Category 5/ Section 303(d) List Waterbody Determination

Kenai River Turbidity

June 21, 2017

Revised November 2, 2018

Contents

Category 5/ Section 303(d) List Waterbody Determination

Waterbody Name: Kenai River, Kenai Peninsula Borough

Final Action: Retaining eight miles of the Lower Kenai River on the Category 5/303(d) list in the 2014/2016 Integrated Report in Category 3 (insufficient information) for Turbidity for Fresh Water Uses.

The lower 7.5 miles of Kenai River is not included on the 303(d) list for turbidity in the 2014-16 Integrated Report. Although turbidity met the listing threshold based on an assessment of turbidity monitoring conducted in July 2008, 2009, and 2010, public comment and further investigation indicated that conditions in the Kenai River and boating behavior have changed substantially since 2010. The Kenai River turbidity listing was publically noticed as part of the draft Integrated Report in December 2017. Public comments were in opposition and support of the listing. Opposition statements indicated that motorized boating use and patterns have changed since data collection. In response to those comments, ADEC contracted to conduct limited turbidity monitoring in July 2018 (previous data indicates the impairment occurs only in July) and delayed the submittal of the 2014-16 Integrated Report until the monitoring results were analyzed. Analysis of the 2018 turbidity data was unable to confirm the previous impairment nor does the study indicate attainment of the turbidity criteria in the lower Kenai River due to changes in the fishery and boat use patterns.

Therefore, the final Report leaves the Kenai River in Category 3 (insufficient information) for turbidity until further information becomes available to reassess the current condition of the river. ADEC will work with local stakeholders to create a prioritized watershed plan to address potential water quality issues affecting the Kenai River.

Location: The Kenai River is a large proglacial river draining 2,200 square miles of the Kenai Mountains and Kenai Peninsula lowlands in south-central Alaska. The Kenai River is located approximately 150 miles south of Anchorage, with headwaters at Kenai Lake in Cooper Landing. The Kenai River has a course of 82 miles, emptying into Cook Inlet near the town of Kenai. Figures 1 and 2 show the location of the Kenai River in relation to the State of Alaska and jurisdictional authorities.

Area of Impairment: Warren Ames Memorial Bridge at River Mile (RM) 5 to RM 12.5 (Figure 3).

Latitude/Longitude: 60.5268442˚N; -151.209041˚W to 60.5344050˚N; -151.094262˚W

Time of Impairment: July, coinciding with the red (Sockeye) salmon fishery, when motorized boats are present.

Water Quality Standards not being met: 18 AAC 70.020(b) (12); Turbidity, for Fresh Water Uses. Water Quality Standards are not met for the Drinking Water Supply, Contact Recreation and Secondary Recreation uses (Table 1).

Pollutant Parameter: Turbidity– measured in nephelometric turbidity units (NTU).

Impairment Source: Motorized boat activity.

Turbidity Listing Methodology [*Listing Methodology for Determining Water Quality Impairments from Turbidity* (ADEC, 2016)]. The waterbody is impaired (Category 5) if it meets the following thresholds:

- the 24-hour (daily) average of turbidity in the waterbody (duration threshold)
- shall not exceed 5 NTUs over natural conditions (magnitude threshold)[1]
- during more than 10% of the days measured (frequency threshold).

[1] For values natural condition values less than 50 NTU; for natural condition over 50 NTU less than a 10% increase not to exceed 15 NTU.

Table 1. Alaska fresh water quality criteria for turbidity (18 AAC 70.020 (b) (12)).

(12) TURBIDITY, FOR FRESH WATER USES (criteria are not applicable to groundwater)	
(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 (12)(A)(iii).

1 Listing Methodology

ADEC developed the *Listing Methodology for Determining Water Quality Impairments from Turbidity* (ADEC, 2016). The document provides guidance on data requirements and statistical tools to use in evaluating turbidity monitoring results for determining the magnitude, duration, and frequency of turbidity pollution that may impair designated water uses protected by the Clean Water Act.

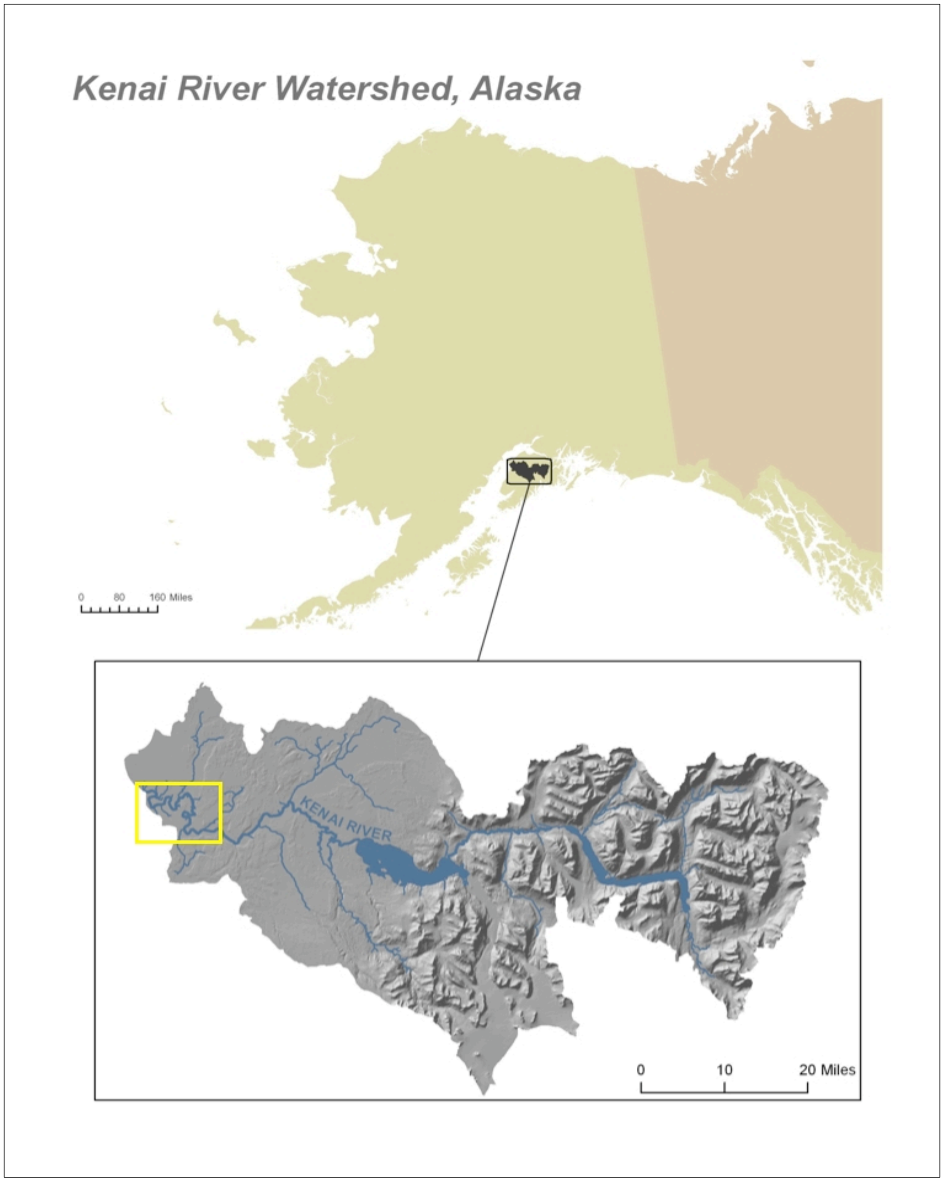


Figure 1. Location of the Kenai River Watershed in Southcentral Alaska with the yellow rectangle identifying the area of concern.

