Water Quality in the Lower Little Susitna River

Cumulative Report: July 2007 through August 2012

FINAL

8/1/2013

Prepared for

Alaska Department of Environmental Conservation

By

ARRI
Aquatic Restoration & Research Institute

Jeffrey C. Davis and Gay A. Davis
P.O. Box 923, Talkeetna AK 99676

Acknowledgements

This summary report was supported with funding provided by the Alaska Department of Environmental Conservation, Alaska Clean Waters Action Program Contract No. 18-6002-12.

Contents

Tables

Figures

Definitions and Acronyms

µg/L	Micrograms per liter, parts per billion
mg	Milligram
m	Meter
km	Kilometer
mm	Millimeter
mi	Mile
BTEX	Constituents of gasoline (Benzene, Toluene, Ethyl Benzene, and Xylene) used to calculate TAH
C	Temperature in centigrade or Celsius units
cfs	Units of flow or discharge in cubic feet per second
CPUT	Catch per unit trap
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
Flux	Movement of mass over time
FTU	Formazine Turbidity Units
hp	Horse power, rating of motor size
mg/L	Milligrams per liter, parts per million
NTU	Nephelometric Turbidity Units
PUF	Public use facility and boat launch in the Lower Little Susitna River operated by the state Departments of Natural Resources and Fish and Game
RM	River mile measured from the river's mouth moving upstream
TAH	Total aromatic hydrocarbons; sum of benzene, toluene, ethyl benzene, and xylene
Thalweg	The main channel of a stream or river. Portion of the stream that contains most of the flow.
VOC	Volatile organic compound
WQC	Water quality criterion (parameter specific criteria contained within the WQS)
WQS	Alaska Water Quality Standards 18 AAC 70

Summary

This report summarizes Little Susitna River water quality studies conducted from 2007 to 2012. The water quality studies monitored petroleum hydrocarbons and turbidity to determine if increases in concentrations were caused by motorized boating and if values were in excess of Alaska Water Quality Standards (WQS). Concerns about Little Susitna River water quality were raised due to the increasing number of boats during the sport fisheries and documentation of hydrocarbon concentrations above WQS due to similar boating activities for fisheries in the Kenai River. In response to these concerns, the Alaska Department of Environmental Conservation (DEC) initiated a water quality monitoring study in 2007 for the lower part of the Little Susitna River (Lower Little Susitna River). Initial study objectives were to determine if total aromatic hydrocarbons (TAH) from gasoline adjacent to the Public Use Facility (PUF) boat launch were present at detectible concentrations and if so, whether concentrations were measured above WQS. Additional studies were conducted from 2008 through 2012 during part or all of the summer season (May – August) to determine the relationship between boat use and hydrocarbon concentrations, the length of stream and duration of time (annual, seasonal, daily) hydrocarbons were present, and exceedances of WQS. Initial study results also detected increases in stream water turbidity. Therefore, study objectives were expanded to include measures of turbidity along with measures of TAH. Biological monitoring was conducted to determine if water quality could be negatively affecting the aquatic community.

TAH Results

The 3-day average concentrations of TAH exceeded the WQS in 2009 and 2010 (Table 8). In 2013, DEC drafted a listing methodology for TAH which recommends that a 4-day average be used to evaluate chronic effects on aquatic life. The concentrations of TAH needed to exceed WQS if a fourth day of sampling had been conducted are estimated to be 11 µg/L in 2009 and 5 µg/L in 2010.

The PUF entrance booth boat count data allowed for estimates of TAH concentrations in the river from the boat launch on week days and weekends when data collection and boat observations were not conducted at the PUF boat launch. Using these regression equations and total boats, TAH concentrations would exceed 10 µg/L on days when 39 or more boats passed the PUF entrance booth, with a 95% confidence interval of 26 to 72 boats. The number of consecutive days when more than 39 boats passed the entrance booth was 5 in 2008, 4 in 2009, and 3 in 2010. Therefore, in both 2008 and 2009 the 4-day average would have likely exceeded the water quality standard.

Using the cumulative dataset, maximum TAH concentrations exceeded WQS[1] during every year except August 2012 (Table 6). Of the 362 samples taken primarily on weekend days (i.e. high boat activity) collected from 2007-2012, 66 samples, or 18.2%, were above WQS. Broken down by day, of the 62 sample days from 2007-2012, 26 of these days (42%) had at least one or more of the sample sites with TAH concentrations greater than 10 µg/L. Maximum and minimum values are shown in Figure 3 for all sample dates and a summary of TAH samples for each site is provided in Table 7.

---

[1] The WQS for Petroleum Hydrocarbons to protect aquatic life is 10 µg/L (18 AAC 70, see Table 5).

TAH concentrations were highest in June and August, on weekends and were highly variable throughout a day ranging from below method detection limits to well over WQS during the day. Average daily TAH values exceed WQS on the busiest use days; however, study results show that TAH concentrations do not remain above WQS throughout an entire 24 hour day. TAH concentrations were highest downstream from the PUF boat launch. TAH concentrations greater than 10 µg/L were recorded at sites located from 4 km (2.5 miles) upstream from the PUF boat launch to 12 km (7.5 miles) downstream.

Turbidity Results

Data collected from 2008-2011 showed turbidity levels exceeded the WQS for all three designated uses: water supply, recreation, and growth and propagation of fish, shellfish, other aquatic life, and wildlife. However, the aquatic life criterion was exceeded less than 10% of the time.

Stream water turbidity was higher downstream from the PUF in comparison to the un-impacted upstream site. The statistically defined “natural conditions” turbidity value at the reference site is 14.9 NTU (90% of the values are lower than this value). Turbidity values downstream from the PUF were above the natural condition and exceeded water quality criteria (WQC) for water supply and recreation and, at times, the aquatic life criterion. Turbidity 4 km (2.5 miles) downstream from the boat launch exceeds this natural condition value by 5 NTU 30% of the time, and by 10 NTU 15% of the time. Increases in turbidity are greater when analyses are limited to times of increased boat activity, June and August and even more so if limited to days of the week with most boating activity (Saturday and Sunday).

The combination of boat activity and presence of fine substrate resulted in turbidity values that exceed WQS. A significant relationship between the number of boats and increases in turbidity exists. In addition, turbidity changes throughout a day, starting with a sharp increase beginning early in the morning at the start of boating activity. Turbidity increases throughout the day by 15 to 20 NTU until around 11:00 PM, and then declines gradually through the night. This pattern is strongest during peak boat activity and is absent when boats are absent. This daily pattern was not observed at the upstream reference site and cannot be explained by any natural processes.

Biological Monitoring

Ecosystem production, invertebrate drift, and juvenile salmon abundance were lower downstream from the PUF compared to the upstream sample site. Declines in primary production were linked to changes in turbidity. This study cannot confirm that differences in macroinvertebrates and juvenile salmon abundance are the result of decreased water quality; however, changes in water quality, and reduced ecosystem production have the potential to negatively affect rearing salmon and invertebrates and could be at least part of the cause of the observed differences. Further biological studies would be needed to identify the exact cause of the biotic differences.

In conclusion, the operation of motor boats in the Lower Little Susitna River causes an increase in TAH concentrations and turbidity. TAH concentrations at the boat launch are closely related to the number of 2-cycle motors but average downstream concentrations are more closely related to the total number of boats, regardless of motor type. TAH concentrations often exceed 10 µg/L, but do not remain above this concentration on all sampling dates. Turbidity downstream from the boat launch exceeds WQC. The abundance of juvenile salmon and aquatic insects is lower downstream from the PUF boat launch compared to upstream which may be due to changes in water quality and the physical environment from motorized boat traffic; or other factors unrelated to human activity.

1.0 Introduction

The Little Susitna River, located in Southcentral Alaska, supports five species of Pacific salmon. The river is accessible from the urban centers of Anchorage and Wasilla resulting in large numbers of anglers during the Chinook and coho salmon fisheries. There are two primary boat access points to the Lower Little Susitna River, private and unimproved boat launches near the City of Houston approximately 100.5 km (62.8 miles) upstream from Cook Inlet, and at the PUF boat launch located approximately 40 km (25 miles) upstream from Cook Inlet. Use of the river is concentrated near the PUF. The number of boats and anglers has been increasing over time along with concerns about water quality.

Outboard motors can discharge burned and unburned hydrocarbons (Butcher 1982, Jüttner et al. 1982, Lerner et al. 2009). The use of outboard motors has been found to result in the discharge of petroleum hydrocarbons to lakes and rivers (Lico 2004, ADEC 2009). Hydrocarbons consist of volatile organic compounds (VOC) (benzene, toluene, ethyl-benzene, and xylene) and the heavier polycyclic aromatic hydrocarbons (PAHs). VOC is synonymous with state hydrocarbon TAH standards. Lico (2004) measured VOCs and PAHs in high boat use areas of Lake Tahoe and the adjacent Donner Lake, California. PAHs have been detected in surface waters and sediments of Crater Lake, Oregon (Oros et al. 2007). Seasonal patterns of PAH concentrations in Auke Lake, Alaska were correlated with the operation of 2-cycle motors (Rice et al. 2008). Using similar methods, Moles et al. (2006) detected PAHs in the Kenai River, Alaska in portions of the river subject to intensive boat use during the salmon fisheries. VOCs have also been detected within the Kenai River and Big Lake, Alaska (DEC 2007, 2009) at concentrations that exceed Alaska Water Quality Standards (DEC 2011) in high boat use areas.

Two-cycle motors have been shown to discharge 10 to 30% unburned fuel, up to 10 times greater than discharge from 4-cycle motors (Jüttner et al. 1982). The discharge from 2-cycle motors is greatest at idle or low operating speeds (Butcher 1982). The partial ban on 2-cycle motors in the Kenai River reduced TAH concentrations (DEC 2010). Concentrations of VOCs in Lake Tahoe also decreased in response to a ban on 2-cycle motors, but did not result in significant declines in PAHs (Lico 2004).

Petroleum hydrocarbons can have lethal and sub-lethal effects to aquatic organisms. Sculpin (*Cottus asper*) condition, number of parasites and the abundance of lesions has been shown to be related to differences in PAH concentrations (Moles and Marty 2005). PAH is hypothesized to be the cause of the loss of mussels (*Anodonta* sp.) and sticklebacks (*Gasterosterus* sp.), and reduced sockeye salmon abundance in Auke Lake (Moles and Marty 2005). Rainbow trout (*Onchorhynchus mykis*) exposed to exhaust from 2-cycle motors exhibited DNA damage and reduced carbohydrate metabolism (Tjarlund et al. 1996). Chinook salmon smolt and juveniles exposed to PAHs can cause reduced biomass and fat content which could affect overwinter survival (Meader et al. 2006). The exposure of pink salmon embryos to 1 µg/L PAH can result in reduced survival and growth (Heintz et al. 1999, 2000 in Rice et al. 2008). Alaska WQC for the protection of aquatic life based on tolerance limits for salmon species are 10 µg/L for VOCs and 15µg/L for the sum of VOCs and PAHs (DEC 2006).

Concentrated boat and shore traffic can result in increased rates of bank erosion, increases in suspended sediments and increases in petroleum hydrocarbon concentrations. Foot traffic along riverbanks can remove vegetation and reduce the sheer strength provided by plant roots leading to bank failure (Beesen and Doyle 1995, Davies-Colley 1997, Anderson and Bledsoe 2001). Bank failures can be exacerbated by boat waves that increase near-shore tractive forces increasing erosion and steepening banks (Nanson et al. 1994). Boat induced changes in streambed tractive forces can elevate concentrations of suspended sediment (Yousef 1974, Hilton and Philips 1982, Garrard and Hey 1987, Osborne and Boak 1999).

The influence of boats on suspended sediment and turbidity is variable. Yousef (1974) showed that in shallow lakes, boats could increase turbidity, depending on water depth, motor size, and bed sediments. Garrard and Hey (1987) demonstrated an increase in turbidity in rivers caused by a single boat passage, and the time in suspension increased with boat speed. By modeling suspended sediments as a function of boat passage in rivers, Hilton and Philips (1982) showed that turbidity can continue to increase if the frequency of boats does not allow for the resettlement of particles. Suspension of bed sediments is a function of tractive forces which are related to vessel wave heights (Nanson et al. 1994, Osborne and Boak 1999) that vary with vessel speed (Garrard and Hey 1987), and hull design or displacement (Garrard and Hey 1987, Maynard 2001). Particles can remain in suspension due to boat-induced turbulence and the passage of additional waves (Garrard and Hey 1987, Osborne and Boak 1999).

Considerable work has been conducted evaluating the effect of turbidity and suspended sediment on stream primary productivity, and macroinvertebrate and fish communities (Oregon DEQ 2007). Suspended sediment reduces primary production by reducing the amount of light reaching the streambed (Laperrier et al. 1989; Davies-Colley 1992) and can remove periphyton through abrasion (Davies-Colley 1992). Small changes in turbidity can cause rapid decreases in primary productivity (Davies-Colley 1992, Lloyd et al. 1987). Loss of periphyton biomass from reduced primary production and abrasion can reduce the abundance of grazing aquatic insects (Fairchild and Lowe 1984, Lamberti et al. 1989). Suspended sediment can reduce the quality of food captured by filter feeders (Lemly 1982, Love and Baily 1992). The reduction of benthic invertebrates can result in lower levels of invertebrate drift (Minshall and Petersen 1985). Reduced visibility due to suspended sediment and lower concentrations of invertebrates can limit the ability of rearing juvenile salmon to capture prey (reviewed in Newcombe and McDonald 1991). Sediment particles also can directly damage fish gills (Lake and Hinch 1999). Therefore, turbidity and suspended sediment can directly affect rearing salmon and indirectly through reductions in the abundance and ability to capture prey.

Concentrated boat use on the Lower Little Susitna River during the Chinook and coho salmon fisheries has raised public concern over potential changes in water quality and affects to salmon populations. In response to these concerns and documentation of hydrocarbon concentrations in the Kenai River above WQC, DEC initiated Little Susitna water quality studies in 2007.

Beginning in 2007, limited water quality sampling was conducted to determine if hydrocarbon concentrations in the Little Susitna River were present at concentrations above detection limits and if so, if results were in compliance with WQC. Sampling sites were located upstream and downstream from boat launches near the city of Houston, and upstream and downstream from the PUF in the lower river (Table 1). These two locations, along with launches at campgrounds within the city of Houston, are the only sites that provide motor-boat access. Sampling was conducted weekly from the middle of July through the middle of September 2007, and from the middle of May through the middle of June 2008. Stream water turbidity was measured concurrent with hydrocarbon sampling and boat use was estimated by counting the number of boat trailers. Initial screening results showed that TAH exceeded WQS on some dates upstream and downstream from the PUF concurrent with high boat use and that stream water turbidity was elevated relative to upstream reference values.

Due to initial findings, water quality in the Lower Little Susitna River became an Alaska Clean Water Action (ACWA) priority (see Table 2 for study summaries). Sampling continued in July of 2008 concentrating on locations extending from 1 km (0.6 miles) upstream to 4 km (2.5 miles) downstream of the PUF boat launch. Sampling was conducted weekly (on Saturday or Sunday) through the Chinook (late May and June) and coho (August) sport fisheries. TAH sampling at these locations continued through 2009 and the spring of 2010. To investigate daily variability in TAH concentrations, more intensive sampling (from 06:00 to 21:00 Saturday through Monday) was conducted at the PUF boat launch. To determine how far along the river corridor concentrations exceeding WQC were distributed, sampling locations were extended in the fall of 2010 to 8 km (5 miles) upstream and 12 km (7.5 miles) downstream from the PUF. In the spring of 2011 TAH monitoring was conducted throughout the day at the PUF boat launch to measure daily variability. In August 2012, sampling was extended to obtain a 4-day average TAH concentration. Boat use was recorded during each sampling event by counting the boats by motor type (2-cycle or 4-cycle) and size (horse power) operating at the PUF, and from counts at the state operated entrance booth.

Turbidity and basic water physical and chemical characteristics (pH, specific conductance, and dissolved oxygen) were measured from grab samples collected concurrent with TAH sampling. Turbidity from grab samples was augmented with data collected by water quality sondes (Hydrolab MS-5) that recorded values hourly beginning in 2008. One sonde was initially placed at a reference site located 8 km upstream from the PUF (LS 8 km up); however, due to frequent boat use at this location, the sonde was moved to a site downstream from the city of Houston (LS 60 km up) in 2009 and 2010. Sondes were also located at potentially impacted sites located 4 km (LS-4 km dn) and later at 8 km (LS-8 km dn) downstream from the PUF.

Biological monitoring was initiated in the fall of 2008 and continued into spring and fall of 2009 and 2010. Biotic monitoring was conducted as a screening tool to test for differences in the abundance of invertebrates and rearing salmon upstream and downstream from the boat launch. Biotic monitoring included measures of macroinvertebrate drift and juvenile salmon abundance at a reference reach 12 km (7.5 miles) upstream of the PUF and a sampling reach located 4 km (2.5 miles) downstream of the PUF. Consistent differences in the biotic community prompted measures of stream channel physical characteristics at these two locations in June of 2012. In 2008, an independent project was conducted to measure ecosystem productivity using the change in dissolved oxygen, and to evaluate these changes relative to differences in stream flow and turbidity.

All sampling, except for measures of ecosystem productivity, followed Alaska Department of Environmental Conservation (DEC) approved Quality Assurance Project Plans (QAPPs). Annual reports were completed and submitted to DEC. The 2010 annual report was submitted for peer review comments and turbidity data was analyzed using DEC's "natural condition" statistical tool (DEC 2006).

2.0 Methods

The Lower Little Susitna River is located in Southcentral Alaska, approximately 28 km (15.5 miles) northwest of Anchorage (61.433 N x -150.177 W, Figure 1). The Little Susitna River flows an estimated 182 km (113 mi) from the Talkeetna Mountains to Cook Inlet, with an elevation change of over 1.2 km (~4,000 ft). Sampling was conducted in the lower river, downstream from the George Parks Highway, 100 km (62 mi) upstream from Cook Inlet (elevation 75 m, 246 ft), and upstream and downstream from the Little Susitna PUF at river km 40 (25 mi, elevation 40 m, 131 ft). Water surface slope between these two locations is 0.1% and decreases to 0.03% from the PUF to Cook Inlet. The sampling reach extended from 12 km (7.5 mi) upstream to 12 km downstream from the PUF boat launch with a turbidity reference site at river km 100 (LS 60 km up) (Figure 2, and Table 1).

2.1 Boat Observations

Boat use was determined from surveys and observations at the PUF boat launch during sampling and from data collected at the state operated entrance fee station. Boat use surveys at the launch were conducted to obtain counts of the number of boats by motor type (2-cycle, 2-cycle direct injection or 4-cycle) and size (horsepower) operating within the sampling reach. Observations began upon arrival, generally between 12:00 and 15:00, except during intensive sampling periods when surveys were conducted throughout the sampling period (~06:00 to 21:00). The observer recorded the time that a boat entered the water from the PUF launch or approached the PUF launch from upstream or downstream. Boats were not counted more than once if they made short trips upstream or downstream after launching, but were counted twice if trips were separated by more than 0.5 hours. Boat operators were interviewed when motor type or size information was not visible on the motor cowling. Time of operation within the launch area was recorded along with route of departure and activity. Boat observations provided an index of boat activity but not a precise measure of the total number of boats operating within the sampling reach that could be a TAH source. Boats launching prior to initiating surveys operated within the sampling reach but were not counted, and hydrocarbons discharged from boats counted near the end of the survey would not contribute to sample concentrations.

Daily boat counts by motor size and type also were collected by Alaska Department of Natural Resources staff at the fee station entrance booth. The entrance booth was open from 08:00 to 17:00 on most days during peak fishing periods in June and from late July through August.

