Turbidity Monitoring on the Lower Kenai River, 2008-2010

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EXECUTIVE SUMMARY

From 2008-2010, the Kenai Watershed Forum (KWF) monitored turbidity at several sites on the lower Kenai River. The objectives of this three-year study were to: (1) observe and determine key characteristics of turbidity in the lower Kenai River; (2) to collect relevant data to define baseline conditions for turbidity in the lower Kenai River; and (3) to analyze how often, if ever, Alaska Department of Environmental Conversation (ADEC) water quality standards for turbidity were exceeded at each sampling location. Monitoring has led to a better understanding of turbidity levels in the lower Kenai River and the establishment of baseline conditions. Based on analysis of data from this project, KWF found evidence that state turbidity standards were exceeded on several occasions. Analysis also revealed a strong correlation between high boat traffic and elevated turbidity. The results presented in this document are intended to assist river managers in making informed decisions regarding human use of the river with respect to established water quality standards.

The Kenai Watershed Forum prepared an original draft report in July 2011. That report underwent a peer review in the winter and spring of 2012 a revised report incorporating peer review comments was prepared in July of 2012. A subsequent internal ADEC review found one mathematical error in the Fall of 2012. The authors prepared a memorandum to revise the natural condition value and hours of exceedances calculations for the Statistical Characterization Methodology contained in Section 3.3.3 and Appendix B of the *Turbidity Monitoring on the Lower Kenai River, 2008-2010* peer reviewed report. This revision incorporates the findings outlined in the Sept. 7, 2012 memorandum from Kenai Watershed Forum to ADEC.

Specifically, the natural condition value for the reference site established at river mile 23 was revised downward. The revision also increased the number of hours river mile 11. 5 exceeded state water quality turbidity standards. Since the changes were purely mathematical a peer review was not conducted.

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1. INTRODUCTION

1.1. Project Background

The Kenai River, located in southcentral Alaska, drains 2,200mi^2 of the Kenai Peninsula (Scott, 1982) and is among the most popular sport fishing destinations in the State of Alaska. Salmon fishing on the river is considered to be world class as evidenced by a number of trophy catches, most notably a world record 97lb 4oz Chinook salmon caught in 1985. The river is accessible by the road system and within a three and a half hour drive for more than half of the State's resident population. Due to the accessibility of the popular fishery, the river receives some of the most concentrated motorized boat traffic in the state. In recent years, the Kenai Watershed Forum (KWF) has documented more than 700 outboard motorboats in simultaneous operation on the lower 50 miles of the river.

Increased human presence on the river is beginning to create concern about potential impacts on the river system. Turbidity is one key water quality parameter that can be influenced by human use patterns, and is defined by the U.S. Environmental Protection Agency (USEPA/EPA) as:

> …an expression of the optical property that causes light to be scattered and absorbed by particles and molecules rather than transmitted in straight lines through a water sample. It is caused by suspended matter or impurities that interfere with the clarity of the water. These impurities may include clay, silt, finely divided inorganic and organic matter, soluble colored organic compounds, and plankton and other microscopic organisms (USEPA 1999).

The Alaska Department of Environmental Conservation (ADEC) has established state standards for turbidity with respect to drinking water resources, water recreation and the health of aquatic ecosystems. Of particular concern on the Kenai River is the effect of elevated turbidity on the health of the fishery. Bendock and Bingham (1988a, 1988b) have documented at least 16 species of fish inhabiting the main stem of the Kenai River. Various studies have been carried out on other water systems to document the harmful biological effects high turbidity can have on fish. These effects included decreased feeding, reduced weight and length gains, increased cough frequencies, increased blood sugar levels, and damage to gills or other tissues (Oregon DEQ 2010, Bash et al. 2001). Severity and presence of these effects can vary between water systems, fish species, and individual fish. Several other factors, such as duration and frequency of exposure, life stage of the fish, physical properties of suspended particles, and accessibility of refugia also play important roles in determining how elevated turbidity levels might affect exposed fishes (Bash et al. 2001).

Instances of elevated turbidity have already been documented in water bodies throughout the state and are the main reason for most of the EPA-listed impaired rivers and streams in Alaska (USEPA, 2008). The vast majority of these turbidity exceedances across the state are the result of placer mining, with the remainder caused by land use issues. Although there are no mining operations contributing to turbidity levels on the Kenai River, it was suspected that human activity in the form of motorboat usage was a factor in elevated turbidity levels in the lower river.

1.2. Project Objectives

This project had three primary objectives coinciding with distinct conceptual phases. The first objective was to initially observe and determine key characteristics of turbidity in the lower Kenai River for both high and low boat traffic reaches. Using this understanding, the second objective was to collect relevant data to determine baseline turbidity conditions for two sites in the lower Kenai River. Once a baseline was established, the third objective was to analyze how often, if ever, ADEC water quality standards for turbidity were exceeded at each sampling location. This report is structured around the three related primary objectives of the project. After briefly discussing the methods employed during the study, this paper will proceed by describing the results under each objective.

2. METHODS

2.1. Schedule

Turbidity sampling on the Kenai River took place during the following summer field seasons:

June 2008-August 2008
June 2009-August 2009
June 2010-August 2010

Data analysis occurred during winter 2010-2011.

2.2. Sampling Locations

In light of project objectives, sampling locations for data collection were chosen based on distance up river, bank composition, boat activity patterns, and accessibility. All sampling locations were named for the river mile (RM) at which they were located and this naming convention is used in this report. **Figure 1** (below) is a map depicting the location of each site. There were two types of sampling locations, fixed monitoring stations (FMS) and transects (TRANS). Some sites had both a FMS and a TRANS. FMS had continuous, real-time sampling during all three field seasons. TRANS sites were periodically visited to take single point measurements across a transect. The following table, **Table 1**, summarizes site locations. Further site description and selection criteria can be found in the subsequent paragraphs.

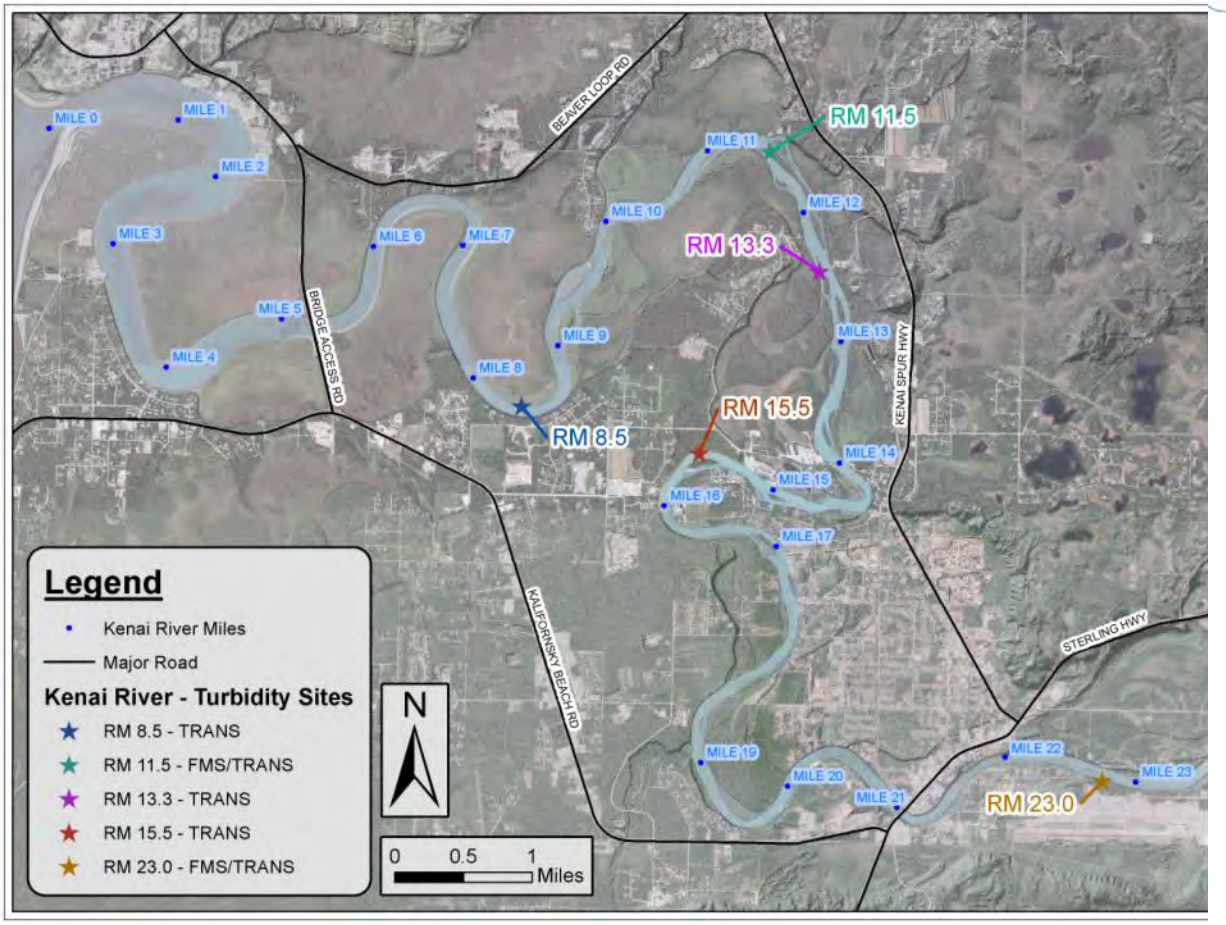

Figure 1: Station and transect location by ID. Miles indicate river miles from Cook Inlet.

2.2.1. Fixed Stations

There were two fixed study sites, RM 11.5 and RM 23. These FMS were consecutively sampled during all three years. They were selected primarily based on boat traffic frequency. Fishing recreation is responsible for the majority of boat traffic on the Kenai River and, therefore, traffic is highest in prime fishing locations.

RM 23, located at the Kenai River Center, was chosen for the infrequent boat traffic in this section of the river. The substrate at RM 23 is predominately gravel and cobble. The bank is comprised of poorly sorted cobble and gravel with minor amounts of sand and silt in the interstices.

RM 11.5, known to local residents for “Eagle Rock,” was selected as a representative high boat traffic site. It was also the site for the 2005-2007 Army Corps of Engineers boat wake study. RM 11.5 consists of moderately sorted gravel overlain with well-sorted, fine-grained sand and silt. The depth of the sand and silt layer varies over the course of the season. It is most prevalent in spring and early summer and largely absent in late summer and early fall. A tidal influence is present at RM 11.5 and sites downstream of this location. During high tide the river water becomes backed up, resulting in slower water velocity and raised water levels. Reduced water velocity allows for the deposition of fine-grained silt, a substrate that is ubiquitous with sites downstream of RM 11.5. This fine material becomes increasingly predominate as distance to the mouth of the river decreases.

2.2.2. Transect Locations

Several TRANS locations were added during the 2008 and 2009 field seasons for periodic, instantaneous measurement of turbidity across a river transect. In addition to RM 11.5 and RM 23, RM 8.5, RM 13.3 and RM 15.5 were also selected as TRANS locations. Selection was based on substrate type and boat traffic frequency. In 2009 these three transect sites also had a continuous monitoring station for part of the summer season.

RM 13.3 and RM 15.5 receive high boat traffic and have a lack of tidal mud deposits. The substrate at both sites is predominately gravel/cobble, similar to that of RM 23. RM 8.5 receives high levels of boat traffic, experiences a backup in river water due to tidal influences, and has the most fine-grained material of any of the sites studied.

Table 1: Site location summary

Site River Mile	Years Active	Type	Site Description	Bank Composition	Tidal	Coords. NAD 83
23	2008, 2009, 2010	FMS / TRANS	River Left; upstream Kenai River Center	Poorly sorted cobble and gravel with minor amounts of sand and silt in the interstices	No	-151.0390 60.4805
15.5	2009	TRANS	River Left; upstream of Ciechanski State Recreation Site	Gravel/cobble substrate with minimal fine material	No	-151.1260 60.5142
13.3	2009, 2010	TRANS	River Left; upstream of Pillar's Launch	Gravel/cobble	No	-151.1010 60.5335
11.5	2008, 2009, 2010	FMS / TRANS	River Right; off Island upstream of Eagle Rock	Moderately sorted gravel overlain with well-sorted, fine-grained sand and silt	Yes	-151.1120 60.5460
8.5	2009	TRANS	River Right; downstream of Chinook sonar counter	Fine grained sand and silt	Yes	-151.1640 60.5188

2.3. Sampling Equipment

Hydrolab MS-5 multi-parameter sondes, pictured in **Figure 2**, were used to collect turbidity data. These versatile instruments can be outfitted with multiple sensors to record various water quality parameters. Each of the 9 identical instruments used was equipped with a data logger and self-cleaning turbidity sensor. These instruments can be used in-situ to record real-time turbidity levels continuously at a site and are recommended for long-term turbidity studies (Christensen et al. 2002). A durable black guard protects the sensors from being damaged by debris.

Figure 2: Hydrolab MS-5 minisonde as configured during deployment, sensors are beneath the black guard on left.

2.4. Sampling Procedure

2.4.1. Equipment Deployment

Prior to each deployment, all Hydrolabs were calibrated using established protocols. The instruments were programmed to record data every 15 minutes. Batteries were replaced just prior to deployment. At each river station a buoy was anchored to the river bottom and set between 10 and 30ft off the low tide water line. A Hydrolab was attached to the buoy 8 to 24in beneath the surface and never deeper than two-thirds of the total water depth. The depth was set to ensure that the instruments remained submerged throughout deployment.

Hydrolabs were deployed for no longer than 15 days at a time. During each deployment there was a minimum of 10% overlap with a freshly calibrated instrument for quality assurance purposes. Date of deployment, position, sensor depth and total water depth were recorded in a dedicated field logbook. Entries were made at the time of each deployment and any time a physical adjustment was made to the station. Stations were inspected a minimum of once a week. Distance from shore was measured on each visit. Sensors found to be outside the specified range were moved accordingly. All changes to stations were recorded in the station logbook.

Upon retrieval, instruments were returned to the KWF lab where data were downloaded from the instrument's data logger memory. Instruments were again checked for calibration.

