WK2	2	5	1	8
Iron Creek	2.5	0	0	20.5

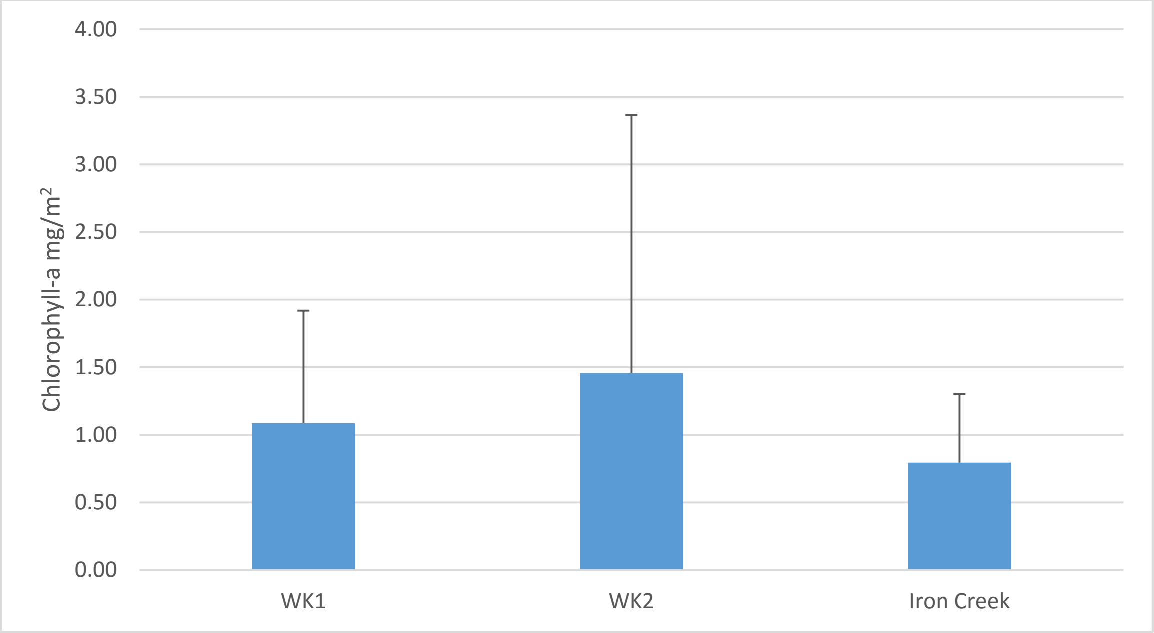

Figure 32. Mean (n = 5) chlorophyll-a density on stones within the three sampling reaches in 2015. Error bars are one standard deviation.

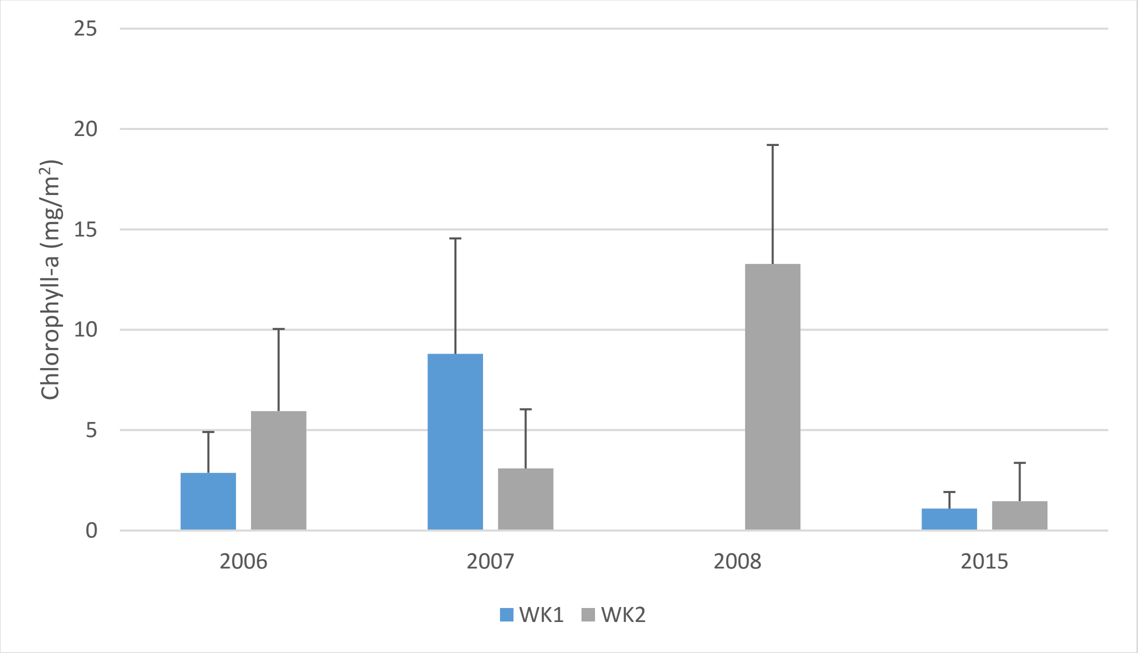

Figure 33. Chlorophyll-a density on natural substrates on multiple sampling dates from WK1 (reference) and WK2 (treatment) sampling sites.

4.3.3 Benthic and Dissolved Organic Matter

Benthic organic matter as coarse and fine fractions, and dissolved organic matter was not significantly different between the reference and treatment sites, and there was no significant trend over time at either site. Benthic organic matter for all sites was divided into CPOM and FPOM and displayed in Figure 34. CPOM and FPOM values were highest at WK1 and lowest at WK2, however values did not differ significantly between sites. Dissolved organic carbon (DOC), shown in Figure 35, ranged from 3.9 mg/L to 6.2 mg/L. DOC decreased from the first to the second sampling event, although values did not differ significantly between sites. DOC values decreased by an average of 27% in the second sampling event.

The density of CPOM and FPOM from previous sampling events is shown in Figures 36 and 37. Paired tests detect no significant difference in CPOM or FPOM between these two sites, or significant regression relationships in organic matter density over time.

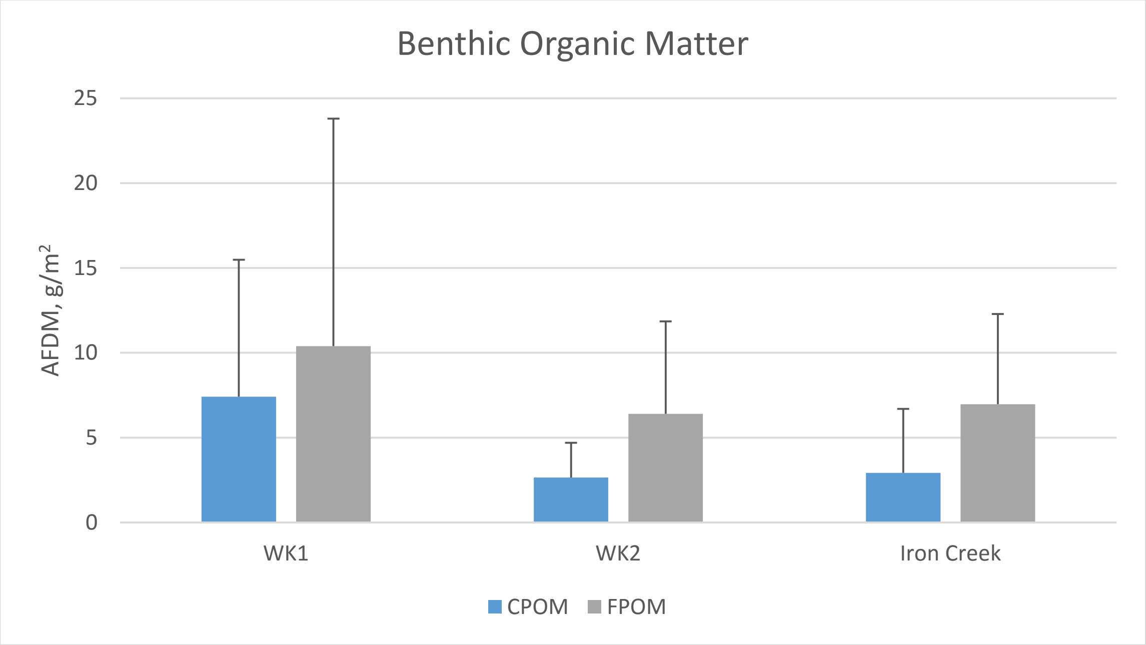

Figure 34. Benthic organic matter in WK1 (reference), WK2, and Iron Creek (treatment) sites in 2015 as coarse (> 1mm) and fine fractions). Error bars are one standard deviation.