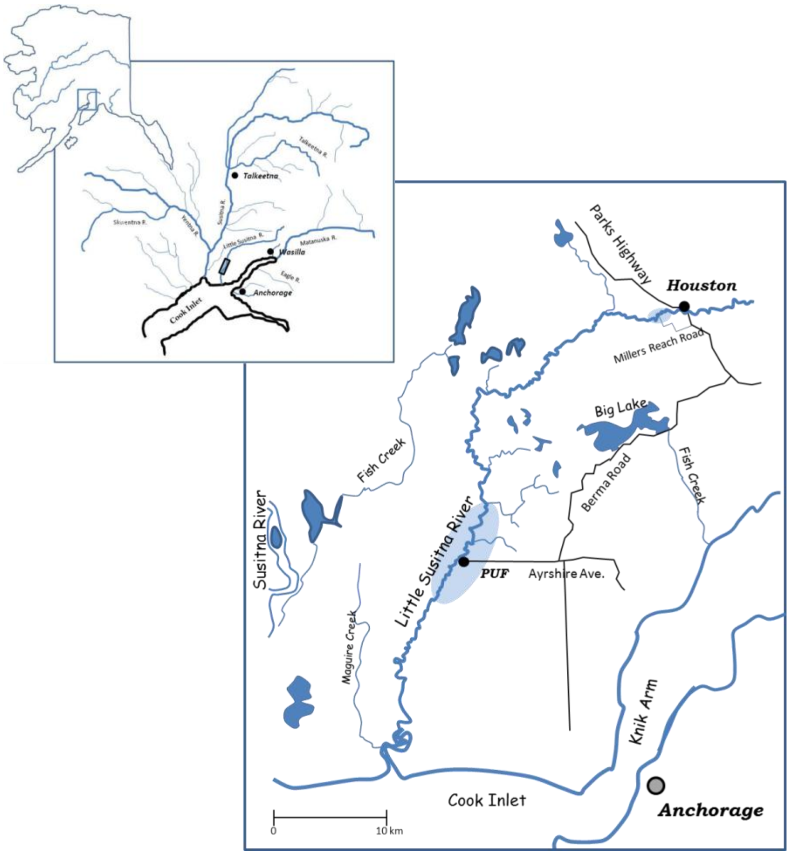


Figure 1. Drawing showing the location of the Little Susitna River in Southcentral Alaska with shaded ovals identifying the primary study areas. Initial TAH sampling was conducted upstream and downstream from the city of Houston and the Parks Highway. Turbidity downstream from the city of Houston was used for reference or natural condition values.

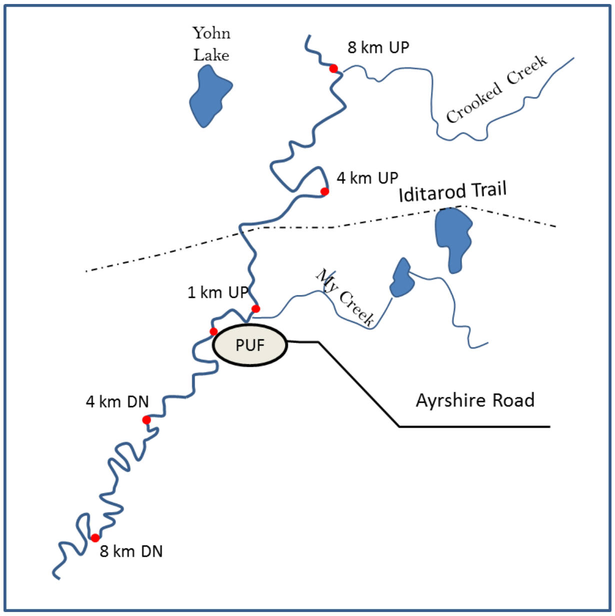


Figure 2. More detailed drawing showing locations of sampling sites used in the fall of 2010.

Table 1. Water quality sampling locations and sample site names used for each study.

Sampling Sites 2007 -2012	Description	Distance from PUF Launch km/mile	Latitude	Longitude
LS 60 km up	Hydrocarbon sampling in 2007/2008. Reference site for turbidity grab samples and turbidity logger from 2009 – 2010. Downstream from the City of Houston and the Parks Highway. Upstream from the Miller's Reach unimproved boat launch.	60.48/37.8	62.62180	-149.84939
LS 12 km up	Upstream biotic and physical sampling station. Upper most site for 2008 metabolism study. References turbidity monitoring site in 2008.	9.6-12.0/5.98	61.46311	-150.14569
LS 8 km up	August 2012 upstream water quality sampling location.	8.0/5.9	61.47112	-150.14136
LS 4 km up	2010 water quality sampling location. Second upstream primary productivity site.	4.0/2.5	61.45642	-150.14433
LS 1 km up	Water quality sampling station 1.0 km upstream from the PUF. Location where discharge was measured. Site located upstream of My Creek.	1.15/0.71	61.44245	-150.15931
LS 0.5 km up	Water quality sampling location 0.5 km upstream from the PUF.	0.44/0.27	61.44236	-150.16751
PUF or LS 0 km	Water quality sampling location located just downstream from the PUF boat launch.	0.00	61.43783	-150.17386
LS 0.5 km dn	Water quality sampling location 0.5 km downstream from the PUF.	-0.51/-0.32	61.43520	-150.17470
LS 1 km dn	Water quality sampling location 1.0 km downstream from the PUF.	-1.35/-0.84	61.43345	-150.17239
LS 2 km dn	Water quality sampling location 2.0 km downstream from the PUF. First primary productivity site downstream from the PUF.	-2.01/-1.25	61.43076	-150.18345
LS-4 km dn	Water quality sampling location 4.0 km downstream from the PUF. Location of turbidity monitoring site 4 km downstream from the PUF. Fish and invertebrate sampling location downstream from the PUF.	-3.87/-2.40	61.42389	-150.18958
LS-8 km dn	Water quality sampling location during intensive sampling and location of turbidity monitoring site 8 km downstream from the PUF.	-8/-4.97	61.41125	-150.20590
LS-12 km dn	Water quality sampling location 12 km downstream from the PUF.	-12/-7.5	61.39647	-150.20579
LS 16 km dn	Water quality sampling location during intensive sampling in 2009 and 2010, 16 km downstream from the PUF.	-16/-9.94	61.38027	-150.24300
LS 32 km dn	Water quality sampling location during intensive sampling in 2009 and 2010 within the intertidal zone 32 km downstream from the PUF.	-32/-19.89	61.342820	-150.27598

2.2 Total Aromatic Hydrocarbons

Water sampling for TAH in the Little Susitna River began in 2007 and extended through 2012 (Table 2). Initial TAH sampling was conducted July through September 2007 and continued May through June 2008. During this study period, water samples were collected weekly at sites located upstream and downstream of the Parks Highway and upstream and downstream of the PUF. From July 2008 through August 2010, water sampling was conducted weekly on weekends from July through early September 2008, late May through early September 2009, the middle of May through June and August 2010. Two sampling locations were located 0.5 and 1.0 km (0.6 miles) upstream from the PUF boat launch, and four sampling locations were located at 0.1, 1.0, 2.0, and 4.0 km (2.4 miles) downstream from the PUF boat launch. On 7 days in June (2009, 2010, 2011) and 6 days in August (2010 and 2011) during the peak Chinook and coho salmon fisheries, respectively, water samples were collected every 3 hours from 06:00 to 21:00 at the PUF. In August 2010 weekly sampling was extended to a site located 8 km upstream and a site 12 km downstream from the boat launch. In August of 2012 samples were collected from 05:00 to 23:00 from Friday through Monday at LS-0 km (PUF) and LS-4km dn.

Water samples were collected from 0.5 x depth adjacent to the thalweg using a VOC sampler and methods described by “Field guide for collecting samples for analysis of volatile organic compounds in stream water for the national Water Quality Assessment Program” (USGS Open File Report 97-401). When sampling sites were accessed by boat, the boat was anchored and motor turned off for 10 minutes prior to collecting the sample from the bow. The sampler was rinsed between each sampling site and a field blank was collected from the PUF drinking water source following sampling to test for residual VOCs within the sampler. Samples were preserved with hydrochloric acid (HCl), cooled to a temperature less than 6°C, and shipped overnight to AM Test Inc. in Kirkland, WA where they were analyzed for concentrations of benzene, ethyl-benzene, toluene, and xylene (BTEX) using EPA method 624. TAH was calculated as the sum of the concentration of these four compounds, excluding values below method detection limits[2] (MDL).

Linear regression was used to test for relationships between hydrocarbon concentrations and boat use by motor type counted during the sampling period. TAH concentrations and TAH flux (concentrations x stream discharge) were used in the regression analysis to account for differences in water volume and dilution. Actual and adjusted counts of 2-cycle motors were used in analyses. Counts of 2-cycle motors were adjusted to account for TAH differences in exhaust based on motor size as reported by Hare and Springer 1973. Boats with 2-cycle motors < 35 hp were counted once, motors 40 to 65 hp were multiplied by 2, and motors > 65 were multiplied by 3. During intensive sampling days, the relationships between the number of boats by motor type operating during the 3 hours between sampling events and those operating 0.5 hours prior to sample collection were analyzed.

---

[2] TAH values below the laboratory method detection limit were analyzed using a zero value throughout the study.

Table 2. Summary of sampling objectives, locations and sampling frequency for the separate studies conducted on the Little Susitna River from 2007 through 2012 (see individual project reports).

	Sampling Objective	Sampling Locations	Sampling Frequency
Jul – Sept 07 **May – Jun 08**	Initial hydrocarbon surveys.	Upstream and downstream from the Parks Highway and upstream and downstream from the PUF.	Weekly
Jul – Sep 08 **May - Jun 09** **Jul – Aug 09** **May – Jun 10**	Seasonal hydrocarbon trends upstream and downstream from the PUF boat launch. Relationship with boat use.	LS-1 through LS-7 (1 km upstream to 4 km downstream from the PUF boat launch).	Weekly
8, 9, 10 Aug 2009	Daily average and range of hydrocarbon concentrations.	LS-0 (PUF boat launch).	Every 3 hours 06:00 to 21:00
9 Aug 2009	Downstream distance of hydrocarbon distribution during heavy use period.	Site 8, 16, and 32 km downstream from the PUF.	Once
19, 20 Jun 2010	Daily average and range of hydrocarbon concentrations.	LS- 0 (PUF boat launch).	Every 3 hours 06:00 to 21:00
Aug 2010	Test for hydrocarbons farther upstream and downstream from the PUF.	LS- 8 km up to LS – 12 km dn (sites from 8 km upstream to 12 km downstream from the PUF boat launch).	Weekly for 4 weeks
7, 8, 9 Aug 2010	Daily average and range of hydrocarbon concentrations.	PUF boat launch (LS-0).	Every 3 hours 05:30 to 21:00
4, 11, 12 June 2011	Monitoring average daily hydrocarbon values.	PUF boat launch (LS-0).	Every 3 hours 09:00 to 18:00
3, 4, 5, and 6 Aug 2012	96 – Hour average hydrocarbon concentrations.	PUF boat launch and 4 km downstream. Once each day 1 km downstream to 8 km downstream from the boat launch.	Daily 05:00 to 23:00 with upper and lower sites at 13:00

2.3 Turbidity

Turbidity was measured from grab samples collected concurrent with TAH sampling at each sampling location and on each sampling date. Reference grab samples for turbidity were collected downstream from the Parks Highway near the city of Houston, 40 km upstream from the PUF.

Turbidity also was measured hourly using Hydrolab MS5 loggers deployed at an upstream reference location and sites downstream from the PUF. In 2008 the upstream reference site was located 12 km (7.5 miles) upstream from the PUF. However, due to frequent boat activity from the PUF at this site, in 2009 the site was relocated 40 km upstream from the PUF (upstream of the unimproved boat launch at Millers Reach and downstream from the the city of Houston). Two Hydrolabs were deployed downstream from the PUF. One Hydrolab was deployed in 2008, 4 km downstream from the PUF and in August 2009 a second Hydrolab was placed at 8 km (5 miles) downstream from the PUF. There are no major tributaries or natural sources of turbidity between the reference site and these two sites downstream from the PUF. Loggers were deployed in the middle to end of May, removed the end of June, redeployed in the middle of July and removed in early September. Loggers were calibrated prior to deployment and set to record turbidity and water temperature hourly. Loggers were suspended vertically within the water column with the probe at 20 to 30 cm above the streambed. Loggers were checked approximately every 3 weeks, cleared of any debris, downloaded, and batteries changed.

Turbidity from grab samples were analyzed using samples collected from July 2008 through June 2010. Paired t-tests were used to test for significant differences between the reference site and the 7 sampling locations. Grab samples were collected at the reference site on the same day as the sampling locations near the PUF, so resulting turbidity could not be offset by the flow times between reference and sampling stations. The total number of days turbidity differed from the reference site by 5 NTU and 10 NTU were counted. Linear regression was used to test for a significant relationship between the change in turbidity (reference – site) and boat activity.

Hourly turbidity data from the Hydrolabs (2009 to 2010) were analyzed using the “Alaska Statistical Spreadsheet Tool for Natural Conditions Evaluation version 2” (DEC 2010). This tool is used to calculate the “natural condition” value for the reference site. Turbidity met the minimum data requirement of two years. Data also were analyzed for two seasons, June and August, corresponding to boat use during the Chinook and coho fisheries. The calculated natural condition values were then used to evaluate compliance with state water quality standards from turbidity data collected 4 km downstream from the PUF boat launch. The percentage of samples were counted at the site 4 km downstream from the boat launch that were 5, 10, and 25 NTU above natural conditions for the two data sets.

2.4 Physical Habitat

Physical habitat characteristics were measured in May 2012 at the biological reference location 12 km upstream and potentially impacted site 4 km downstream from the PUF, coinciding with macroinvertebrate and juvenile salmon sampling locations. Five channel cross-section surveys were measured at 20 m intervals. Water surface and bed height were measured using a laser level and leveling rod. The elevation of ordinary high water, or vegetation line, was noted at each transect and bank undercut measured. Substrate size was measured at 20 points across each transect with a gravelometer. Water velocity was measured every 20 cm from the right bank at 0.6 x depth until velocity exceeded 60 cm/s. The number of pieces of large woody debris (> 1.0 m in length and 0.10 m in diameter) at each transect was counted. Riparian vegetation extending 100 m lateral to the bank at each transect was characterized using the methods of Vireck et al. (1992).

Water surface and bed slope were calculated at the thalweg and 20 m from the right bank using linear regression between distance and elevations. Average cross-sectional area, wetted perimeter, channel width, width/depth ratios, and the percent of the fine substrate (< 2mm) were calculated for both reaches.

2.5 Ecosystem Metabolism

(Independent project, not funded by DEC but related)

Ecosystem metabolism was measured using the open system single station method (Odum 1956, Bott 2007). Study sites were selected based on appropriate depth (> 1m), local flow regime (flowing water) and riparian anchor points (limbs extending out from the bank parallel to the water surface) for water quality sondes. Two sites were located upstream from the PUF (LS 12 km up and LS 4 km up) and two sites were located downstream from the PUF (LS 2 km dn and LS 4 km dn). Dissolved oxygen (DO) and temperature were recorded on 1 h or 0.5 h intervals using two Hach minisondes and two YSI 600QS sondes deployed for 14-28 days. Dissolved oxygen sensors were calibrated in water-saturated air at sea level prior to each deployment. Turbidity was also monitored (Hach sondes only; LS 12 km up, n = 42; LS 4 km up, n = 12; and LS 4 km dn, n = 54) and checked against known turbidity samples prior to deployment. Turbidity and DO data were compared to field measurements or grab samples for accuracy. In addition, all sondes were evaluated for sensor drift following retrieval and corrections were made as necessary.

To correct for gas exchange with the atmosphere, the energy dissipation model (Tsivoglou and Neal 1976, Bott 2007) was selected to calculate the re-aeration coefficient using the equation:

$$k_t = (K' \times S \times V) \times 1.024(t - 20)$$

Where k_t is the temperature corrected re-aeration coefficient, K' is a constant (15.3×10^3 s m-1 d-1), S is water surface slope (m/m), V is average stream velocity (m/s), and t is temperature (°C). Slope was determined as the average of all recorded measurements (n = 4). Daily average velocity was calculated as a function of discharge ($V = 0.0232 \times QPUF + 0.3074$, $R^2 = 0.72$).

Gross primary production and ecosystem respiration were determined according to Bott (2007) based on the equation:

$$\Delta DO = P - R + Dk_t$$

Where ΔDO (net ecosystem production) is the change in dissolved oxygen concentration (g O_2/m^3) and P (g O_2/m^3) and R (g O_2/m^3) correspond to gross primary production (GPP) and community respiration

(CR) respectively. The product of the re-aeration coefficient and the oxygen deficit (D in g O_2 /m^3) quantifies the net gas exchange with the atmosphere over a time interval (1 h or 0.5 h in this study). During the night, primary production does not occur and changes in DO concentration are due to respiration only. Hence, day-length CR was determined as the average hourly respiration in the dark extrapolated over a 24-hour period. GPP was determined as the sum of CR and cumulative change in DO during the photoperiod. GPP and ER were converted to area units (g O_2 m^{-2} d^{-1}) by multiplying volumetric rates by site specific average depth at base flow. Net daily metabolism (NDM) was determined as the difference between GPP and ER.

2.6 Macroinvertebrate Drift

Macroinvertebrates were collected in drift nets (drift sampling) (283 µm mesh, 45.7 x 30.5 cm opening) within sampling reaches located at the biological reference site (LS 12 km up) and a potentially impacted site 4 km (2.4 mi) downstream (LS 4 km dn) from the PUF. Sampling was conducted on 5 dates: August 2008, mid-June and mid-August of 2009 and 2010 following the methods described in Davis et al. 2001. Drift nets were deployed 10 to 20 cm below the water surface at three locations; representing the right, middle, and left thirds of the channel cross-section. In August 2008, 2009, and June 2009 and 2010 drifting invertebrates were collected from a single transect upstream and downstream for a sample size of three reference and three downstream from the PUF; in August 2010 samples were collected at three cross-section locations at the upstream biological reference site and three cross-sections downstream of the PUF for a sample size of 9 upstream and downstream from the PUF. Water flow into the nets was measured with a General Oceanics flow meter centered in the net opening. Nets remained in the water until there was a visible decrease in flow due to accumulated biomass within the net, usually less than 5 minutes. All material within the nets was transferred to 500-ml Nalgene bottles and preserved with ethyl-alcohol. Samples were sorted in the laboratory using a microscope at 30 power and all invertebrates identified to genus. One tailed T-tests (alpha 0.05) were used to test for differences in drift abundance (organisms/m^3) between samples ($n = 3$ for the first 4 sample dates, and $n = 9$ for the remaining sample date). Two-way ANOVA (alpha 0.05) was used to test for differences in drift using average values from June and August samples ($n = 5$).

2.7 Juvenile Salmon

Juvenile salmon were sampled using baited minnow traps within sampling reaches located at the biological reference site 12 km upstream, and potentially impacted site 4 km downstream from the PUF. Minnow traps (Gee minnow traps, Memphis Net and Twine) were baited with salmon roe in perforated whirl-pak bags and placed in low velocity areas near or under cover along an outside bend. Ten minnow traps were used in each location on the first 4 sampling dates, and 30 traps were used at each location on the final sampling date. Each trap was approximately 5 meters from the next nearest trap. Traps were fished for 20 to 24 hours. Fish traps were emptied into plastic buckets with stream water and fish anesthetized with MS222. All fish were identified to species, and all salmonids measured to fork length. Catches from each trap were recorded individually to provide catch per unit trap (CPUT) values. Size frequency distributions were calculated using the number of fish within 2 mm fork length intervals. One tailed T-tests (alpha 0.05) were used to test for significant differences in average CPUT between traps placed 12 km upstream from the boat launch and 4 km downstream from the boat launch ($n = 10$ for the first 4 sampling dates and n = 30 for the final sampling date). Two way ANOVA (alpha 0.05) without replication was used to test for differences in average CPUT values upstream and downstream from the boat launch for all sampling dates (n = 5).

3.0 Results[3]

3.1 Boat Observations

Peak boat use periods were during the last week of May and the first week of June, and during the first two weeks of August, coinciding with the Chinook and coho salmon fisheries, respectively (Table 3). Based on counts at the PUF entrance booth, 60 to 70% of weekly boat activity was on Friday, Saturday, and Sunday. The percent of total boats counted at the booth operating with a 2-cycle motor was near 30% in 2008 and 2009, and dropped to 26% in 2010.

Boat use observations at the PUF boat launch were conducted concurrent with water sampling from approximately 12:00 to 16:00 (Table 4) with observation times ranging from 1.5 to 4 hours. A range of 3 to 34 boats per hour operated within the sampling reach on the 33 days observations were conducted. The percent of boats using 2-cycle motors averaged 39% and ranged from 7% to 64%, and the number from < 1.0 to 13.7 operating per hour in the sampling reach. Boat counts during intensive surveys conducted from 06:00 to 21:00 during high use days, were generally highest from 12:00 to 15:00. Total daily counts of boats operating within the sampling reach ranged from 59 to 260. An average of 42% of the boats that launched travelled past the two upstream sampling locations (LS 1 km up and LS 4 km up); however, this varied from 20% to 72% (Table 4). The turbidity reference (LS 60 km up) is upstream of all motorized boating activity. The Alaska Department of Fish and Game does not allow salmon fishing in the Little Susitna River upstream of the Parks Highway near the city of Houston and this, along with poor river navigability, keeps all motorized boating downstream of the turbidity reference site.