Any drift greater than 5% was noted. A strict deployment, calibration, and post-deployment log tracked instrument use and accuracy by the unique serial numbers. Following recalibration and reprogramming, each Hydrolab was placed back in the instrument rotation.

2.4.2. Transect Monitoring

In 2008 and 2009, Hydrolabs were also used periodically to collect instantaneous turbidity data across a cross-sectional transect of the river. All Mondays in July, when fishing from powerboats is prohibited, were included. A complete set of dates and locations of transect data collection are compiled in **Appendix A**.

Observations across the transect were taken at nine locations: 5ft, 10ft, 20ft from shore on both the left and right banks, ¼ the channel width, ½ the channel width and ¾ the channel width. Distances were determined with a laser range finder and a measuring tape. Where water depth was greater than 3ft, turbidity samples were collected 1.5ft below the water surface. Where the water was less than 3ft, the sample was collected at mid-depth.

Slight procedural deviations, noted in the field logbooks, were occasionally necessary for reasons of safety. If a well-defined turbidity plume was visible, additional measurements were taken 3 to 5ft into the plume and 3 to 5ft outside the plume (into the clear water). A photograph was also taken to show the width and nature of the plume.

All transect data collected were recorded on standardized field sheets. The following directional, date stamped photographs were taken every time transect data were collected:

1. upstream
2. downstream
3. across the transect
4. both banks

2.4.4. Boat Counts

An intensive boat count spanning several days was conducted at RM 11.5 from July 17-22, 2009 using a security camera that was programmed to take and store photographs every six seconds. KWF staff manually counted boat wakes per fifteen minute time bin to create an indicator of boat activity which could be linked to continuous Hydrolab data taken at the same location at the same time. The start and end times of the count period were recorded as well as the number of motorboats that had passed through the transect. Boats drifting and back-trolling were not included in the count.

2.4.5. Data Processing and Treatment of Outliers

Prior to any analysis, data were processed in order to remove anomalies that were the result of instrument malfunction or undesirable changes in sampling conditions. The method for doing so varied at sites where turbidity was constant versus sites where spikes were common.

In general, points were considered outliers and were removed from the data set if they met any of the following conditions:

- differed by more than 10 NTU from both the preceding and following points
- were part of an anomalous cluster of points which differed by more than 10 NTU from the points preceding and following the cluster
- have a value of zero (These showed up periodically in the dataset, but never seemed consistent with the day's trends. A turbidity reading of zero is seen on some very clear streams, but is not likely to occur on the Kenai River during the summer.)
- were recorded during a period of erratic readings—could last multiple hours or days

Exceptions to these conditions were made at RM 11.5 during times of high motorboat activity when data spikes were consistently seen as turbidity rapidly increased and decreased relative to natural conditions. Because of the consistency of this trend at RM 11.5, data points and clusters of points more than 10 NTU from the preceding and following points were *not* considered outliers if they occurred within one of these spikes.

The total number of outliers removed from the long term dataset, not including those removed during periods of erratic readings, was 210 out of 24,997 points collected for RM 11.5 and 212 out of 25,576 points collected for RM 23. Outliers represented 0.84% of the total points collected at RM 11.5 and 0.83% of the total at RM 23.

The occurrence of outliers in this study is believed to be predominately due to grass or debris entering the sensor guard cup. While the guard protects the sensors from damage by strong water flow and large debris, smaller debris may become trapped. Trapped debris may dramatically alter localized turbidity readings at the sensor relative to that of the surrounding river water.

3. RESULTS

3.1. Characterization of Turbidity on the Lower Kenai River

As mentioned in the introduction, the initial objective of this project was to observe and determine key characteristics of turbidity in the lower Kenai River at both high and low boat traffic reaches. Understanding the system is crucial for defining natural conditions with respect to state water quality standards for turbidity (ADEC 2006). Boat traffic, bank composition, tides (where applicable), river flow rates, and upstream melt events were among the factors found to likely affect observed turbidity levels in the lower Kenai River. This section will first examine observed variability in turbidity across transects at each monitoring site. Next it will use continuous Hydrolab data to explore observed changes in turbidity over time. Finally, this section will utilize observations of a major melt event to explore relationships between turbidity behavior at two monitoring sites along the river.

3.1.1. Variations Across Transects

Observed turbidity levels were consistently greater along the banks for the downstream locations (RM 8.5 and 11.5). This trend provides potential evidence for the influence of boat activity, tides, and bank composition. Regarding bank composition, RM 15.5 and RM 23 have banks consisting mostly of cobbles and gravel. These sites displayed fairly consistent turbidity across the channel width (See **Figure 3(a)** and **(b)** and **Table 1** below). RM 11.5 and especially RM 8.5 had much finer bank material. With respect to boat activity, the July turbidity trends at RM 8.5 and RM 11.5 were steeper and more pronounced on days other than Monday when fishing for Chinook from a motorized craft is prohibited. Chinook is the primary species sought after by in-river motorized fishing boats and due to the closure, motorized traffic on Mondays in July is a small fraction of traffic on other days of the week. This closure allows for a natural turbidity patterns to be observed at RM 11.5. **Figure 3** displays transect data from a representative Monday and Wednesday in July 2009. At RM 11.5 and 8.5 the average turbidity on non-Mondays was about 40% higher than the average turbidity on Mondays. Average turbidity levels on Mondays versus non-Mondays for all other locations varied by less than 3 NTU.

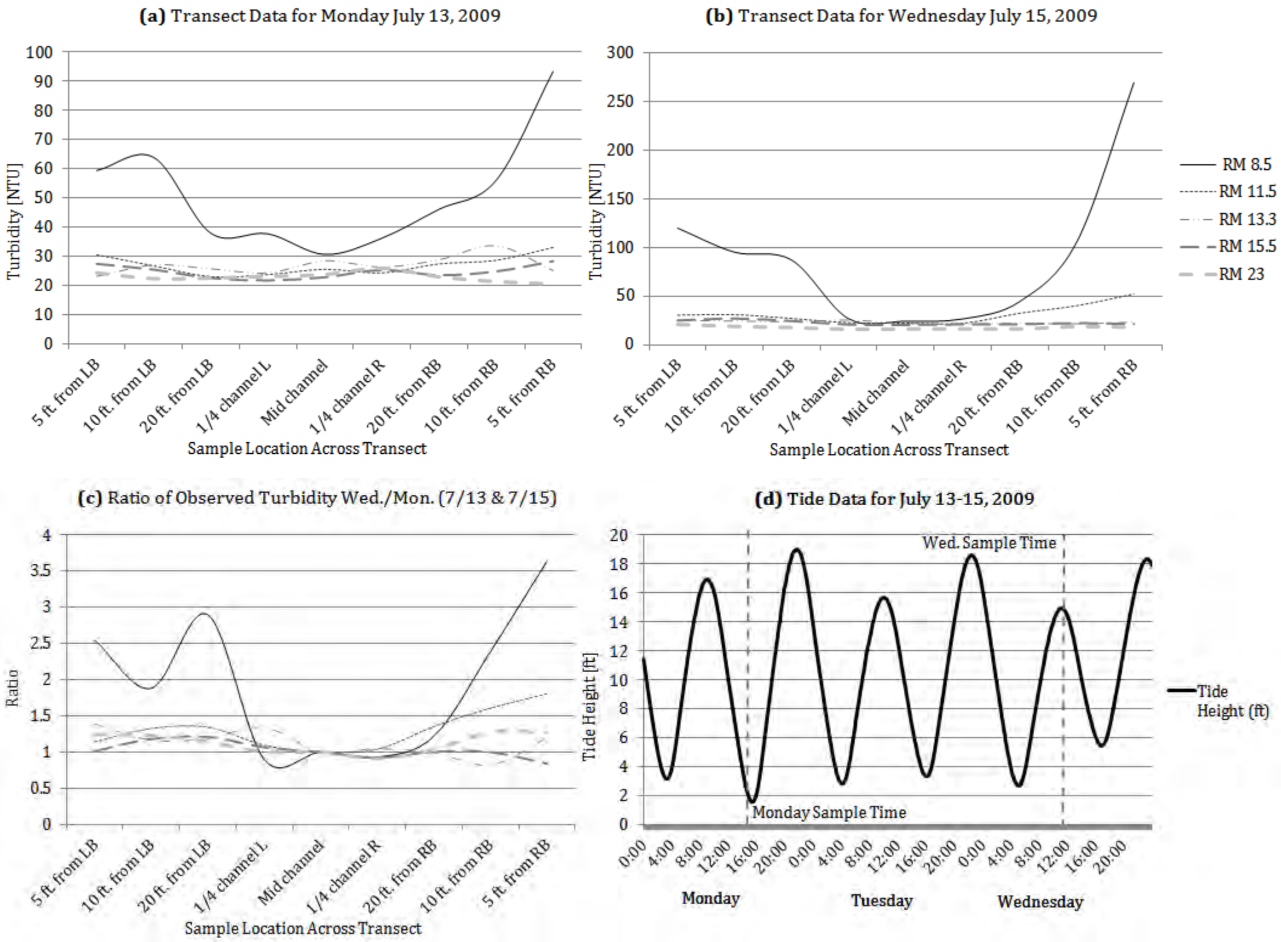

Figure 3: Comparison of Representative Transect Samples.

In **Figure 3(c)** above, transect data from Monday July 13 and Wednesday July 15, 2009 are compared. When dividing Wednesday turbidity levels by Monday turbidity levels for each location along the transect, it is clear that the biggest difference between Mondays and Wednesdays occurs at the banks in the lower river (RM 8.5). However, the lower river is tidally influenced and the water depth fluctuates by several feet at RM 8.5 and RM 11.5 depending on tidal cycles. **Figure 3(d)** above shows the time at which sampling took place on Monday July 13 and Wednesday July 15, 2009 in relation to the tide cycle for those days. Monday's transect sampling took place at low tide while Wednesday's transect sampling took place at high tide, albeit a relatively moderate high tide. A high tide causes a slowing of water velocity and rise in water level. With respect to the tidal cycle, using currently available data it is unclear how much of an effect tides have on turbidity in the lower Kenai River and future study is needed.

3.1.2. Variations over Time

The variability of turbidity levels over time differed substantially between the sampling sites. RM 23 exhibited fairly constant turbidity curves with gradual changes in turbidity. RM 11.5 exhibited a similar constant background overlain with large spikes that rapidly rose above the baseline (see **Figure 4** below). These spikes were largely absent, or greatly reduced on Mondays. Turbidity patterns for RM 23, even on high traffic days on the lower river exhibited very similar patterns to those seen on RM 11.5 during no motor Mondays. For RM 11.5, days of high boat traffic have distinctly different turbidity graphs with large spikes in the data that were not seen at RM 23 or on Mondays at RM 11.5. **Figure 4** below shows the results of an intensive boat counting effort at RM 11.5 compared with Hydrolab data taken during the same time period. The frequent jagged spikes in the turbidity levels at RM 11.5 often coincide with peaks in boat traffic on the lower Kenai River.

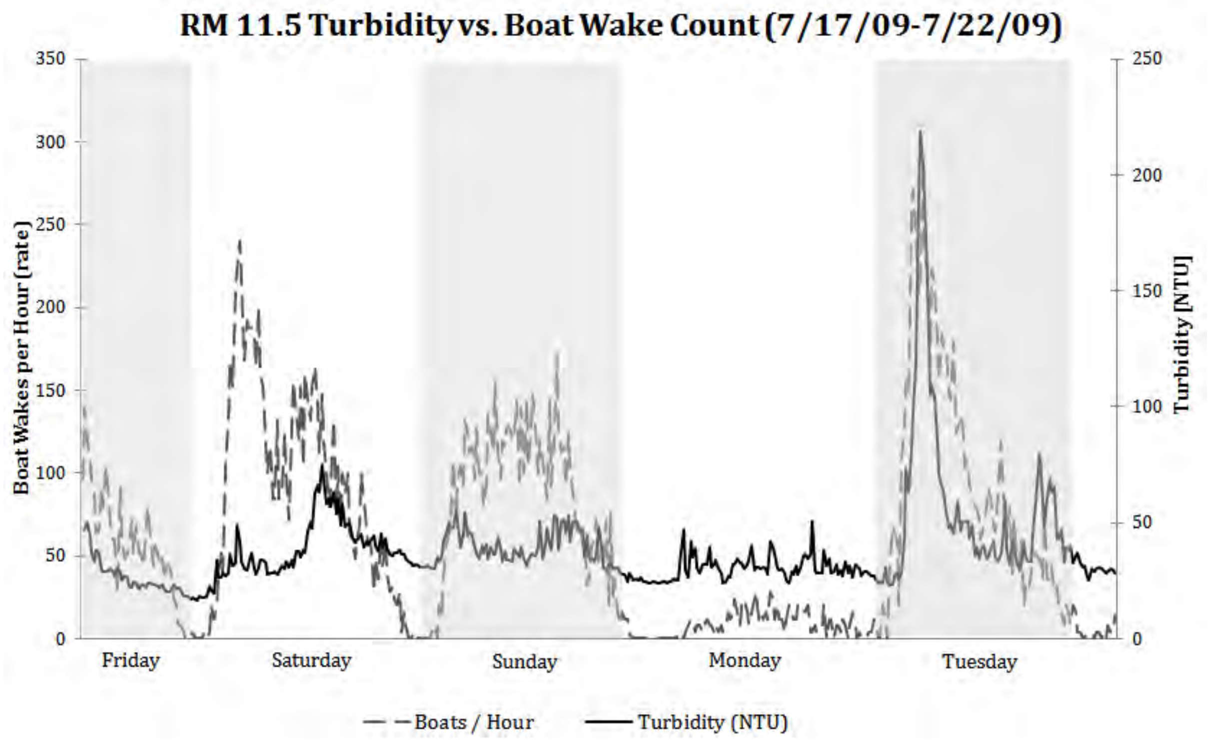

Figure 4: Turbidity Levels and Boat Count Data from RM 11.5 for July 17-22, 2009.