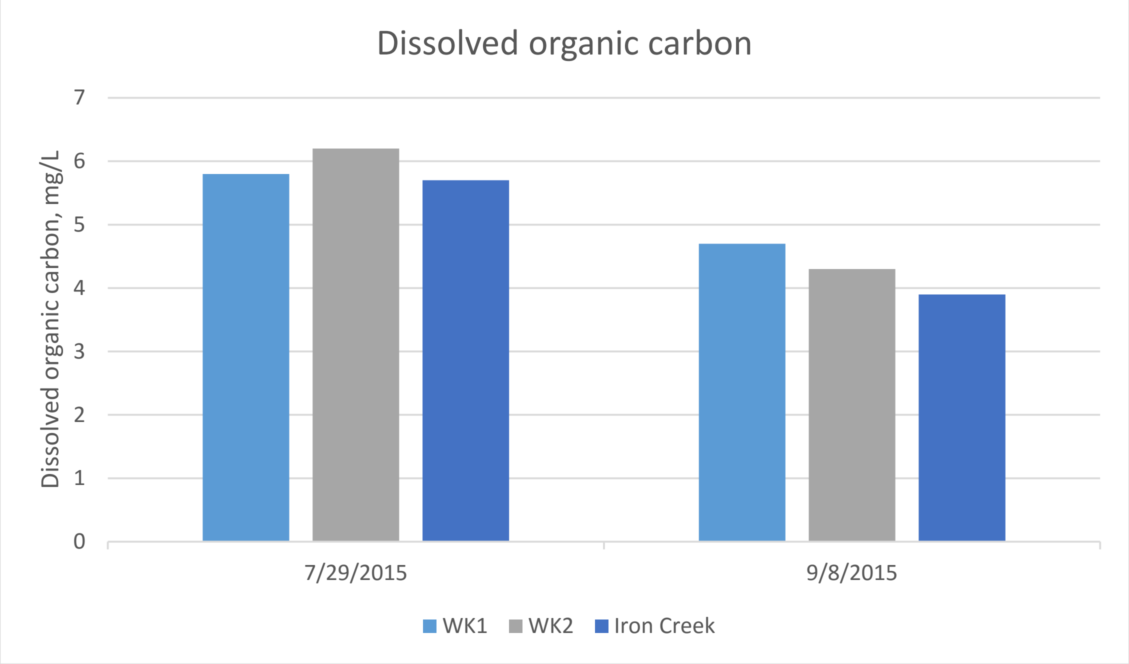

Figure 35. Dissolved organic carbon concentrations in water samples collected in late July and early September.

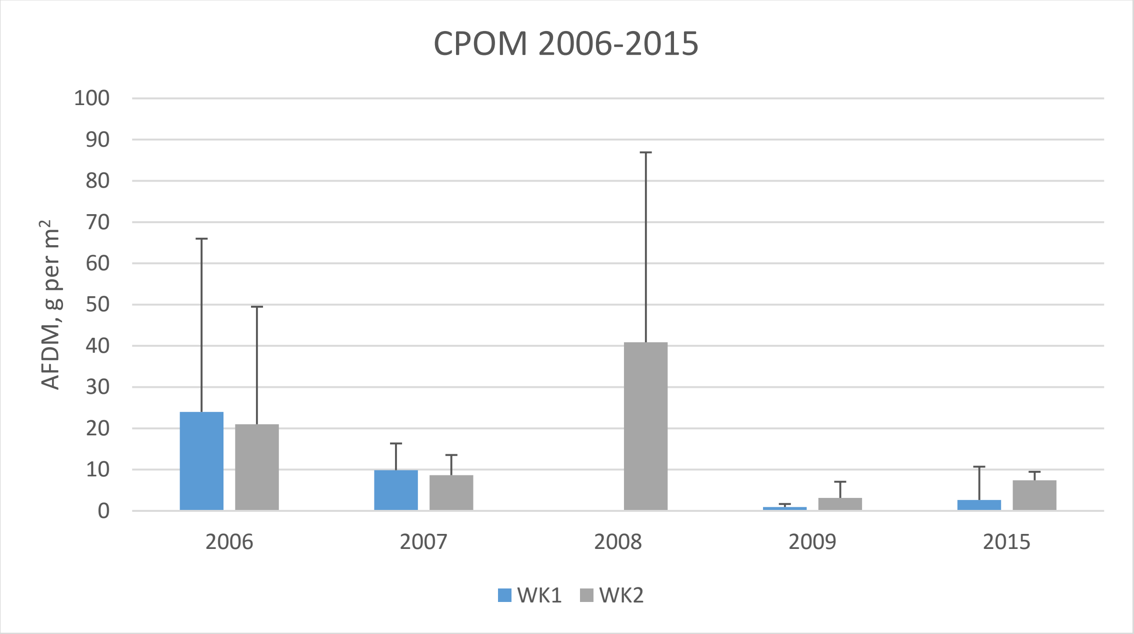

Figure 36. Density of coarse particulate organic matter on the stream bed on 4 sampling dates at WK1 (reference) and WK2 (treatment) sampling sites.

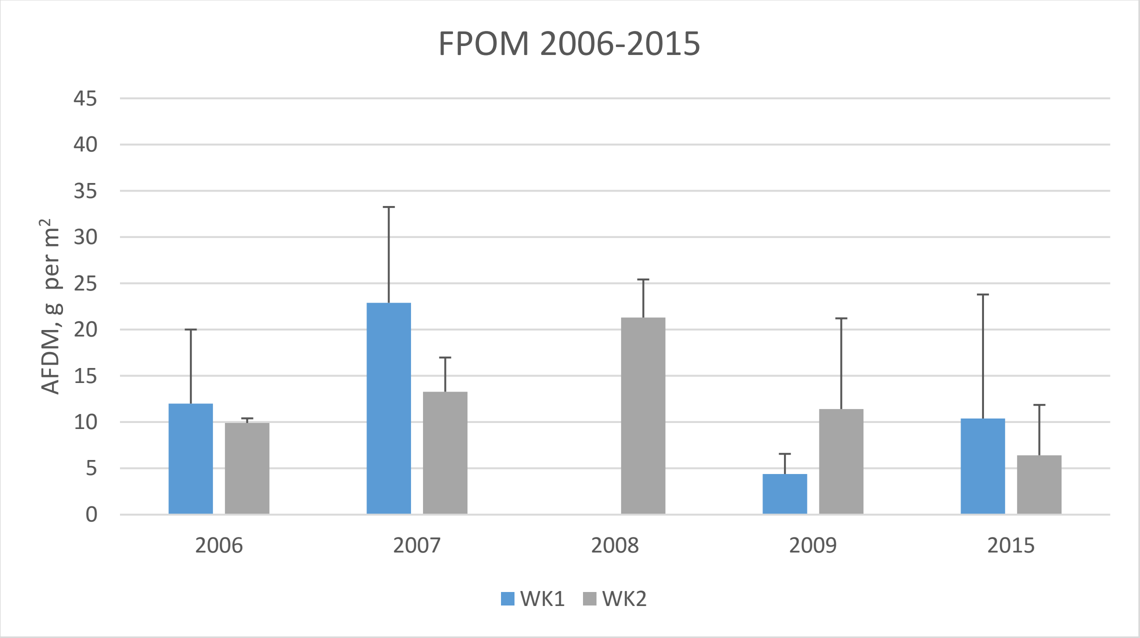

Figure 37. Density of coarse particulate organic matter on the stream bed on 4 sampling dates at WK1 (reference) and WK2 (treatment) sampling sites.