3.2 Total Aromatic Hydrocarbons

3.2.1 Water Quality Standards

State WQS for Petroleum Hydrocarbons are shown in Table 5. TAH concentrations for all sampling dates and sites are provided in Appendix 2.Using the cumulative dataset, maximum TAH concentrations exceeded WQS during every year except August 2012 (Table 6). Of the 362 samples collected from 2007-2012, 66 samples, or 18.2%, were above WQS. Broken down by day, of the 62 sample days from 2007-2012, 26 of these days (42%) had TAH concentrations greater than 10 µg/L. Maximum and minimum values are shown in Figure 3 for all sample dates and a summary of TAH samples for each site is provided in Table 7.

The draft DEC TAH listing methodology states that the water is impaired if a four (4) day average value exceeds that water quality standard more than once in three (3) years. The 3-day average

---

[3] Detailed project results and data tables for each year are contained in annual project reports (Davis et al. 2011, Davis and Davis 2010, Davis et al. 2009, Davis and Davis 2008, Davis and Davis 2007) and can be obtained from the Alaska Department of Environmental Conservation, Anchorage, AK or at www.arrialaska.org

concentrations of TAH exceeded the WQS in 2009 and 2010 (Table 8). The concentrations of TAH needed to exceed WQS if a fourth day of sampling had been conducted are estimated to be 11 µg/L in 2009 and 5 µg/L in 2010.

Table 3. Boat counts from DNR PUF entrance booth for 2008 through 2010 and percent of boats using 2-cycle motors. Percent of weekly use by day of week show low boat use on Tuesday and Wednesdays and percent of annual use that occurs during the first week in June and the first 2 weeks of August.

	2008	2009	2010
Total Count	1810	1348	1504
2-Cycle Count	575	410	393
Percent 2-Cycle	31.77	30.42	26.13
Percent of Weekly Use by Day			
Mon	15.73	13.78	12.14
Tues	5.36	13.10	7.65
Wed	8.52	9.71	10.29
Thurs	14.89	15.79	13.50
Fri	18.91	19.18	19.73
Sat	17.94	25.07	27.90
Sun	23.38	23.05	24.05
Percent of Seasonal Use by Week			
1st Week June	10.5	9.2	11.4
2nd Week June	9.6	7.1	11.1
3rd Week June	8.0	9.5	9.7
4th Week June	5.7	2.1	6.0
1st Week Aug	10.0	18.3	15.1
2nd Week Aug	13.0	14.1	14.3
3rd Week Aug	10.3	9.4	4.6
4th Week Aug	5.5	4.1	1.2

Table 4. Results of boat use surveys from counts conducted at the PUF boat launch during sampling. HP adjusted 2-cycle are counts adjusted for boat motor size. Percent Up is the percentage boats counted that operated upstream of the boat launch.

Date	Observation Time (hours)	2-cycle	HP Adjusted 2-cycle	2 cycle DI	4 cycle	Total Boats	No. Up	No. Down	2-cycle/ hour	4-cycle/ hour	Total/hr	Percent 2-cycle	Percent Up
7/27/2008	3.92	11	21	0	28	39	12	23	2.81	7.14	9.95	28.21	30.8
8/2/2008	1.87	8	13	0	25	33	15	18	4.28	13.37	17.65	24.24	45.5
8/10/2008	2.37	15	27	0	28	43	17	26	6.33	11.81	18.14	34.88	39.5
8/13/2008	3.00	10	15	0	19	29	9	18	3.33	6.33	9.67	34.48	31.0
8/17/2008	2.26	19	33	0	18	37	18	21	8.41	7.96	16.37	51.35	48.6
8/24/2008	2.48	8	14	0	12	20	10	13	3.23	4.84	8.06	40.00	50.0
8/30/2008	1.75	3	5	0	6	9	5	3	1.71	3.43	5.14	33.33	55.6
9/6/2008	1.50	1	3	0	4	5	1	4	0.67	2.67	3.33	20.00	20.0
5/17/2009	2.50	1	3	3	10	14	6	5	0.40	4.00	5.60	7.14	42.9
5/24/2009	3.12	20	35	3	24	47	28	30	6.41	7.69	15.06	42.55	59.6
5/31/2009	3.80	13	23	1	23	37	8	30	3.42	6.05	9.74	35.14	21.6
6/7/2009	2.47	34	66	2	48	84	44	35	13.77	19.43	34.01	40.48	52.4
6/14/2009	2.25	9	14	1	26	36	10	16	4.00	11.56	16.00	25.00	27.8
6/21/2009	2.00	8	14	0	8	16	5	8	4.00	4.00	8.00	50.00	31.3
6/28/2009	3.00	14	29	1	16	31	17	12	4.67	5.33	10.33	45.16	54.8
7/19/2009	3.78	13	29	0	11	24	12	14	3.44	2.91	6.35	54.17	50.0
7/26/2009	2.32	17	41	0	12	29	14	13	7.33	5.17	12.50	58.62	48.3
8/2/2009	3.01	18	40	0	17	35	11	20	5.98	5.65	11.63	51.43	31.4
8/9/2009	2.50	18	38	0	32	50	14	37	7.20	12.80	20.00	36.00	28.0
8/16/2009	2.36	13	28	0	22	35	17	15	5.51	9.32	14.83	37.14	48.6
8/23/2009	2.08	10	18	0	12	22	11	9	4.81	5.77	10.58	45.45	50.0
8/30/2009	2.55	6	15	0	12	18	5	14	2.35	4.71	7.06	33.33	27.8
9/5/2009	1.87	3	3	0	4	7	4	6	1.60	2.14	3.74	42.86	57.1
5/15/2010	2.37	5	14	0	7	12	6	5	2.11	2.95	5.06	41.67	50.0

Date	Observation Time (hours)	2-cycle	HP Adjusted 2-cycle	2 cycle DI	4 cycle	Total Boats	No. Up	No. Down	2-cycle/ hour	4-cycle/ hour	Total/hr	Percent 2-cycle	Percent Up
5/23/2010	2.63	16	39	0	9	25	18	7	6.08	3.42	9.51	64.00	72.0
5/30/2010	1.95	7	16	1	18	26	9	17	3.59	9.23	13.33	26.92	34.6
6/6/2010	2.98	16	38	0	27	43	17	18	5.37	9.06	14.43	37.21	39.5
6/13/2010	2.17	13	25	1	20	34	16	23	5.99	9.22	15.67	38.24	47.1
6/20/2010	3.00	9	14	0	10	19	7	13	3.00	3.33	6.33	47.37	36.8
8/1/2010	3.00	14	28	2	15	31	13	21	4.67	5.00	10.33	45.16	41.9
8/8/2010	2.80	22	42	0	21	43	15	24	7.86	7.50	15.36	51.16	34.9
8/15/2010	3.53	22	48	5	27	54	19	32	6.23	7.65	15.30	40.74	35.2
8/21/2010	2.65	13	27	0	11	24	11	11	4.91	4.15	9.06	54.17	45.8

Table 5. State Water Quality Standards (WQS) for Petroleum Hydrocarbons, Oils, and Grease for Freshwater (DEC 2006).

Designated Use	Water Quality Standard
(A) Water Supply **(i) Drinking, Culinary, and Food Processing**	May not cause a visible sheen upon the surface of the water. May not exceed concentrations that individually or in combination impart odor or taste as determined by organoleptic tests.
(ii)Agriculture, including irrigation and stock watering	May not cause a visible sheen upon the surface of the water.
(iii) Aquaculture	Total aqueous hydrocarbons (TAqH) in the water column may not exceed 15 µg/l (see note 7). Total aromatic hydrocarbons (TAH) in the water column may not exceed 10 µg/l (see note 7). There may be no concentrations of petroleum hydrocarbons, animal fats, or vegetable oils in shoreline or bottom sediments that cause deleterious effects to aquatic life. Surface waters and adjoining shorelines must be virtually free from floating oil, film, sheen, or discoloration.
(iv) Industrial	May not make the water unfit or unsafe for the use.
(B) Recreation **(i) Contact**	May not cause a film, sheen, or discoloration on the surface or floor of the waterbody or adjoining shorelines. Surface waters must be virtually free from floating oils.
Recreation **(ii) Secondary**	Same as (5)(B)(i).
(C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife.	Same as (5)(A)(iii).

Table 6. Summary table of TAH concentrations for each sampling period.

WQS	Max Observed Value (µg/L)	# Samples Exceeding WQS	Total # Samples	Sampling Period
10 µg/L	10.17	1	15	July – Sept 2007
	75.2	29	72	May - Aug 2008
	12.7	2	49	May - June 2009
	27.2	11	70	July - Sept 2009
	15.8	4	52	May - June 2010
	30.4	14	40	Aug 2010
	20.5	5	12	Jun 2011*
	4.4	0	50	Aug 2012*
Total	75	65	362	

* The Chinook fishery was closed in June 2011 and the coho fishery closed in August 2012 due to low returns.

Table 7. Summary table of TAH concentrations by sampling location from sites located 8 km upstream from the boat launch (km up) to 32 km downstream from the boat launch (km dn).

Site	Max Observed Value (µg/L)	# Samples Exceeding WQS	Total # Samples	Percent > WQS
LS-8 km up	1.8	0	4	0.0
LS-4 km up	9.9	0	4	0.0
LS-1 km up	36.7	7	53	13.2
LS-0.5 km up	27.1	3	28	10.7
LS-0 PUF	30.4	26	107	24.3
LS-0.5 km dn	75.2	9	38	23.7
LS-1 km dn	26.1	6	28	21.4
LS-2 km dn	28.3	4	28	14.3
LS-4 km dn	27.7	7	55	12.7
LS-8 km dn	12.0	3	10	30.0
LS-12 km dn	16.2	1	4	25.0
LS-16 km dn	9.5	0	2	0.0
LS-32 km dn	0.0	0	1	0.0

Table 8. TAH concentrations for the intensive sampling events when samples were collected every 3 hours between 6 AM and 9 PM at site LS-0 over consecutive days.

	Maximum Observed Value (µg/L)	Average TAH for Sample Period* (µg/L)	Estimated TAH Value Needed for 4-Day Average to Exceed WQS (µg/L)
August 2009 (3 day event)	27.2	10.2	11.0
August 2010 (3 day event)	30.4	11.4	5.0
August 2012 (4 day event)^	4.4	1.4	NA

* Calculated using ProUCL to determine a value for the non-detect samples.

^ Low TAH concentrations over this 4-day weekend were likely due to low numbers of returning salmon and boats.

Concentrations of hydrocarbons were highly variable throughout a day. Water samples collected every 3 hours at the PUF boat launch (LS-0) ranged from below method detection limits (1 µg/L) to 30 µg/L. Average daily TAH concentrations exceeded WQC on 4 of the 15 days sampled (36%), whereas maximum daily values during intensive sampling were greater than WQC on 9 out of 15 days (60%, Figure 4).

TAH concentrations were low in August 2012 with maximum recorded value of 4.4 µg/L. Average TAH concentrations over 4 days in August of 2012 were 1.4 µg/L at the PUF boat launch (LS-0), and 1.8 µg/L 4 km downstream (Figure 5). Low TAH concentrations over this 4 day weekend were likely due to low numbers of returning salmon and boats. The salmon fishery was closed shortly after this sampling event.

TAH concentrations did not exceed WQC 4 km or 8 km upstream from the PUF but exceeded WQC from 1 km upstream to 12 km downstream from the PUF. TAH were detected at sites 8 km upstream to 16 km downstream from the launch. Hydrocarbon concentrations were below detection limits 8 km upstream from the launch on 3 of the 4 sampling dates in August 2010. At 4 km upstream from the launch, the maximum concentration was 9.99 µg/L on one sampling date and less than 2 µg/L on the other 3 sampling dates. In August 2010, TAH concentrations 8 km downstream from the launch exceeded 10 µg/L on 2 of the 4 sampling dates and on 1 of 4 sampling dates 12 km downstream from the launch.

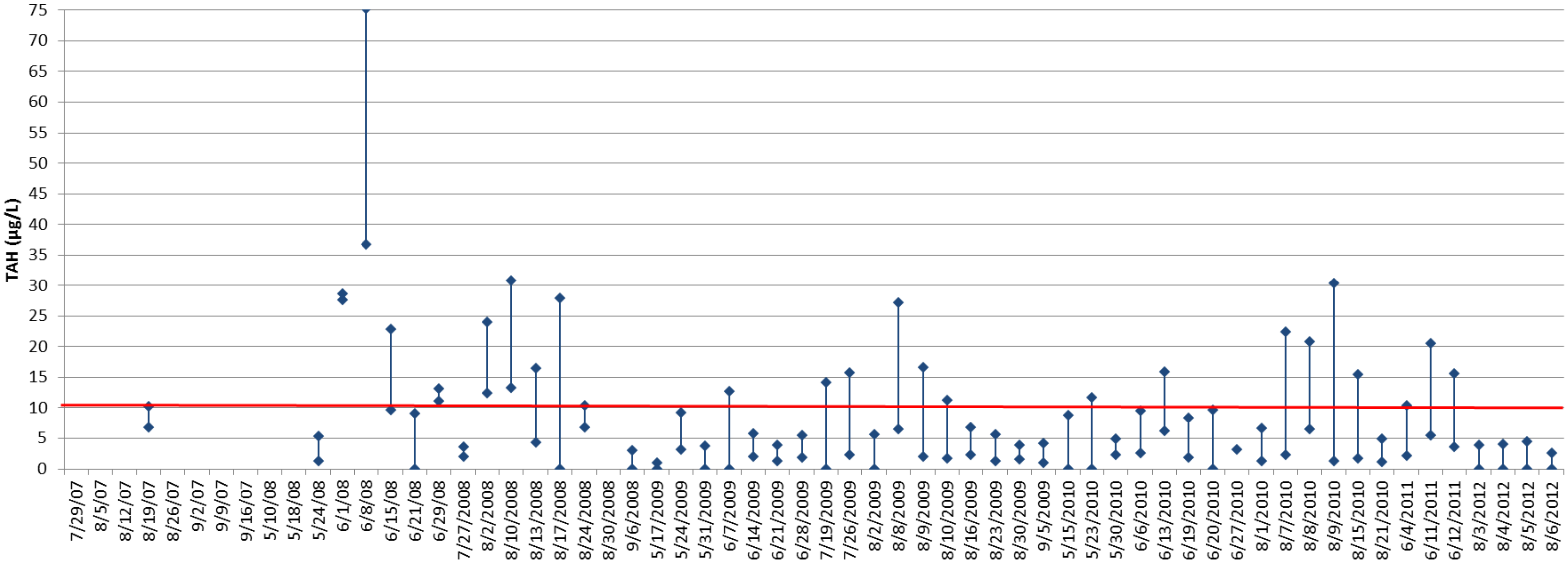


Figure 3. Maximum and minimum TAH concentrations for each sampling date. Red line is at TAH WQC of 10 µg/L.

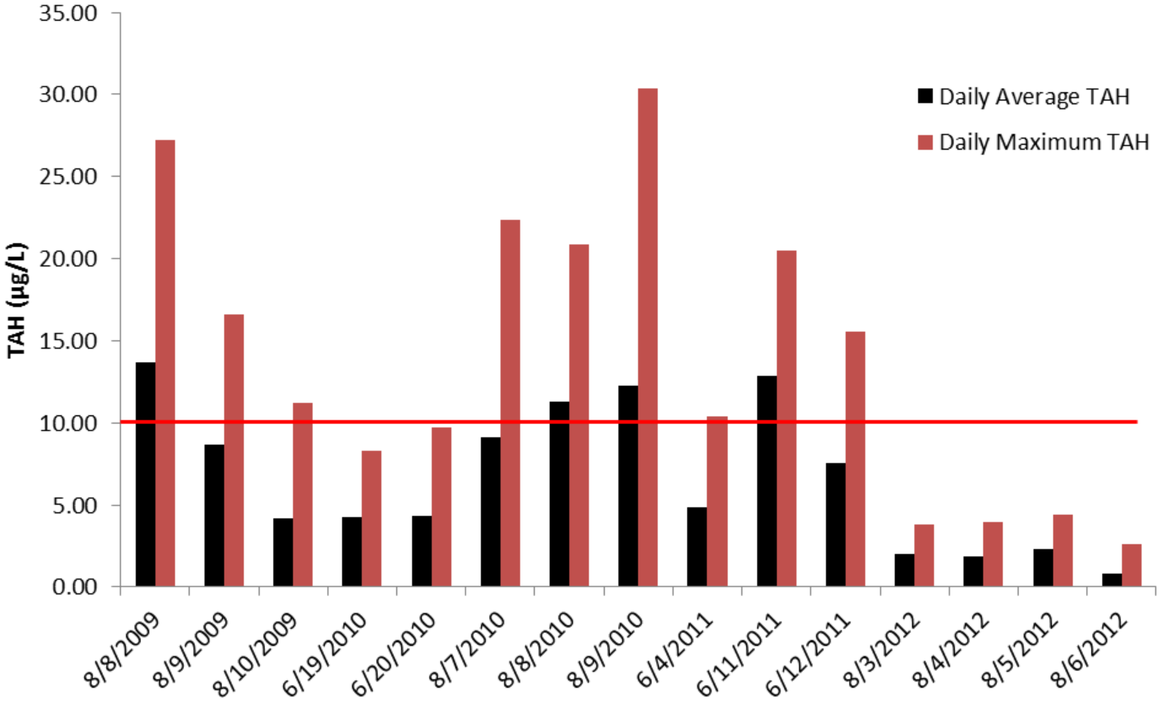


Figure 4. Average and maximum daily TAH concentrations at the boat launch for days when samples were collected every 3 hours from 06:00 to 21:00, and from 05:00 to 23:00 in 2012. Red line marks WQC concentrations. The coho salmon fishery was closed in 2012.

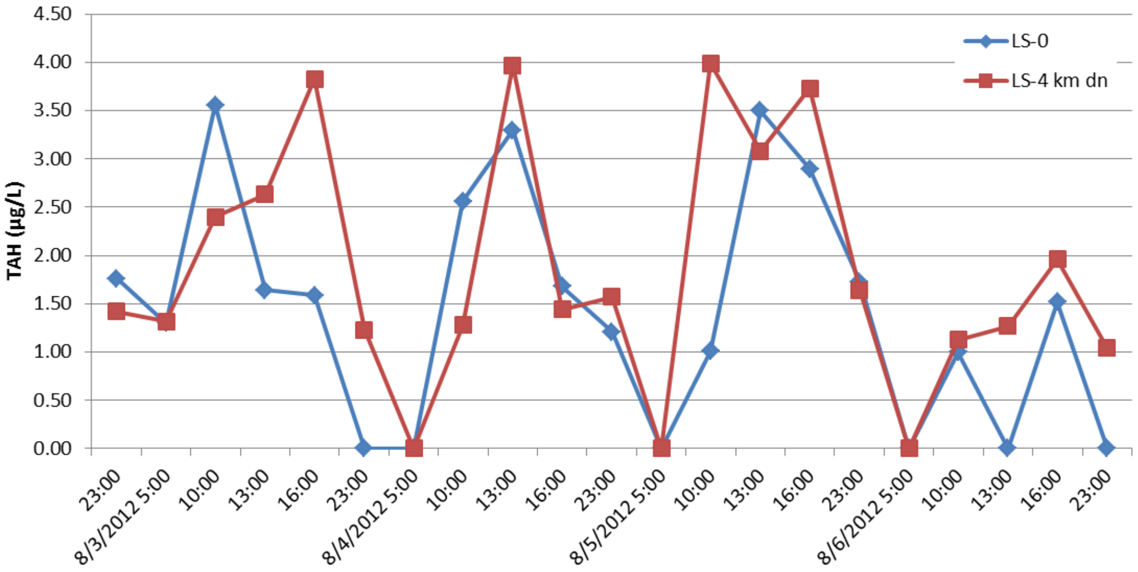


Figure 5. TAH concentrations during 4 day sampling in August 2012 at the PUF boat Launch (LS-0) and 4 km downstream from the boat launch. Even though the results are not above the WQC, they demonstrate the daily variability in TAH concentrations.

3.2.2 Relationships with Boat Motor Use by Motor Type

TAH concentrations were converted to TAH flux values prior to testing for relationships with boat use in order to remove the effect of water volume. TAH flux downstream was calculated as the product of average concentration and stream flow. TAH and flow data used for the analyses are shown in Table 9. TAH flux during weekly sampling events was significantly correlated with total boats/hr ($r = 0.51$, $p < 0.001$), 4-cycle boats/hr ($r = 0.52$, $p < 0.001$), and 2-cycle boats/hr ($r = 0.27$, $p = 0.001$) (Figure 6). Using multiple linear regression including total boats and 2-cycle boats per hour, there was a significant relationship with total boats ($p = 0.006$) but not 2-cycle motors ($p = 0.44$). The relationship between average TAH flux downstream from the boat launch and 2-cycle motors was not improved by correcting for engine HP. HP adjusted 2-cycle boats were correlated with TAH flux ($r = 0.19$, $p = 0.01$) but the relationship was not as good as unadjusted 2-cycle boat counts.