2 Background

2.1 Location, Governance and Use

The Kenai River drains a large section of the Kenai Peninsula, with a course extending for 82 miles. Headwaters of the Kenai River are lakes formed from accumulations of glacial meltwater in the Kenai Mountains, a section of the Chugach Mountain Range. The Kenai River provides habitat for multiple species of fish, including five species of Pacific salmon and the river is a world-famous salmon fishing destination, as evidenced by a number of trophy catches, including a world record 97 lb 4 oz king (Chinook) salmon, caught in 1985. The Kenai River commercial fishery contributes significant portion of the commercial red (Sockeye) salmon harvest in Alaska. In addition to salmon, the Kenai River supports at least eleven other fish species, including rainbow trout and Dolly Varden and the Kenai River watershed provides important habitat for many species of birds and animals. The Kenai River and its tributaries are also a critical stopover point for migratory birds in the spring and fall.

More than half of Alaska's population live within a three and a half hour drive of the Kenai River. Most of the river is accessible by the road system. As such, the river is actively used by the public for non-contact (e.g., boating, wading, recreational fishing) recreation. The river receives some of the most concentrated motorized boat traffic in the state. Although fishing practices have changed over the years (e.g., the king salmon fishery was closed for several years in July, but has recently been reinstated while the red (Sockeye) salmon fishery increased in popularity during the same month), overall motorized boat activity has continued to be prevalent.

The Kenai River flows through portions of the Kenai National Wildlife Refuge, the Kenai State Park and the Kenai Special Management Area (KRSMA) (Figure 2).

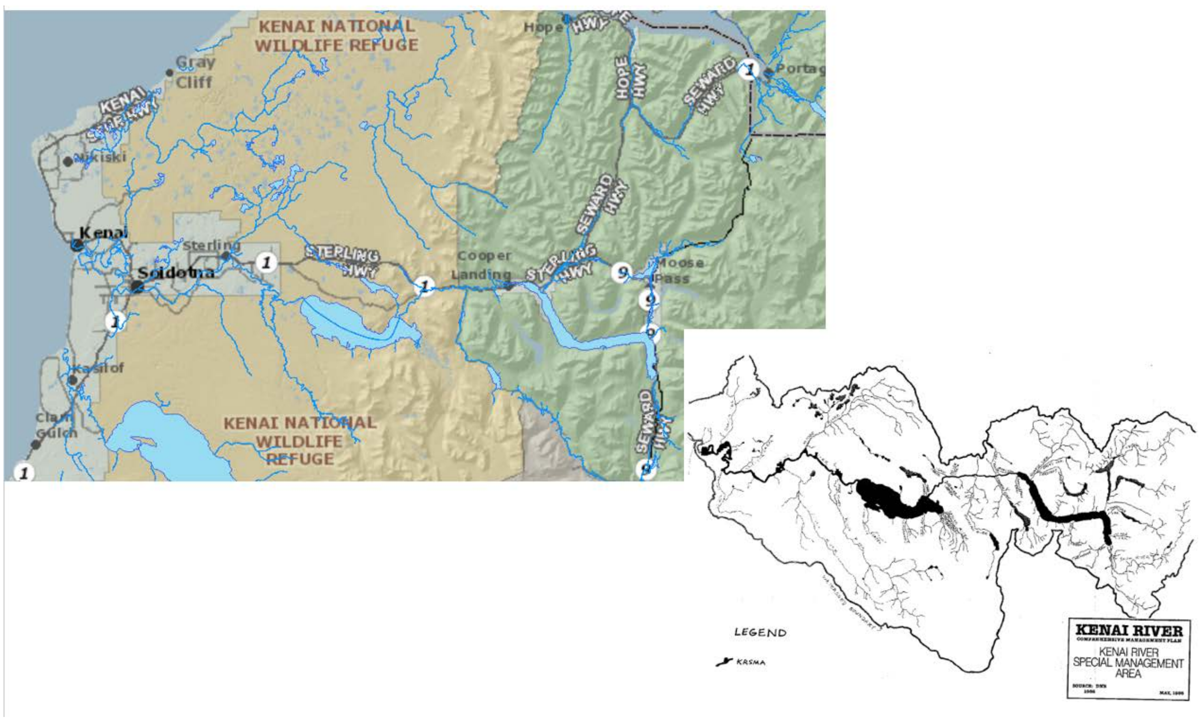


Figure 2. Spatial relationship of KRSMA to the Kenai Peninsula Borough's geographic features.

The KRSMA was established in 1984 by the Alaska Legislature, as a unit of the state park system, in response to the increasing public use and strain on the health of the Kenai River, including rapid growth in the river's sport fishery, the emergence of the sport fish guiding industry, and settlement of the shoreline of the river. The KRSMA consists of more than 105 miles of rivers and lakes and extends along the reach of the main stem of the Kenai River from River Mile (RM) 82 to four miles above the outlet of the Kenai River into Cook Inlet (RM 4). The KRSMA Advisory Board (Board) makes recommendations to the Department of Natural Resources about KRSMA. The Board was originally created in 1985 under the authority of A.S. 41.21.510 in order to develop a comprehensive management plan for the Kenai River and was dismissed in 1986, after the comprehensive management plan was finalized. In 1988, another KRSMA Board was convened with new members and tasked with addressing a broad spectrum of interests concerned with Kenai River habitat, fish and wildlife resources and recreation. The section of the Lower Kenai River that is proposed to be impaired by turbidity caused by motorized boat activity is within the KRSMA boundaries and is one of the items of interest to the Board.

The Kenai River is of great cultural and economic importance to Alaska. A 1994 study (Liepitz, 1994) concluded that the Kenai River generated as much as $78 million annually in direct benefits to the local economy. This is probably a conservative estimate of the importance of the Kenai River to the local economy in 2017. The Kenai River is perhaps Alaska's most famous fishing river.

2.1.1. Fishing Closures on Mondays on the Kenai River

In the early 1980s concern about the future productivity of the Kenai River and growing conflicts between users precipitated public demand for reallocation of fishing opportunity, protection of the river, and regulation for some activities. One of the actions that was taken was to address concerns regarding motorized boating activity. A brief chronology of the motorized boating activity restrictions on Mondays is listed below:

- The Kenai River was closed to all fishing on Mondays in July after July 5, beginning in 1983.
- In 1986, the restriction of closure to all fishing on Mondays was expanded to May, June, and July.
- In 1999, the Alaska Board of Fish relaxed the regulations in effect to allow a non-guided, drift-only fishery on Mondays in July.
- In 2003, non-guided drift-boat fishing on Mondays was expanded to May, June and July.