4.3.4 Macroinvertebrates

Macroinvertebrate samples were used to compute a multimetric score per site in order to assess the biological condition of aquatic communities in the Willer-Kash area. Metrics for community richness, composition, functional organization, and pollution tolerance were calculated as outlined by the Alaska Stream Condition Index (Major et al 2001). ASCI metrics vary by stream type, therefore, the three sites sampled were first categorized based on pebble count and habitat classification results. All three sites were classified as low gradient-coarse substrate, based on abundance of cobble (>40%) and on stream slope (<2%). The ASCI metrics for low gradient-coarse substrate stream types include: number of Ephemeroptera taxa, percent Ephemeroptera (excluding Baetids), percent Plecoptera, ratio of Baetidae to Ephemeroptera, percent non-insects, ratio of observed to expected taxa, percent scrapers, and Hilsenhoff Biotic Index (HBI).

Iron Creek and WK2 were both considered in good condition for their stream type, with ASCI scores of 55.58 and 51.82, respectively. WK1 was considered in fair condition for a low-gradient coarse substrate stream, with a score of 46.72. ASCI scores for all three sites are shown in Figure 38. Table 9 shows the metrics used to calculate the ASCI scores. All three sites had relatively low numbers of Plecoptera, which contributed to lower ASCI scores. Most of the Ephemeroptera were Baetidae, so the percentage of Ephemeroptera excluding Baetidae was generally low for the three sites. The percentage of scrapers was also low. All three sites had high HBI scores, indicating the presence of organisms with low tolerance to pollution.

Macroinvertebrate sampling began in 2006, and occurred over five seasons, including 2015. Trends over time show a general decline in ASCI score at WK1 (reference), however scores at WK2 (treatment) remain fairly constant (Figure 39). In 2006 and 2007, WK1 was considered in excellent condition, dropping 30.35 points to a rating of fair in 2015. This change is marked by the decline of Ephemeroptera, non-Baetid Ephemeroptera, Plecoptera, and the ratio of observed to expected taxa present at this site. WK2 was consistently rated as being in good condition, with a high score of 64.17 in 2009 and a low score of 51.82 in 2015 (Table 10).

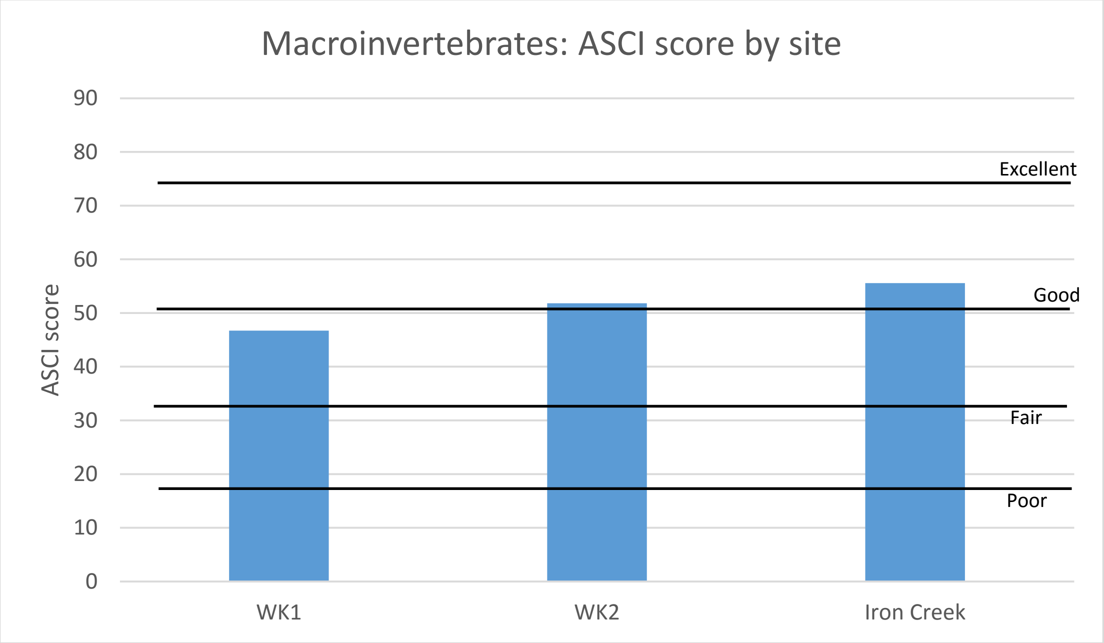

Figure 38. Alaska stream condition index scores based on macroinvertebrate metric for moderate sloped streams with cobble substrate. WK1, the reference site, had the lowest ASCI score.

Table 9. Macroinvertebrate metrics used to calculate ASCI scores and stream condition.

Metric	WK1	WK2	Iron Creek
Ephemeroptera taxa	36.36	54.55	72.73
% Plecoptera	0.00	10.20	2.10
% Ephemeroptera (excluding Baetidae)	5.00	14.29	8.82
Baetidae/Ephemeroptera	99.05	99.07	99.04
% Non-Insects	98.89	94.05	96.08
Observed/Expected	30.00	40.00	60.00
% Scrapers	4.44	2.38	5.88
HBI	100.00	100.00	100.00
ASCI Score	46.72	51.82	55.58
Condition	Fair	Good	Good