The relationship between TAH concentrations and boat numbers by motor type also was calculated using boat counts and information collected at the PUF entrance booth. The regression relationship between total boats passing the entrance booth and average TAH concentrations from sites downstream from the launch was significant ($r = 0.43$, $p = 0.0001$). The number of 2-cycle boats passing the entrance booth also was significantly related to average TAH concentrations ($r = 0.30$, $p = 0.002$); however, the relationship was not as good a fit as when using total boat counts. The use of booth count data allowed for estimates of TAH concentrations downstream from the boat launch on week days and weekends when observations were not conducted at the PUF boat launch. Using these regression equations and total boats, TAH concentrations would exceed 10 µg/L on days when 39 or more boats passed the entrance booth, with a 95% confidence interval of 26 to 72 boats. Therefore, based on booth counts, TAH concentrations greater than 10 µg/L were estimated to have occurred 12 times in 2008 (95% CI, 0 to 28), 4 times in 2009 (95% CI, 0 to 18), and 7 times in 2010 (95% CI, 0 to 18). The maximum number of consecutive days when more than 39 boats passed the entrance booth was 5 in 2008, 4 in 2009, and 3 in 2010.

TAH mass flux (mg/s) was converted to a volume using the density of gasoline (0.737 g/ml) and to volume of gasoline using a ratio of 0.369 (TAH:Gasoline) (Oasis 2006). Based on these calculations, gasoline discharge average 1.22 L/hr and ranged from 0 to 5.39 L/hr. Total gasoline discharge per boat was 0.10 L/boat (95% CI ± 0.02). The differences in gasoline discharge per boat were not correlated with the portion of total boats operating 2-cycle motors ($p = 0.47$).

TAH concentrations from samples collected every 3 hours during intensive sampling were correlated with the total number of boats ($r = 0.24$, $p < 0.001$), 4-cycle boats ($r = 0.09$, $p = 0.04$), and 2-cycle boats ($r = 0.25$, $p < 0.001$) operating within the 3 hours between sample collection. The relationship improved for 2-cycle boats ($r = 0.42$, $p < 0.0001$), decreased for total boats ($r = 0.17$, $p = 0.004$), and was no longer significant for 4-cycle boats when using just those boats operating within 30 minutes prior to sample collection (Figure 7). The significant relationship with 2 strokes operating ½ hour prior to sample collection is consistent with laboratory studies that document higher TAH discharge from 2-cycle motors at low idle speeds.

Table 9. Little Susitna River TAH concentrations at the 7 primary sampling locations and daily averages for sites upstream and downstream from the PUF boat launch (LS-0) and used to test for boat use relationships. Values < MDL reported as 0; Ave is average; cfs is cubic feet per second.

Date	LS-1 km up	LS-0.5 km up	LS-0 PUF	LS-0.5 km dn	LS-1 km dn	LS-2 km dn	LS-4 km dn	LS-4 km dn Rep	Ave. Above PUF	Ave. Below PUF	Ave. Flux Below PUF (mg/s)	Flow (cfs)
7/27/2008	2.8	3.6	2.5	2.1	2.0	2.4	3.6	6.8	3.2	3.2	64.2	703
8/2/2008	17.2	16.1	18.1	12.4	23.9	18.3	17.6	17.7	16.6	18.0	247.2	485
8/10/2008	13.2	16.1	23.5	30.8	26.1	28.3	27.7	28.1	14.7	27.4	407.4	525
8/13/2008	4.3	4.2	6.2	5.2	11.1	16.5	10.7	13.7	4.3	10.6	143.1	479
8/17/2008	26.2	27.1	27.9	22.3	2.5	0.0	4.8	7.3	26.6	10.8	118.2	387
8/24/2008	6.9	6.8	6.8	10.4	8.4	7.5	9.3	9.3	6.8	8.6	92.5	379
8/30/2008	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	386
9/6/2008	0.0	0.0	0.0	0.0	0.0	2.9	0.0	5.6	0.0	1.4	13.1	325
5/17/2009	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.2	3.7	788
5/24/2009	3.1	4.2	8.3	6.8	5.0	9.2	6.9	4.5	3.7	6.8	138.8	723
5/31/2009	0.0	0.0	3.7	0.0	0.0	1.4	3.6	3.2	0.0	2.0	42.5	757
6/7/2009	0.0	3.2	10.4	9.1	9.7	9.3	12.7	9.6	1.6	10.1	211.0	736
6/14/2009	1.9	2.2	5.3	5.4	4.5	5.8	2.9	6.0	2.1	5.0	116.0	822
6/21/2009	3.3	1.9	1.2	1.8	3.0	3.9	3.1	3.4	2.6	2.7	43.6	564
6/28/2009	1.8	1.8	2.3	5.4	4.6	4.6	5.2	4.8	1.8	4.5	51.7	407
7/19/2009	1.4	0.0	14.1	6.5	4.9	4.6	2.6	4.1	0.7	6.1	83.7	482
7/26/2009	2.2	2.7	3.8	4.4	15.7	7.1	10.1	11.5	2.5	8.8	78.9	318
8/2/2009	0.0	3.6	5.0	1.8	5.6	2.0	5.3	6.0	1.8	4.3	48.6	401
8/9/2009	5.4	4.5	5.0	5.3	7.4	9.0	8.3	14.1	5.0	8.2	87.6	378
8/16/2009	2.2	2.3	4.7	6.7	5.4	5.3	5.5	5.6	2.3	5.5	48.7	311
8/23/2009	1.3	1.5	1.6	1.7	1.3	2.1	5.6	2.8	1.4	2.5	37.0	520
8/30/2009	3.4	3.1	1.6	3.6	3.3	3.8	1.8		3.3	2.8	33.1	414
9/5/2009	1.3		1.0				4.1		1.3	2.6	24.8	344
5/15/2010	0.0	0.0	0.0		8.8	4.9	2.8	2.9	0.0	3.9	34.5	315
5/23/2010	0.0	1.3	5.6		11.7	3.0	3.4	3.0	0.6	5.4	54.6	361
5/30/2010	4.2	4.2	4.9		2.6	2.2	4.7	7.9	4.2	4.5	89.9	713
6/6/2010	2.6	4.6	5.5		6.0	9.4	9.5	8.4	3.6	7.8	109.3	497
6/13/2010	8.7	6.2	15.8		13.9	13.7	8.5	8.1	7.5	12.0	113.7	335
6/20/2010	2.0	2.1	2.5		2.8	4.2	6.3		2.1	3.9	35.0	314
8/1/2010	1.2		1.5				5.4		1.2	3.5	54.1	552
8/8/2010	13.4		14.6				20.0		13.4	17.3	228.2	466
8/15/2010	1.6		7.4				15.4		1.6	11.4	136.5	424
8/21/2010	1.2		4.1				4.9		1.2	4.5	46.3	362
Total Number > 10µg/L	4	3	7	4	6	4	7	5	4			

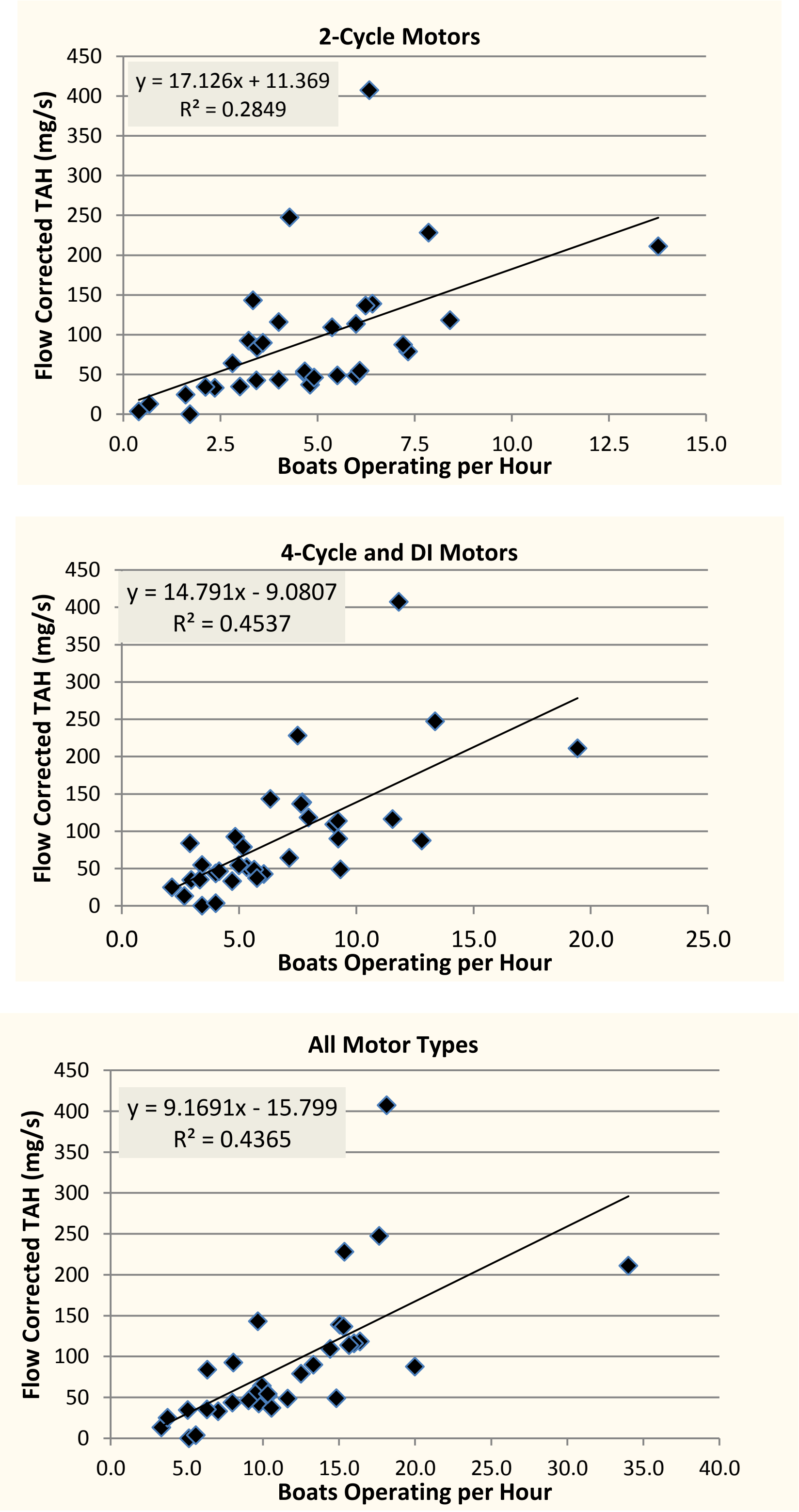


Figure 6. Relationships between TAH flux and number of boats operating during the sampling period by motor type.

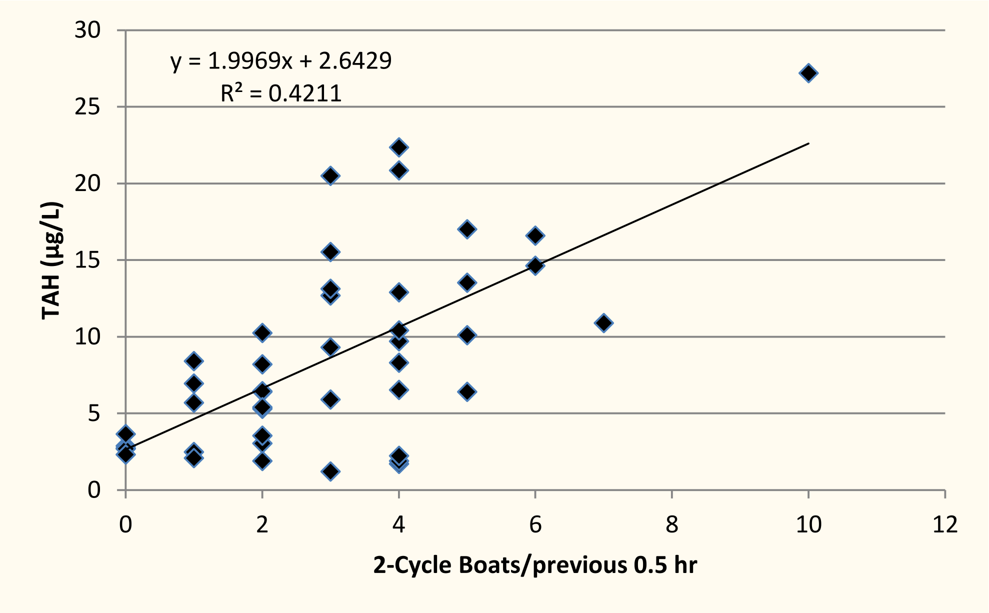


Figure 7. Relationship between TAH concentration and 2-cycle boats operating 0.5 hours prior to sample collection at the boat launch.

3.3 Turbidity

3.3.1 Grab Samples

Turbidity in the Little Susitna River increased at sampling sites immediately upstream and downstream of the PUF and turbidity increases were related to boat use. Ninety percent of the stream water turbidity grab samples collected at the reference location were ≤ 7 NTU and 43% of the samples were less than 3 NTU (Figure 8 and Table 10). Comparatively, turbidity at the site located 1 km upstream of the boat launch was less than 7 NTU in 65% of the samples, and less than 3 NTU in only 22% of the samples collected. At 4 km downstream from the boat launch turbidity was less than 7 NTU only in 27% of the samples and less than 3 NTU only in 3% of the samples. Average turbidity from 54 grab samples collected throughout the study were 4 NTU at the reference site, near 6 NTU 1 km upstream from the PUF boat launch, and 10 NTU 4 km downstream from the boat launch. Turbidity 1 km upstream and 4 km downstream from the launch were significantly higher than reference values ($p < 0.001$). The increase in turbidity from the reference site to the site 4 km downstream from the boat launch was significantly related to total boats counted at the launch during sampling ($r = 0.12$, $p = 0.05$).

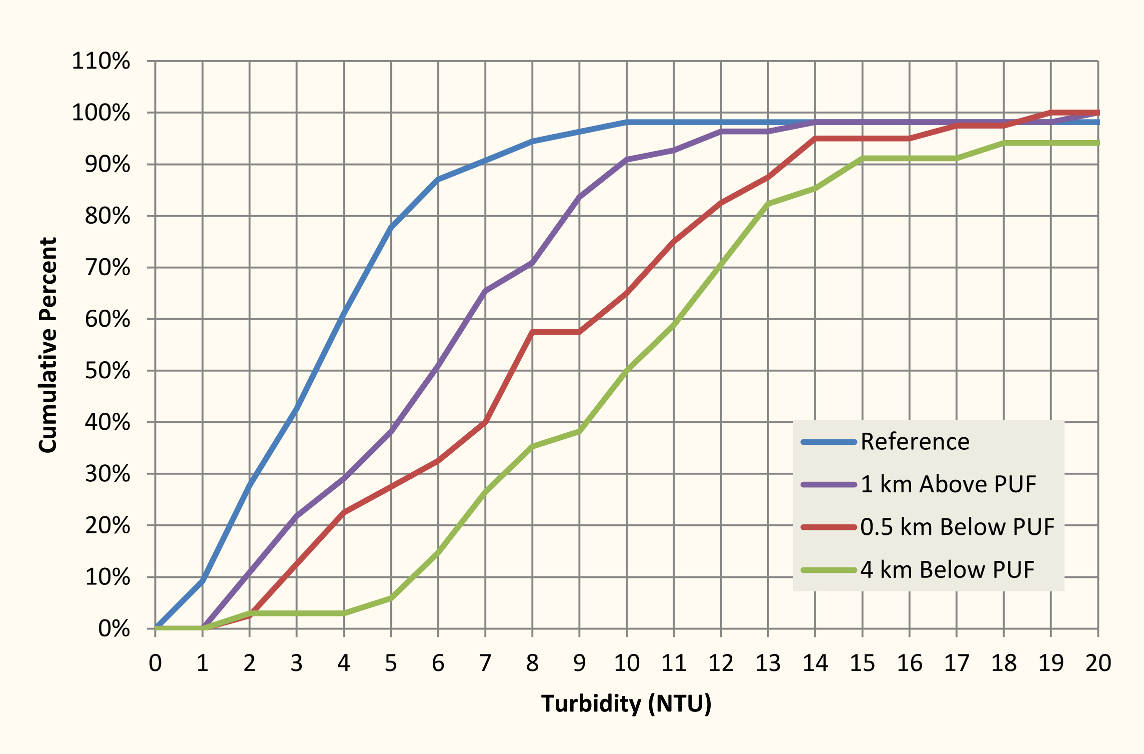


Figure 8. Cumulative frequency distribution of turbidity for grab samples collected at a reference site, and sites located upstream and downstream from the PUF boat launch. At the reference site 90% of the values are less than 7 NTU whereas at the site 4 km downstream from the PUF turbidity is close to 8 NTU higher with 90% of the values less than 15 NTU.

Table 10. Comparison of the percent of grab sample turbidity values less than 3 and 7 NTU at the references site, and sites 1 km upstream and 4 km downstream from the PUF.

Site	% of Samples < 3 NTU	% of Samples < 7 NTU
Reference	43	90
1 km Upstream from the PUF	22	65
4 km Downstream from the PUF	3	27

3.3.2 Hourly Data Loggers

Similar results were obtained through analysis of hourly turbidity data. Figure 9 shows the cumulative frequency distribution for turbidity values recorded at the reference site, 8 km upstream of the PUF boat launch, and 4 km and 8 km downstream from the boat launch. Cumulative frequency curves show the percent of all of the hourly measures, or percent of time, turbidity was below a specific value. Turbidity at the reference site was less than 15 NTU 90% of the time and less than 5 NTU 65% of the time. Comparatively, the sample site at 4 km downstream of the boat launch was only less than 15 NTU 55% of the time and less than 5 NTU only 12% of the time. The site at 8 km downstream of the boat PUF boat launch was less the 5 NTU approximately 3% of the time. Table 11 also demonstrates the differences in NTU values between the sample sites. Unlike grab samples which were collected on the same day at the reference and all other sampling locations, turbidity from data loggers could be adjusted to account for flow time between stations. Increases in turbidity from the reference site to the site 4 km downstream from the PUF, offset by one day (24 hrs) to allow for flow time, was significantly related to total daily boat counts at the entrance booth (Figure 10, r = 0.22, p < 0.001).

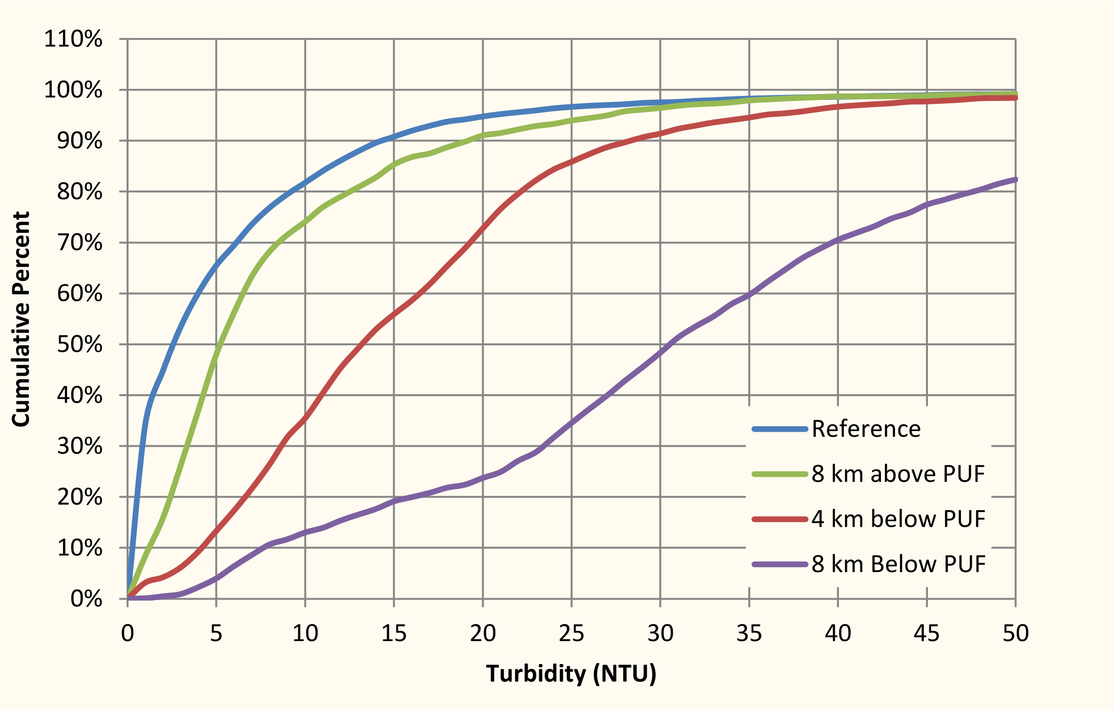


Figure 9. Cumulative frequency distributions for turbidity from Hydrolab sondes located at the upstream reference site (60 km upstream from PUF boat launch) and sites 8 km upstream and 4 and 8 km downstream from the boat launch. The DEC Natural Conditions tool uses the 90th percentile distribution.