In **Figure 4** above, it is also important to note the different behavior of observed turbidity trends on Monday versus other days of the week. Data from Monday are missing large peaks in turbidity and this trend is consistent throughout the Hydrolab data from the three summers of this study. In the dataset depicted above, rises in turbidity correlate with periods in which boat activity is on the upswing, and reductions in turbidity follow a decrease in boat traffic. These trends are shown in greater detail in a close up of the data for Saturday in **Figure 5** below. Although it is apparent that boat traffic makes a significant contribution, there are certainly other factors affecting turbidity levels. In addition to possible influences from tidal action when river water is backed up at RM 11.5, upstream changes such as large melt events may also influence turbidity levels.

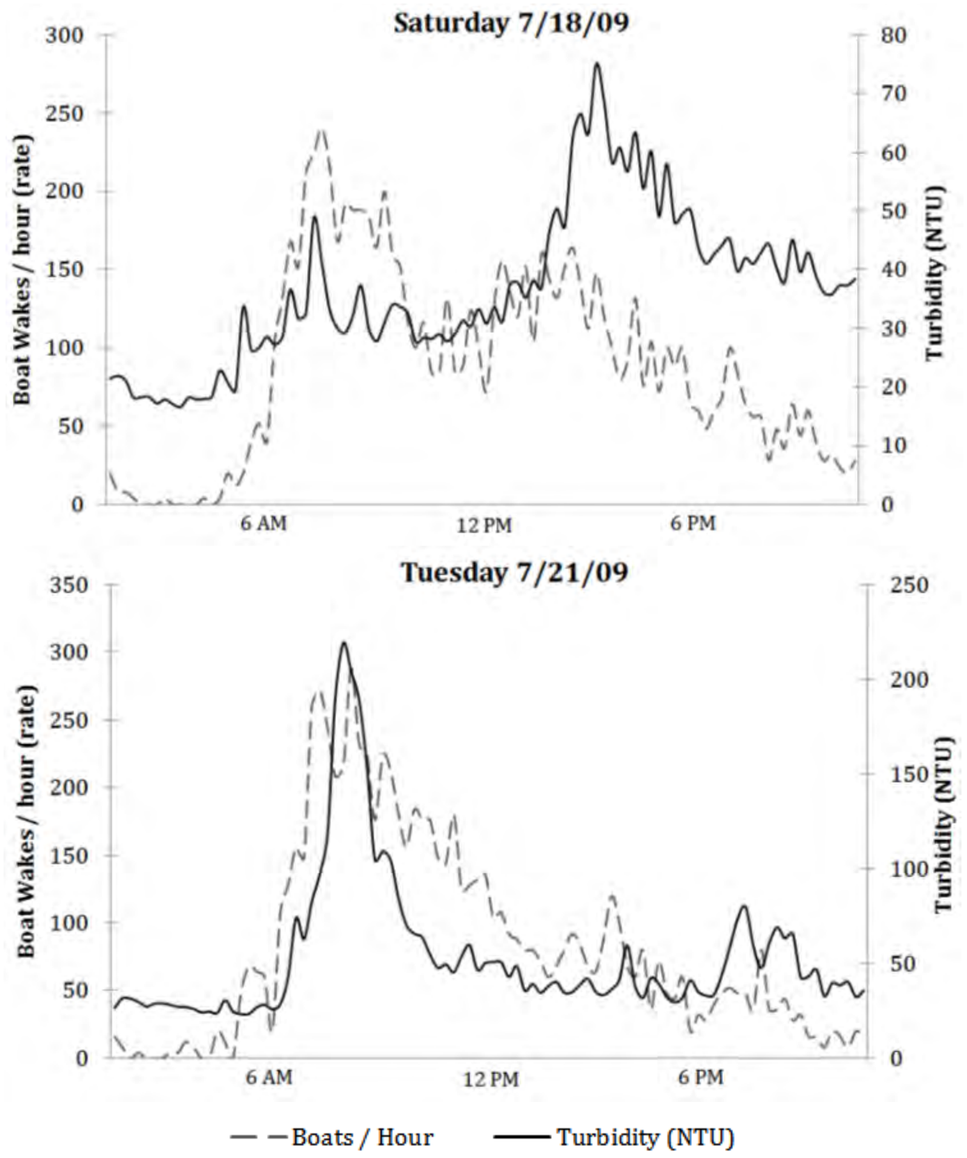

Figure 5: Turbidity Levels and Boat Count Data for Saturday July 18, 2009 and Tuesday July 21, 2009.

One way to describe differences in turbidity variation for upstream versus downstream sites is to evaluate observed rates of turbidity increase. **Table 2** reflects the top eight observed 12-hr. running rates of turbidity increase for RM 23 and RM 11.5. The largest rate of increase was related to a melt event described below. In general, the highest recorded rates of turbidity increase at RM 11.5 are two to three times higher than the highest recorded rates of turbidity increase at RM 23. The downstream sites, especially RM 11.5, tend to have sharper peaks in turbidity and more extreme rises and falls. In contrast, when turbidity is plotted over time at RM 23, the curve tends to be much smoother and changes over time are gradual.

Table 2: Top Eight 12-hr. Running Rates of Turbidity Increase for RM 23 and RM 11.5.

	RM 23				RM 11.5			
Rank	**Running rate of increase (NTU/hr)**	**Date**	**Start time**	**End time**	**Running rate of increase (NTU/hr)**	**Date**	**Start time**	**End time**
1	5.45	7/22/09	7:15	19:00	14.19	7/20/09	19:00	6:45
2	2.92	7/8/10	10:30	22:15	9.77	7/21/08	21:15	9:00
3	2.50	6/5/09	10:15	22:00	6.16	7/21/09	20:15	8:00
4	2.14	7/9/10	22:15	10:00	5.83	7/26/10	19:45	7:30
5	1.90	6/18/08	10:30	22:15	5.62	7/17/08	18:45	6:30
6	1.76	7/9/10	23:15	11:00	5.20	7/22/09	11:30	23:15
7	1.56	7/6/08	9:15	21:00	5.06	7/26/10	19:45	7:30
8	1.52	7/5/08	6:15	18:00	4.63	7/4/08	21:15	9:00

3.1.3. Relationships between Turbidity Values Observed at Different Monitoring Sites

During the extensive sampling campaign, a number of naturally occurring turbidity spikes on the Kenai River were captured in the dataset. Periodically, large melt events at the Kenai River headwaters or in major tributaries cause relatively rapid increases in turbidity levels downriver. The significant differences in the shape of the turbidity graphs during these natural events call for further analysis.

The most dramatic of these spikes was seen July 22, 2009, reaching nearly 100 NTU at its peak. At RM 23, this time period showed both the most rapid sustained turbidity increase and the highest turbidity level seen over the course of three seasons' data collection. On July 22, turbidity increased steadily throughout the day to a peak of 95 NTU at 20:30. From 7:15 to 19:00, the 12-hr. running rate of increase in turbidity was 5.45 NTU/hr. This natural rise in baseline turbidity was observed at both RM 23 and RM 11.5. At RM 11.5, the melt event is visible as an abnormally large and steep spike in **Figure 6**. The 12-hr running rate of increase in turbidity at RM 11.5 was 5.20 NTU/hr from 11:30-23:15. During this melt event RM 23 and RM 11.5 had similar 12-hr. running rates. However, the steady rise in baseline at RM 11.5 was overlaid by consistent rapid spikes that were unseen in RM 23. These rapid spikes were drastically different in shape than the rise in baseline for the natural event. The melt event as recorded by the Hydrolabs located at RM 23, 15.5, 13.3 and 11.5 is shown in **Figure 6** below. Note the difference in the level of variability of turbidity between the different sampling sites. While RM 23 and RM 13.3 have relatively low variability, RM 15.5 and especially RM 11.5 are subject to frequent large spikes.

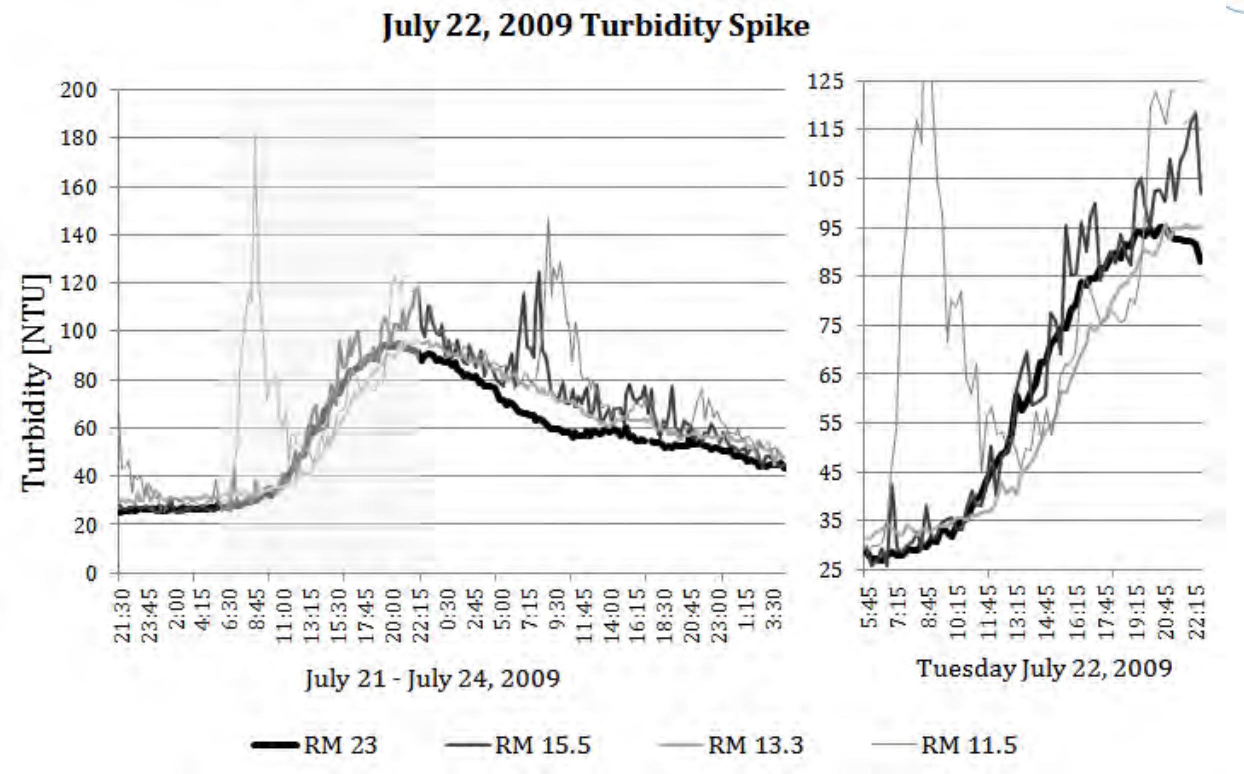

Figure 6: July 22, 2009 Melt Event as Recorded by Hydrolabs at RM 23, 15.5, 13.3, and 11.5.

Examining the rising leg of the melt event provides insight into the suitability for using RM 23 as a reference site for natural or background conditions. This topic will be discussed further in the following section. Strong support for using RM 23 as a reference site for natural conditions can be seen between 10:45 am and 7:15 pm on July 22, 2009. During this period the turbidity levels measured at RM 23 and RM 13.3 show very similar, near-linear increases (See **Figure 7(a)** below). Using the linear regression equations shown in the figure below, the average lag time between RM 23 and RM 13.3 during this time window was approximately 1.75 hours; this equates to roughly 5.5 RM per hour. Note however that velocity is likely to increase as flow increases and during this time window, the river's flow rate increased rapidly as shown in **Figure 7(b)**. The average river flow rate during this time window was approximately 16,750 cubic feet per second (cfs). The flow rate rose approximately 3,000 cfs during the event. Each of the datasets from the three sampling years displayed several of these natural events.

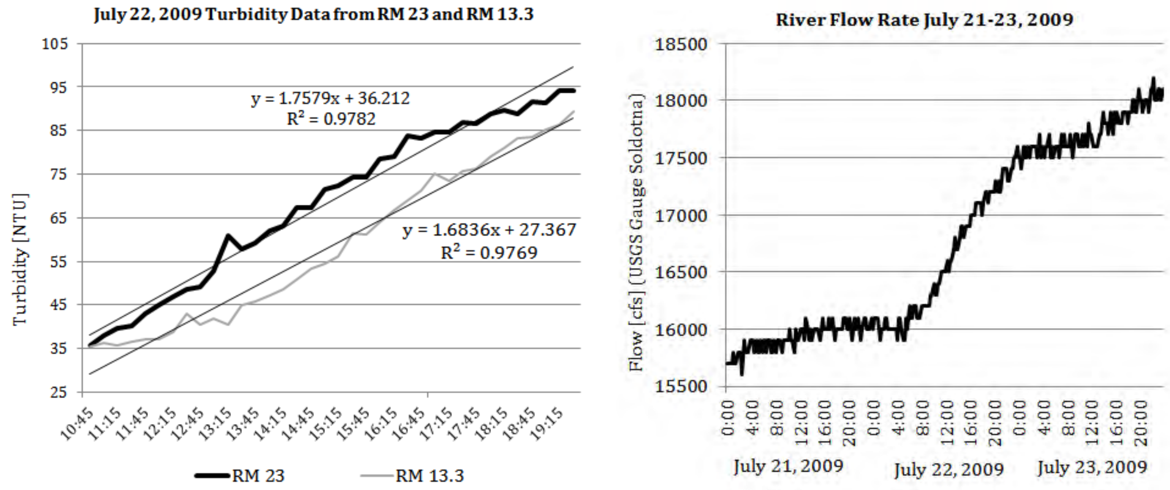

Figure 7: (a) Using the July 22, 2009 Melt Event to Estimate Lag Time between Sampling Sites; **(b)** Kenai River Flow Rate for July 21-23, 2009.

3.2. Definition of Natural Conditions for RM 23 and RM 11.5

Water quality standards for turbidity in fresh water in the state of Alaska are written with reference to “natural conditions” (See **Table 3)**. *Natural conditions* are defined by state regulations as any physical, chemical, biological, or radiological condition existing in a waterbody before any human-caused influence on, discharge to, or addition of material to, the waterbody (ADEC 2006; 18 AAC 70.990(41)). Prior to this project, natural conditions for turbidity on the lower Kenai River had not been established. KWF used ADEC’s “Guidance for the Implementation of Natural Condition-Based Water Quality Standards” (ADEC 2006) as well as associated software programs to assist in defining natural conditions.