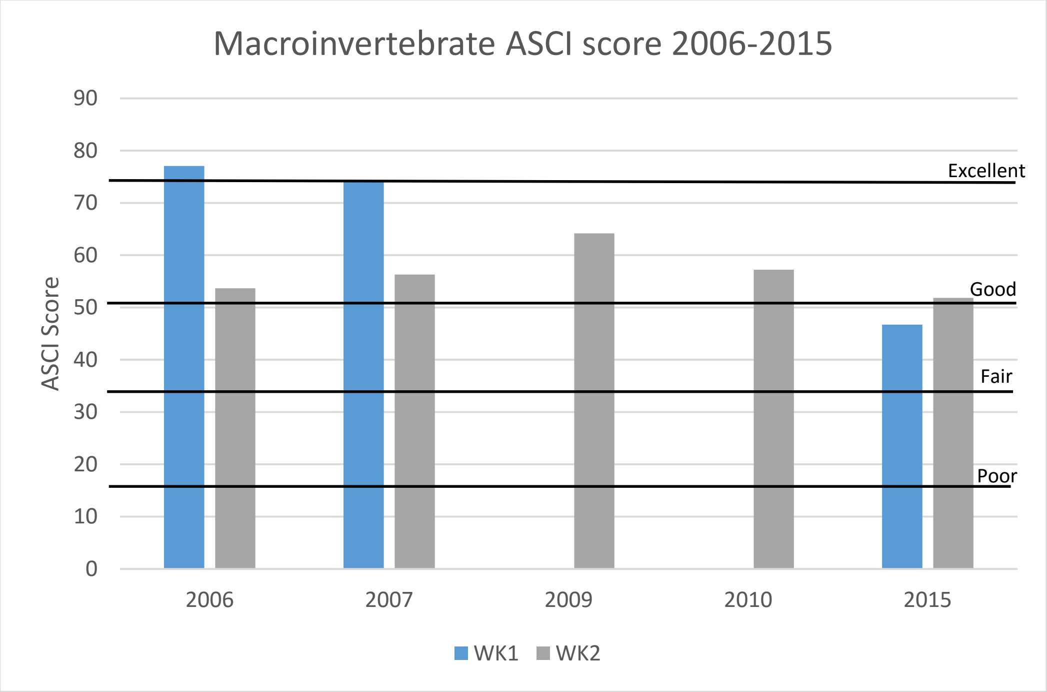

Figure 39. ASCI scores on muliple sampling dates from 2006 through 2015 showing no decline at WK2 the treatment stream reach.

Table 10. Individual macroinvertebrate metrics used to develop the ASCI score for each site and sampling date.

	2006		2007		2009	2010
Metric Score	**WK1**	**WK2**	**WK1**	**WK2**	**WK2**	**WK2**
Ephemeroptera taxa	72.73	54.55	90.91	72.73	100.00	72.73
%Plecoptera	74.98	24.52	100.00	31.25	34.24	14.79
%Ephemeroptera (no Baetidae)	74.59	30.04	82.38	44.64	45.75	19.23
Baedidae/Ephemeroptera	31.40	8.81	32.33	10.56	20.55	99.08
%Non-Insects	98.16	95.71	96.17	97.22	87.65	100.00
Observed/Expected	80.00	90.00	90.00	80.00	70.00	50.00
%Scrapers	84.71	25.75	2.55	13.89	55.19	1.97
HBI	100.00	100.00	100.00	100.00	100.00	100.00
Score	77.07	53.67	74.29	56.29	64.17	57.23
Rating	**Excellent**	**Good**	**Excellent**	**Good**	**Good**	**Good**

4.3.5 Juvenile Salmon

Five fish species were present during 2015 fish sampling. Species included juvenile coho salmon (*Onchorynchus kisutch*), juvenile Chinook salmon (*O. tshawytscha*), rainbow trout *(O. mykiss*), Dolly Varden char (*Salvelinus malma*), and sculpin (*Cottus sp.*). All five species were observed at all three sampling sites.

Coho salmon were the most abundant fish among all sites, followed by Chinook salmon, Dolly Varden, and rainbow trout. Sculpin were present at all three sites in low numbers. There was no significant difference in coho or Chinook salmon CPUT between the reference (WK1) and treatment (WK2) sites. Relative abundance data as catch per unit trap (CPUT) for each site is presented in Table 11 and displayed in Figure 40. Relative abundance of all species was highest at Iron Creek, with a mean total CPUT of 23.63 fish. Iron Creek also had the highest average relative abundance of salmonid species.

Fork length frequency distributions for coho and Chinook salmon are shown in Figures 41 and 42. Coho fork lengths ranged from 44-110 mm across all three sites. All sites had bimodal fork length distributions, indicating the presence of two distinct age classes: Age 0 (Young of Year) and Age 1+. A fork length of 70 mm was used to differentiate between the two age classes. Salmon with a fork length of less than 70 mm were classified as Young of Year (YOY). The ratio of Age 0 to Age 1+ coho salmon at each site is shown in Figure 43. YOY outnumbered Age 1+ coho at both WK2 and Iron Creek, while WK1 had more Age 1+ coho. All three sites had similar juvenile Chinook salmon size distributions representing a single age class. Median Chinook salmon fork lengths were 61 mm, 63 mm, and 59 mm at WK1, WK2, and Iron Creek, respectively.

Anadromous fish outnumbered resident fish at all three sites. The ratio of anadromous to resident fish at each site is shown in Figure 44. WK2 had the highest proportion of resident fish, while Iron Creek and WK1 had lower proportions of resident fish.

Average condition factor was calculated for sites WK1 and Iron Creek. Due to weigh scale lapse, no condition factor values were calculated for WK2. Average condition factor for Chinook salmon, Age 0 coho salmon, and Age 1+ coho salmon was higher at Iron Creek than WK1, however values did not differ significantly (Figure 45).

Table 11. Mean catch per unit trap (n = 20) at each sampling site by fish species.

	coho salmon	**Chinook salmon**	**Dolly Varden**	**rainbow trout**	**sculpin**	**Total CPUT**
WK1	6.95	1.10	0.60	0.60	0.30	9.55
WK2	11.00	1.95	1.40	1.20	0.50	16.05
Iron Creek	13.58	6.68	1.74	1.37	0.26	23.63

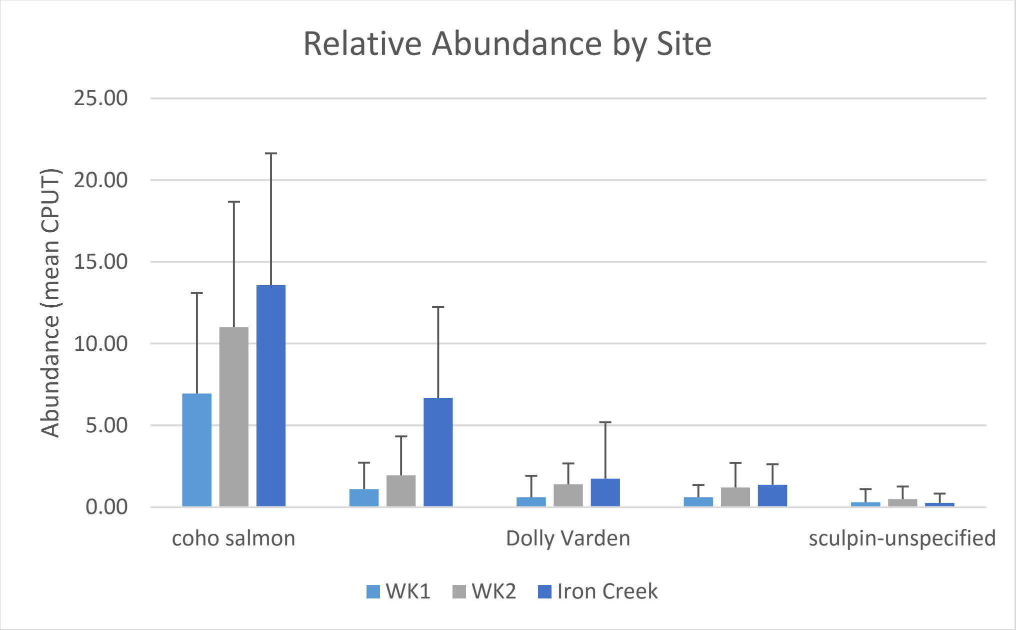

Figure 40. Mean 2015 fish CPUT by site.Error bars are one standard deviation.