Table 11. Comparison of the percent of continuous turbidity values less than 3 and 7 NTU at the references site, and sites 8 km upstream and 4 km and 8 downstream from the PUF.

Site	% of Samples < 3 NTU	% of Samples < 7 NTU
Reference	54	74
8 km Upstream of the PUF	26	63
4 km Downstream from PUF	6	26
8 km Downstream from PUF	1	9

3.3.3 Water Quality Standard Evaluation

Data collection and analyses met or exceeded the sampling criteria for turbidity listed in the 2010 Integrated Water Quality Monitoring and Assessment Report. Turbidity downstream from the PUF exceeded the water quality criteria for water supply, drinking water, and primary and secondary recreation, but 10% of the values did not exceed the criteria for aquaculture or the growth and propagation of fish (see Table 12 for WQS for Turbidity).

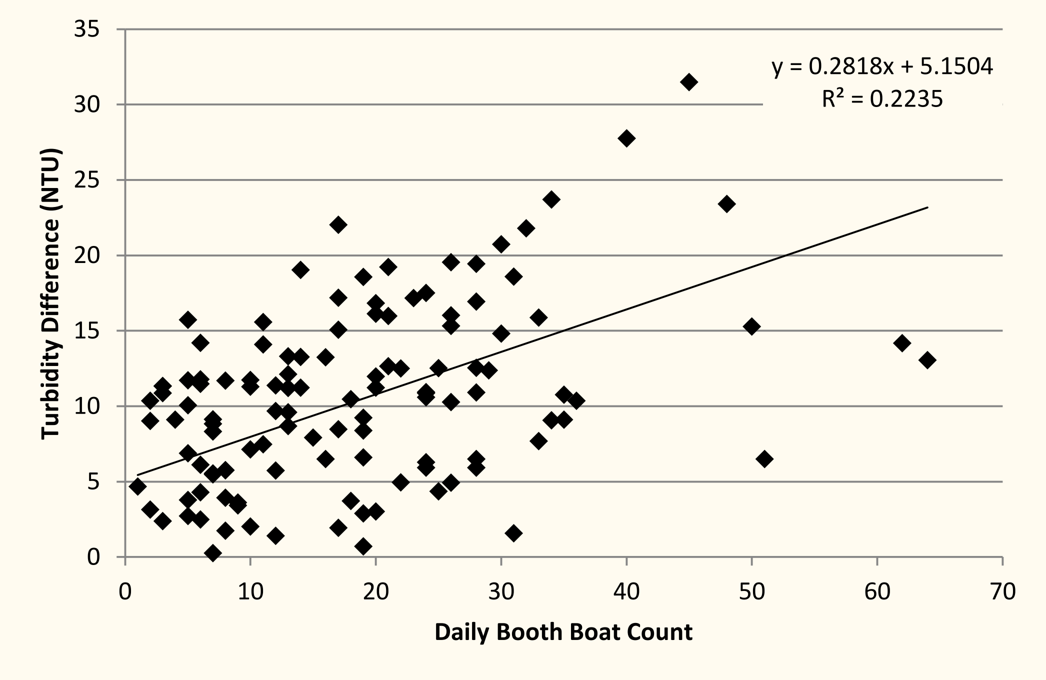


Figure 10. Regression relationship of daily boat counts at the PUF entrance booth and the increase in turbidity from the reference site and 4 km downstream from the PUF offset by 1 day.

Table 12. Alaska water quality standards for turbidity in fresh water (DEC 2006).

Designated Use	Water Quality Standard
(A) Water Supply **(i) Drinking, Culinary, and Food Processing**	May not exceed 5 nephelometric turbidity units (NTU) above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 25 NTU.
(ii)Agriculture, including irrigation and stock watering	May not cause detrimental effects on indicated use.
(iii) Aquaculture	May not exceed 25 NTU above natural conditions. For all lake waters may not exceed 5 NTU above natural conditions.
(iv) Industrial	May not cause detrimental effects on established water supply treatment levels.
(B) Recreation **(i) Contact**	May not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU. May not exceed 5 NTU above natural turbidity for all lake waters.
Recreation **(ii) Secondary**	May not exceed 10 NTU above natural conditions when natural turbidity is 50 NTU or less, and may not have more than 20% increase in turbidity when the natural turbidity is greater than 50 NTU, not to exceed a maximum increase of 15 NTU. For all lake waters, turbidity may not exceed 5 NTU above natural turbidity.
(C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife.	Same as (12)(A)(iii) above.

Natural condition values were used to evaluate compliance with state water quality standards from turbidity data collected downstream from the PUF boat launch. Results of water quality evaluation show that approximately 29% of the turbidity measures 4 km downstream of the PUF were 5 NTU above the natural condition using the entire data set from 2009-2010. These years are representative of the entire dataset. This percentage increased to approximately 39% of the time when using data collected during peak use periods in June or August (Table 13). The less restrictive aquatic life criteria (25 NTU), was exceeded over 170 times, but accounted for approximately 4% of the total values. This percentage increased to 5% of values 25 NTU above natural conditions when using the August data set. The natural condition for June is 13.8 NTU and for August is 13.1 NTU. Using these natural condition values, the percentage of time hourly turbidity values exceeded the water quality criteria are listed in Table 14.

Table 13. Natural condition analyses results for the Little Susitna River reference site and evaluation of water quality standard exceedances of the turbidity standard for data collected in 2009 and 2010.

	Entire Data Set (values >1000 removed)	Adjusted Data Set (values >300 NTU removed)	June	August
Reference				
Total Number of Values	4,609	4,594	1,324	1,817
Natural Conditions (NC) Value	14.9	14.6	13.8	13.1
4 km Downstream from PUF				
Total Number of Values	4,280	4,257	1,324	1,486
% of Values >5 NTU above NC	28.7%	29.4%	39.2%	39.6%
% of Values >10 NTU above NC	15.1%	15.2%	12.8%	23.2%
% of Values >25 NTU above NC	4.1%	3.7%	1.4%	5.2%

Table 14. Natural condition analyses results for the Little Susitna River comparing reference site to the site located 4 km downstream of the PUF.

State Standard for Designated Use		Estimated Percent Time of Exceedance at 4 km Downstream of PUF	
		June	August
Water Supply	**(5 NTU)**	39.2%	39.6%
Primary Recreation	**(5 NTU)**	39.2%	39.6%
Secondary Recreation	**(10 NTU)**	12.8%	23.2%
Aquatic Life	**(25 NTU)**	1.4%	5.2%

3.3.4 Turbidity Relationship with Boat Use

Daily patterns supported the relationship between turbidity and boat use downstream from the PUF. An example of turbidity recorded hourly at the site 4 km downstream from the PUF is shown in Figures 11 and 12. Hourly turbidity increased up to 15 NTU from early morning lows and the magnitude of change was greatest during heavy boat use periods in the first two weeks of August. Daily declines in turbidity occurred from 23:00 to 06:00 (Figure 12).

Declines in turbidity from 23:00 to 06:00 were fitted to an exponential decay model,

$$T = T_o e^{-kt}$$

Where T is turbidity, T_o is initial turbidity, and t is time in hours, and k is the decay constant. Fitting the turbidity data from 23:00 to 06:00 to this model resulted in an average decay constant of -0.12. Using this decay rate constant it would take 12 hours for turbidity to decline from 20 NTU to less than 5 NTU or 15 hours if initial turbidity was 30 NTU. Therefore, high turbidity conditions decline overnight but do not reach reference values until boating activity declines following the coho fishery.

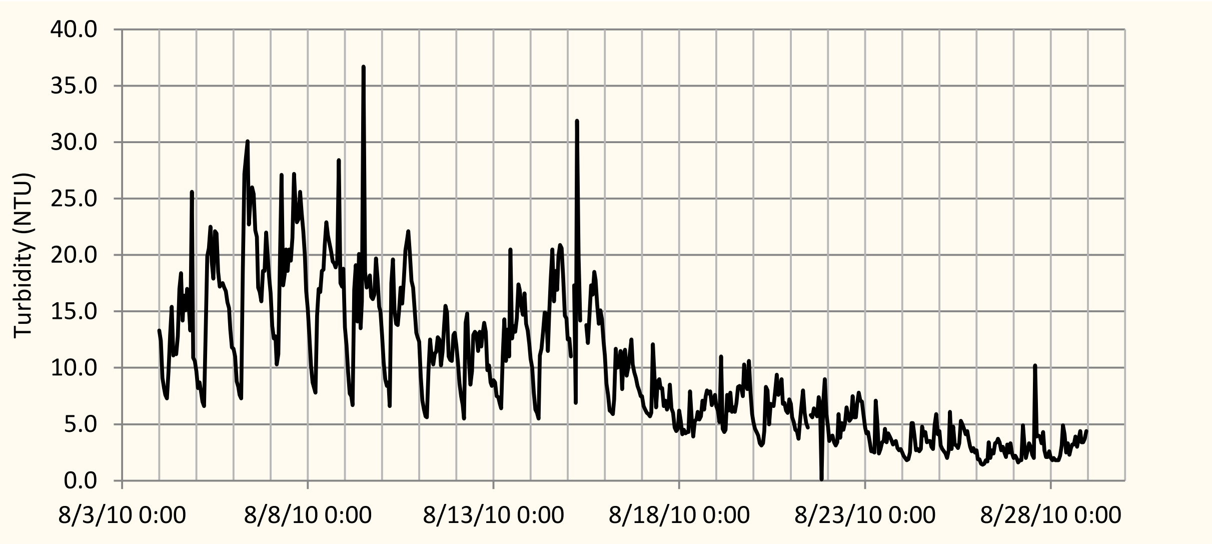


Figure 11. Hourly turbidity data from the HACH Sondes located 4 km downstream from the PUF during August 2010, showing daily and seasonal trends coinciding with high boat activity in early August to low boat activity in late August.

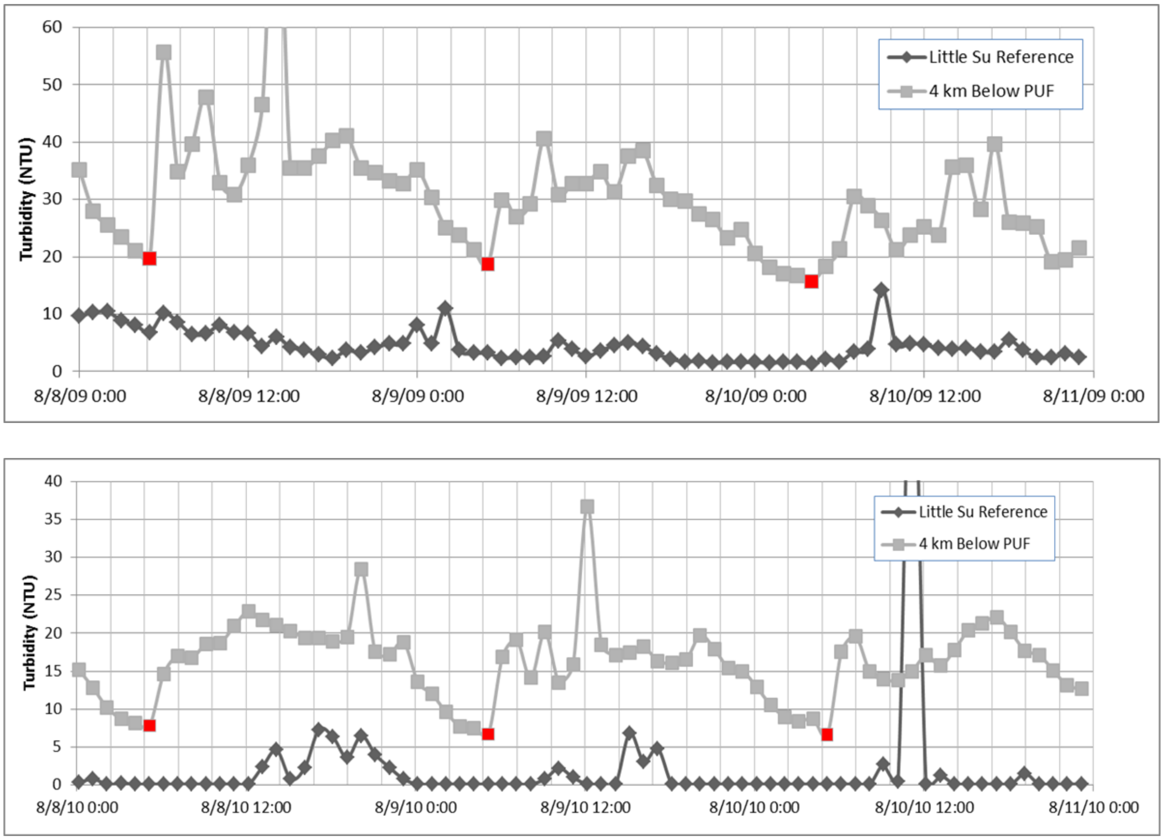


Figure 12. Turbidity during the coho salmon fishery in August 2009 and August 2010 at the reference site and the site 4 km downstream from the PUF boat launch. Red dots mark 05:00. Turbidity data show a consistent pattern of decline from 23:00 to 05:00 and then an increase immediately following the first few boats in the early morning. Boat counts at the booth on these dates in 2009 were 40, 48, and 30 and in 2010 were 64, 11, and 6. In both years daily turbidity increased over 10 NTU from 05:00 values.

3.4 Stream Channel Physical Characteristics

Stream channel physical characteristics at the site located 12 km (7.5 miles) upstream from the PUF and 4 km (2.4 miles) downstream from the PUF are shown in Table 14. These locations coincided with the upstream reference and downstream sampling locations for macroinvertebrate drift, and rearing juvenile salmon. There were no significant differences in mean channel area or depth, however, average channel width and width to depth ratio was greater at the impacted reach (downstream sampling location). The substrate within both reaches was dominated by fines less than 2 mm but the percent fines was greater downstream (Table 14). Differences in the abundance of fines may be due to the slightly lower water surface slopes and resulting lower bed tractive force.

The riparian vegetation at both locations consisted of an approximately 20 m zone of tall alder scrub. The alder zone on the right bank outside bend upstream was open while downstream was a closed canopy. Upstream the alder zone was followed by a closed mixed spruce and birch forest or bluejoint grass meadow. Downstream the closed alder zone on the outside of the right bank was followed by 20 to 100 m of bluejoint meadow and then the closed birch and spruce forest. Bank heights at both locations were 1.5 to 2 m and near vertical. There were small areas of bank undercutting downstream but not at the upstream reference site. While woody debris was present at more transects upstream, the nearshore zone at the downstream reach contained debris accumulations of living and dead alder branches. The dense alder zone also provided cover 3 to 4 m over the channel downstream but there was little overhead cover at the upstream reference site. The substrate along the outside bend of both reaches was 100% fine material. The total area where water velocity was less than 0.39 m/s (the sustained swimming speed of juvenile coho salmon 55 mm fork length) was larger at the downstream reference site.

Table 15. Stream channel physical characteristics at the reference and impacted reaches. Asterisks denote significant differences between means ($p < 0.05$).

	Reference Reach (12 kmup)	Impacted Reach (4 kmdn)
Average Cross-Sectional Area (m^2)	33.8 (9.1)	48.3 (11.8)
Channel Width (m)	34.9 (1.7)	39.9 (3.6)*
Average Depth (m)	0.96 (0.22)	0.76 (0.20)
W/D Ratio (m/m)	37.6 (7.6)	52.2 (3.9)*
Wetted Perimeter (m)	31.4 (1.8)	33.3 (5.4)
WS Slope -Thalweg (%)	0.07	0.03
Bed Slope -Thalweg (%)	0.35	-0.53
Tractive Force (kg/m^3)*	0.76	0.43
% Fines ≤2mm	60.6%	90.4%
Bank Undercut (cm)	None	10-20
% Transects with LWD	80	60
Bank Area Vel≤0.39 m/s (m^2)	259	308

Low slope and fine substrate conditions continue upstream from the reference site. Downstream from the reference location, stream slope increases and the percent fine substrate decreases. These conditions persist downstream to the PUF boat launch. Downstream of the PUF boat launch, stream slopes decrease and the percent fine substrate increases until the Little Susitna River discharges into Cook Inlet.

3.5 Ecosystem Metabolism – Primary Production

Gross primary production (GPP) was consistently higher at the upstream reference location, compared to downstream impact sites. Strong seasonal patterns in GPP were observed at upstream sites, but this effect was dampened at downstream sites. Ecosystem respiration (ER) was similar at all sites throughout the summer, however greater variation in ER was observed earlier in the sampling season. Net daily metabolism (NDM) was consistently autotrophic (NDM > 0) at upstream sites during June and shifted to heterotrophic conditions (NDM < 0) in July and August. Downstream sites exhibited variable NDM until August when NDM was consistently heterotrophic.

On occasion, Oxygen (O_2) concentration change during the night was positive yielding average ER values low in magnitude or positive. Similarly, net O_2 concentration change during the day was sometimes negative and GPP was occasionally negative. Approximately 2 % of GPP data was negative and 10 % of ER data was positive. Considering all sites, GPP ranged from -0.51 to 1.22, ER from -0.90 to 0.41 and NDM from -0.61 to 1.10 (g $O_2/m^2/d^1$). Mean GPP and NDM were significantly different by site (ANOVA; $P < 0.001$), but ER was not (Figure 5). Mean GPP was approximately 50% greater at LS 12 km up and LS 4 km up vs. LS 2 km dn and LS 4 km dn. NDM decreased from upstream to downstream and was significantly greater at upstream sites with LS 12 km up > LS 4 km up (Figure 13). Cumulative GPP at LS 12 km up (41.24 g O_2/m^2) and LS 2 km dn (21.71 g O_2/m^2) over 98 days also exhibited a reduction in downstream productivity of approximately 50% resulting in a cumulative NDM difference of 15.67 g O_2/m^2.

GPP showed several correlations to environmental variables. Periods of high turbidity and high discharge occurred during mid-summer when solar radiation was also high creating a complex relationship between environmental variables and GPP. In order to eliminate solar radiation and discharge as co-variants of turbidity and investigate the impact of turbidity on GPP, regression between the difference in GPP (downstream - upstream) and downstream turbidity was performed. Based on field observations, discharge and solar radiation were assumed equal upstream and downstream of the PUF, thus allowing evaluation of any relationship between turbidity and GPP. When upstream turbidity was low (< 7 NTU), there was a significant, and negative relationship between the change in GPP and turbidity ($N = 33$, $P < 0.001$, Figure 14). The average downstream GPP as a percent of upstream values decreased exponentially (Figure 15) with changes in turbidity. Using this equation, an increase of 7 NTU resulted in a 60% decline in GPP.

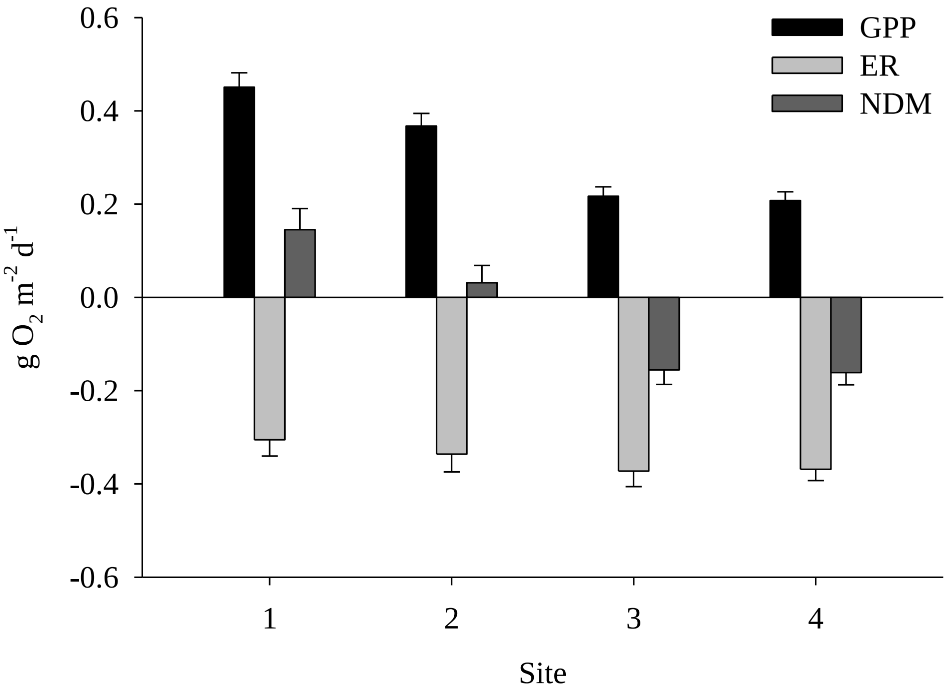


Figure 13. Mean metabolic rates (± SE) at all four sampling reaches. There were no significant differences in GPP or NDM between the two upstream reaches (1 and 2) or the two downstream reaches (3 and 4) but upstream GPP and NDM were significantly different from downstream GPP and NDM (ANOVA and Tukey post hoc tests; n = 53 days, p = 0.001).