Table 3: Alaska State Water Quality Standards for Turbidity, 2011 (18 AAC 70).

Designated Use	Water Quality Standard for Turbidity
(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.
(A) Water Supply (ii) agriculture, including irrigation and stock watering	May not cause detrimental effects on indicated use.

(A) Water Supply (iii) aquaculture	May not exceed 25 NTU above natural conditions. For all lake waters, may not exceed 5 NTU above natural conditions.
(A) Water Supply (iv) industrial	May not cause detrimental effects on established water supply treatment levels.
(B) Water Recreation (i) contact recreation	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.
(B) Water Recreation (ii) secondary recreation	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 for aquaculture.

Turbidity is a water quality parameter that varies over time and, as explored in the previous section, is potentially a function of many interrelated factors including: boat activity, river flow, tidal action, and bank composition. In such a case, statistical characterization through analysis of historical data or comparison to a reference site is appropriate (ADEC 2006). Because of the sharp difference between winter and summer conditions on the Kenai, natural conditions were determined for the summer months of June, July, and August only. Using all data taken at RM 11.5 and RM 23 during these months, a distribution and cumulative frequency curve was developed for each site, **Figure 8**. As outlined by ADEC protocol (ADEC 2006), this curve represents the long-term turbidity trends for a given location. Descriptive statistics characterizing the dataset are given in **Table 4**. For the purposes of this study, the site furthest upstream, RM 23, is the background site, and RM 11.5 is the test site.

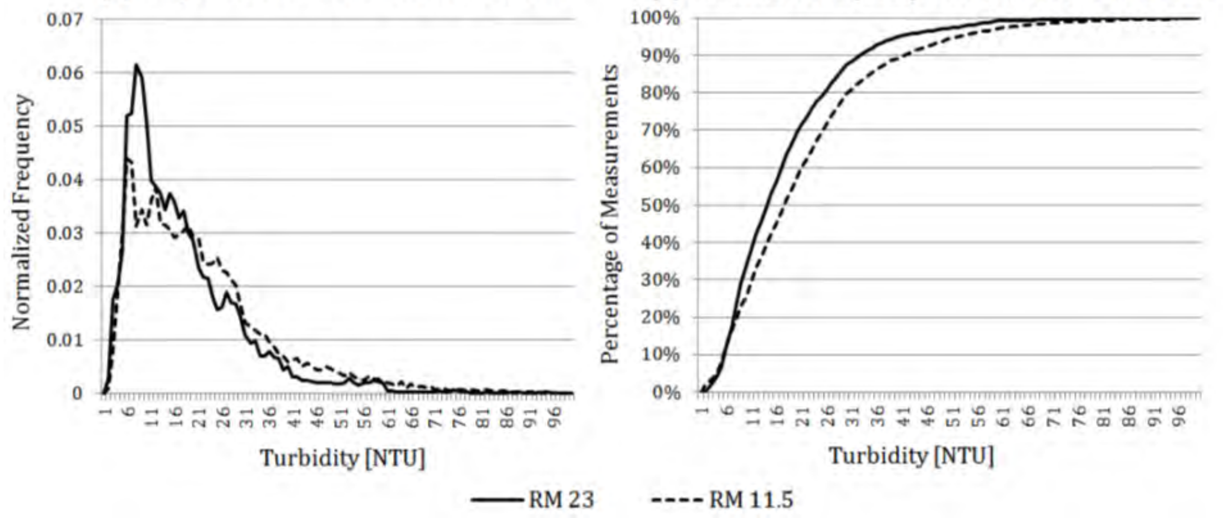

Figure 8: **(a)** Sample Distribution and **(b)** Cumulative Frequency Curves for All Hydrolab Data from Summers 2008-2010 for RM 23 and RM 11.5.

Table 4: Comparison of data from RM 11.5 with data from RM 23.

Descriptive Statistics	**RM 23 (all data)**	**RM 11.5 (all data)**	**RM 11.5 (AM data)**	**RM 23 (AM data)**
Sample Size (n)	25364	24793	5553	5646
Mean [NTU]	17.3	21.5	18.5	17.3
Median [NTU]	14.2	18.1	16.1	14.6
Standard Deviation [NTU]	12.2	15.8	13.2	12.1
Range [NTU]	93.5	218.7	100.5	86.8
Confidence Level Bound (95%) [NTU]	0.2	0.2	0.3	0.3
95th Percentile [NTU]	40.5	52.7	44.7	42.1
90th Percentile [NTU]	32.7	41.9	36.5	32.4
75th Percentile [NTU]	22.7	27.9	24.9	22.5
50th Percentile [NTU]	14.2	18.1	16.2	14.7
25th Percentile [NTU]	8.4	10.4	8.6	8.2

Statistical characterization of Hydrolab data collected from RM 23 and RM 11.5 provides evidence of the impact of boat activity on turbidity levels. When all Hydrolab data from RM 23 and RM 11.5 are compared, several differences between the sites emerge, most notably during the daytime hours. While both datasets cover roughly the same time period, RM 11.5 has a higher mean turbidity value, and a distribution that is more spread out towards higher turbidity values, as evidenced by the larger standard deviation. However, when the period between midnight and 5 AM is compared, the observed differences between RM 23 and RM 11.5 become much smaller (See **Figure 9** and **Table 4**). During this time window, boat activity is essentially absent and data from the downstream site at RM 11.5 are much closer to he data from the upstream site at RM 23. Other factors that could potentially make data at RM 11.5 differ from data at RM 23 including tidal action and bank composition, should in theory be the same during the day and night.

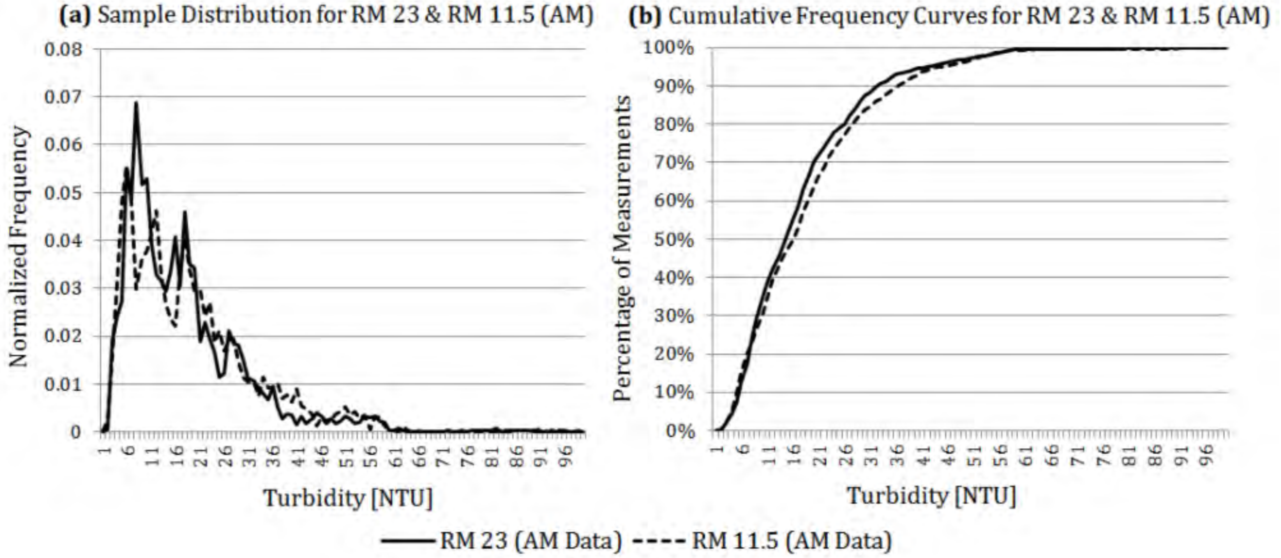

Figure 9: Cumulative Frequency Curves for RM 11.5 AM Data and All RM 23 Data.

3.3. Determination of Exceedances of State Water Quality Standards for Turbidity

Two methods for quantifying exceedances are discussed in the ADEC guidance document: the concurrent measurement approach and the statistical characterization approach. Several sub-methods using slight deviations of these main two methods also exist. For the purpose of this report, three separate calculations for hours during which turbidity was in exceedance of ADEC defined standards for water quality were evaluated and results generated.

3.3.1 Concurrent Method

Of the two ADEC methods, the concurrent approach is preferred where feasible, and relies upon a comparison between a reference site and the site at which exceedances are suspected. Difficulty arises, however, in applying the concurrent method in this study. Because of the distance separating RM 23 and RM 11.5, turbidity levels would not be expected to be the same at these two sites at any given point in time. Natural increases in turbidity caused, for example, by discharge from flood events in tributaries upstream of both sites would raise turbidity levels first at RM 23 and somewhat later at RM 11.5. To properly predict this time lag a hydrologic model would need to be developed and is beyond the scope of this study.

3.3.2. A Variation of the Concurrent Method, a Temporal Reference Method

Although a time lag model was not developed in this study, it is appropriate in this case to use a "reference time" in the same space, rather than using a "reference site" at a different spatial location, to establish natural conditions. For RM 11.5, this reference time would be between 0:00 and 5:00 when the lack of boat traffic allows for a view of the river's natural turbidity levels. This is based on an assumption that natural turbidity levels do not exhibit much natural fluctuation within a given day. Within this method each site has its own established natural conditions based on data collected at that site from 00:00-05:00. Hours of turbidity exceedances are then compared during the reference time at both the test, RM 11.5, and reference site, RM 23.

Exceedances were calculated using ADEC's Natural Conditions tool for continuous monitoring applied temporally. Natural conditions were established using data from 0:00 to 5:00 at both RM 11.5 and RM 23 individually. This produced a natural condition for each site rather than relying on the natural conditions from a single reference site. Based on this method, the natural turbidity condition for the entire data set at RM 11.5 was 35.7 NTU and at RM 23 it was 31.5 NTU. For the month of July during peak fishing season, the natural turbidity condition at RM 11.5 was 43.3 NTU and at RM 23 is 39.1 NTU. From these natural conditions, exceedances of standards for drinking water, secondary recreation, and fish and wildlife were calculated for each site and tabulated in **Appendix B**. **Table 5** shows the estimated number of hours of exceedance for RM 11.5 and RM 23 during the month of July.

Table 5: Estimated Hours and percent time exceeding ADEC Turbidity Standards in July: Temporal Reference.

	Estimated Hours of Exceedance							
	July 2008		**July 2009**		**July 2010**		**AVERAGE**	
State Standard for Designated Use	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**
Drinking water (5 NTU)	96.75	56	142.5	41.5	71	54	103.42	50.50
Secondary rec. (10 NTU)	65.25	36.5	98.5	36	54.5	47.5	72.75	40.00
Fish & Wildlife (25 NTU)	22.75	0	36.5	17.5	18.5	10.25	25.92	9.25
	Estimated Percent time of Exceedance							
	July 2008		**July 2009**		**July 2010**		**AVERAGE**	
State Standard for Designated Use	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**
Drinking water (5 NTU)	13	7.5	19.2	5.6	9.5	7.3	13.90	6.80
Secondary rec. (10 NTU)	8.8	4.9	13.2	4.9	7.3	6.4	9.77	5.40
Fish & Wildlife (25 NTU)	3.1	0	4.9	2.4	2.5	1.4	3.50	1.27

It is worth noting that the hours of exceedance between 0:00 and 5:00 when there is minimal boat traffic, is comparable between the two sites analyzed. However, the number of exceedances observed over a full day at RM 11.5 is substantially greater than the number of exceedances observed at RM 23. **Table 6** contains the cumulative hours of exceedance for the fish and wildlife standard over the three July seasons broken up into just 0:00 to 5:00 exceedances and then exceedances during the full day.

Table 6: Estimated Hours Exceeding ADEC Fish and Wildlife Turbidity Standard over Three Julys.

	Midnight to 5am		Full Day	
	RM 11.5	**RM 23**	**RM 11.5**	**RM 23**
Fish & Wildlife	5.5 hrs	5.25 hrs	77.75 hrs	27.75 hrs

3.3.3. Statistical Characterization Method

The statistical characterization method uses all data from RM 23 and RM 11.5 for analysis with ADEC's Natural Conditions Tool for continuous monitoring. This generated a natural condition turbidity value from which both exceedances at RM 11.5 and RM 23, the reference site itself, were calculated. A comparison of exceedances between both sites can then establish how much more frequent exceedances were at the effected site, that being RM 11.5 where boat traffic was significantly higher.

The Natural Conditions tool requires a correction for serial correlation to account for the continuous sampling. This tool has the correction built in as a user option and can be used to determine data outliers. Additional outliers were not found in the RM 23 dataset since the processed data already had outliers removed. This tool generated a natural condition for RM 23 of 32.2 NTU for the Lower 95% confidence limit on the 90th percentile (Conover's Nonparametric Method). When recalculated using only data from July at RM 23, the natural condition was 39.9 NTU for the Lower 95% confidence limit on the 90th percentile. Exceedances from these natural conditions were then calculated by subtracting the natural condition value from the entire RM 23 and RM 11.5 datasets. If the remainder were greater than the ADEC standards for turbidity, this was an exceedance point. Total hours of exceedance were generated and are tabulated in **Appendix B**. **Table 7** shows the estimated hours of exceedance for three July's at RM 11.5 and RM 23. The three standards used were for drinking water, secondary recreation, and fish and wildlife (5 NTU over natural conditions, 10 NTU over, and 25 NTU over, respectively).