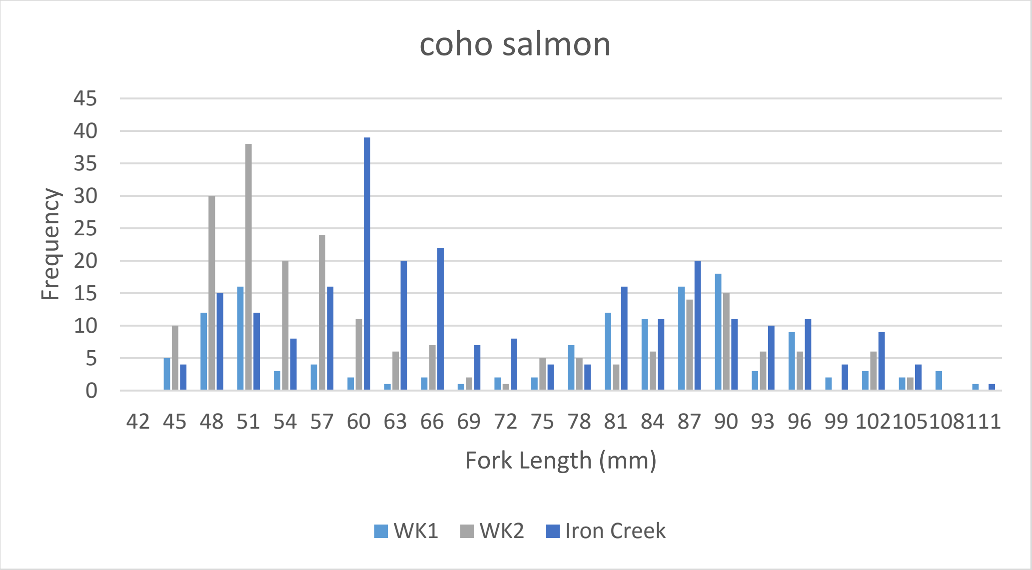

Figure 41. Size frequency distribution of juvenile coho salmon from the three sampling sites showing two distict age classes.

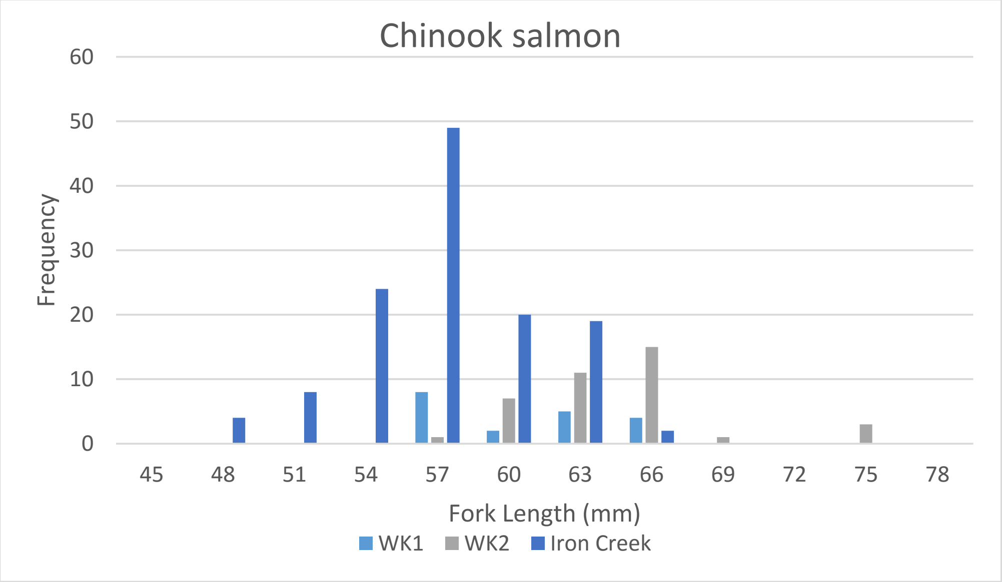

Figure 42. Size frequency distribution of Chinook salmon from the three sampling sites showing a single age class.

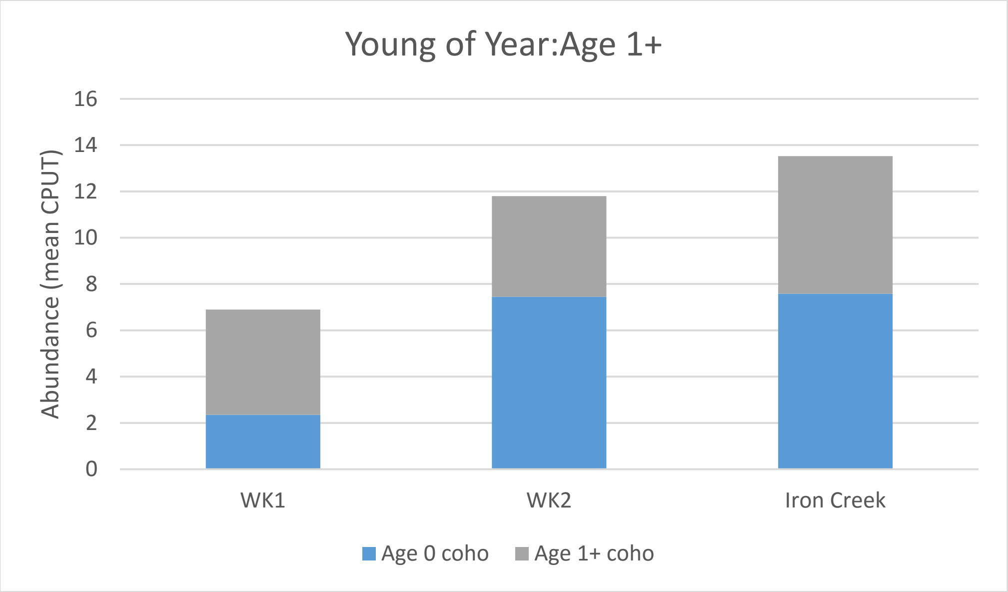

Figure 43. Abundance of age-0 and age-1 coho salmon in the three sampling sites.

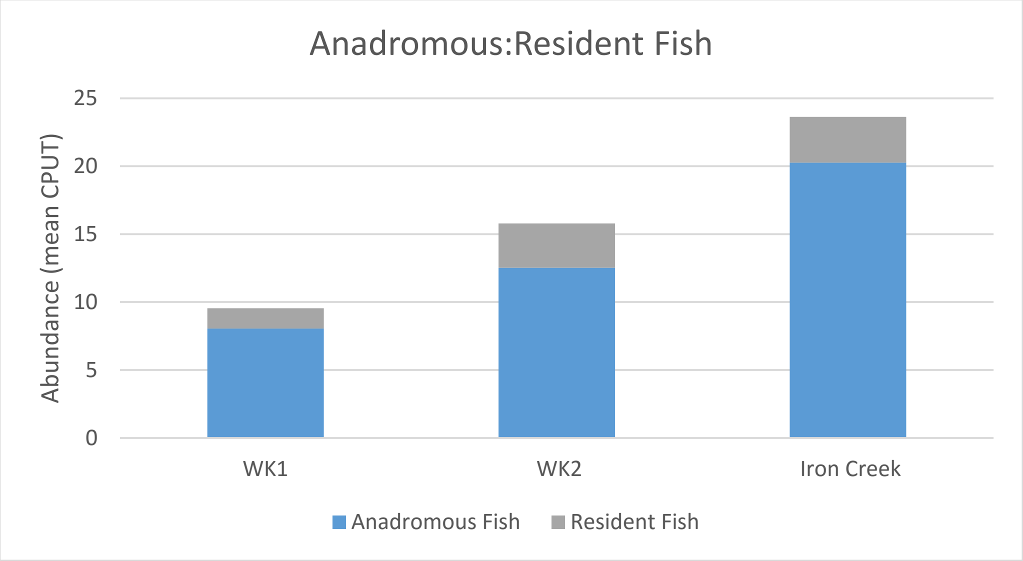

Figure 44. Abundance of anadromous and resident fish within the three sampling sites.