The fishing closures and drift-boat–only regulations reduced the number of powerboat trips on the Kenai River on the Mondays when the regulations were in effect.

2.2 Previous Studies

A number of studies on suspended sediment and turbidity have been conducted. These include:

- US Geological Survey (Dorava and Moore, USGS, 1997). Effects of boat wakes on streambank erosion, Kenai River, Alaska. This study correlated areas of stream bank erosion of the Kenai River with high levels of motorized boat activity.
- US Army Corps of Engineers (Maynord, et al, ACoE, 2008). Boat-wave-induced bank erosion on the Kenai River, Alaska. These field studies were conducted in order to establish a link between the effect of boat wakes on bank erosion in the Lower Kenai River that concluded, "in areas of high boat traffic, such as that observed between RM 10 and 12, boat

wakes are estimated to contribute the majority of computed shoreline streamflow energy during a 30-minute high-traffic window."

- Kenai Watershed Forum (KWF, unpublished data). KWF collected turbidity data from RM 8.5 in 2007 that raised questions about turbidity levels and motorized boating activity. Analysis of the 2007 turbidity data showed turbidity pattern differences between Mondays and other days of the week (non-Mondays). The fisheries managers had previously closed fishing for king salmon from motorized boats on Mondays in July. The significance of the finding of turbidity pattern differences between Mondays and non-Mondays provided support for conducting a more comprehensive turbidity study to investigate a direct link between motorized boat activity and episodes of elevated turbidity.

3 Study Design for Waterbody Turbidity Assessment, 2008-2010

From 2008-2010 KWF monitored turbidity at several sites. The objectives of the assessment of the lower Kenai River were to (1) observe and determine key characteristics of turbidity (2) collect relevant data to define baseline conditions and (3) analyze how often the river exceeded water quality standards for turbidity (Table 1). The results were published in July 2012 in a peer-reviewed report, "*Turbidity Monitoring on the Lower Kenai River, 2008-2010*" (KWF, 2012) and are being used for this waterbody determination. Figure 3 shows the study area.

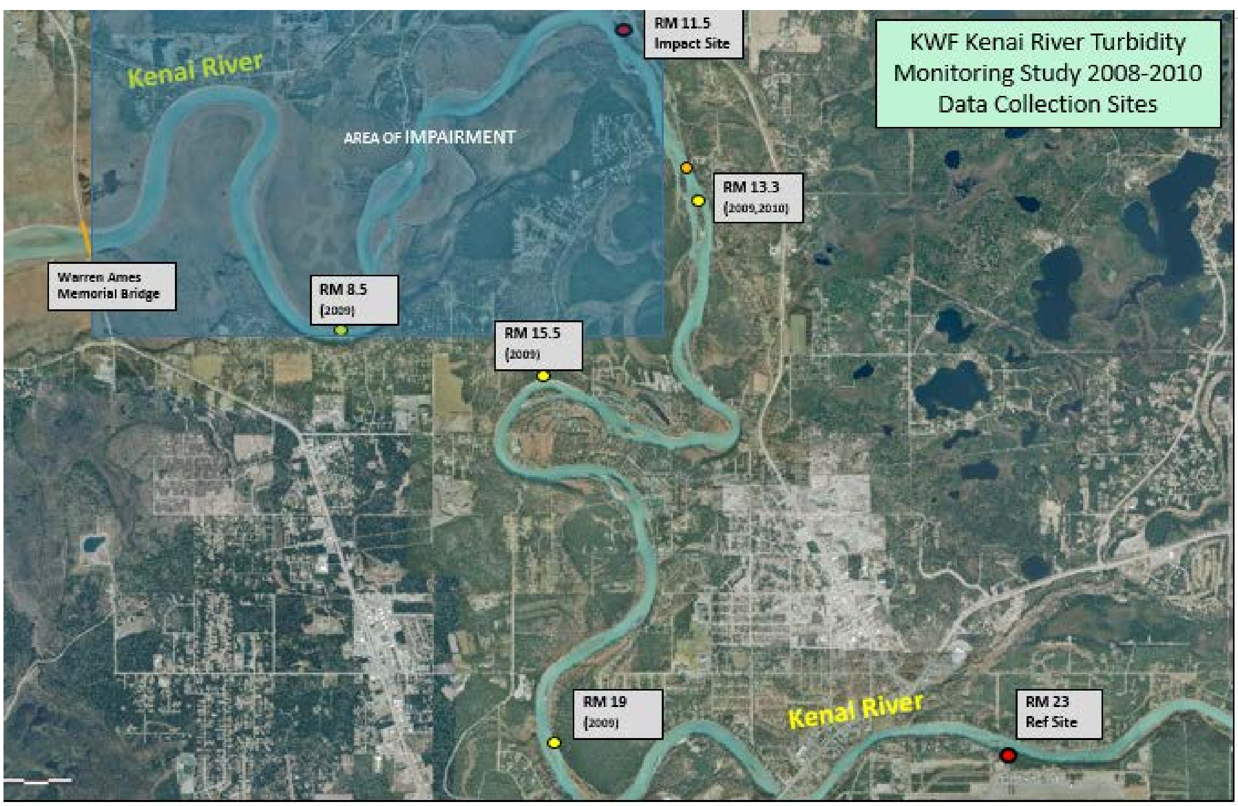


Figure 3. Locations of turbidity sample sites showing criteria location (natural condition at RM 23) and impacted site (RM 11.5).

The upstream/downstream (concurrent measurement) approach using a reference or natural condition site was used for this determination. This approach is the recommended method in both the *Guidance for Implementation of Natural Condition-Based Water Quality Standards* (ADEC, 2006) and the *Listing Methodology for Determining Water Quality Impairments from Turbidity* (ADEC, 2016). Sampling was conducted in accordance with the Quality Assurance Project Plan (QAPP) (Martin and others, 2009) and sample data met the data quality objectives prescribed in the QAPP.

3.1 Site Selection

The sampling site at RM 23, at the Kenai River Center, was chosen as a natural conditions site in 2008, because the site does not receive heavy boat traffic, has comparable biologic and hydrologic conditions, and although it is outside the tidally-influenced zone, is in relative geographical proximity to the suspected sites of impairment by turbidity caused by boat activity on the lower section of the Kenai River. Additionally, RM 23 is considered to represent natural conditions on the lower river. The site at RM 11.5 was chosen as the monitoring site impacted by human activity (See Appendix A). RM 11.5 is at the upstream edge of the tidally influenced area of the Kenai River, but tides are not a significant contributor to turbidity at this site (see Appendix B).