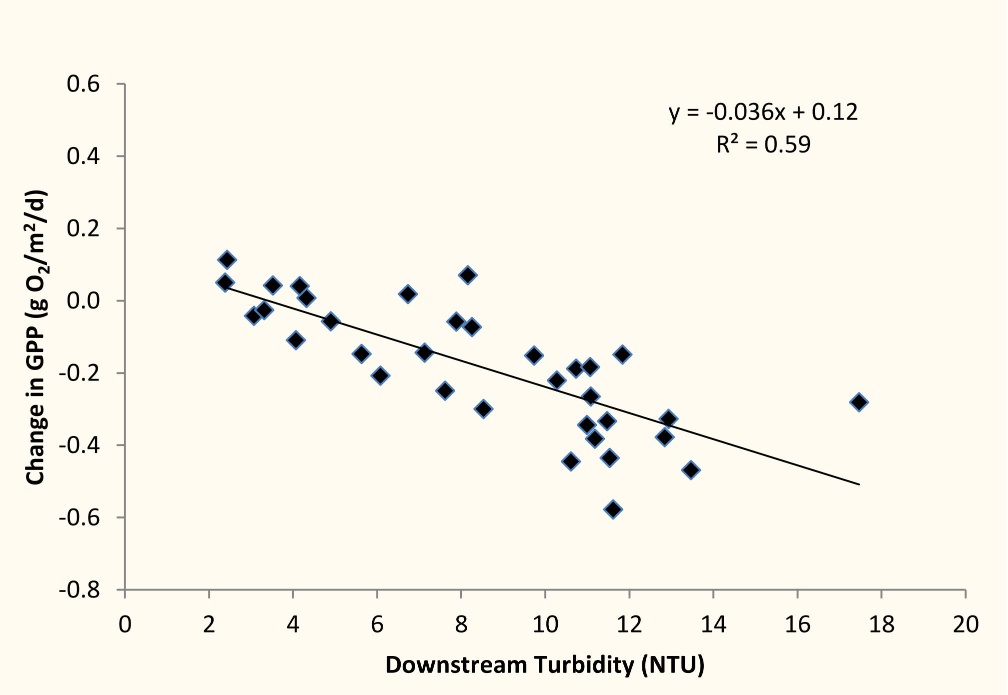


Figure 14. Regression relationship between the change in GPP from upstream to downstream as a function of downstream turbidity when upstream turbidity is low (< 7 NTU).

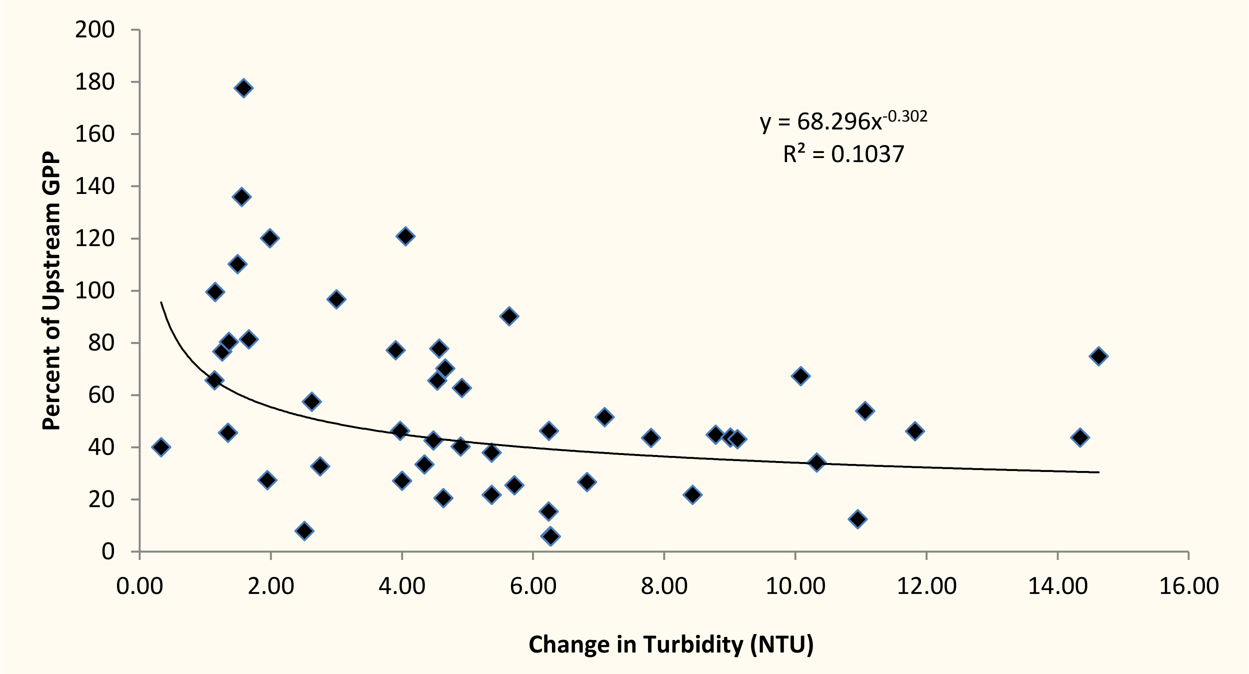


Figure 15. Percent of GPP as a function of the change in turbidity. A 7 NTU increase in turbidity can result in a 60% decline in GPP.

3.6 Macroinvertebrates

Macroinvertebrates within the drift were more abundant at the biological reference site upstream of the boat launch compared to the sampling site 4 km downstream from the PUF. Macroinvertebrates within the drift were dominated by Diptera on most sampling dates, either Chironomidae or *Probezzia*. However, in August of 2008, the Trichoptera, *Brachycentrus* was the dominant taxa. Taxa richness ranged from 4 to 7. Average taxa richness was 9.5 upstream and 7.5 downstream but were not significantly different ($p = 0.13$).

Average invertebrate drift density was 6.2 m^{-3} upstream and 3.8 m^{-3} downstream from the PUF boat launch. At an average discharge of 484 cfs, a difference of 2.4 insects m^{-3} is equal to 33 insects every second, 119,000 insects every hour, or 2.9 million insects a day. Drift density was significantly higher upstream on 4 of the 5 sampling dates (Figure 16, $p < 0.05$). When considering all sampling dates, total drift density also was significantly different between locations ($p = 0.01$). Drift density was significantly different when comparing all Diptera ($p = 0.03$) or Chironomidae ($p = 0.05$), but was not significant between locations for total Ephemoptera, Plecoptera, or Trichoptera (EPT taxa) ($p = 0.35$).

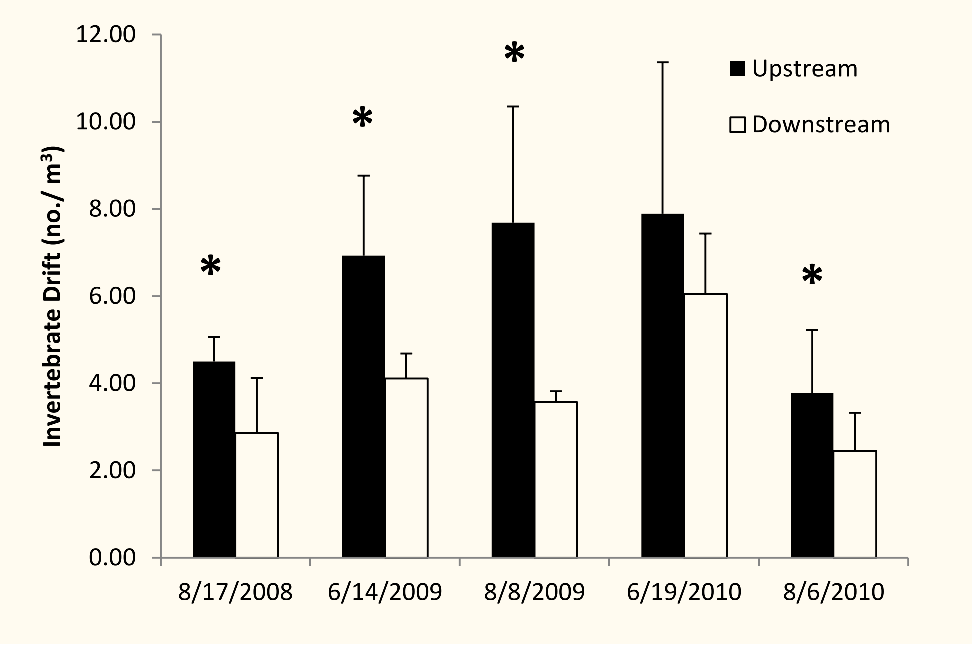


Figure 16. Mean drift density within the upstream reference reach and downstream impacted reach for all sampling dates. Asterisks denote statistically significant differences in means, error bars are one standard deviation.

3.7 Juvenile Salmon

Juvenile coho and Chinook salmon were captured within both sampling reaches on all sampling dates. In June of 2009 and 2010, there were a mixture of presumed age-0 and age-1 coho and Chinook salmon at the upstream and downstream locations (Figure 17). In June 2009, only three coho salmon juveniles were captured downstream with fork lengths from 62 to 78 mm and were likely age-1 fish. Whereas in June 2009, upstream coho salmon juveniles were predominately age-0 with fork lengths from 42 to 56 mm and one age-1 fish with fork length of 71 mm. In June 2010, downstream and upstream juvenile coho salmon ranged from 44 to 89 mm representing two age classes. By August, the coho salmon population was dominated by one size class with 90% of the fish between 44 and 64 mm in fork length (Figure 18). Therefore, the larger age-1 fish present in June were no longer present in August, likely due to migration out of the sampling reach. The mode of the distribution in August was 50 mm upstream and 56 mm downstream.

Similar to coho salmon, two size classes of Chinook salmon juveniles were present in June and one size class in August. In June 2009, a small portion of the fish captured upstream were age-0 with fork lengths ranging from 44 to 49 mm and the remainder age-1 with fork lengths from 62 to 88 mm. Downstream, only age-1 fish were present with fork lengths from 75 to 115 mm. In June 2010, two size classes were present upstream and downstream with fork lengths from 44 to 60 mm, likely age-0 fish, and fork lengths from 64 to 98 mm, likely representing age-1+ fish. By August only one size was present. In August 2009, over 90% of the Chinook salmon fork lengths were 50 to 64 mm fork length upstream and 54 to 72 mm in fork length downstream. In August 2010, over 90% of the Chinook salmon fork lengths were 54 to 68 mm upstream and 56 to 76 mm upstream. The mode of the distribution in August was 60 mm upstream and 66 mm downstream.

The abundance of rearing juvenile salmon was higher upstream than downstream from the PUF boat launch. When testing each sampling date independently the CPUT of all juvenile salmon was significantly higher at the upstream reference site (Figure 19, $p < 0.05$) on all 5 sampling dates. Chinook salmon CPUT was higher upstream on 4 of the 5 sampling dates, and coho salmon on 3 of the 5 sampling dates. Chinook salmon CPUT was not significantly different in August 2009, and coho salmon CPUT was similar upstream and downstream from the boat launch in June and August 2010. When testing for differences using all sampling dates, total salmon and Chinook salmon CPUT was significantly different ($p = 0.03$ for both), but coho CPUT was not ($p = 0.15$).

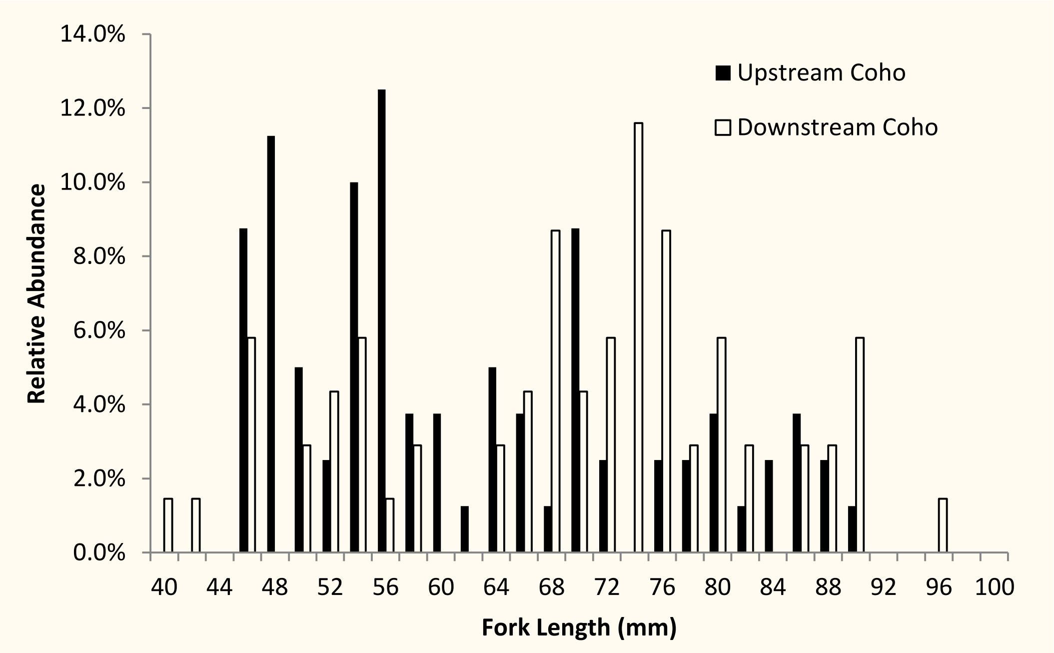


Figure 17. Size frequency distribution of juvenile coho salmon during June sampling showing multiple age classes at both sampling locations.

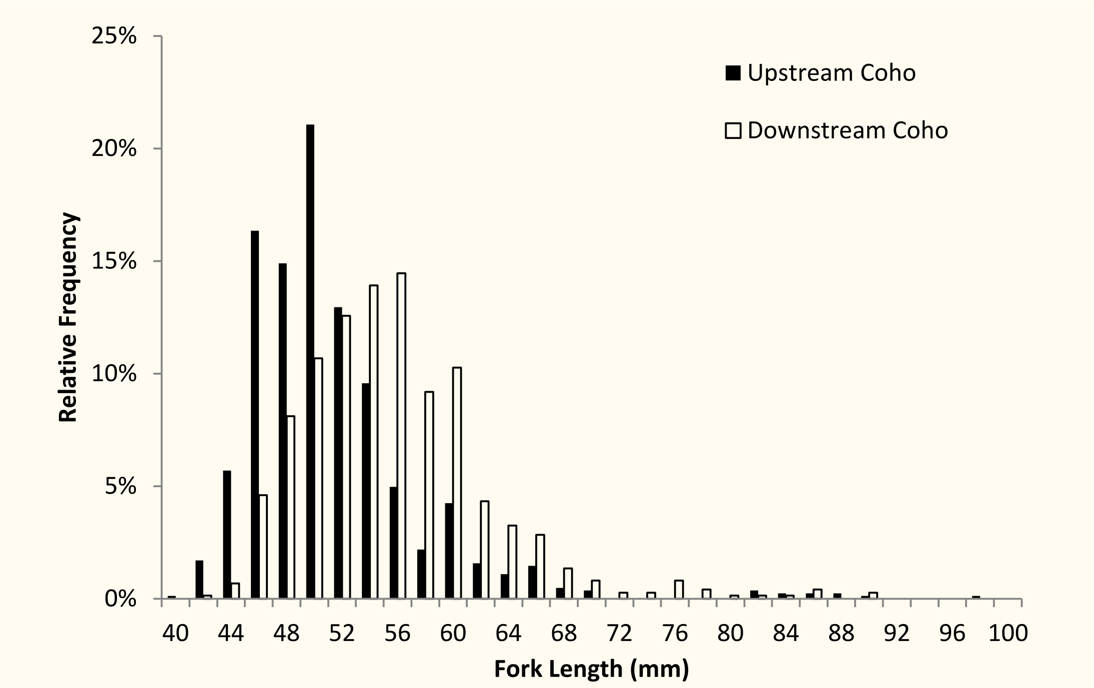


Figure 18. Size frequency distribution during August showing single age class and the greater abundance of small fish at the upstream site.

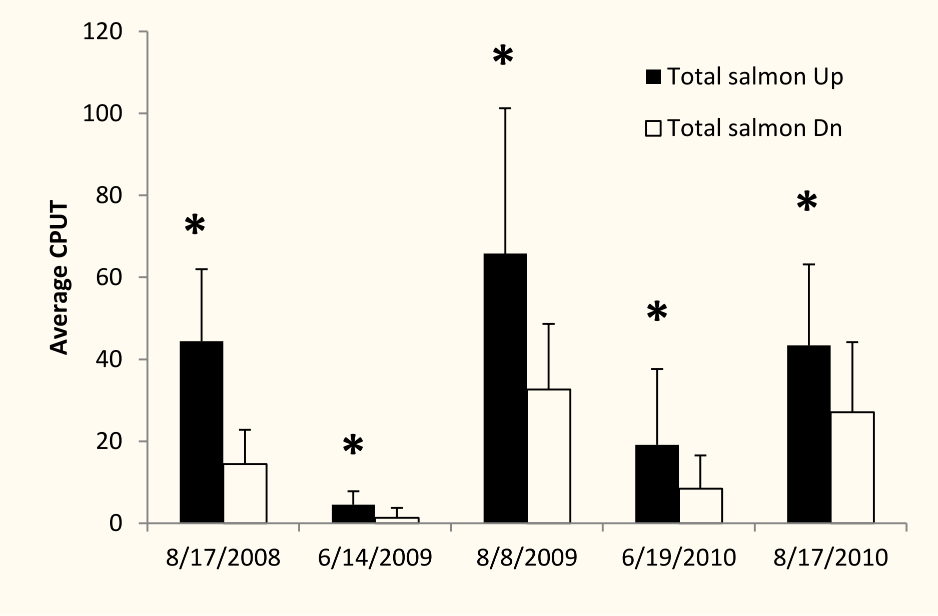


Figure 19. Average total salmon CPUT at the upstream and downstream sampling reaches. Asterisks denote significant differences and error bars are one standard deviation.

4.0 Discussion

The operation of motor boats on the Lower Little Susitna River alters water quality through the discharge of gasoline and suspension of bed sediments. The increase in boat-induced turbidity is causing a decrease in primary production. Hydrocarbon toxicity, the direct effects of suspended sediment, reduced primary production, physical habitat differences and boat wave physical impacts all may be contributing to the decline in macroinvertebrate and juvenile salmon abundance downstream from the boat launch; however, factors causing the differences in the biotic community are unknown.

The increase in TAH concentrations with boat use is consistent with other studies (Lico 2004, DEC 2004, Moles et al. 2006, Orso et al. 2007). Previous studies, however, have shown that aromatic hydrocarbon discharge is greater for 2-cycle motors and that reduction in the numbers of boats using 2-cycle motors can reduce volatile hydrocarbon concentrations (Lico 2004, DEC 2009). However, a strong a relationship between 2-cycle motors and average hydrocarbon concentrations downstream from the PUF boat launch did not exist. In addition, TAH discharge per boat was not different between days when only a small portion of the boats used 2-cycle motors and when a large portion of the boats used 2-cycle motors. The initial hypothesis was that the lack of a strong correlation was due to the variability in discharge among 2-cycle motors based on motor size (Hare and Springier 1973). However, even after adjusting for motor size, the relationship between 2-cycle motors and hydrocarbons was not as good as the relationship using total boats. The analyses was then restricted to intensive sampling days, samples collected at the boat launch, and boat use by motor type operating 0.5 hours prior to sample collection. The relationship between 2-cycle motors and hydrocarbons then improved and was better than when using the total number of boats or boats using 4-cycle motors.