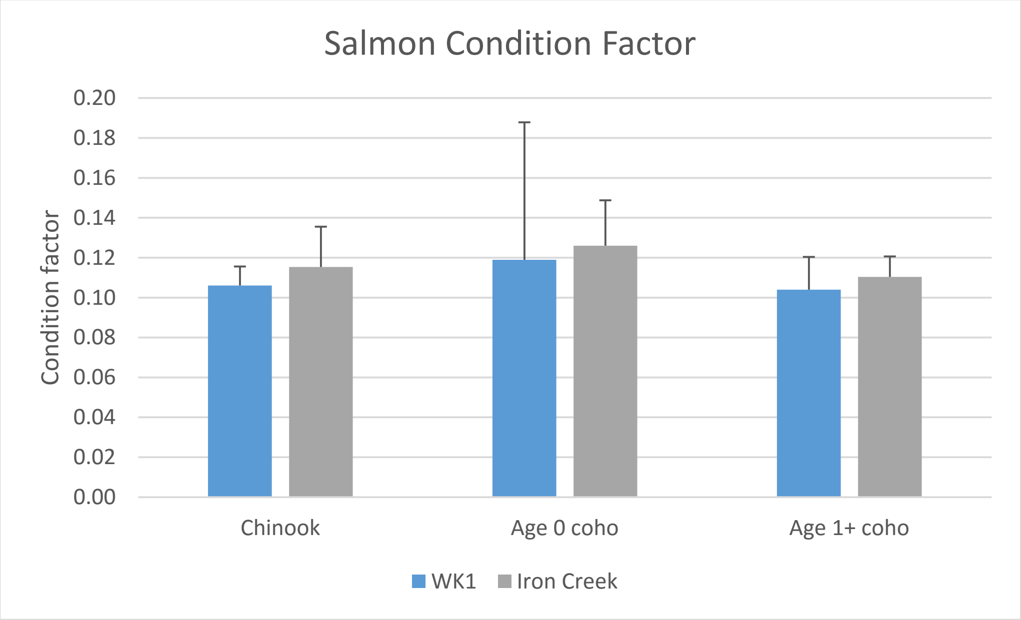

Figure 45. Condition factors of Chinook salmon and age-0 and age-1 coho salmon.

Fish sampling at Willer-Kash began in 2007 and was conducted one to three times per year at WK1 and WK2 all years except 2012. Fish species present included Chinook salmon, coho salmon, Dolly Varden, rainbow trout, sculpin, and stickleback (*Gasterosteus sp.*). Relative abundance by year and site is shown in Figure 46. For all fish species, relative abundance was variable over time with no significant temporal trends. The lowest mean total CPUT was in spring 2008, with 1.00 fish per trap at WK1 and 1.36 fish per trap at WK2. The high mean total CPUT was in fall 2009, with 16.9 fish per trap at WK1 and 26.10 fish per trap at WK2. Abundance of juvenile salmon over time per site are shown in Figures 47 and 48. Coho salmon tended to be more abundant than Chinook salmon, particularly in 2013 when no Chinook salmon were captured. Chinook salmon showed more variation in abundance than coho salmon, ranging from a mean CPUT of 0 to 17.85, while coho salmon ranged from 0.47 to 11.0.

Ratios of anadromous to resident fish for WK1 and WK2 are shown in Figures 49 and 50. Generally, anadromous fish were more abundant than resident fish. However, resident fish were more abundant than anadromous fish in fall 2013, when salmon abundance was very low.

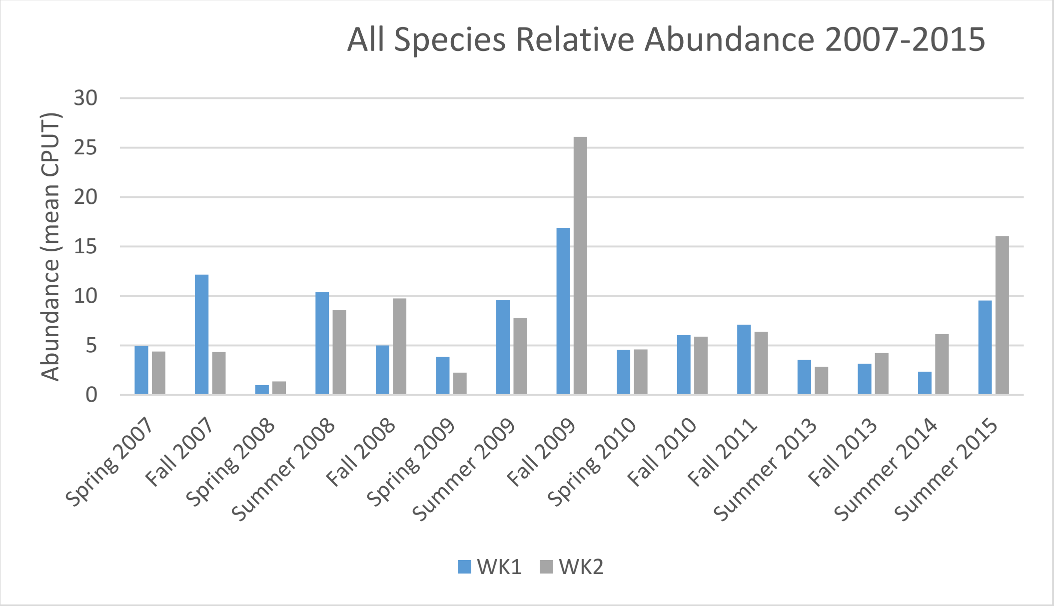

Figure 46. Relative abundance of all fish species on multiple sampling dates.

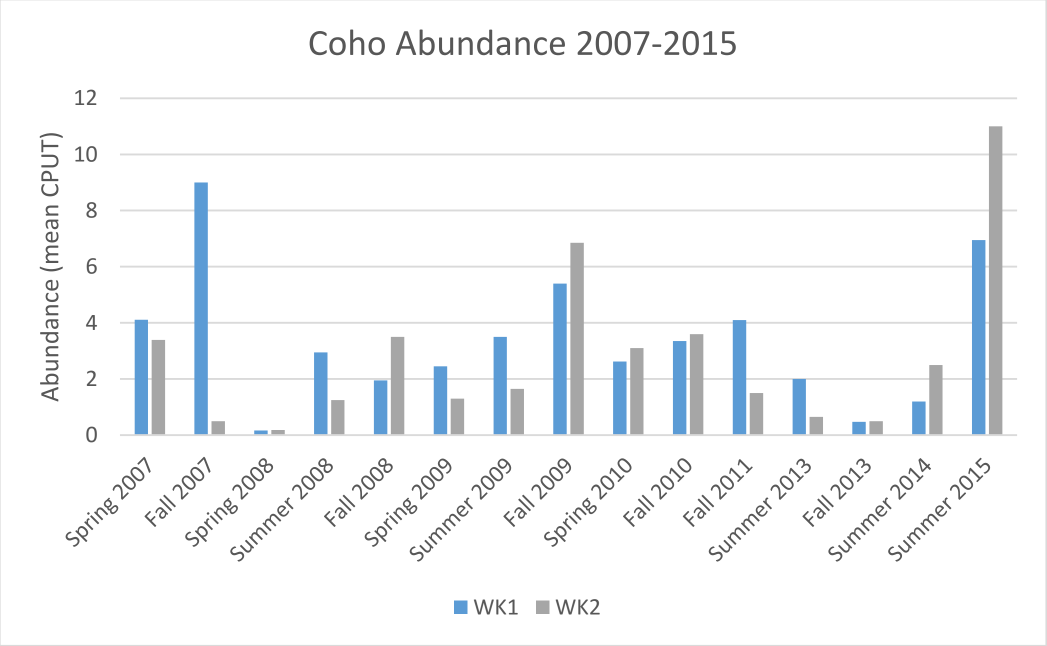

Figure 47. Relative abundance of coho salmon at WK1 (reference) and WK2 (treatment) sites showing not difference between sites or consistent trends over time.