Table 2 provides information on all sampling locations including month/year sampled and reason for selection: Monitoring locations included:

(A) Fixed Monitoring Stations (FMS) were established to record turbidity data every 15 minutes throughout the study period each year.
(B) Roving Monitoring Stations (RMS) captured additional information at fixed locations or monitored additional locations.

In addition, point sampling across river transects, monitoring turbidity at both FMS locations and active Roving Monitoring Stations (RMS) was conducted. Station inspections were coupled with cross-sectional transect monitoring.

Table 2. Summary of information about sampling locations in KWF (2012).

Sampling Location	Year/Month Sampled	Reason for Selection	Sampling Design Component	Comments
RM 23	2008 May 16-Aug 24 2009 May 19 - Aug 31 2010 June 30-Aug 5	• Does not receive heavy boat traffic • Represents natural conditions on lower river • Turbidity pattern similar to RM 11.5 • Poorly sorted cobble and gravel with minor amounts of sand and silt in the interstices	2008 – FMS 2009 – FMS 2010 - FMS	• Range of turbidity measurements: 2.7-99.9 NTU • No observed influence of boat traffic
RM 19	2009 July	• Chosen as screening site to see if turbidity pattern was similar to RM 23 or RM 11.5	2009 – RMS (short period)	• Data was collected at RM 19 because the site has moderate boat traffic
RM 15.5	2009 July - Sept	• Chosen as screening site to see if turbidity pattern was similar to RM 23 or RM 11.5	2009 – RMS (intermittent)	• Turbidity spikes similar to those observed at RM 11.5 during July 22, 2009 melt event
RM 12.6 & RM 13.3	2009 (RM 12.6) June 30 –Sept 1 2010 June 30-July 27	• Receives heavy boat traffic • Is in close proximity to RM 11.5 • Has gravel substrate	2009 – RMS (intermittent) 2010 – FMS (short period)	• Left bank (downstream view) chosen to reduce interference with boat traffic and fishing
RM 11.5	2008 May 16-Aug 24 2009 May 19 to Aug 31 2010 June 30-August 5	• One of busiest locations • Has fine substrate and bank composition • Tidally-influenced • Moderately sorted gravel overlain with well-sorted, fine grained sand and silts • ACoE 2007 boat wake study location	2008 – FMS 2009 – FMS 2010 - FMS	• Range of turbidity measurements: 1.9-300 NTU • Turbidity profile varied; on non-Mondays, turbidity nearshore increased from average of 49 NTU to 136 NTU
RM 8.5	2009 June 29-Aug 25	• Chosen as screening site to see if turbidity pattern was similar to RM 23 or RM 11.5 • Location also monitored in 2007	2009 – RMS	Riverbank material finer than that at RM 23; similar to RM 11.5, the average turbidity on non-Mondays was about 40% higher than on Mondays

3.2 Data Selection for Impairment Determination

Data collected during the month of July at the designated natural conditions site (RM 23) and the designated impacted site (RM 11.5), corresponding to the highest boat traffic time period during the king (Chinook) and red (Sockeye) salmon fisheries, were used. Both sites were continuously monitored for all three years of data collection meeting the minimum assessment period of two years in the listing methodology (ADEC, 2016).

3.2.1 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 determining outliers for a particular site varied depending on whether turbidity levels were generally constant or spikes were common. The occurrence of outliers is believed to be predominately due to grass or debris entering the sensor guard cup. While a guard cup protects the turbidity sensors from damage by strong water flow and large debris, smaller debris can become trapped in the sensor cup. Trapped debris may dramatically alter localized turbidity readings at the sensor relative to that of the surrounding river water (KWF, 2012).

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
- had 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
- Data values above 300 NTU

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 (KWF, 2012).

4 Listing Determination Analysis

Findings are presented using the guidance provided in the *Listing Methodology for Determining Water Quality Impairments from Turbidity* (ADEC, 2016). Per guidance, the 24-hour or daily average is based on the average of turbidity readings taken once every 15 minutes over 24 hours (96 individual data points per daily average). The guidance also requires tidal influence be taken into consideration, if applicable. Appendix B provides an analysis of tidal influence as a part of an overall source assessment.

4.1 Data Evaluation

4.1.1 Magnitude and Duration of Exceedances

For most samples, the data were used to calculate the percentages of samples above the water quality criteria of 5, 10, and 25 NTU above natural conditions. For data values above 50 NTU at the natural conditions site (RM 23), the exceedance threshold for the impacted site was determined to be 10% or higher than the natural conditions site consistent with the water quality criteria (Table 1).

For turbidity values less than 50 NTU, the most stringent criterion is calculated by adding 5 NTU to the 24-hour daily average. Two time series of daily averages – one for the most stringent criterion and one for the impacted site - collected during July 2008, 2009, and 2010 are shown in Figures 4, 5, and 6, respectively. The figures illustrate the criteria (natural conditions site: RM 23 + 5 NTU) and the impacted site (RM 11.5). Data are displayed in series, in chronologic order, trending left to right. Daily average turbidity values for criteria are shown in blue-colored columns, one average for each day. Daily average turbidity values for the impacted site (RM 11.5) logged on the same days are displayed in red-colored columns. Mondays are indicated with green colored arrows.

The turbidity pattern shown in Figures 4-6 illustrate increases in the criteria site that are generally reflected in corresponding increases at the impacted site. However, higher overall daily average turbidity values at the impacted site can be regularly observed.