Laboratory studies have determined that 2-cycle motors discharge much more unburned fuel when idling and when operating at low speeds (Jüttner et al. 1995). The differences between the results presented and other studies are then explained. Boats operating on the Lower Little Susitna River spend time at the boat launch loading and warming up engines resulting in a time of maximum discharge for 2-cycle motors and would explain the close relationship we observed with samples collected at this location. Similarly, high hydrocarbon concentrations from other studies are generally observed near marinas and boat launches where boat speeds would be low (Lico 2004, Oros et al. 2007). However, when travelling on the Little Susitna, speeds must be maintained to avoid contact with the stream bottom, and when reaching a fishing location, boat motors are shut off. The difference in discharge between 2-cycle and 4-cycle motors is much lower at high speeds reducing the relationship between 2-cycle motors and hydrocarbon concentrations.

The combination of boat waves and the abundance of fine substrate resulted in high turbidity that exceeded WQS for water supply, and contact recreation (> 10 NTU above background). These findings are consistent with other published turbidity studies. Vessel speed, hull design, and particle size can influence the suspension and settling rate of particles (Garrard and Hey 1987). Results in the Lower Little Susitna River, as well as the broadland rivers studies by Garrard and Hey (1987), show that the time necessary for particles to settle can be longer than the time period between boat passages. Increases in turbidity due to natural events could persist for a much longer duration because of turbulence caused by boat waves. This could increase the effects of turbidity on primary production and aquatic organisms. Newcome and McDonald (1991) found that not only concentration, but duration of exposure, were important for predicting the effects of increasing sediments.

The combination of hydrocarbon inputs and suspended sediments also could be acting synergistically. Hydrocarbons are known to bind to sediment (Hwang and Foster 2006, Krein and Schorer 2000) and are often greater within the sediments than the water column (Larkin and Hall 1998). TAH are often found in high boat use areas and in association with volatile compounds (Lico 2004, Moles et al. 2006, Oros et al. 2007, Rice et al. 2008). TAH can be toxic to fish and other aquatic organisms (Meader et al. 2006, Tjarland et al. 1996, Blanc et al. 2010) and the suspension of sediment could increase their availability.

Gross ecosystem production decreased with an increase in turbidity in the Lower Little Susitna River. The decline in productivity was greater than previously predicted for Alaskan rivers. Lloyd et al. (1987) predicted a 13 to 50% decrease in primary production with a 25 NTU increase in turbidity. However, we found a 40% decrease in productivity with only a 5 NTU change in turbidity. Equations used by Lloyd et al. (1987) were based on the relationship between GPP and light penetration developed by Van Nieuwenhuyse and LaPerriere (1986) for shallow interior Alaska streams and may not be applicable to the Little Susitna River due to differences in channel morphology and suspended sediment size.

The decrease in the abundance of rearing juvenile salmon and drifting invertebrates downstream from the PUF boat launch could be due to natural variability, differences in physical habitat, water quality or other factors such as boat waves, reduced food availability or a combination of factors. In order to determine the exact cause or causes for the difference in abundance of juvenile fish and macroinvertebrates, a more extensive biological study would need to occur.

4.1 Conclusion

The operation of motor boats in the Lower Little Susitna River causes an increase in hydrocarbon concentrations and turbidity. The increase in hydrocarbons is lower upstream of the boat launch because only a portion of the boats travel in this direction. Hydrocarbon concentrations at the boat launch are closely related to the number of 2-cycle motors but average downstream concentrations are more closely related to the total number of boats, regardless of motor type. Hydrocarbon concentrations often exceed 10 µg/L, but do not remain above this concentration consistently. Increases in turbidity also are lower upstream of the boat launch because of the lower amount of fine particles in the streambed. Turbidity downstream from the boat launch exceeds WQS for some designated uses. The study also documented a difference in the abundance of rearing juvenile salmon and marcroinvertebrates from upstream of the public boat launch to downstream of it. This could be caused by many factors or a combination of factors.

References

Alaska Department of Environmental Conservation. 2006. Guidance for the Implementation of Natural Condition-Based Water Quality Standards. Juneau, Alaska.

Alaska Department of Environmental Conservation. 2006. 18 AAC 70, Water Quality Standards. Juneau, Alaska.

Alaska Department of Environmental Conservation. 2010. 2009 Kenai River Hydrocarbon Assessment. Downloaded from the State of Alaska web site April 2013. (www.dec.alaska.gov/water/wnpspc/pdfs/Kenai_River_2009_Petroeum_Assessment_Report.pdf)

Alaska Department of Environmental Conservation. 2010b. Alaska Statistical Spreadsheet Tools for Natural Condition Evaluation, User guides, Version 2. Prepared by Tetra Tech, Inc.

Alaska Department of Environmental Conservation. 2009. Kenai River 2008 Petroleum Assessment Final Report.

Anderson, R.J., and B.P. Bledsoe. 2001. A combined analytical and empirical approach for design of stable channel width in channels having vegetative influences. Proceedings of American Society of Civil Engineers: Wetlands Engineering and River Restoration Conference. Reno, NV, 25-31 August 2001.

Beeson, C.E., and P.F. Doyle. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. Water Resources Bulletin 31: 983-990.

Bishop, M. 2007. Impacts of boat generated waves on Macroinfauna: towards a mechanistic understanding. Journal of Experimental Marine Biology and Ecology. 343: 187-196.

Bott, T.L. 2007. Primary productivity and community respiration. Pages 663-690 *in* “Methods in Stream Ecology 2nd Edition (eds R. Hauer & G.A. Lamberti), Academic Press, 896 pgs.

Butcher, G. A. 1982. The effects of outboard engine usage and exhaust emissions on the aquatic environment. A review. APD Bulletin 31. Aquatic Studies Branch, Ministry of Environment, Province of British Columbia.

Davies-Colley, R. J., C. W. Hickey, J. M. Quinn, and P. A. Ryan. Effects of clay discharges on streams 1, optical properties and epilithon. Hydrofiologia 248:215-234.

Davies-Colley, R.J. 1997. Stream channels are narrower in pasture than in forest. New Zealand Journal of Marine and Freshwater Research 31:599-608.

Davis, J.C., G.A. Davis, and L. Eldred. 2011. Hydrocarbons and Turbidity on the Lower Little Susitna River. Final Report for the Alaska Department of Environmental Conservation. ACWA 10-03. Talkeetna, AK.

Davis, J.C., and G.A. Davis 2010. Hydrocarbons and turbidity in the Lower Little Susitna River. Final Report for the Alaska Department of Environmental Conservation. ACWA 10-03. Aquatic Restoration and Research Institute, Talkeetna, Alaska.

Davis, J.C. G.A. Davis, and N.R. Ettema. 2009. Water Quality Evaluation of the Lower Little Susitna River: July 2008 through June 2009. Final Report for the Alaska Department of Environmental Conservation. ACWA 09-02. Talkeetna, AK.

Davis, J.C., and G.A. Davis. 2008. Water quality evaluation of the lower Little Susitna River. Final Report for the Alaska Department of Environmental Conservation. ACWA 08-02. Aquatic Restoration and Research Institute. Talkeetna, Alaska.

Davis, J.C., and G.A. Davis. 2007. The Little Susitna River—An ecological assessment. Final Report for the Alaska Department of Environmental Conservation. ACWA 07-11. Aquatic Restoration and Research Institute. Talkeetna, Alaska.

Davis, J. C., G. W. Minshall, C. T. Robinson, and P. Landrus. 2001. Monitoring wilderness stream ecosystems. USDA Forest Service, Rocky Mountain Research Station, General Technical Report, RMRS-GTR-70.

Fairchild G.W. and R.L. Lowe. 1984. Artificial substrates which release nutrients: effects on periphyton and invertebrate succession. Hydrobiologia 114:29-37.

Garrad, P.N. and R.D. Hey. 1987. Boat traffic, sediment resuspension and turbidity in a broadland river. Journal of Hydrology. 95: 289-297.

Hare, C.T. and K.J. Springier. 1973. Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines. Final Report, Part Two, Outboard motor, Contract No. EHS 70-108. Rep. for US Environmental Protection Agency by Southwest Research Institute. San Antonio, Texas. 57p.

Heintz, R.A., J.W. Short, and S.D. Rice. 1999. Sensitivity of fish embryos to weathered crude oil: Part II. Incubating downstream from weathered Exxon Valdez crude oil caused increased mortality of pink salmon (Oncorhynchus gorbuscha) embryos. Environ. Toxicol. Chem. 18: 494-503.

Heintz, R.A., S.D. rice, A.C. Wertheimer, R.F. Bradshaw, F.P. Thrower, J.E. Joyce, and J.W. Short 2000. Delayed effects on growth and marine survival of pink salmon *Oncorhynchus gorbuscha* after exposure to crude oil during embryonic development. Mar. Ecol. Prog. Ser. 208:205-216.

Hilton, J., and G.L. Phillips. 1982. The effect of boat activity in a shallow broadland river. Journal of Applied Ecology. 19: 143-150.

Hwang, H-M., and G.D. Foster. 2006. Characterization of polycyclic aromatic hydrocarbons in urban stormwater runoff flowing into the tidal Anacostia River, Washington, DC. Environmental Pollution 140(3): 416-426.

Jüttner, F., D. Backhaus, U. Matthias, U. Essers, R. Greiner, and B. Mahr. 1995. Emissions of two-stroke and four-stroke outboard engines: quantification of gases and VOC. Water Resources. 29: 1976-1982.

Krein, A., and M. Schorer. 2000. Road runoff by polycyclic aromatic hydrocarbons and its contribution to river sediments. Water Research 34(16): 4110-4115.

Lamberti, G. A., S. V. Gregory, L. R. Ashkenas, A. D. Steinman, and C. D. McIntire. 1989. Productive capacity of periphyton as a determinant of plant-herbivore interactions in streams. Ecology 70:1840-1856.

LaPerriere, J. D., E. E. Van Nieuwenhuyse, and P. R. Anderson. 1989. Benthic algal biomass and productivity in high subarctic streams, Alaska. Hydorbiologia 172:63-75.

Lake, R.G., and S.G. Hinch. 1999. Acute effects of suspended sediment angularity on juvenile salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Science. 56: 862-867.

Larkin, G.A. and K.J. Hall. 1998. Hydrocarbon pollution in the Brunette River watershed. Water Quality Research Journal of Canada 33(1): 73-94.

Lemly, A. D. 1982. Modification of benthic insect communities in polluted streams: combined effects of sedimentation and nutrient enrichment. Hydrobiologia 87:229-245.

Lerner, B.M., Murphy, P.C., and Williams E.J. 2009. Field Measurements of Small Marine Craft Gaseous Emission Factors during NEAQS 2004 and TexAQS 2006. Environmental Science and Technology. 43: 8213-8219.

Lico, M.S. 2004. Gasoline-related organics in Lake Tahoe before and after prohibition of carbureted two-stroke engines. 2004. Lake and Reservoir Management. 20: 164-174.

Lloyd, D. S., J. P. Koenings, and J. D. LaPerriere. 1987. Effects of turbidity in fresh waters of Alaska. North American Journal of Fisheries Management 7:18-33.

Love, S.D., and R.C. Baily. 1992. Community development of epilithic invertebrates in streams: independent and interactive effects of substratum properties. Can. J. Zool. 70: 1976-1983.

Maynord, S. 2001. Boat waves on Johnson Lake and Kenai River, Alaska. Technical Report ERDC/CHL TR-01-31, U.S. Army Corps of Engineers, prepared for the Alaska Department of Fish and Game.

Meader, J.P., F.C. Sommers, G.M. Ylitalo, and C.A. Sloan. 2006. Altered growth and related physiological responses in juvenile Chinook salmon (Oncorhynchus tshawytsha) from dietary exposure to polycyclic aromatic hydrocarbons (PAH). Can. J. Fish. Aquat. Sci. 63:2364-2376.

Minshall, G. W., and R. C. Petersen, Jr. 1985. Towards a theory of macroinvertebrate community structure in stream ecosystems. Arch. Hydrobiol. 104:49-76.

Moles, A., L. Holland and O. Andersson. 2006. Assessment of the significance of direct and indirect pollution inputs to a major Salmon-producing river using polyethylene membrane devices. Environmental Toxicology and Chemistry. 25: 2011-2017.

Moles, A., Marty, G.D. 2005 .Physiological changes in prickly sculpin (Cottus asper) inhabiting a lake used by jet-propelled watercraft. Bull. Environ. Contam. Toxicol. 74, 1151–1158.

Nanson, G. C., Von Krusenstierna, A., Bryant, E. A. and Renilson, M. R. (1994), Experimental measurements of river-bank erosion caused by boat-generated waves on the Gordon river, Tasmania. Regulated Rivers: Research & Management, 9: 1–14.

Newcombe, C.P., and Macdonald, D.D. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management. 11: 72-82.

Odum, H. T., 1956. Primary production in flowing waters. Limnol. Oceanogr. 1: 102-117.

Oregon Department of Environmental Quality. 2007. Turbidity Technical Review Summary of Sources, Effects, and Issues Related to Revising the Statewide Water Quality Standard for Turbidity.

Oros, D.R., R.W. Collier, and B.R.T. Simoneit. 2007. The extent and significance of petroleum hydrocarbon contamination in Crater Lake, Oregon. Hydrobiology. 574: 85-105.

Osborne, P.D., Boak, E.H., 1999. Sediment suspension and morphological response under vessel-generated wave groups: Torpedo Bay, Auckland, New Zealand. J. Coast. Res. 15, 388–398.

Rice, S.D., L. Holland, and A. Moles. 2008. Seasonal increases in polycyclic aromatic hydrocarbons related to two-stroke engine use in a small Alaskan lake. Journal of Lake and Reservoir Management. 23: 10-17.

Scannell, P.W., D. Dasher, L. Duffy, R. Perkins, and T. O'Hara. 2005. Acute and chronic toxicity of hydrocarbons in marine and fresh water with an emphasis on Alaska species. Alaska Department of Environmental Conservation, 610 University Avenue. Fairbanks, Alaska 99709.

Tjarnlund, U., Ericson, U., Lindesjoo, E., Petterson, I., Akerman, G., and Balk, L. 1996. Further studies of the effects of exhaust from two-stroke outboard motors on fish. Marine Environmental Research. 42: 267-271.

Tsivoglou, E.C., and L.A. Neal. 1976. Trtacer measurement of reparation, 3. Predicting reparation capacity of inland streams. Journal of the Water Pollution Control Federation 48:2669-2689.

Viereck, L.A., C.T. Dyrness, A.R. Batten, and K.J. Wenzlick. 1992. The Alaska vegetation classification. USDA Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-286.

Yousef, U. A. (1974). Assessing effects on water quality by boating activity. United States Environmental Protection Agency, Environment Protection Technology Series EPA-670/2-74-072.

Appendix A. Site Photographs

Photograph 1. Location of Houston reference turbidity logger looking upstream (6/12/11).

Photograph 2. Millers Reach boat launch downstream from Houston (9/24/10).

Photograph 3. Non-motorized boat use at the Millers Reach reference site (6/12/11).

Photograph 4. Site 12 km upstream from the PUF, location of upstream invertebrate and fish sampling (6/12).

Photograph 5. Installing drift nets at site 12 km upstream from the PUF (8/08)

Photograph 6. Sampling site 8 km upstream from the PUF looking downstream (8/1/10).

Photograph 7. Sampling site 8 km upstream from the PUF looking upstream (8/1/10).

Photograph 8. Site 4 km upstream from the PUF looking downstream (8/1/10).

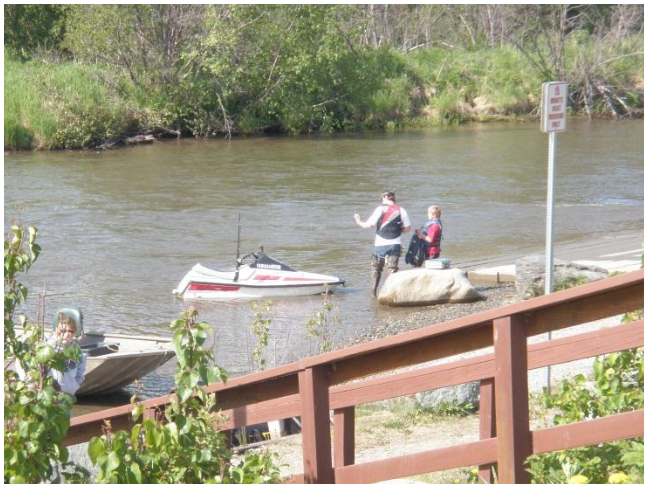
Photograph 9. Site 1 km upstream from the PUF looking upstream. Location where stream discharge was measured (8/1/10).

Photograph 10. PUF from upstream (8/8/10).

Photograph 11. Boat repairs at the PUF (8/9/10).

Photograph 12. PUF 2-cycle motors (8/9/10).

Photograph 13. Cold start at the PUF (8/9/10).



Photograph 14. Personal water craft used during the Chinook sport fishery at the PUF boat launch (6/11/11).

Photograph 15. Non-motorized boats at the PUF boat launch (6/12/11).

Photograph 16. Turbid water (6.7 NTU) at the PUF looking downstream (8/21/10).

Photograph 17. Collecting invertebrate drift samples and setting minnow traps at the site 4 km downstream from the PUF boat launch (8/08).

Photograph 18. Sampling location 4 km downstream from the PUF 6/11/11).

Photograph 19. Sampling location 4 km downstream from PUF looking upstream (8/21/10).

Photograph 20. Defoliated alders at 5 km downstream from the PUF (8/8/10).

Photograph 21. Site 8 km downstream from the PUF looking upstream (8/21/10).

Photograph 22. Sampling location 8 km downstream from the PUF (6/11/11).

Photograph 23. Site 12 km downstream from the PUF looking upstream (8/1/10).

Photograph 24. Little Susitna River 32 km downstream from the PUF boat launch.

Appendix B. TAH (µg/L) concentrations for all sampling dates and all sampling locations. Sites downstream of the PUF are kmdn and sites upstream of the PUF are kmup.