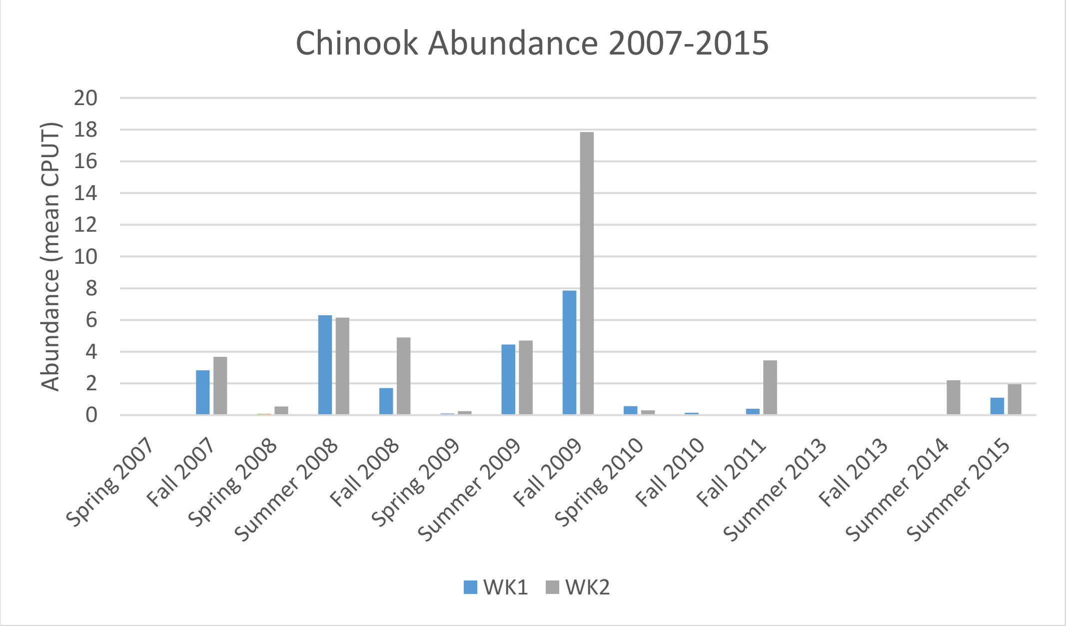

Figure 48. Relative abundance of juvenile Chinook salmon at WK1 (reference) and WK2 (treatment) sites showing not difference between sites or consistent trends over time.

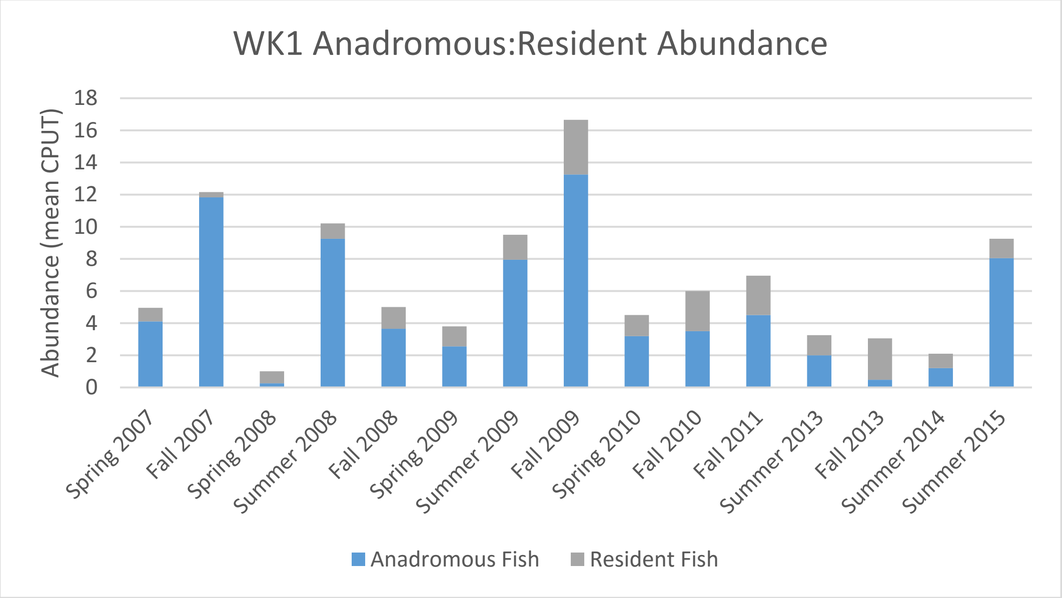

Figure 49. Relative abunance of resident fish and juvenile salmon on multiple sampling events at WK1 (reference).

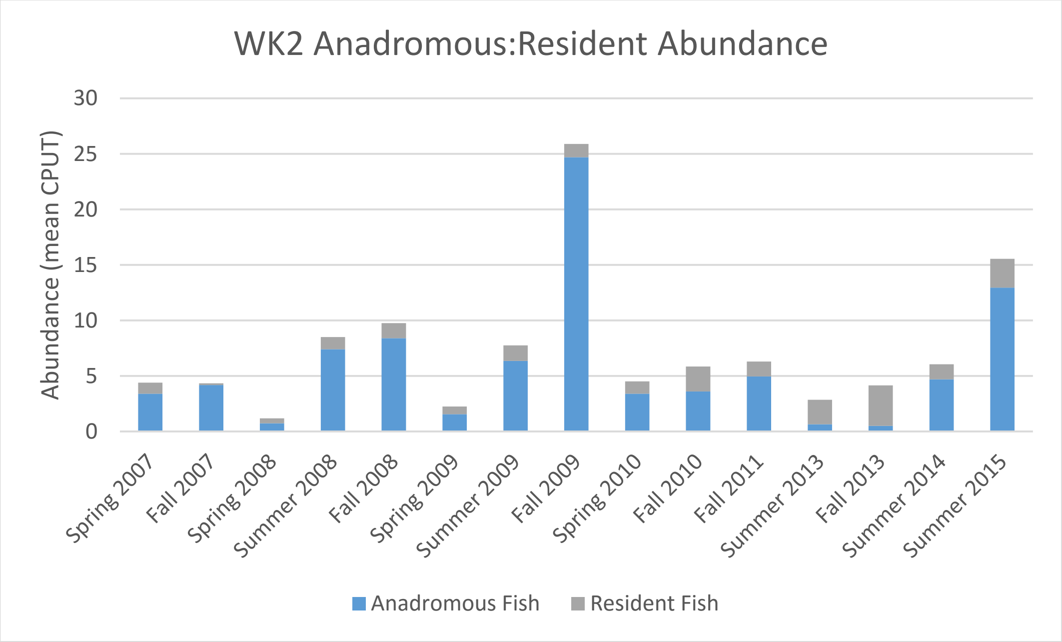

Figure 50. Relative abunance of resident fish and juvenile salmon on multiple sampling events at WK2 (reference).

5.0 Discussion

There was no indication of changes in water quality, physical habitats, or the biotic community that could be attributed to timber harvest related activities. The low level of timber harvest and road construction did not allow for a comprehensive evaluation of the effectiveness of FRPA best management practices. Therefore, if the extent of harvesting and road building increases, reevaluation of FRPA effectiveness is recommended.