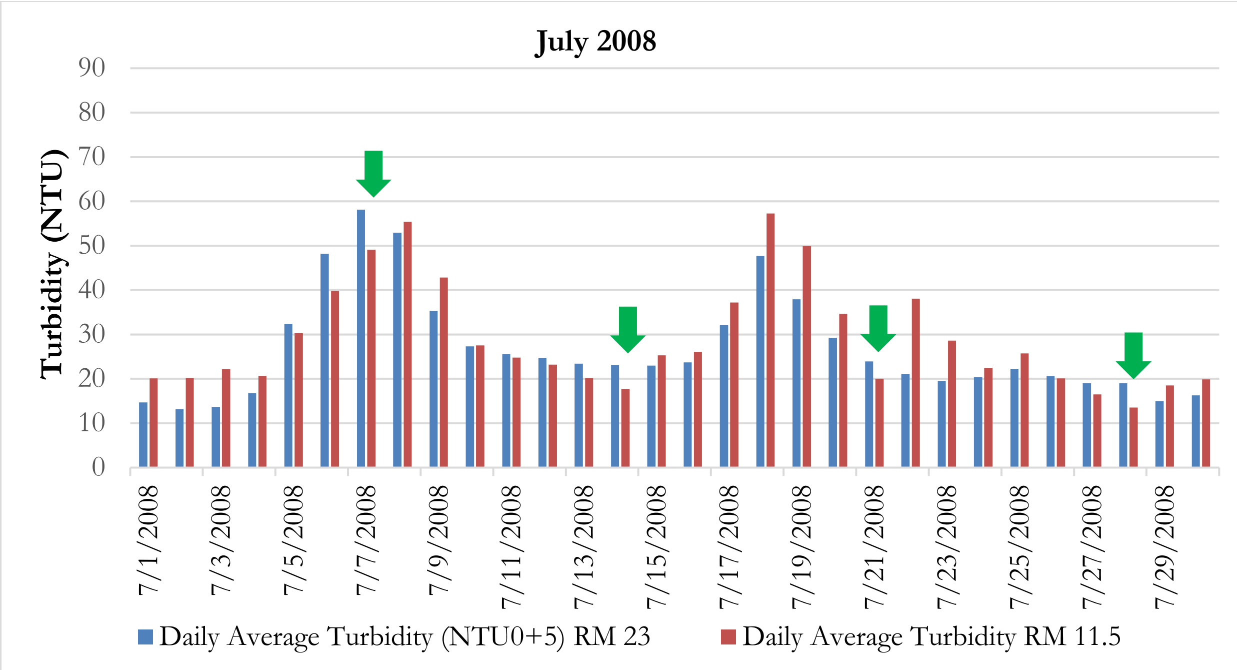


Figure 4. Time series plot of the criteria (daily average turbidity at the natural conditions site: RM 23 + 5 NTU) and at the impacted site (RM 11.5) for the month of July, 2008. Green arrows indicate Mondays (fishing using motorized boat activity prohibited).

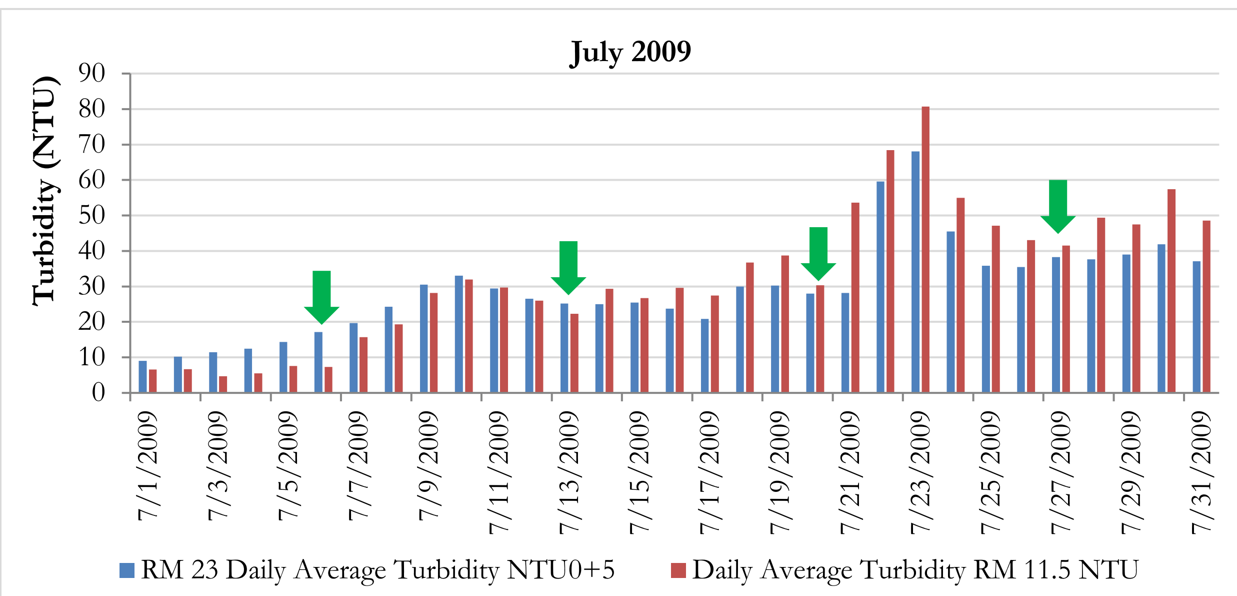


Figure 5. Time series plot of criteria (daily average turbidity at the natural conditions site: RM 23 + 5 NTU) and at the impacted site (RM 11.5) for the month of July, 2009. Green arrows indicate Mondays (motorized boat activity prohibited).

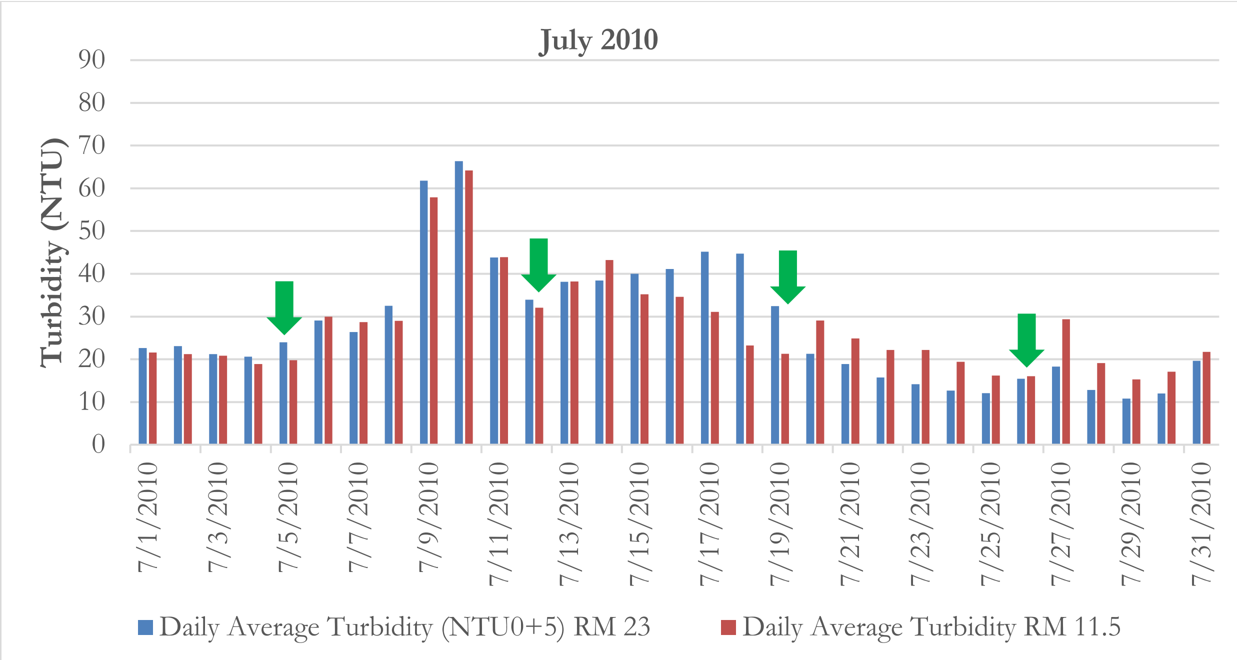


Figure 6. Time series plot of criteria (daily average at the natural conditions site: RM 23 + 5 NTU) and at the impacted site (RM 11.5) for the month of July, 2010. Green arrows indicate Mondays (motorized boat activity prohibited).