Date Time	LS-8 kmup	LS-4 kmup	LS-1 kmup	LS-0.5 kmup	LS-0 PUF	LS-0.5 kmdn	LS-1 kmdn	LS-2 kmdn	LS-4 kmdn	LS- 8 kmdn	LS-12 kmdn	LS-16 kmdn	LS-32 kmdn
7/29/07			2.6			5.1							
8/5/07			0			0							
8/12/07			0			0							
8/19/07			6.7			10.17							
8/26/07						0							
9/2/07			0			0							
9/9/07			0			0							
9/16/07			0			0							
5/10/08			0.0			0.0							
5/18/08			0.0			0.0							
5/24/08			1.2			5.3							
6/1/08			28.6			27.6							
6/8/08			36.7			75.2							
6/15/08			9.6			22.8							
6/21/08			0.0			9.1							
6/29/08			11.0			13.1							
7/27/2008			2.8	3.6	2.5	2.1	2.0	2.4	3.6				
8/2/2008			17.2	16.1	18.1	12.4	23.9	18.3	17.6				
8/10/2008			13.2	16.1	23.5	30.8	26.1	28.3	27.7				
8/13/2008			4.3	4.2	6.2	5.2	11.1	16.5	10.7				
8/17/2008			26.2	27.1	27.9	22.3	2.5	0.0	4.8				
8/24/2008			6.9	6.8	6.8	10.4	8.4	7.5	9.3				

Date Time	LS-8 kmup	LS-4 kmup	LS-1 kmup	LS-0.5 kmup	LS-0 PUF	LS-0.5 kmdn	LS-1 kmdn	LS-2 kmdn	LS-4 kmdn	LS- 8 kmdn	LS-12 kmdn	LS-16 kmdn	LS-32 kmdn
8/30/2008			0.0	0.0	0.0	0.0	0.0	0.0	0.0				
9/6/2008			0.0	0.0	0.0	0.0	0.0	2.9	0.0				
5/17/2009			0.0	0.0	0.0	1.0	0.0	0.0	0.0				
5/24/2009			3.1	4.2	8.3	6.8	5.0	9.2	6.9				
5/31/2009			0.0	0.0	3.7	0.0	0.0	1.4	3.6				
6/7/2009			0.0	3.2	10.4	9.1	9.7	9.3	12.7				
6/14/2009			1.9	2.2	5.3	5.4	4.5	5.8	2.9				
6/21/2009			3.3	1.9	1.2	1.8	3.0	3.9	3.1				
6/28/2009			1.8	1.8	2.3	5.4	4.6	4.6	5.2				
7/19/2009			1.4	0.0	14.1	6.5	4.9	4.6	2.6				
7/26/2009			2.2	2.7	3.8	4.4	15.7	7.1	10.1				
8/2/2009			0.0	3.6	5.0	1.8	5.6	2.0	5.3				
8/8/09 6:00					11.50								
8/8/09 9:00					17.00								
8/8/09 12:00					27.20								
8/8/09 15:00					6.40								
8/8/09 18:00					10.90								
8/8/09 21:00					9.30								
8/9/09 6:00					1.90								
8/9/09 9:00					8.20								
8/9/09 12:00					12.90								
8/9/09 15:00			5.4	4.5	5.90	5.3	7.4	9.0	8.3	12		8.9	0
8/9/09 18:00					16.60								
8/9/09 21:00					6.40								
8/10/09 6:00					11.20								
8/10/09 9:00					1.70								
8/10/09 12:00					1.90								

Date Time	LS-8 kmup	LS-4 kmup	LS-1 kmup	LS-0.5 kmup	LS-0 PUF	LS-0.5 kmdn	LS-1 kmdn	LS-2 kmdn	LS-4 kmdn	LS- 8 kmdn	LS-12 kmdn	LS-16 kmdn	LS-32 kmdn
8/10/09 15:00					1.90								
8/16/2009			2.2	2.3	4.7	6.7	5.4	5.3	5.5				
8/23/2009			1.3	1.5	1.6	1.7	1.3	2.1	5.6				
8/30/2009			3.4	3.1	1.6	3.6	3.3	3.8	1.8				
9/5/2009			1.3		1.0				4.1				
5/15/2010			0.0	0.0	0.0		8.8	4.9	2.8				
5/23/2010			0.0	1.3	5.6		11.7	3.0	3.4				
5/30/2010			4.2	4.2	4.9		2.6	2.2	4.7				
6/6/2010			2.6	4.6	5.5		6.0	9.4	9.5				
6/13/2010			8.7	6.2	15.8		13.9	13.7	8.5				
6/19/10 6:00					1.76								
6/19/10 9:00					2.88								
6/19/10 12:00					2.73								
6/19/10 15:00					8.31								
6/19/10 18:00					2.70								
6/19/10 21:00					6.94								
6/20/10 6:00					0.00								
6/20/10 9:00					9.70								
6/20/10 12:00			2.0	2.1	2.49		2.8	4.2	6.3	6.14		9.51	
6/20/10 15:00					3.05								
6/20/10 18:00					8.40								
6/20/10 21:00					2.32								
6/27/2010			2.7		3.1				2.3				
8/1/2010	0	1.36	1.17		1.5				5.42	6.61	5.4		
8/7/10 5:30					0.00								
8/7/10 9:00					10.11								
8/7/10 12:00					2.24								

Date Time	LS-8 kmup	LS-4 kmup	LS-1 kmup	LS-0.5 kmup	LS-0 PUF	LS-0.5 kmdn	LS-1 kmdn	LS-2 kmdn	LS-4 kmdn	LS- 8 kmdn	LS-12 kmdn	LS-16 kmdn	LS-32 kmdn
8/7/10 15:00					22.35								
8/7/10 18:00					13.52								
8/7/10 21:00					6.54								
8/8/10 5:30					0.00								
8/8/10 9:00					20.84								
8/8/10 12:00	1.82	9.99	13.36		14.62				19.98	11.05	8.71		
8/8/10 15:00					12.69								
8/8/10 18:00					6.44								
8/8/10 21:00					13.12								
8/9/10 5:30					30.35								
8/9/10 9:00					1.21								
8/9/10 12:00					5.31								
8/15/2010	<1	1.34	1.61		7.35				15.42	10.92	16.2		
8/21/2010	<1	1.93	1.16		4.1				4.93	4.06	1.58		
6/4/11 9:30					3.31								
6/4/11 12:00					10.41								
6/4/11 15:00					3.65								
6/4/11 18:00					2.08								
6/11/11 9:45					15.38								
6/11/11 12:00					5.41								
6/11/11 15:00					10.26								
6/11/11 19:45					20.49								
6/12/11 9:15					5.27								
6/12/11 12:00					3.55								
6/12/11 15:00					15.53								
6/12/11 17:30					5.69								
8/2/12 23:00					1.76				1.42				

Date Time	**LS-8 kmup**	**LS-4 kmup**	**LS-1 kmup**	**LS-0.5 kmup**	**LS-0 PUF**	**LS-0.5 kmdn**	**LS-1 kmdn**	**LS-2 kmdn**	**LS-4 kmdn**	**LS- 8 kmdn**	**LS-12 kmdn**	**LS-16 kmdn**	**LS-32 kmdn**
8/3/12 5:00					1.3				1.32				
8/3/12 10:00					3.56				2.4				
8/3/12 13:00			1.62		1.64				2.63	3.36			
8/3/12 16:00					1.59				3.83				
8/3/12 23:00					0				1.23				
8/4/12 5:00					0				0				
8/4/12 10:00					2.56				1.28				
8/4/12 13:00			2.63		3.3				3.97	2.86			
8/4/12 16:00					1.68				1.44				
8/4/12 23:00					1.21				1.57				
8/5/12 5:00					0				0				
8/5/12 10:00					1.01				3.99				
8/5/12 13:00			1.72		3.5				3.08	4.44			
8/5/12 16:00					2.9				3.73				
8/5/12 23:00					1.73				1.64				
8/6/12 5:00					0				0				
8/6/12 10:00					1				1.13				
8/6/12 13:00			0		0				1.27	2.61			
8/6/12 16:00					1.52				1.96				
8/6/12 23:00					0				1.04				

Appendix C. Public Use Facility Entrance Booth Boat Count Data 2008, 2009, 2010 and 2012

Blue highlighted bold text notes the 2-day, 3-day and 4-day intensive water sampling events when samples were collected approximately every 3 hours between 6 AM and 9 PM at site LS-0 immediately downstream of the PUF boat launch. An additional 2-day sample event occurred June 11-12, 2011 which is not shown in this table.

Date	Day	Boat Totals	2-Cycle	Percent 2-Cycle	Total/Week
5/22/2008	Thurs	4	2	50	
5/23/2008	Fri	13	5	38	
5/24/2008	Sat	12	6	50	
5/25/2008	Sun	17	7	41	46
5/26/2008	Mon	42	7	17	
5/27/2008	Tues	6	1	17	
5/28/2008	Wed	2	1	50	
5/29/2008	Thurs	17	8	47	
5/30/2008	Fri	22	7	32	
5/31/2008	Sat	30	7	23	
6/1/2008	Sun	36	10	28	155
6/2/2008	Mon	20	3	15	
6/3/2008	Tues	15	6	40	
6/4/2008	Wed	4	2	50	
6/5/2008	Thurs	25	10	40	
6/6/2008	Fri	37	18	49	
6/7/2008	Sat	40	17	43	
6/8/2008	Sun	49	16	33	190
6/9/2008	Mon	29	6	21	
6/10/2008	Tues	7	1	14	
6/11/2008	Wed	7	2	29	
6/12/2008	Thurs	18	9	50	
6/13/2008	Fri	29	11	38	
6/14/2008	Sat	35	9	26	
6/15/2008	Sun	49	14	29	174
6/16/2008	Mon	22	4	18	
6/17/2008	Tues	12	1	8	
6/18/2008	Wed	5	2	40	
6/19/2008	Thurs	26	14	54	
6/20/2008	Fri	28	17	61	
6/21/2008	Sat	19	1	5	
6/22/2008	Sun	33	10	30	145
6/23/2008	Mon	18	2	11	

Date	Day	Boat Totals	2-Cycle	Percent 2-Cycle	Total/Week
6/24/2008	Tues	5	0	0	
6/25/2008	Wed	12	4	33	
6/26/2008	Thurs	17	7	41	
6/27/2008	Fri	21	2	10	
6/28/2008	Sat	11	3	27	
6/29/2008	Sun	19	8	42	103
6/30/2008	Mon	15	4	27	
7/1/2008	Tues	11	3	27	
7/2/2008	Wed	12	5	42	
7/3/2008	Thurs	14	7	50	
7/4/2008	Fri	15	1	7	
7/5/2008	Sat	14	4	29	
7/6/2008	Sun	11	5	45	92
7/7/2008	Mon	3	2	67	
7/8/2008	Tues	2	0	0	
7/9/2008	Wed	8	2	25	
7/10/2008	Thurs	10	4	40	
7/11/2008	Fri	5	2	40	
7/12/2008	Sat	5	1	20	
7/13/2008	Sun	8	0	0	41
7/14/2008	Mon	3	0	0	
7/15/2008	Tues				
7/16/2008	Wed				
7/17/2008	Thurs	5	3	60	
7/18/2008	Fri	7	0	0	
7/19/2008	Sat	6	0	0	
7/20/2008	Sun	17	3	18	38
7/21/2008	Mon	3	1	33	
7/22/2008	Tues	4	0	0	
7/23/2008	Wed	5	1	20	
7/24/2008	Thurs	13	4	31	
7/25/2008	Fri	30	10	33	
7/26/2008	Sat	32	9	28	
7/27/2008	Sun	21	6	29	108
7/28/2008	Mon	17	5	29	
7/29/2008	Tues	3	1	33	
7/30/2008	Wed	12	3	25	
7/31/2008	Thurs	33	20	6	
8/1/2008	Fri	45	12	27	
8/2/2008	Sat	31	10	32	
8/3/2008	Sun	40	9	23	181
8/4/2008	Mon	29	7	24	

Date	Day	Boat Totals	2-Cycle	Percent 2-Cycle	Total/Week
8/5/2008	Tues	6	4	67	
8/6/2008	Wed	32	7	22	
8/7/2008	Thurs	40	15	38	
8/8/2008	Fri	43	11	26	
8/9/2008	Sat	37	18	49	
8/10/2008	Sun	48	13	27	235
8/11/2008	Mon	41	13	32	
8/12/2008	Tues	4	1	25	
8/13/2008	Wed	21	5	24	
8/14/2008	Thurs	19	4	21	
8/15/2008	Fri	14	6	43	
8/16/2008	Sat	45	20	44	
8/17/2008	Sun	42	16	38	186
8/18/2008	Mon	14	3	21	
8/19/2008	Tues	8	3	38	
8/20/2008	Wed	11	4	36	
8/21/2008	Thurs	12	5	42	
8/22/2008	Fri	21	10	48	
8/23/2008	Sat	17	3	18	
8/24/2008	Sun	17	6	35	100
8/25/2008	Mon	7	2	29	
8/26/2008	Tues	1	0	0	
8/27/2008	Wed				
8/28/2008	Thurs	4	0	0	
8/29/2008	Fri				
8/30/2008	Sat	1	1	50	
8/31/2008	Sun	3	1	33	17
					2008 Total 1,810
5/16/2009	Sat	12	0	0	
5/17/2009	Sun	4	0	0	16
5/20/2009	Wed	3	0	0	
5/21/2009	Thurs	4	0	0	
5/22/2009	Fri	11	0	0	
5/23/2009	Sat	10	0	0	28
6/8/2009	Mon	16	5	31.3	
6/9/2009	Tues	13	1	7.7	
6/10/2009	Wed	6	2	33.3	
6/11/2009	Thurs	7	1	14.3	
6/12/2009	Fri	28	5	17.9	
6/13/2009	Sat	19	4	21.1	
6/14/2009	Sun	35	12	34.3	124
6/15/2009	Mon	7	2	28.6	

Date	Day	Boat Totals	2-Cycle	Percent 2-Cycle	Total/Week
6/16/2009	Tues	6	3	50.0	
6/18/2009	Thurs	7	2	28.6	
6/19/2009	Fri	25	9	36.0	
6/20/2009	Sat	29	10	34.5	
6/21/2009	Sun	21	7	33.3	95
6/22/2009	Mon	22	10	45.5	
6/23/2009	Tues	13	4	30.8	
6/25/2009	Thurs	20	4	20.0	
6/26/2009	Fri	23	8	34.8	
6/27/2009	Sat	26	8	30.8	
6/28/2009	Sun	24	8	33.3	128
6/29/2009	Mon	8	2	25.0	
6/30/2009	Tues	2	1	50.0	
7/1/2009*	Wed	5	0	0	
7/2/2009	Thurs	15	3	20.0	30
7/13/2009	Mon	3	1	33.3	
7/14/2009	Tues	3	0	0	
7/15/2009	Wed	3	0	0	
7/16/2009	Thurs	8	1	12.5	
7/17/2009	Fri	3	1	33.3	
7/18/2009	Sat	8	1	12.5	
7/19/2009	Sun	21	5	23.8	49
7/20/2009	Mon	7	3	42.9	
7/21/2009	Tues	5	3	60.0	
7/22/2009	Wed	6	1	16.7	
7/23/2009	Thurs	8	3	37.5	
7/24/2009	Fri	17	7	41.2	
7/25/2009	sat	20	10	50.0	
7/26/2009	Sun	22	9	40.9	85
7/27/2009	Mon	8	6	75.0	
7/28/2009	Tues	8	4	50.0	
7/29/2009	Wed	16	5	31.3	
7/30/2009	Thurs	28	8	28.6	
7/31/2009	Fri	26	9	34.6	
8/1/2009	Sat	33	11	33.3	
8/2/2009	Sun	16	6	37.5	135
8/3/2009	Mon	42	16	38.1	
8/4/2009	Tues	14	2	14.3	
8/5/2009	Wed	17	0	0	
8/6/2009	Thurs	45	10	22.2	
8/7/2009	Fri	50	19	38.0	
8/8/2009	**Sat**	**40**	**14**	**35.0**	

Date	Day	Boat Totals	2-Cycle	Percent 2-Cycle	Total/Week
8/9/2009	**Sun**	**48**	**16**	**33.3**	256
8/10/2009	**Mon**	**30**	**12**	**40.0**	
8/11/2009	Tues	20	10	50.0	
8/12/2009	Wed	21	8	38.1	
8/13/2009	Thurs	33	10	30.3	
8/14/2009	Fri	28	7	25.0	
8/15/2009	Sat	34	8	23.5	
8/16/2009	Sun	24	8	33.3	190
8/17/2009	Mon	17	6	35.3	
8/18/2009	Tues	12	3	25.0	
8/19/2009	Wed	6	3	50.0	
8/20/2009	Thurs	13	7	53.8	
8/21/2009	Fri	19	6	31.6	
8/22/2009	Sat	25	8	32.0	
8/23/2009	Sun	35	11	31.4	127
8/24/2009	Mon	2	1	50.0	
8/25/2009	Tues	10	1	10.0	
8/26/2009	Wed	12	4	33.3	
8/27/2009	Thurs	5	1	20.0	
8/28/2009	Fri	6	2	33.3	
8/29/2009	Sat	13	5	38.5	
8/30/2009	Sun	8	2	25.0	56
8/31/2009	Mon	3	0	0	
9/1/2009	Tues	5	2	40.0	
9/2/2009	Wed	2	0	0	
9/3/2009	Thurs	4	0	0	
9/5/2009	Sat	3	0	0	
9/6/2009	Sun	7	2	28.6	32
9/7/2009	Mon	2	1	50.0	
9/8/2009	Tues	3	0	0	5
					2009 Total 1,348
5/22/2010	Sat	10	2	20.0	
5/23/2010	Sun	17	4	23.5	27
5/24/2010	Mon	3	0	0	
5/26/2010	Wed	11	0	0	
5/27/2010	Thurs	19	2	10.5	
5/28/2010	Fri	17	1	5.9	
5/29/2010	Sat	16	0	0	
5/30/2010	Sun	24	5	20.8	90
5/31/2010	Mon	24	7	29.2	
6/1/2010	Tues	4	0	0	
6/2/2010	Wed	15	5	33.3	

Date	Day	Boat Totals	2-Cycle	Percent 2-Cycle	Total/Week
6/3/2010	Thurs	21	5	23.8	
6/4/2010	Fri	25	2	8.0	
6/5/2010	Sat	41	7	17.1	
6/6/2010	Sun	42	5	11.9	172
6/7/2010	Mon	17	3	17.6	
6/8/2010	Tues	28	3	10.7	
6/9/2010	Wed	14	2	14.3	
6/10/2010	Thurs	24	4	16.7	
6/11/2010	Fri	26	3	11.5	
6/12/2010	Sat	28	8	28.6	
6/13/2010	Sun	31	5	16.1	168
6/14/2010	Mon	19	4	21.5	
6/15/2010	Tues	19	5	26.3	
6/16/2010	Wed	12	0	0	
6/17/2010	Thurs	21	3	14.3	
6/18/2010	Fri	28	3	10.7	
6/19/2010	**Sat**	**21**	**1**	**4.8**	
6/20/2010	**Sun**	**26**	**9**	**34.6**	146
6/21/2010	Mon	19	6	31.6	
6/22/2010	Tues	7	1	14.3	
6/23/2010	Wed	10	0	0	
6/24/2010	Thurs	13	2	15.4	
6/25/2010	Fri	12	2	16.7	
6/26/2010	Sat	18	7	38.9	
6/27/2010	Sun	11	3	27.2	90
6/28/2010	Mon	3	1	33.3	
6/30/2010	Wed	4	0	0	
7/1/2010	Thurs	3	1	33.3	
7/2/2010*	Fri	9	4	44.4	
7/15/2010	Thurs	4	1	25.0	
7/16/2010	Fri	3	0	0	
7/17/2010	Sat	17	3	17.6	
7/18/2010	Sun	11	6	54.5	54
7/20/2010	Tues	9	1	11.1	
7/21/2010	Wed	9	3	33.3	
7/22/2010	Thurs	9	0	0	
7/23/2010	Fri	17	5	29.4	
7/24/2010	Sat	24	4	16.7	
7/25/2010	Sun	24	6	25.0	92
7/26/2010	Mon	5	1	20.0	
7/27/2010	Tues	5	1	20.0	
7/28/2010	Wed	17	8	47.1	

Date	Day	Boat Totals	2-Cycle	Percent 2-Cycle	Total/Week
7/29/2010	Thurs	20	8	40.0	
7/30/2010	Fri	30	8	26.7	
7/31/2010	Sat	29	11	37.9	
8/1/2010	Sun	20	3	15.0	126
8/2/2010	Mon	7	4	57.1	
8/4/2010	Wed	14	9	64.3	
8/5/2010	Thurs	31	12	38.7	
8/6/2010	Fri	50	18	36.0	
8/7/2010	**Sat**	**62**	**25**	**40.3**	
8/8/2010	**Sun**	**64**	**27**	**42.2**	228
8/9/2010	**Mon**	**11**	**4**	**36.3**	
8/10/2010	Tues	6	5	83.3	
8/11/2010	Wed	15	3	20.0	
8/12/2010	Thurs	34	16	47.1	
8/13/2010	Fri	51	22	43.1	
8/14/2010	Sat	36	11	30.6	
8/15/2010	Sun	63	21	33.3	216
8/16/2010	Mon	5	1	20.0	
8/17/2010	Tues	8	1	12.5	
8/18/2010	Wed	1	1	100	
8/19/2010	Thurs	3	1	33.3	
8/20/2010	Fri	18	5	27.8	
8/21/2010	Sat	24	8	33.3	
8/22/2010	Sun	11	3	27.2	70
8/23/2010	Mon	2	1	50	
8/26/2010	Thurs	3	2	66.6	
8/27/2010	Fri	2	1	50.0	
8/28/2010	Sat	10	4	40.0	
8/29/2010	Sun	1	0	0	18
8/30/2010	Mon	3	0	0	
8/31/2010	Tues	1	0	0	
9/1/2010	Wed	1	0	0	
9/2/2010	Thurs	2	1	50.0	
9/3/2010	Fri	2	0	0	
9/4/2010	Sat	4	0	0	13
					2010 Total 1,504
7/31/2012	Tues	15	4	26.6	
8/1/2012	Wed	9	2	22.2	
8/2/2012	Thurs	18	6	33.3	
8/3/2012	**Fri**	**18**	**5**	**27.8**	
8/4/2012	**Sat**	**24**	**1**	**4.2**	
8/5/2012	**Sun**	**26**	**7**	**26.9**	

Date	Day	Boat Totals	2-Cycle	Percent 2-Cycle	Total/Week
8/6/2012	**Mon**	**9**	**4**	**44.4**	
8/7/2012	Tues	24	10	41.7	
8/8/2012	Wed	14	3	21.4	
8/9/2012	Thurs	16	3	18.8	
8/10/2012*	Fri	8	1	12.5	
8/11/2012	Sat	2	0	0	
8/12/2012	Sun	1	0	0	
					2012 Total (partial record) 184

*Dates Alaska Department of Fish and Game closed the river to king (June/July) or silver (August) salmon fishing.