The concentrations of nitrogen and phosphorus, and water temperatures were the primary differences between the reference and treatment stream reaches. The reference stream (WK1) had higher concentrations of phosphorus and lower concentrations of nitrogen that the treatment stream (WK2). This resulted in ratios of nitrogen to phosphorus suggesting nitrogen limitation in the reference stream and phosphorus limitation in the treatment stream. Concentrations of nitrogen and phosphorus would be expected to increase following timber harvest due to reduced nutrient uptake and increased rates of decomposition (Carignan et al. 2000, Steedman 2000). In addition, there was no reduction in hardness (calcium and magnesium ions), or specific conductivity as has been observed following timber harvest (Steedman 2000).

Stream water temperatures are increasing in both streams; however, these changes cannot be attributed to timber harvest activities. Partial or complete removal of riparian vegetation and changes in flow pathways can result in an increase in maximum water temperature due to forest harvest (Sridhar 2004). Water temperature in the treatment stream has been increasing annually; however, there has not been an annual incremental increase in harvest area. Although not investigated in this study, changes in stream temperatures are more likely due to annual differences in air temperatures.

There was no change in the density of algal chlorophyll-*a*, or organic matter over time or between the reference and treatment streams. This is consistent with similar concentrations of nutrients and solar radiation, and intact riparian zones.

There was no indication of changes in hydrology, bank erosion or sedimentation in the treatment stream. Timber harvest and road construction can result in an increase in peak storm flows (Whitaker et al. 2001) resulting in accelerated rates of bank erosion and increases in fine sediment. While we do not have a long –term measures of hydrology in either stream, there was no indication of a different hydrologic response to storm events between the reference and treatment streams. There was no indication of increased bank erosion, changes in channel morphology, or increases in fine sediment. Turbidity increased during storm events, but the rate of increase was greater in the reference stream than in Iron Creek, downstream of the confluence with the treatment stream and road crossing. There was no indication that hydraulic changes had influenced the input of woody debris through bank erosion or increased the rate of wood transport from the sampling reaches.

The macroinvertebrate and fish community did not differ between the reference and treatment sites and there were no consistent trends that could be attributed to timber harvest activity. The ASCI index score in the reference site decreased from previous measures in 2006 and 2007. The reduced ASCI scores were due to the large number of *Baetis* and the absence of Plecoptera. Additional sampling would need to be conducted to determine if these changes observed in 2015 are consistent. There has been no consistent change in the relative abundance of juvenile coho or Chinook salmon or the ratio of resident to anadromous fish. Low abundance of juvenile Chinook salmon in 2013 and 2014 is most likely due to lower adult returns.

The amount of timber harvest and road construction within the South Fork of Iron Creek (WK2) provides does not allow for a robust evaluation of the effectiveness of the best management practices of the FRPA. Harvested units are estimated to be < 10% of the watershed, and currently only one unit approaches designated riparian areas. There are no temporary or permanent road crossings. Temporary roads are accessed primarily for recreational, rather than timber harvest activities. However, based on personal observations, and the 5-year schedule of timber sales, the level of harvest within the Willer-Kash block is similar to what has occurred in the West Petersville, Rabideux, and Fish Creek timber blocks and slightly less than has occurred within the Houston timber block. Results from this study are likely representative of timber harvest effects on water quality and fish habitat within the Mat-Su Area. This study should be repeated if the level of harvest and road building increases significantly. Pre-harvest data are available for the Fish Creek timber block (Davis and Davis 2009) and multiple years of sampling has been conducted by ARRI on Queer Creek (unpublished). Future evaluation of timber harvest effects to fish habitat and water quality could be extended to those watersheds.

6.0 References

Alaska Department of Natural Resources (ADNR). 2014. Alaska Department of Natural Resources, Division of Forestry, Annual Report 2014.

Allan, J.D., M.S. Wipfli, J.P. Caouette, A. Prussian, and J. Rodgers. 2003. Influence of streamside vegetation on inputs of terrestrial invertebrates to salmonid food webs. Canadian Journal of Fisheries and Aquatic Sciences. 60: 309-320.

Bevenger, G. S., and R. M. King. 1995. A pebble count procedure for assessing watershed cumulative effects. USDA Forest Service. Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO. Research Paper RM-RP-319.

Carignan, R., P. D'Arcy, and S. Lamontagne. 2000. Comparative impacts of fire and forest harvesting on water quality in Boreal Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences. 57: 105-117.

Davis, J. C., and G. A. Davis. 2005. Cottonwood Creek TMDL Development—Residue. Aquatic Restoration and Research Institute. Final Report for the Alaska Department of Environmental Conservation, ACWA 05-02. Talkeetna, Alaska.

Davis, J.C., and G.A. Davis 2009. FRPA Region II effectiveness monitoring. Final Report for the Alaska Department of Environmental Conservation. Aquatic Restoration and Research Institute, Talkeetna, Alaska. (available from www.arrialaska.org)

Davis, J.C., and G.A. Davis. 2008. FRPA Effectiveness Monitoring within the Willer-Kash State Forest Harvest Area: July 2006 through May 2008 Summary. Final Report for the Alaska Department of Environmental Conservation. Aquatic Restoration and Research Institute, Talkeetna, Alaska. (available from www.arrialaska.org)

Davis, J.C., and G.A. Davis. 2013. Water quality in the lower Little Susitna River, Cumulative draft report: July 2007 through June 2012. Final report for the Alaska Department of Environmental Conservation. Aquatic Restoration and Research Institute, Talkeetna, Alaska. (available from www.arrialaska.org)

Davis, J.C., G.W. Minshall, C.T. Robinson, and P. Landres. 2001. Monitoring wilderness stream ecosystems. Gen. Tech. Rep. RMRS-GTR-70. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 137p.

Kahlert, M. 1998. C:N:P ratios of freshwater benthic algae. Archiv fur Hydrobiologie, Special Issues: Advances in Limnology 51:105-114.

Major, E.B., B.K. Jessup, A. Prussian, and D. Rinella. 2001. Alaska stream condition index: biological index development for Cook Inlet 1997-2000 summary. University of Alaska Anchorage, Alaska Department of Environmental Conservation, Anchorage, Alaska.

Murphy, M.L., and A.M. Milner. 1997. Alaska timber harvest and fish habitat. Freshwaters of Alaska. Ecological Syntheses, Springer, New York. Ecological Studies 119: 229-263.

Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross, and R. M. Hughes. 1989. Rapid Bioassessment Protocols for use in streams and rivers: benthic macroinvertebrates and fish. U.S. Environmental Protection Agency, Washington D.C. EPA-444/4-89-001.

Redfield, A.C. 1958. The biological control of chemical factors in the environment. American Scientist 46:205-221.

Sridhar, V., A.L. Sansone, J. LaMarche, T. Dubin, and D.P. Lettenmaier. 2004. Prediction of stream temperature in forested watersheds. Journal of the American Water Resources Association. 40: 197-213.

Steedman, R.J. 2000. Effects of experimental clearcut logging on water quality in three small boreal forest lake trout (Salvelinus namaycush) lakes. Canadian Journal of Fisheries and Aquatic Sciences. 57(S2): 92-96.

Viereck, L.A., Dyrness, C.T., Batten, A.R., Wenzlick, K.J. 1992. The Alaska vegetation classification. General Technical Report PNW-GTR-286. U.S. Department of Agriculture, Forest Service. Pacific Northwest Research Station, Portland, OR. 278 p.

Whitaker, A., Y. Alila, and D.A.A. Toews. 2001. Modelling of peak flow change using the DHSVM model. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 94-111.