4.1.2 Raw Exceedance Frequency

The raw exceedance frequency is calculated by comparing the 24-hour (daily) averages of the impacted dataset to the 24-hour (daily) averages of the natural conditions dataset. If the daily average values at the impacted site exceeds the daily average values at the natural conditions by +5 NTU (the magnitude threshold) then it is counted as a raw exceedance for turbidity values less than 50 NTU. When the daily average of the natural conditions site (RM 23) exceeds 50 NTU, the value of the daily average of the impacted site (RM 11.5) must be greater than 10% of the daily average of the natural conditions site to count as an exceedance. Table 3 presents the raw exceedance frequency for July of the combined years, 2008-2010. Red font indicates an exceedance of the 10% frequency threshold for impairment. Analysis of the individual year's data show similar raw exceedance frequencies (e.g., Drinking Water/Contact Recreation range: 55-60%; Secondary Recreation range: 26-35%).

Table 3. Summary of raw exceedance frequencies at the impacted site (RM 11.5) for the month of July in 2008, 2009, and 2010, using daily averages.

	Drinking water, contact recreation (natural conditions + 5 NTU)	Secondary recreation (natural conditions + 10 NTU)	Growth and propagation of fish, shellfish, other aquatic life and wildlife (natural conditions + 25 NTU)
Total exceedances	52	29	3
Total samples (24-hour averages)	92	92	92
Raw exceedance frequency	**57%**	**32%**	**3%**

4.2 Binomial Statistical Test

The turbidity listing methodology (ADEC, 2016) recommends conducting a binomial statistical test for making an impairment determination for concurrent (i.e., temporally paired) datasets such as the upstream/downstream approach used on the lower Kenai River. The binomial test is a non-parametric method for characterizing the probability of proportions. In the case of turbidity, the test is used to determine if the turbidity criterion, based on natural conditions plus 5 NTU, is exceeded more than 10% of the time (critical impairment threshold) or less than 10% of the time (critical attainment threshold). Additional detail and discussion of the binomial test is provided by the U.S. Environmental Protection Agency (EPA) *Consolidated Assessment and Listing Methodology* (CALM) (USEPA, 2002).

The 2008 Lower Kenai River daily average turbidity criterion (NTU_{0+5}) was exceeded at the impacted site on 18 of 30 days, resulting in a raw exceedance frequency of 60%. For 2009, the daily average turbidity criterion (NTU_{0+5}) was exceeded at the impacted site on 17 of 31 days, resulting in a raw exceedance frequency of 55%. For 2010, the daily average turbidity criterion (NTU_{0+5}) was exceeded at the impacted site on 17 of 31 days, resulting in a raw exceedance frequency of 55%.

Because the raw frequency magnitude on the lower Kenai River data exceeded 10% (Table 3) a binomial test for significance was conducted. The binomial test is performed on downstream impacted site data from criteria determined by upstream samples representing the natural conditions site.

Tables 4, 5, and 6 present the results of the binomial statistical significance test for contact recreation (NTU +5), secondary recreation (NTU +10) and aquatic life (NTU +25), respectively. The tables provide information on the inputs, outputs, and test outcomes.

Table 4. Drinking Water and Contact Recreation ($NTU_{0+5 \text{ or } >10\% \text{ for values } >50 \text{ NTU}}$) Binomial Determination.

Metric or Parameter	Value
Target Type 1 Error [α_t]	0.2
Allowed Exceedance Frequency [p_a]	10%
Total Exceedances [r]	52
Total Trials [n]	92
Raw Exceedance Frequency [r/n]	57%
Minimum Exceedance to Impair	13
Minimum Frequency to Impair	14%
Binomial Test Statistic (P)	0.000
Is Water Impaired?	**Yes**

**For impairment determination:

Null Hypothesis: Exceedance Frequency ≤ 10% (not impaired)

Alternate Hypothesis: Exceedance Frequency > 10% (impaired)

Table 5. Secondary Recreation ($NTU_{0+10 \text{ or } >10\% \text{ for values } >50 \text{ NTU}}$) Binomial Determination.

Metric or Parameter	Value
Target Type 1 Error [α_t]	0.2
Allowed Exceedance Frequency [p_a]	10%
Total Exceedances [r]	29
Total Trials [n]	92
Raw Exceedance Frequency [r/n]	32%
Minimum Exceedance to Impair	13
Minimum Frequency to Impair	14%
Binomial Test Statistic (P)	0.000
Is Water Impaired?	**Yes**

Table 6. Growth and Propagation of Fish, Shellfish, Other Aquatic Life and Wildlife ($NTU_{0+25 \text{ or } >10\% \text{ for values } >50 \text{ NTU}}$) Binomial Determination.

Metric or Parameter	Value
Target Type 1 Error [α_t]	0.1
Allowed Exceedance Frequency [p_a]	10%
Total Exceedances [r]	3
Total Trials [n]	92
Raw Exceedance Frequency [r/n]	3%
Minimum Exceedance to Impair	14
Minimum Frequency to Impair	15%
Binomial Test Statistic (P)	0.985
Is Water Impaired?	**No**

4.2.1 Binomial Test Outcome

The analyses shows the 24-hour (daily) average criterion is exceeded more than 10% of the time for contact and non-contact recreation, with low type 1 and type 2 error. The alternative hypothesis is supported, i.e. the water is impaired. The 24-hour hour (daily) average criterion is not exceeded more than 10% of the time for aquatic life.

4.3 Area of Impairment

The impairment area is from the Warren Ames Memorial Bridge (River Mile [RM] 5.0) to RM 12.5 during the month of July coinciding with the red (Sockeye) salmon fishery. The downstream boundary of the impairment area was set at the bridge as a visible landmark that is relatively close to the point where the river becomes estuarine, i.e., a salt water system, and the freshwater turbidity standards are no longer applicable. Conductivity readings indicate that salt water does not reach upstream of the bridge crossing. Heavy boat traffic extends upstream of the impacted site, RM 11.5 to RM 13.5. The upstream extent of the impairment area is set at approximately RM 12.5.

4.4 Impairment Source

The primary pollutant source is motorized boats based on the source assessment in Appendix B.

5 Conclusion

Turbidity exceedances in the lower Kenai River are persistent and meet the thresholds for impairment. The 24-hour (daily) average of turbidity in the waterbody (duration threshold) exceed the most stringent turbidity criterion of 5 NTUs over natural condition (magnitude threshold) in more than 10% of the samples measured (frequency threshold). The analysis in this listing determination and the information contained in *Turbidity Monitoring on the Lower Kenai River, 2008-*

2010 final report (KWF, 2012) support the conclusion. The impaired uses are Drinking Water Supply, Contact Recreation, and Secondary Recreation.

After public comment, ADEC contracted to conduct limited turbidity monitoring in July, 2018 (previous data indicates the impairment occurs only in July) and delayed the submittal of the 2014-16 Integrated Report until the monitoring results were analyzed. Analysis of the 2018 turbidity data was unable to confirm the previous impairment nor does the study indicate attainment of the turbidity criteria in the lower Kenai River due to changes in the fishery and boat use patterns.