Table 7: Estimated Hours and percent time exceeding ADEC Turbidity Standards: Statistical characterization

	Estimated Hours of Exceedance							
	July 2008		**July 2009**		**July 2010**		**AVERAGE**	
State Standard for Designated Use	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**
Drinking water (5 NTU)	131	56	169	34	129	91	143.00	60.33
Secondary rec. (10 NTU)	94	36	123	30	100	81	105.67	49.00
Fish & Wildlife (25 NTU)	32	0	42	15	38	17	37.33	10.67

	Estimated Percent time of Exceedance							
	July 2008		**July 2009**		**July 2010**		**AVERAGE**	
State Standard for Designated Use	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**	**RM 11.5**	**RM 23**
Drinking water (5 NTU)	17.6	7.5	22.7	4.5	17.3	12.2	19.20	8.07
Secondary rec. (10 NTU)	12.6	4.8	16.5	4.0	13.4	10.9	14.17	6.57
Fish & Wildlife (25 NTU)	4.3	0	5.6	2.0	5.1	2.3	5.00	1.43

3.3.4. Estimation of Background Turbidity Method

A more simple method used to calculate exceedances of state water quality standards was to estimate background turbidity levels at RM 11.5 for a given day and to then count the number of data points that exceeded that threshold by 5, 10, or 25 NTU. This was accomplished by determining a representative average value before 5:00 and drawing a line to a representative average value after 23:00 in the same day. All points from the 5:00-23:00 data that were found to be in exceedance of this line were recorded. This method depended on a human estimation of threshold levels for a given day based on professional judgment. Estimations of daily threshold levels were generated by visual analysis of the data at RM 11.5, RM 23, and other locations for which data was available during that time period. On days when natural turbidity levels were increasing or decreasing rapidly, two or three threshold levels were determined for different portions of the day. **Table 8** indicates the estimated exceedances of ADEC water quality standards for RM 11.5 during July 2008, 2009, and 2010 based upon daily estimated background turbidity levels. Data for days with duplicate data sets were averaged. This method was only done at RM 11.5.

Table 8: Estimated Hours Exceeding ADEC Turbidity Standards at RM 11.5.

State Standard for Designated Use	Estimated Hours of Exceedance			
	July 2008	July 2009	July 2010	July Average
Drinking water (5 NTU)	195.25	163.5	109.75	156.2
Secondary rec. (10 NTU)	121	87.75	55	87.9
Fish & Wildlife (25 NTU)	42.75	17.25	10.5	23.5
State Standard for Designated Use	**Estimated Percent time of Exceedance**			
	July 2008	**July 2009**	**July 2010**	**July Average**
Drinking water (5 NTU)	26.2	22.0	14.8	21
Secondary rec. (10 NTU)	16.3	11.8	7.4	11.8
Fish & Wildlife (25 NTU)	5.7	2.3	1.4	3.1

4. DISCUSSION

4.1. Establishment of Baseline Conditions

The task of establishing individual baseline conditions at RM 11.5 and RM 23 was accomplished using the cumulative frequency curves displayed in Section 3.2. For RM 11.5 this baseline condition included both the natural fluxes of turbidity as well as any anthropogenic influences from high boat traffic. For RM 23 this baseline condition represented a more accurate picture of natural conditions for the lower Kenai River. With that said, the difficult step in this study was deciding how to treat this reference site. The study itself focused on extracting effects of boat traffic. Site selection was made with traffic frequency in mind. In characterizing turbidity trends on the lower Kenai River it was recognized that this was a simplified look at the overall conditions that can affect turbidity.

Significant time and resources could be devoted to including influences such as overall discharge, detailed substrate analysis and tide cycles. All of these would be important factors in the larger understanding of turbidity on the Kenai River but are not critical for analysis by the statistical characterization method.

Knowing the limitations in using RM 23 as a reference site allowed for these limitations to be considered when analyzing the data. RM 23 met the minimum acceptability criteria for a reference site in the statistical characterization method (ADEC 2006). It is free of channel and habitat modification, and no logging, mining, intensive recreational uses, farming or livestock grazing take place there. Further, at the point where monitoring equipment was deployed, the nearest road on the left bank, Funny River Road, is separated from the river by 420 feet of wooded area. On the right bank the nearest dirt road is through 120 feet of wooded area and it is another 0.4 miles through Swiftwater Park to the closest paved road. There are no withdrawal structures, impoundments, or water return outfalls in proximity to the site. There are scattered structural developments near the riverbank, but these are all well established and have not actively disturbed the bank for some time. There is little evidence of sources of sediment delivery associated with human disturbance. Though not required by the criteria, the choice of RM 23 as a reference site is strengthened by the fact that there are no known point-sources for turbidity between it and the test site, eliminating major confounding variables other than boat traffic. The small tributaries between the two sites, Soldotna Creek and Slikok Creek, have flows of less than 20 cfs and carry tannic, clear water that is not a significant source of turbidity.

4.2. The Statistical Characterization Method

The ADEC Natural Condition Tool allowed for data calculations to be made that extracted overall differences in the turbidity data between these two sites. In the strictly spatial Statistical Characterization Method, RM 23 was used establish a natural baseline condition with which to compare both the site in question, RM 11.5 as well as the reference site itself, RM 23. By exploring the differences in these two comparisons an overall affect of how much more the RM 11.5 exceeded standards could be calculated. It became apparent from the data in **Table 5** that RM 11.5 had often double and occasionally ten times the hours of exceedances that RM 23 had. RM 11.5 was clearly exceeding water quality standards much more frequently than the reference site.

4.3. The Temporal Application of the Concurrent Method

The temporal application of the concurrent method allowed for a self-comparison at each site with the reference being a time frame of low boat traffic. This does remove the problems arising from lag time that prevent RM 23 from being a baseline for the concurrent method. It does, however, rely on an assumption that natural turbidity does not vary drastically within the timeframe of a day. The potential errors in this assumption are somewhat addressed by comparing results from this method for both RM 23 and RM 11.5. Exceedances arising from natural daily or periodic storm events should be captured at both

RM 23 and RM 11.5. This is assuming that daily events and storm events would affect turbidity at RM 23 and RM 11.5 in a similar manner. Using this application of analysis, RM 11.5 had double the hours of exceedance that RM 23 had.

4.4. The Estimation of Background Turbidity Method

The estimation method that used human professional judgment to produce a daily turbidity background value was the weakest of the three methods. The biggest potential downfall is human error. A possible strength of this method is the ability to look at an individual day with regards to overall baseline trends. This specialization could add greater accuracy. This method produced the highest hours or exceedances of the three methods used. The hours were closest to those seen in the Temporal Application of the Concurrent Method. The hours of exceedances were double those seen in the Statistical Characterization Method. In future studies this method could be improved by using a more rigorous approach with the slope in the early AM and late PM hours, rather than a single average value, used to estimate background.

4.5. Overall Implications of Exceedance Hours

Regardless of the method used for analysis there are clearly more hours of exceedance at RM 11.5. Four sources of data from this study point to the correlation between boat wakes and elevated turbidity. First, there was a consistent pattern in the turbidity graphs at RM 11.5 when examining the no motor Mondays. These days where boat traffic at both RM 11.5 and RM 23 was minimal consistently produced similar looking graphs with relatively flat baselines and an absence of spikes. Other days of the week in July had almost daily rapid rises in turbidity that were not seen at RM 23. Second, these daily spikes failed to mimic any other natural event seen at RM 23 during the study period. Natural rises in the baseline at RM 23 were seen in the RM 11.5 data in **Figure 6**. However, these rises at RM 11.5 were overlaid by a series of rapid spikes that were largely absent on Mondays when motorized activity was minimal. Third, data from an intensive boat count, when compared to turbidity data from the same time period, points to a correlation between peak boating activity and daily peaks in turbidity, as explored in **Figure 4**. And lastly, the similarity between Hydrolab data distributions from RM 23 and RM 11.5 between midnight and 5 AM (and the differences between those distributions during the daytime hours) point to the importance of a cause that occurs and peaks only during the daytime. Changes in tides, bank composition or flows, in theory, would not have such a time discriminatory effect.

Previous studies on the Kenai River have also pointed to motor boat activity as a significant factor contributing to turbidity levels. In 1996, the US Geological Survey (USGS) conducted studies that correlated areas of higher motorized boat traffic with increased bank erosion on the Kenai River (Dorava and Moore 1997). In 2005-2007, the Army Corps of Engineers conducted field studies to determine the effect of boat wakes on bank erosion in the Kenai River (Maynord et al. 2008). They concluded that, while the effect of boat wakes on the river as a whole makes up only about 0.46% of the total channel power, in areas of high boat traffic, such as that seen between RM 10 and RM 12, boat wakes are estimated to contribute 59% of computed shoreline streamflow energy during a 30-minute high-traffic window. Total contribution of boat wakes to bank erosion in this 2-mile reach between 21 June and 30 September is estimated at 16% of streamflow energy, a significant contribution to bank erosion. An increase in erosion from motor boats likely would result in an increase in turbidity.

Based on observations from transect sampling, elevation of turbidity was much more pronounced along the banks of RM 11.5 and RM 8.5. This is particularly important because the near bank habitat, within six feet, is where juvenile salmonids spend most of their time (Bendock and Bingham 1988b). Furthermore, juvenile fishes appear to be more sensitive to elevated turbidity levels than do adults (Lloyd 1987). Since the data for the continuous monitoring portion of this study was obtained from sensors that were placed between 10 and 30 ft of shore, the turbidity exceedances actually experienced by juvenile fishes in the near bank habitat may in fact be higher in the lower Kenai River than what has been recorded in this paper.

5. CONCLUSIONS

Based on this three year study a baseline dataset was established representing natural conditions for turbidity in the lower Kenai River during the summer. Using this baseline data the occurrence of exceedances hours could be calculated with three different methods. While each method had its own strengths and weaknesses, the consistent message was that RM 11.5 did experience significant exceedances of ADEC water quality standards for turbidity.

A probable link between boat traffic and elevated turbidity was supported through analysis of weekly turbidity data at RM 11.5 where fishing was prohibited from a motorized boat on Mondays. This distinct and repeatable pattern showed that natural daily variations in turbidity could not alone account for the spikes in data seen at RM 11.5. This, combined with the drastically different shape and slope seen in the spikes at RM 11.5 when compared to natural event at RM 23, and the brief boat count study provide a strong argument for a relationship between boat wakes and elevation in turbidity.

The intent of this study was simply to prompt discussion and response to the documented elevation in baseline turbidity levels with high volumes of boat traffic. Moving forward, unless this issue is addressed and managed, there is the potential to cause damage to this important riverine ecosystem. This study is not meant to be, nor should be viewed as a complete picture of all possible factors that affect turbidity on the Kenai River. Future studies should be conducted to give insight into the effects that other factors such as tidal influences, daily glacial melting cycles and discharge patterns have on turbidity in the Kenai River. Other future steps should include modeling the relationship between boat activity, tides, and turbidity levels to aid in understanding this complex system and exploring management options.

6. NOTATIONS AND ABBREVIATIONS

ADEC:	Alaska Department of Environmental Conservation
CFS:	Cubic Feet per Second
FMS:	Fixed Monitoring Station
KWF:	Kenai Watershed Forum
LB:	Left Bank
NTU:	Nephelometric Turbidity Units
RB:	Right Bank
RM:	River Mile
TRANS:	Transect
USEPA:	United States Environmental Protection Agency
USGS:	United States Geological Survey

7. REFERENCES

Alaska Department of Environmental Conservation (ADEC). 2006. Guidance for the Implementation of Natural Condition-Based Water Quality Standards. ADEC, Division of Water, Anchorage, AK.

Alaska Department of Environmental Conservation (ADEC). 2011. Water Quality Standards. 18 AAC 70, as amended through May 26, 2011. ADEC, Juneau, AK.

Bash, J., C. Berman, and S. Bolton. 2001. Effects of turbidity and suspended solids on salmonids. Report No. WA-RD 526.1. Washington State Department of Transportation, Olympia, WA.

Bendock, T. and A. Bingham. 1988a. Feasibility of estimating winter distribution and habitat preference for juvenile salmonids in the mainstem Kenai River, Alaska, 1986-1987. Fishery Data Series No. 38. Alaska Department of Fish and Game, Division of Sportfish, Juneau, AK.

Bendock, T. and A. Bingham. 1988b. Juvenile salmon seasonal abundance and habitat preference in selected reaches of the Kenai River, Alaska, 1987-1988. Fishery Data Series No. 70. Alaska Department of Fish and Game, Division of Sportfish, Juneau, AK.

Christensen, V.G., P.P. Rasmussen, and A.C. Ziegler. 2002. Comparison of Estimated Sediment Loads Using Continuous Turbidity Measurements and Regression Analysis, Turbidity and Other Sediment Surrogates Workshop, Reno, NV, 30 April -2 May 2002.

Dorava, J.M. and G.W. Moore. 1997. Effects of boatwakes on streambank erosion, Kenai River, Alaska. U.S. Geological Survey Water-Resources Investigations Report 97-4105. Prepared in cooperation with the Alaska Department of Fish and Game, Anchorage, AK.

Lloyd, Denby S. 1985. Turbidity in freshwater habitats of Alaska: a review of published and unpublished literature relevant to the use of turbidity as a water quality standard. Report No. 85-1. Alaska Department of Fish & Game, Habitat Division, Juneau, AK.

Lloyd, Denby S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. North American Journal of Fisheries Mangement. Vol. 7, Issue 1, pp. 34-45.

Maynord, S.T., D.S. Biedenharn, C.J. Fischenich, and J.E. Zuflet. 2008. Boat-wave-induced bank erosion on the Kenai River, Alaska. ERDC TR-08-5. U.S. Army Corps of Engineers, prepared for the Kenaitze Indian Tribe, Kenai, AK.

Newcombe, Charles P. 2003. Impact Assessment Model for Clear Water Fishes Exposed to Excessively Cloudy Water. Journal of the American Water Resources Association. Volume 39, Issue 3, pp. 529-544.

Oregon Department of Environmental Quality (DEQ). 2010. Turbidity Technical Review: summary of sources, effects, and issues related to revising the statewide water quality standard for turbidity. Report No. 10-WQ-022. Oregon DEQ, Portland, OR.

USEPA (U.S. Environmental Protection Agency). 1999. EPA Guidance Manual, Turbidity Provisions. http://www.epa.gov/ogwdw000/mdbp/pdf/turbidity/chap_07.pdf, accessed June 2011.

USEPA (U.S. Environmental Protection Agency). 2008. Alaska Water Quality Assessment Report. http://iaspub.epa.gov/waters10/attains_state.control?p_state=AK, accessed June 2011.