Therefore, the final 2014/2016 Integrated Report leaves the Kenai River in Category 3 (insufficient information) for turbidity until further information becomes available to reassess the current condition of the river.

6.0 References

ADEC. 2012. Title 18 Alaska Administrative Code Chapter 70, Water Quality Standards. As amended through April 12, 2012.

ADEC. 2006**.** Guidance for Implementation of Natural Condition-Based Water Quality Standards. ADEC, Division of Water.

ADEC. 2006. Alaska Natural Condition Tool Continuous. ADEC, Division of Water.

ADEC. 2016. Listing Methodology for Determining Water Quality Impairments from Turbidity Guidance. ADEC, Division of Water.

Bruton, M.N. 1985, 'The effects of suspensoids on fish', Hydrobiologia, vol. 125, pp. 221–241.

City of Soldotna (Soldotna). 2008. Discharge Monitoring Report for July 2008 Permit No. AK-002003-6.

City of Soldotna (Soldotna). 2009. Discharge Monitoring Report for July 2009 Permit No. AK-002003-6.

City of Soldotna (Soldotna). 2010. Discharge Monitoring Report for July 2010 Permit No. AK-002003-6.

CMOP internet link, accessed 03/2017. http://www.stccmop.org/. Center for Coastal Margin Observation and Prediction.

Cragg B. A., Fry J. C., Bacchus Z. and S. Thurley. 1980. The aquatic vegetation of Llangorse Lake, Wales. Aquat. Bot. 8, 187-196.

Dorava, J. M. and Moore, G. W. 1997. Effects of boatwakes on streambank erosion Kenai River, Alaska, USGS Water-Resources Investigations Report 97-4105.

Fallen W. 1985. Effects of power boating upon a water storage. In: Report on the 11th Seminar for Swimming Pool, Water Supply and Sewerage System Operators, pp. 1-4. Department of Local Government, Brisbane.

Garman D. E. J. & Geering D. 1985a. Recreational use of urban water storages and their environs: environmental issues - 1. An analysis. Aust. Parks Recr. 21, 17-20.

Garrad P. N. & Hey R. D. 1988. The effect of boat traffic on river regime. In: International Conference on River Regime (ed. W. R. White) pp. 395-409. Wiley & Sons, Chichester.

Hilton J. & Phillips G. L. 1982. The effect of boat activity on turbidity in a shallow broadland river. J. Appl. Ecol. 19, 143-150.

Horsfall L., Jelinek A. & Timms B. 1988. The influence of recreation, mainly power boating, on the ecology of the Thirlmere Lakes, N.S.W., Australia. Verh. Internat. Verein. Limnol. 23, 580-587.

King, M. A. & Hansen, P. A. 2015. Assessment of shore angling impacts to Kenai River riparian habits, 2001. Fishery Data Series No. 15-34, Alaska Department of Fish and Game.

King, R. S, Walker, C. M., et al. "Catchment topography and wetland geomorphology drive macroinvertebrate community structure and juvenile salmonid distributions in south-central Alaska headwater streams," *Freshwater Science* 31, no. 2 (June 2012): 341-364.Kirk J. T. O. 1985. Effects of suspensoids (turbidity) on penetration of solar radiation in aquatic ecosystems. Hydrobiologia 125, 195-208.

Kuss F., Graefe A. & Vaske J. 1990. Visitor Impact Management. Vol. I. National Parks and Conservation Association, Washington.

KWF. 2012. *Turbidity Monitoring on the Lower Kenai River, 2008-2010,* prepared for ADEC.

Liddle M. J. & Scorgie H. R. A. (1980) The effects of recreation on freshwater plants and animals: a review. Biol. Conserv. 17, 183-206.

Alaska Department of Natural Resources (ADNR). 1986. Kenai River Comprehensive Management Plan.

Cook Inletkeeper, Alaska Tide Tables, 2008, 2009, 2010.

Liepitz, Gary S. 1994. *Final Report: An Assessment of the Cumulative Impacts of Development and Human Uses on Fish Habitat in the Kenai River.* Vol. 94. No. 6. Alaska Department of Fish and Game, Habitat and Restoration Division,

Martin, M., Charbonnet, J, Jones, E.,Czarnezki, J., Ruffner, R. June. 2009. *Kenai River Turbidity Monitoring Quality Assurance Project Plan* for the Alaska Department of Environmental Conservation. Kenai Watershed Forum, Soldotna, AK.

Martin, M., Charbonnet, J, Jones, E.,Czarnezki, J., Ruffner, R. July. 2011. *Turbidity Monitoring on the Lower Kenai River, 2008-2010*. Approved by the Alaska Department of Environmental Conservation. Kenai Watershed Forum, Soldotna, AK.

Maynord, S.T., Biedenharn D.S., Fischenich, C.J., and Zufelt, E. March 2008. *Boat-Wake-Induced Bank Erosion on the Kenai River, Alaska*. ERDC TR-08-5. US Army Corps of Engineers. Prepared for Kenatize Indian Tribe.

Mosisch, T. D. and A.H. Arthington. 1998. A review of literature examining the effects of water-based, powered recreational activities on lakes and rivers. Lakes and Reservoirs: Research and Management 3: 1-17.

Moss B. 1977. Conservation problems in the Norfolk Broads and rivers of East Anglia, England - phytoplankton, boats and the causes of turbidity. Biol. Conserv. 12, 95-114.

Murphy K., Willby N. J. & Eaton J. W. 1995. Ecological impacts and management of boat traffic on navigable inland waterways. In: The Ecological Basis for River Management (eds D. M. Harper & A. J. D. Ferguson) pp. 427-442. John Wiley & Sons Ltd, Chichester.

Orejuela, E. G. July 2015. *Water Quality Assessment of the Kenai River Watershed from July 2000 to July 2014*. Approved by the Alaska Department of Environmental Conservation. Kenai Watershed Forum, Soldotna, AK.

Pressey R. L. & Harris J. H. 1988. Wetlands of New South Wales. In: The Conservation of Australian Wetlands (eds A. J. McComb & P. S. Lake) pp. 35-57. Surrey Beatty & Sons, Sydney.

Ruffner, R. A. 2009. Lower Kenai River Boat Counts: To Augment Petroleum Hydrocarbon Pollution Sampling. Approved by the Alaska Department of Environmental Conservation. Kenai Watershed Forum, Soldotna, AK.

Scott, K.M. 1982. Erosion and sedimentation in the Kenai River, Alaska: U.S. Geological Survey Professional Paper 1235, 35 p.

Smart M. M., Rada R. G., Nielsen D. N. & Claflin T. O. 1985. The effect of commercial and recreational traffic on the resuspension of sediment in Navigation Pool 9 of the Upper Mississippi River. Hydrobiologia 126, 263-274.

Tanner M. F. 1973. Water Resources and Recreation. Report No. 3, Sports Council, London.