Appendices

APPENDIX A: Dates and Locations of Cross-sectional Transects

2008	**RM 8.5**	**RM 11.5**	**RM 13.3**	**RM 14.5**	**RM 15.5**	**RM 19**	**RM 23**
May 23		X		X			X
May 27	X	X		X			X
May 29	X	X		X			X
June 4	X	X		X			X
June 10	X	X		X			X
June 12	X	X		X			X
June 17	X	X		X			X
June 25	X	X		X			X
June 27	X	X		X			X
June 30	X	X		X			X
July 1	X	X		X			X
July 7, Mon.	X	X		X			X
July 8	X	X		X			X
July 10	X	X		X			X
July 14, Mon.	X	X		X			X
July 15	X	X		X			X
July 17	X	X		X			X
July 21, Mon.	X	X		X			X
July 22	X	X		X			X
July 28, Mon.	X	X		X			X
July 29	X	X		X			X
July 30	X	X		X			X
August 4	X	X		X			X
August 5	X	X		X			X
August 12	X	X		X			X
August 14	X	X		X			X
August 19	X	X		X			X
August 25	X	X		X			X
2009							
May 18	X	X		X			X
May 21	X	X		X			X
May 27	X	X		X			X
May 29	X	X		X			X
June 1	X	X		X			X
June 3	X	X		X			X
June 8	X	X		X			X
June 11	X	X		X			X
June 16	X	X		X			X
June 18	X	X		X			X
June 22	X	X		X			X
June 24	X	X		X			X
June 29	X	X	X	X			X
July 2	X	X	X	X			X
July 6, Mon.	X	X	X	X		X	X
July 10	X	X	X	X			X
July 13, Mon.	X	X	X	X		X	X
July 15	X	X	X	X		X	X
July 20, Mon.	X	X	X	X	X	X	X
July 24	X	X	X	X	X		X

July 27, Mon.	X	X	X	X	X		X
July 30	X	X	X	X	X		X
August 3	X	X	X	X	X		X
August 5	X	X	X	X	X		X
August 12	X	X	X	X	X		X
August 14	X	X	X	X	X		X

APPENDIX B: Exceedances of Alaska Water Quality Standards, based on ADEC's Natural Conditions Tool

Exceedances were calculated for both RM 23 and RM 11.5, and exceedances during midnight to 5am are shown in addition to overall exceedances. The month of July is also shown separately.

Temporal Reference Method

RM 11.5

			Julys	All Summers
Midnight to 5am	**Natural Condition (Based on RM 11.5 Midnight to 5am Data)**		43.3 NTU	35.7 NTU
	Estimated Exceedances of ADEC Turbidity Standards	**2008**		
		Drinking water	9.5 hrs.	17.5 hrs.
		Secondary rec.	5 hrs.	11.25 hrs.
		Fish & Wildlife	0.25 hrs.	0.5 hrs.
		2009		
		Drinking water	15.75 hrs.	31.75 hrs.
		Secondary rec.	9.25 hrs.	18.5 hrs.
		Fish & Wildlife	5.25 hrs.	5.5 hrs.
		2010		
		Drinking water	13.25 hrs.	15.75 hrs.
		Secondary rec.	5.5 hrs.	14.75 hrs.
		Fish & Wildlife	0 hrs.	0 hrs.
Full Day	**Estimated Exceedances of ADEC Turbidity Standards**	**2008**		
		Drinking water	96.75 hrs.	155.75 hrs.
		Secondary rec.	65.25 hrs.	116.25 hrs.
		Fish & Wildlife	22.75 hrs.	37.5 hrs.
		2009		
		Drinking water	142.5 hrs.	239 hrs.
		Secondary rec.	98.5 hrs.	173.75 hrs.
		Fish & Wildlife	36.5 hrs.	58.75 hrs.
		2010		
		Drinking water	71 hrs.	106.5 hrs.
		Secondary rec.	54.5 hrs.	81 hrs.
		Fish & Wildlife	18.5 hrs.	35 hrs.

Spatial Reference Method

RM 11.5

			Julys	All Summers
Midnight to 5am	**Natural Condition (Based on RM 23 All Data)**		39.9 NTU	32.2 NTU
	Estimated Exceedances of ADEC Turbidity Standards	**2008**		
		Drinking water	NC* hrs.	30.5 hrs.
		Secondary rec.	NC hrs.	14.5 hrs.
		Fish & Wildlife	NC hrs.	1.25 hrs.
		2009		
		Drinking water	NC hrs.	46.25 hrs.
		Secondary rec.	NC hrs.	41.5 hrs.
		Fish & Wildlife	hrs.	6.75 hrs.
		2010		
		Drinking water	NC hrs.	17 hrs.
		Secondary rec.	NC hrs.	0 hrs.
		Fish & Wildlife	NC hrs.	0 hrs.
Full Day	**Estimated Exceedances of ADEC Turbidity Standards**	**2008**		
		Drinking water	131 hrs.	198.5 hrs.
		Secondary rec.	94 hrs.	140.5 hrs.
		Fish & Wildlife	32 hrs.	48 hrs.
		2009		
		Drinking water	169 hrs.	292.75 hrs.
		Secondary rec.	123 hrs.	219 hrs.
		Fish & Wildlife	42 hrs.	74.75 hrs.
		2010		
		Drinking water	129 hrs.	125.75 hrs.
		Secondary rec.	100 hrs.	98.5 hrs.
		Fish & Wildlife	38 hrs.	45.5 hrs.

*Exceedance Values for the Midnight to 5AM were not recalculated after the adjustment to 39.9 reference.

Temporal Reference Method

RM 23

			Julys		All Summers	
Midnight to 5am	**Natural Condition (Based on RM 11.5 Midnight to 5am Data)**		39.1 NTU		31.5 NTU	
	Estimated Exceedances of ADEC Turbidity Standards	**2008**				
		Drinking water	13.75	hrs.	38.75	hrs.
		Secondary rec.	10.5	hrs.	24.25	hrs.
		Fish & Wildlife	0	hrs.	2	hrs.
		2009				
		Drinking water	9.75	hrs.	18.5	hrs.
		Secondary rec.	5.75	hrs.	16.25	hrs.
		Fish & Wildlife	5.25	hrs.	5.5	hrs.
		2010				
		Drinking water	11.5	hrs.	15.75	hrs.
		Secondary rec.	9.25	hrs.	12.75	hrs.
		Fish & Wildlife	0	hrs.	2.25	hrs.
Full Day	**Estimated Exceedances of ADEC Turbidity Standards**	**2008**				
		Drinking water	56	hrs.	164.25	hrs.
		Secondary rec.	36.5	hrs.	99.25	hrs.
		Fish & Wildlife	0	hrs.	9.25	hrs.
		2009				
		Drinking water	41.5	hrs.	111	hrs.
		Secondary rec.	36	hrs.	60.25	hrs.
		Fish & Wildlife	17.5	hrs.	27	hrs.
		2010				
		Drinking water	54	hrs.	70.5	hrs.
		Secondary rec.	47.75	hrs.	56.25	hrs.
		Fish & Wildlife	10.25	hrs.	28.75	hrs.

Spatial Reference Method

RM 23

			Julys	All Summers
Midnight to 5am	**Natural Condition (Based on RM 23 All Data)**		39.9 NTU	32.2 NTU
	Estimated Exceedances of ADEC Turbidity Standards	**2008**		
		Drinking water	NC* hrs.	36.25 hrs.
		Secondary rec.	NC hrs.	23.75 hrs.
		Fish & Wildlife	NC hrs.	1.5 hrs.
		2009		
		Drinking water	NC hrs.	18 hrs.
		Secondary rec.	NC hrs.	15.75 hrs.
		Fish & Wildlife	NC hrs.	5.5 hrs.
		2010		
		Drinking water	NC hrs.	15.75 hrs.
		Secondary rec.	NC hrs.	12.5 hrs.
		Fish & Wildlife	NC hrs.	1.25 hrs.
Full Day	**Estimated Exceedances of ADEC Turbidity Standards**	**2008**		
		Drinking water	56 hrs.	151.25 hrs.
		Secondary rec.	36 hrs.	94 hrs.
		Fish & Wildlife	0 hrs.	8 hrs.
		2009		
		Drinking water	34 hrs.	100 hrs.
		Secondary rec.	30 hrs.	57.5 hrs.
		Fish & Wildlife	15 hrs.	25.75 hrs.
		2010		
		Drinking water	91 hrs.	69.25 hrs.
		Secondary rec.	81 hrs.	56 hrs.
		Fish & Wildlife	17 hrs.	24.75 hrs.

*Exceedance Values for the Midnight to 5AM were not recalculated after the adjustment to 39.9 reference.

APPENDIX C: Summary of Reviewer Comments

An earlier draft version of this report was circulated for comments. A summary of the received comments is provided below.

Draft Report Reviewers

Dan Rinella, University of Alaska Anchorage **[DR]**
Mary Ann Madej, Research Geologist, USGS **[MAM]**
Richard Winslow, ME, CnR Tech Services **[RW]**
Sue Mauger, Science Director, Cook Inletkeeper **[SM]**
Anonymous Reviewer No. 1 **[AR1]**

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1. COMMENTS ON SUBSTANTIVE MATTERS

1.1. Contributions from glacial melt and diurnal melting cycles

Reviewer	*Page*	*Comment*
MAM	--	**1.1.1.** You mention that a source of turbidity is glacial silt from the headwaters. Is there a diurnal signal to this contribution? I didn't see much in Fig. 9 but the vertical scale did not allow me to see the details of the little blips. If the meltwater contribution is lowest during early morning hours, one would expect the low turbidity values you measured from midnight to 5 a.m. to be at least partly due to the lower glacial silt contribution. This wouldn't change your ratios between RM 23 and RM11.5, but it gives more insight into the mechanisms of turbidity production.
Response/Action:		*Based on the data analysis done in this study there was no apparent diurnal signal. An understanding of diurnal signals would be an interesting study in the future but it was not a necessary component in the calculation of exceedances.*
SM	*p. 22*	**1.1.2.** You'd have to show that there were no other potential sources of turbidity during non-morning hours to conclude it was motorized use. For example, glacial melt increases turbidity during the day also. [referring to "Because these turbidities are comparable despite the lack of boat traffic at RM 23, it appears that turbidity levels are not affected by boat traffic at RM 11.5 during these early-morning hours, i.e. the river displays its natural condition."]
Response/Action:		*The data from no motor Mondays gave valuable insight into natural daily variations at RM 11.5. During Monday when boat traffic was low the turbidity baseline remained relatively flat unless a large melt event was occurring. These windows into the natural conditions support the argument for a lack of significant daily variations in natural turbidity at RM 11.5.*
SM	*p. 27*	**1.1.3.** So melt events due to their long duration result in high SEV scores. Any thoughts about the relative importance of increased melt rates due to higher air temperatures might be in the future relative to boat-caused turbidities? Might be worth noting that establishing "natural conditions" for a parameter with distinct connections to climate-induced patterns is chasing a shifting baseline.
Response/Action:		*Establishing climatic patterns in turbidity was beyond the scope of this study. It could be addressed in a future study.*
SM	*p. 17*	**1.1.4.** Why wouldn't you/don't you see the same gradual increase during a natural melt-water event at RM 11.5 as you saw at RM 23?

Does the tidal influence play a role?

Response/Action: *A gradual rise in the turbidity baseline during melt events is indeed seen at RM 11.5 and RM 23. At RM 11.5 short, sharp spikes within a general rise overlie this rise.*

SM *p. 16* **1.1.5.** Does this correlate to air temp data at all? Or gauge data? Do you think this is due to higher stream velocities resulting in bank erosion? Or overland flow carrying sediment into the system? [referring to "Periodically, large melt events at the Kenai River headwaters or in major tributaries cause relatively rapid increases in turbidity levels downriver ."]

Response/Action: *There is definitely a correlation between turbidity and discharge. A rise in discharge can occur due to a melt event and/or rain event. While this is an important factor in understanding the nature of the natural conditions, understanding this relationship is not necessary to quantifying natural conditions or calculating exceedance hours. A future study could be done to further explore this issue.*

MAM *--* **1.1.6.** The report mentions spikes in turbidity due to large melt events. I looked at the highest spike of July 22, 2009. It seems to occur on the initial part of rising limb of the hydrograph [image omitted]. Is this true for the other spikes as well? It's interesting that streamflow continued to rise, but turbidity decreased, suggesting a supply limitation of fine-grained sediment? On P. 16 the report suggests that turbidity increases are not associated with natural flow rates, but without reporting natural flow rates the readers are unable to evaluate that statement.

Response/Action: *There is a definite relationship between turbidity and melt events. Throughout the study these natural events were seen at both RM 11.5 and RM 23. This study was not designed to examine the relationship between turbidity and melt events. The examination of hydrographs was beyond the scope of this study but could be an insightful future study.*

1.2. Weather-related causes of the July 22, 2009 turbidity spike

DR *p. 15* **1.2.1.** Was there anything interesting/unusual about the weather (heat, rain) that might have caused this? [referring to the dramatic turbidity spike seen on July 22, 2009]

Response/Action: *This turbidity spike was due to a large melt event. Events such as this do occur periodically and, while infrequent, are an important natural contributor to turbidity.*

1.3. SEV and biological effects of turbidity on fish

MAM *--* **1.3.1.** Newcombe's scores are semi-quantitative and to some extent use professional judgment. He used integers to express his SEV index. I have only seen the values assessed to one decimal place, so the use of SEV's to the precision of hundredths (Table 11, "4.69" "3.94") is unreasonable. To interpret an increase of SEV from 4.6 to 4.7 (July 2009) as increased impairment and biologically significant is a stretch. On P. 24 the report states "…the data indicate that daily spikes could additionally impair aquatic life." Based on the limitations I've stated above, I think this statement is too strong for your data set.

DR *p. 22* **1.3.2.** This SEV seems like a good approach, but I agree with your caveat that index scores may be meaningless since Kenai fish probably have adaptations that allow them to cope with naturally high turbidity. I suggest taking a look at the published papers that cite the Newcome paper. There are a couple that describe attempts to validate the SEV, and it didn't perform very well. And those studies were conducted in clear water systems.

MAM -- **1.3.3.** The consensus of the scientific community regarding the effect of turbidity on fish is murky, so to speak. Turbidity can reduce feeding rates in visually oriented fish, but some studies have documented that fish just shift their feeding strategies at higher turbidity. Some fish, especially juveniles, may experience a positive effect of increased turbidity as it helps them escape predation. For example, Gregory and Levings (1998) showed juvenile salmon were less likely to be preyed upon in the Frazer River (27-108 NTU's) than in waters of 1-6 NTUs. So, higher turbidity near the banks may even give the juveniles an advantage. Acclimation durations may also influence how fish respond to elevated turbidities. In north coastal California streams we're finding that adult salmon just hunker down during moderately high turbidity events (< 200 NTUs) without obvious impairment if turbidity only lasts a few days.

DR -- **1.3.4.** As pointed out in the report, large numbers of juvenile fish (including lots of Chinook) use the near-shore intertidal habitats impacted by boat-induced turbidity. Given the value of the Kenai River's salmon populations and the recent declines in Chinook salmon runs, understanding the effects of episodic turbidity on the ecology and physiology of Kenai River salmon populations should be a priority.

MAM -- **1.3.5.** The evidence to support significant differences in turbidity levels between RM 11.5 and RM 23 is strong; however, it is more difficult to make a case for biological significance. The report uses

	Newcombe's 2003 criteria for impairment. As you acknowledge on P. 23, Newcombe's model is based on clear water fishes (calibrated for trout). Fish that live in rivers with glacial silt presumably are not totally "clear water fish." Newcombe's paper dealt with clay and water clarity. What is the dominant particle size of suspended sediment in the Kenai – silt?? If so, if would behave differently than clay, settling out quicker. If there is a high component of particulate organic matter, that affects turbidity dynamics too, because the lighter organics stay suspended in the water column longer than the heavier inorganics. Also, Newcombe states that the relationship between water clarity (which he was using) and turbidity is weak. You would need to make Secchi disk measurements along your transects at the same locations as your turbidity measurements to make a correlation between clarity and turbidity.
Response/Action to all comments related to SEV:	*The SEV calculations were not included in the final report. After careful review of the comments provided it became apparent that the SEV method is not widely accepted and was detracting from the report.*

1.4. Data reporting, units, and correlation coefficients and samples sizes for correlation assertions

DR	*p. 17*	**1.4.1.** It would be helpful to include the correlations coefficients and sample sizes for these two correlations. [referring to statement that "Turbidity levels taken from early morning (0:00 to 5:00) and Monday readings at RM 11.5, correlate well for the two sites, both for this week and for the entire study period."
Response/Action:		*A statistical characterization of the cumulative frequency curve data was added to the final report.*
AR1	--	**1.4.2.** In the History section: in the paragraph that begins: "In 2008 …First, when you are reporting results you need to define the units the first time they are used when you first report a value(s). In this paragraph NTU is not defined and the acronym is at the end of the paragraph not after the first value. Secondly, a range of values is meaningless to the reader without some measure of center, such as mean, median, mode, etc. then a range of variability around the mean should be used such as standard deviation or standard error, then the full range of the data can be listed. With these three results the reader can then understand the data that was collected. Just reporting the overall range of the data is not enough for the reader to interpret the results/data.
Response/Action:		*A definition of NTU was added. A statistical characterization was done on the data used in the cumulative frequency curves. This included calculating the mean, mode, range, sample distribution and standard*

deviation.

1.5. Time lag determination and the concurrent measurement approach

DR	*p. 20*	**1.5.1**. The concurrent measurement approach is so straightforward; it's a shame to not use it. Maybe I'm overlooking something, but it seems like the time lapse between RM 23 and RM 11.5 would simply be a function of discharge. If so, a hydrologist might be able to model the relationship. A tracer study could really nail this down, but it would take some money and effort. It's worth noting that when the turbidity at RM 23 is pretty stable (like in Figure 9) you would have a lot of forgiveness. Lag times as different as 2 hours or 2 days wouldn't have a huge effect on your estimated background turbidity level. *A hydrologic model would allow for calculations with the concurrent method but the development of such a model was beyond the scope of this study. Using the data from this study such a model could easily be developed in the future.*
DR	*p. 21*	**1.5.2.** Do any of the natural turbidity plumes that passed the RM 23 Hydrolab show up on the RM 11.5 Hydrolab? Or are there any peaks/dips in temperature or conductivity that can be followed from one station to the other? These could help answer the lag time question. … Linking turbidity data to state water quality standards is an important step, particularly from a regulatory perspective. A number of options are presented in the report, each with noted shortcomings. The concurrent measurement approach is noted as the preferred method and, in my opinion, is the most straightforward and defensible. The inability to predict the time lag between the RM 23 and RM 11.5 monitoring stations is given as an obstacle. Before this method is dismissed, however, I urge the authors to consult with a hydrologist to see if the lag time can be modeled. The lag time will certainly vary with discharge, and a hydrologist may be able to come up with a defensible way to adjust the lag time according to varying levels of discharge. The KWF Hydrolab data and/or USGS stream gage data may be useful for this. *The peaks of natural events did show up in both the RM 11.5 and RM 23 data. A derivation of lag time from these peaks was attempted. The calculated lag times from these events varied from two to twelve hours depending on the discharge. In essence, a single lag time would not be accurate. To acquire the changing lag times a hydrologic model would need to be created. While feasible in the future, that was beyond the scope of this study.*
MAM	--	**1.5.3.** It's common that water quality standards use "natural condition" as a factor, but that "natural condition" isn't defined. The report makes valid points about the range of variability and the

exceedance of turbidity thresholds even at the reference site. To track a sediment plume from RM 23, one needs to know average velocity, dilution and dispersion effects, and the settling velocity of particles of sediment in the plume. For example, a particle would take more than 8 hours to traverse the 11.5 miles from RM 23 to RM 11.5 if the Kenai has an average summer velocity of 2 ft/sec. and if it didn't settle out of the water column during that time. Do you see any evidence for such a lag? The use of a "reference time" would work as long the streamflow was also steady during the time period.

Response/Action: *There definitely was evidence of lag time. During natural melt events there was a several hour delay of when the peak turbidity passed RM 23 and RM 11.5. The problem was this delay was not a constant number; it varied with discharge. While not flawless, the temporal application of the concurrent method using a reference time is a fairly accurate method of exceedance estimation. The early morning references time did indeed have fairly constant turbidity levels.*

1.6. More information on the Kenai River Watershed needed (stream flow, drainage area, tributaries)

MAM -- **1.6.1.** What is the drainage area of the Kenai River at the upstream end of your study reach, and at RM 11.5? It was unclear to me whether there were any turbidity-contributing tributaries entering the study reach. Page 14 mentions the Killey River, but I couldn't tell from the text where the Killey enters the Kenai. The next paragraph states that the small tributaries entering the study reach are not significant sources of turbidity, though. Please clarify, or include a larger location map for readers unfamiliar with the area.

Response/Action: *The drainage area was added to the report. The only substantial tributaries between RM 23 and RM 11.5 were Slikok and Soldotna Creeks. As mentioned in the report, both of these are clear water streams and are not significant sources of turbidity. The Killey River is upstream of both study sites. This glacially fed tributary is a major source of turbidity in the lower Kenai River.*

MAM -- **1.6.2.** The report would benefit by the inclusion of water discharge data because turbidity and suspended sediment loads are commonly associated with streamflow. You can download discharge data from the USGS site at Soldatna (Station 15266300) at:

http://waterdata.usgs.gov/ak/nwis/inventory/?site_no=15266300&agency_cd=USGS&amp I don't know if there are any other gages farther downstream run by other agencies.

Response/Action: *Looking at turbidity with respect to discharge would be a valuable addition to understanding variance in the natural conditions. With* *respect to calculating affects from an anthropogenic disturbance, an understanding of what makes natural conditions is not necessary when using the statistical characterization method by DEC. Discharge may be an important factor in issues such as evaluating under what conditions boat wakes have the greatest impact on turbidity.*

1.7. Ratios of turbidity values from test site and control site

MAM -- **1.7.1.** Figures 8 and 9 are convincing plots to make your point. I also find it useful to make plots of ratios: (turbidity at RM 11.5)/ (turbidity at the control). You can then discuss how maximum daily turbidity values are up to 8 times (?) higher at RM11.5 than at the reference site, for example.

Response/Action: *A graph of ratios was included in **Figure 3.***

1.8. Lack of temporal independence of turbidity data points

MAM -- **1.8.1.** You may have a problem with lack of independence of data. For example, if turbidity is high at Time 1, it is likely to also be high at Time 1 + 15 minutes. So, the cumulative curves in Fig. 3 may not be based on independent data. You can also plot just the daily maximum turbidity values at RM 23 and RM 11.5 (daily maxima should be independent of one another because turbidity seems to "recover" at night).

Response/Action: *This study was done using ADEC protocols. The cumulative frequency curves were an ADEC method for evaluating natural conditions with respect to turbidity.*

1.9. Temporal precision in tables

MAM -- **1.9.1.** Table 10. The units of time show a precision that is unrealistic. 0.001 hour is equivalent to 3.6 seconds. The data loggers recorded on a 15-minute interval (0.25 hour).

Response/Action: *This was corrected in the final report.*

1.10. Tidal influence on turbidity levels

MAM -- **1.10.1.** I am concerned about the confounding factor of tidal influence with turbidity levels at RM 11.5. It would be a straightforward task to plot timing of high tides with your turbidity levels, perhaps as Figure 11-b, to show the degree to which peak turbidities correspond to high tides.

Response/Action: *Initial plotting of tide and turbidity data did not generate a simple, straightforward relationship. A more in depth analysis would be necessary to derive this information. While not impossible, it was beyond the scope of this study. This would be interesting and valuable to*

		understanding natural conditions but does not effect the calculation of exceedance hours.
SM	*p. 13*	**1.10.2.** Isn't RM 11.5 also tidally influenced? How are you defining the intertidal zone? [referring to "This is consistent with previous research, which indicates that the intertidal zone is the most turbid section of the Kenai River (Bendock & Bingham 1988a)."]
Response/Action:		*The tidally influenced zone as referenced in this report is the section of river where river water is backed up during high tides. This can cause a slowing of velocity and a rise in water level. The uppermost point this occurs on the Kenai River is around RM 11.5.*
RW	*p. 15-16*	**1.10.3.** The turbidity spikes and rates of turbidity change at RM 11.5 are unique when compared to the other three RM measurement locations. - The uniqueness of the turbidity spikes and rates of turbidity change at RM 11.5 indicate that there are natural events contributing to this data set. If boat traffic was solely responsible for these rates and spikes than similar data profiles should be visible at the other RM measurement stations. -RM 11.5 may be at a very unique location where the intertidal zone mixing is a poorly understood and difficult to measure phenomena. - Reference tidal charts for the mouth of the Kenai River on these dates and times will not be useful in 'back-calculating" tidal zone influence for RM 11.5; once tides enter into rivers, their flow characteristics cannot be predicted based on mouth of the river tidal predictions.
Response/Action:		*The importance of natural conditions is minimal when evaluating spikes since the spikes are consistently absent on Mondays. If natural in origin they would have been present in the Monday data as well.*

1.11. Boat activity sampling and data characterization

MAM	--	**1.11.1.** Future monitoring could incorporate a more detailed count of boat traffic. Presumably a boat could have churned up silt before you were sampling the transects and would not have been included in the counts. Perhaps call your traffic counts an activity "index" because they did not include all boat traffic on the river.
Response/Action:		*The intensive boat sampling done during the three-day boat count was done with a camera that took frames every six second, twenty-four hours a day. This was an accurate count of boat traffic in this section of the river. In the future, a longer boat count could be done with simultaneous turbidity measurements.*

1.12. Additional factors must be analyzed before characterization of a background turbidity level

RW	--	**1.12.1.** …[T]he review of this project report raises additional scientific

questions about multiple river environmental factors. These factors may directly or indirectly impact natural background turbidity levels. These factors need to be understood and quantified before the natural background turbidity levels can be established with confidence. * Tidal zone interface effects * Bottom structure effects * Current and flow profile * Channel shape / size * Silt / turbidity characteristics; particle sizing and distribution range; settling characteristics, suspension half life, organic vs in-organic content, etc.

Response/Action: *While an understanding of the factors mentioned would lead to a greater understanding what exactly is contributing to natural turbidity, what areas are most prone to turbidity exceedances and what conditions lead to the greatest turbidity, these do not detract from a simple understanding of what the baseline turbidity levels are, as established in the cumulative frequency curve. Knowing what these levels are and what causes this curve, although related, are two different subjects. Future studies could be done to address these.*

RW *p. 10-11* **1.12.2.** The discussion and tables presented in the report appear to indicate that some other natural phenomena(s) may be contributing to the higher turbidity levels at these locations. - The river transect data for 5/29/2009 shows much higher turbidity levels along the bank for RM 8.5 and 11.5. Historically, this is not a high boat traffic time frame, compared to July. -The river transect data for 7/27/2009 shows that only RM 8.5 has significant elevated turbidity near the bank while the other RM measurement sites show very similar shaped transect curves. Late July would be a period of high river boat traffic past both RM 8.5 and 11.5 since it is during the Sockeye dip-netting season

Response/Action: *In addition to anthropogenic sources, turbidity comes from a number of natural sources. Some of these occur continually, some sporadically. A large melt event or storm event can lead to increased turbidity for a period of time. There was such an event around 5/29/09 that contributed to a several day elevation in turbidity levels.*

RW *p. 10-11* **1.12.3.** The turbidity values at RM 23 do not approach the values of RM 11.5, however during select periods of time in the early AM the values are relatively close both in range and magnitude. - The similarity in turbidity measurement values and range between the two locations may indicate that two separate phenomena or a combination of factors contribute to natural background turbidity. -RM 11.5 is influenced by tidal factors while RM 23 is not. The early AM data range referenced for RM 11.5 does not have tidal influences accounted for, yet the min, max, and range of values are almost identical. - Based on this data set comparison is it possible that the river has different natural background turbidity mechanisms at different locations?

Response/Action: *During the tide cycle, the time of day when high and low tide occur changes. Throughout a cycle, high and low tide peaks occur at all times of the day. A tidal influence would not solely appear in the early AM data at RM 11.5 and, therefore, tides alone cannot account for the lower turbidity levels seen in the AM data. The early AM data for RM 11.5 is similar to the no motor Monday data at RM 11.5 and all the data for RM 23. This suggests that RM 23 and RM 11.5 would have a very similar baseline datasets if boat motors were not present at RM 11.5. While similar, differences in substrate and tidal influences would still cause slightly different natural background turbidity levels at these two sites.*

1.13. Clarifying the purpose/objectives of the report

AR1 -- **1.13.1.** [Executive Summary:] This summary is confusing. First, the two purposes stated: to 1) characterize the natural range of variability for turbidity and 2) to identify and quantify variation in turbidity levels from anthropogenic sources…is not what is reported in this document. Secondly, a goal statement such as this should not be accompanied with caveats that minimize the goals. Boundary statements about what the report does not do should be separated somehow, as in another paragraph, or section like at the beginning of the Project Background etc. They should be phrased so that they are not limitations on the goals. They should not cast doubt on what was accomplished but tell the reader what was beyond the scope of the project.

Goals are what you did, not what could have been done better that you did not do. Goal statements should be written after the final data results or products have been decided upon after all the data and statistical exploration has been done and you decide which ones you want to include in the Results section. Then goal statements should be written so that a figure and or a table can be used to fulfill it, so that the authors and readers will know which results fulfill each goal statement. That way all results can have a goal statement. And all goal statements can have one or more results.

A report such as this should have three purposes that should also be stated in this section so the reader knows what to expect. First, this report should document the field data collection that was done during this time of monitoring on the river. Ideally, this monitoring has ecologically valid methodology determined before the monitoring started so the data has biological meaning. The second purpose of a report like this is to summarize the results of the monitoring in figures and tables that show what the authors are trying to say. Thirdly, the authors need to make the reader aware, from the beginning, that these summarized results will be used to make determinations about legally binding definitions about the acceptable levels of turbidity that will be placed into EPA rules and regulations. For example, we found this level of turbidity, so therefore, 25% above this number is going to be level we report as the limit of turbidity that will be allowed by law and you will be held to it.

The Executive Summary of the report should be rewritten with this in mind. For example, "the purpose of this report is to summarize the results of river monitoring on the lower Kenai River that was used to make comparisons between areas with heavy boat traffic vs. areas with less or no boat traffic so that turbidity levels could be compared with the intention of determining legal levels of acceptable turbidity so that river managers will have a base level of turbidity to begin the process of managing for turbidity in terms of understanding the impact that boats are having so that biological impacts to the river from turbidity can be minimized". See how the three purposes are stated in a main goal statement. Then in order to accomplish this main goal, other more specific goal statements can be written that each table or figure you want to include will fulfill. This way no result will be a surprise to the reader. Goal statements may be combined but do so after they are written individually so that the authors are clear on how many results fulfill the goal and the goal is written such that the readers know multiple tables or figures will be included in the paper to fulfill it.

Response/Action: *The goals were rewritten for the final report.*

SM *p. 15-16* **1.13.2**. This is a new objective! Where are these methods and results? [referring to "A significant component of this work was to determine how the substrate differences influence differences in turbidity"]

Response/Action: *This was removed from the final report.*

SM *p. 26* **1.13.3.** Is the project objective to establish natural conditions or to compare the methods in the guidance document? Do you think the sampling techniques you used are the right methods for establishing natural conditions?

Response/Action: *Baseline, not natural, conditions were established using the cumulative frequency curve. These were established separately for RM 11.5 and RM 23. These conditions included all natural turbidity as well as any anthropogenic contributions to turbidity.*

AR1 -- **1.13.4.** My recommendation is that the Executive Summary and Methods be rewritten. The Results and Discussion are okay but they need to be made to fit with the goals to see if any results are missing or can be removed. The results surprise the reader because they appear to be random and not fulfilling an objective statement. This can be fixed when the Executive Summary is rewritten with the results in mind.

Response/Action: *This was corrected in the final report.*

SM *p. 5* **1.13.5.** Not a very clearly defined project objective. See comments in the conclusion section. [referring to "The purpose of this study was to begin the process of establishing this background turbidity level."]

Response/Action: *This was corrected in the final report.*

1.14. Turbidity sensor calibration methodology

SM *p. 13* **1.14.1.** Based on the sensor specs, you should have been within 5% for only the 1,000 standard and closer to 1% and 3% for other standards...

Response/Action: *Based on ADEC standards for turbidity monitoring calibrations are required to be within 5% of standards.*

2. COMMENTS ON REPORT ORGANIZATION

Reviewer *Page* *Comment*

2.1. Description of the sampling sites is confusing

AR1 -- **2.1.1.** In the Methods section: in sampling locations, this summary is very confusing, it should be rewritten using the map in study site figure 1, start from one end of your sampling points and go to the other end describing each location, why it was chosen, and how it is similar or different biotically and abiotically from the other sampling sites. Try to distinguish logistic reasons for including sampling points from ecological reasons for including sites, or just state that you used all the river mile markers down river from marker 23. All of your reasons are thrown together in this section without any order.

This section should paint a mental picture of the map and give the reader enough information to determine what is at each sampling point/river mile marker. At this section of the paper, the reader will see, just as you point out, that river mile 23 has no boat traffic and that all the rest do. This is the time to state that ecological assumptions about the sites are not met (i.e., the tidal influence at the mouth of the river, the substrate differences between sites, etc.) but state that you can use legal definitions and fishing use by boats as your reasons for comparing the turbidity at the sites with boats vs. those without boats, in the way that you do.

This report is not about obtaining background natural turbidity but about comparing boat to no boat sites. You have a valid reason to do this so make it clear. Your Discussion section is full of why this study does not meet ecological assumptions so let the reader know early that this is okay for your purposes.

2.2. Necessity of Appendices

AR1	--	**2.2.1.** In the Appendix you do not need to include your blank data sheets or photos of the sites, they do not contribute to the report and are not meaningful to the reader unless you make them into a figure and make them a specific goal and result out of them that you want to show. For example, "RM 11.5 has grassy banks and RM 23 has forested banks (see photos figure 3 or Appendix A).
AR1	--	**2.2.2.** Lastly, I would take a look at this report and ask "can some of this information such as that in the Appendix and Discussion be more properly placed into a field manual"? This report seems to be both a report of this year's accomplishments; plus photos, datasheets, instrument calibration instructions and background information that is more applicable to a field turbidity monitor than to a reader of this report such as a the public, a manager or policy maker who wants the results of this report to help in their river management efforts but does not need to know how you calibrated the instruments.

2.3. Consolidating paragraphs on methods and results

SM	*p. 5*	**2.3.1**. This section has methods and results thrown in – I would delete it here and incorporate into the later sections. [referring to last few paragraphs on p. 5]
DR	*p. 14*	**2.3.2.** This entire "Selection of a reference site..." section would fit better in the Methods.
DR	*p. 4*	**2.3.3**. Much of this History section should be rolled into the Methods. The first paragraph is good introductory material and should remain as part of the Introduction (sans heading, perhaps). Information in the rest of these paragraphs would fit better in the Methods.
SM	*p. 15*	**2.3.4.** A lot of the information in the Discussion section should really be in the result section.

2.4. Add a section discussing recommended next steps

SM	*p. 27*	**2.4.1**. Add a section on recommended next steps. What do you want DEC to do with this info? What is KWF going to do next ?
Response/Action to all section 2 comments:		*The final report included a general reorganization and reformatting. This process addressed the issues stated above.*

3. MINOR COMMENTS REQUESTING CLARIFICATION, CORRECTION OR WRITING IMPROVEMENTS

Reviewer	*Page*	*Comment*
SM	*p. 3*	**3.1**. I'm not used to seeing nearshore environment in this context as it usually refers to a marine or lake habitat. How about near-bank environment?
SM	*p. 3*	**3.2.** From whom? [referring to "Along with its notable fishing opportunity comes concern about the impacts such levels of use may have on the riverine environment"]
SM	*p. 3*	**3.3.** By whom? [referring to "In recent years, more than 700 outboard motorboats have been documented to be in operation at the same time in the lower 50 miles of the river."]
SM	*p. 3*	**3.4.** By whom? The state, borough, private land owners? [referring to "Tens of millions of dollars have been invested in protecting stream banks and providing responsible access to the river."]
SM	*p. 3*	**3.5.** Might include some references as examples. [referring to "Numerous studies have been conducted to evaluate a wide range of natural and anthropogenic impacts in the Kenai River Watershed."]
SM	--	**3.6.** Miscellaneous typo, formatting and grammar corrections (see SM comments).
AR1	--	**3.7**. In the paragraph for Estimation of background turbidity on page 22, there is a repeated phrase, number of number of, delete one. Remember to do a full spelling and grammar checks on the entire document.
AR1	--	**3.8.** The authors should review their technical writing skills. First, this paper could use a good rewriting of most of the sections and the paragraphs within sections. A paragraph should have a topic, or summary sentence, first that tells the reader what the paragraph is about, with no details. Then the paragraph should follow with sentences that make up the data or the specifics that you want to say.

Lastly, there should be a concluding sentence at the end stating the consequences of the points you just told us. Ending with a “Therefore….” sentence is a good wrap up sentence for a paragraph.

Secondly, tables and figures should not start a sentence, such as “Table 11 shows…” (See page 24, second paragraph, Table 11). Table and figure numbers go at the end of sentence to take readers to them to reflect the point that you just made in that sentence. For example, “Comparing the most severe (SEV) events in turbidity between RM 11.5 and 23, the duration is usually similar between the two sites or slightly longer at RM 23, though SEV is generally slightly higher at RM 11.5 (Table11)”.

SM	*p. 4*	**3.9.** Can you be more specific? Road building, logging, residential development? [referring to “Elevated turbidity levels are the reason for most of the miles of EPA-listed impaired rivers and streams in Alaska (USEPA, 2008). The vast majority of these turbidity exceedances are the result of placer mining, with the remainder caused by land- use issues .”]
SM	--	**3.10.** Change shore to bank throughout.
SM	*p. 9-10*	**3.11.** Insert a new column in tables 2 and 3 containing the difference in values between RM 11.5 and RM 23
SM	--	**3.12.** Insert figure and table labels throughout document, see e.g., Figure 2.
SM	*p. 15*	**3.13.** I don’t understand this sentence. [referring to “Further, RM 23 is well qualified as a reference site due to its similarity to the test site in factors pertaining specifically to natural sources of turbidity, such as major tributaries, including Killey River.”]
SM	*p. 15*	**3.14.** Based on actual data or flow contribution? [referring to “The small tributaries between the two sites, including Soldotna Creek and Slikok Creek, are not significant sources of turbidity.”]
SM	*p. 15*	**3.15.** Between banks or between sites? [referring to “Differences do exist in bank morphology and sediment substrate.”]
SM	*p. 17*	**3.16.** A graph of these data would help. [referring to “This pattern can be contrasted with the highest turbidity spikes and steepest rates of increase seen at RM 11.5.”]
SM	*p. 21*	**3.17.** Why are the hydrolabs relevant? [referring to “With this tool, a correction for serial correlation was incorporated because Hydrolabs were used for continuous sampling .
DR	*p. 12*	**3.18.** This paragraph and the following paragraph refer strictly to the July data, right? If so, this should be made clear. [referring to second and third paragraphs of p. 12]

DR	*p. 16*	**3.19.** Consider revising Table 5 to include all of the same column headings in Table 4.
DR	*p. 7*	**3.20.** Consider adding a column to Table 1 that describes when each monitoring site was active.
MAM	--	**3.21.** Figures 4 and 5. These are very illustrative of the near bank processes, but strictly speaking “5 ft. from LB” is not a “Percent”. Change the horizontal axis title to something like “Location across river channel”

Response/Action to all section 3 comments:	*These minor comments were not addressed individually but a general editing of the final report did occur.*

4. OTHER GENERAL FEEDBACK (NO ACTION REQUIRED)

Reviewer	*Page*	*Comment*
DR	*p. 20*	**4.1.** Agreed. The "natural" exceedances when applying the statistical characterization approach are bothersome.
DR	*p. 16*	**4.2.** This is some pretty convincing evidence. [referring to figures showing variation in turbidity during typical weeks]
DR	--	**4.3.** I’d like to commend the authors at Kenai Watershed Forum for a report that is well written and easy to follow. Additionally, the authors did a good job of pointing out uncertainties and shortcomings in the methods and data.
RW	--	**4.4.** This report is very well written and concise. The study was ground breaking in several aspects: * Multiple years of ‘in-river’ measurements at the same locations * Multiple measurement points for each one of the measurement years * Standardized measurement units * Standardized instrumentation for all measurement years * Impeccable data analysis
DR	--	**4.5.** Drawing from a 3-year data set, the authors convincingly use multiple analyses to link increased near-shore turbidity in the lower Kenai River to power boat activity. Regardless of how the data are analyzed, it is clear that periodic exceedance of state water quality standards can be attributed to power boats. These exceedances

consist of episodic spikes in turbidity associated with periods of heavy fishing activity that attenuate relatively quickly after fishing activity ceases.

RW -- **4.6.** The data gathered to date and discussed in this report provides an excellent spring board for additional data collection and river study. The design and implementation of this study could benefit from a team based approach using resources from both within and outside of the Kenai Watershed Forum. In order to obtain more complete river profiling and understanding of natural turbidity levels, additional areas of investigation should include:

1) River traffic counts by RM, date, time, and boat horsepower.

2) Turbidity particle studies including size, type, size distribution, suspension and settling characteristics, organic / inorganic content, for each RM and throughout the study period.

3) River tidal mapping including flow profile, mixing zones and turbidity influences.

4) River flow rates and flow profiles at the mapping locations.

5) Bottom mapping at the measurement locations for profile and structure.

6) Continue with turbidity measurement rates at the previously utilized RM locations while attempting to measure over a longer period of time.

MAM -- **4.7**. In conclusion, I agree that RM23 is a reasonable proxy to characterize natural turbidity levels, to which RM 11.5 can be compared. The turbidity data show significant differences in turbidity values between the two sites. The rate of change of turbidity increases is an interesting aspect to explore (in addition to magnitude of turbidity) as acclimation to changing turbidity levels has been raised as a concern in other fish studies. Including discharge information would be a useful addition to the analysis. You truthfully acknowledge that “We cannot quantify any ill effects on the biota at this time…” (P. 26). At this point, that is true, and I hope that the readership does not extrapolate the results of the study outside of the bounds of the study (but it’s a good argument for further monitoring!). I hope more monitoring can be funded because this is an interesting question to investigate.