USEPA 2002. EPA Consolidated Assessment and Listing Methodology (CALM) Guidance

USGS, 2017 internet link, accessed 02/2017.
https://waterdata.usgs.gov/ak/nwis/monthly/?referred_module=sw&site_no=15266300&por_15266300_698=623500,00060,698,1965-05,2016-10&site_no=15266300&por_15266300_700=623500,80155,700,1979-08,2001-

09&format=html_table&date_format=YYYY-MM-DD&rdb_compression=file&submitted_form=parameter_selection_list

Vermaat J. E. & De Bruyne R. J. 1993. Factors limiting the distribution of submerged waterplants in the lowland River Vecht (The Netherlands). Freshw. Biol. 30, 147-157.

Ward D. & Andrews J. 1993. Waterfowl and recreational disturbance on inland waters. Brit. Wildl. 4, 62-68.

Williamson J., Kite J., Henderson P. & Bowman Bishaw and Associates .1989. Waroona Reservoir and Catchment Area Management Plan 1990-2000. Department of Conservation and Land Management / Water Authority of Western Australia, Perth.

Woodward, J. and Foster, I.A.N. 1997. Erosion and suspended sediment transfer in river catchments: environmental controls, processes and problems. Geography, pp.353-376.

Appendix A – Natural Conditions Site Selection

RM 23 meets the minimum acceptability criteria as a reference site in the statistical characterization method specified in ADEC's "*Guidance for Implementation for Natural Condition-Based Water Quality Standards, (2006)*. RM 23 is free of channel and habitat modification and no logging, mining, intensive recreational uses, farming or livestock grazing takes 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 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 river bank, 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.

The Final Report from the 2012 KWF study used data collected to evaluate the relationship between turbidity values observed at different monitoring sites (KWF, 2012, Section 3.1.3). The study found that although there are moderate differences in geomorphic characteristics of the stream bed, examination of the turbidity patterns during natural storm events and periods when few boats were present on the river showed similar turbidity levels between the sites, which supports the use of RM 23 as the best available natural conditions site.

KWF reported information about differences in stream bank characteristics between the natural conditions site (RM 23) and the impacted site (RM 11.5), which support the description of differences in the geomorphological conditions of the Kenai River in its position on the Soldotna terrace and the conditions further downstream, in the present Kenai River flood plain. Table A1 is adapted from the information presented in the 2012 KWF study about the stream bank composition.

Table A1. Summary of river bank characteristics of the natural conditions site (RM 23) and the impacted site (RM 11.5) (KWF, 2012).

Site (River Miles)	Site Description	Bank Composition	Tidal
23	River Left; upstream of the Kenai River Center	Poorly sorted cobble and gravel with minor amounts of sand and silt in the interstices	No
11.5	River Right; off Island upstream of Eagle Rock	Moderately sorted gravel overlain with well-sorted, fine grained sand and silt	Yes

Geomorphic Characteristics – Upstream Reach

The bed material below RM 39.4 is coarser than that upstream, remaining in the range 1.6-2.4 inches throughout the entrenched part of the channel downstream from the Moose River. The bed material of the Kenai River is highly permeable and contains a relatively small proportion of fine sediment. The bed material within the entrenched channel (between RMs 39.4 and 17.6) has a size distribution in which a significant proportion of the particles is not erodible under the present flow regime, and the evidence of this condition includes sediment size and channel stability. The causes are threefold: the long term decline in flow accompanying glacial recession, the reservoir like effects of Skilak Lake that traps fine sediment, and, to an unknown extent, the presence of coarser underlying gravel that is present outside the entrenched reaches. (Scott, 1982).

Geomorphic Characteristics – Impacted Reach

Below RM 20, bed material becomes gradually finer, and, correspondingly, bank-erosion rates locally increase. The low banks downstream from approximately RM 14 are composed of cohesive, clay-rich sediment interbedded with less cohesive silt and sand, and locally with coarser sediment. Erosion progresses most rapidly in the sand and gravel layers and triggers bank failure by slumping. This bank material represents tidal and shallow marine deposition during the marine transgression near the close of the Naptowne Glaciation. Modern tidal deposition is occurring as far upstream as RM 12, but the deposits now subject to erosion mainly represent the earlier interval of deposition. (Scott, 1982).

Patterns of Turbidity

The comparison of the natural conditions site (RM 23) and the impacted site (RM 11.5) in the 2012 KWF report examined rapid increases of turbidity during natural melt conditions during the July 2009 fishery. Figure A1 illustrates a rapid spike drastically different in shape at the impacted site (RM 11.5) than that the more gradual rise in baseline for the natural event seen in RM 23.

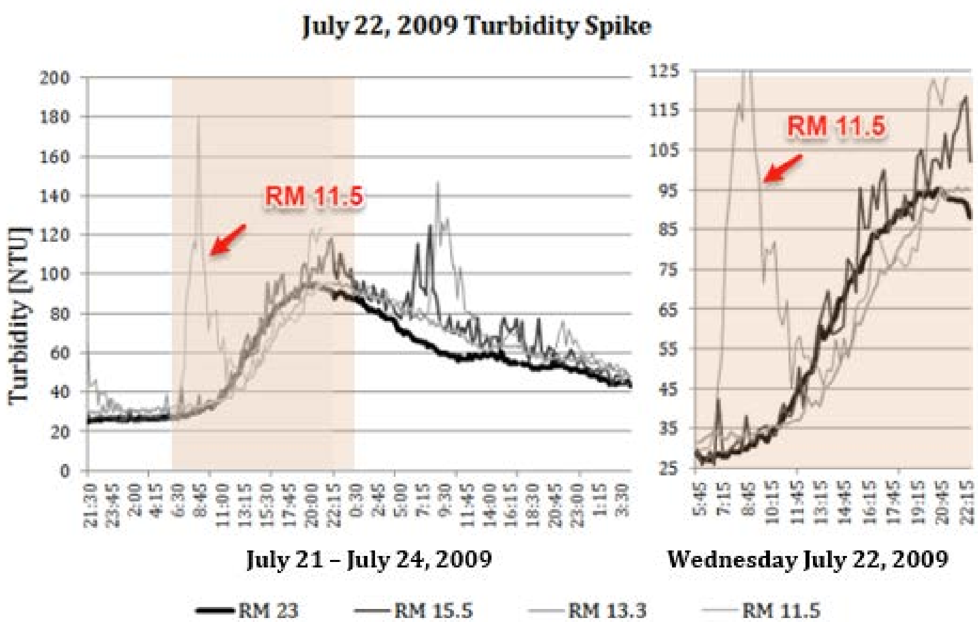


Figure A1. Turbidity vs Time plots for RMs 23, 15.5, 13.3, and 11.5 for the July 22, 2009 melt event (KWF, 2012).

In addition, if site data collected in May (i.e., before the July salmon fisheries), illustrated in Figure A3 is compared to Figures 4, 5, and 6; it can be demonstrated that turbidity at the natural condition site (RM 23) is consistently higher than the impacted site (RM 11.5).

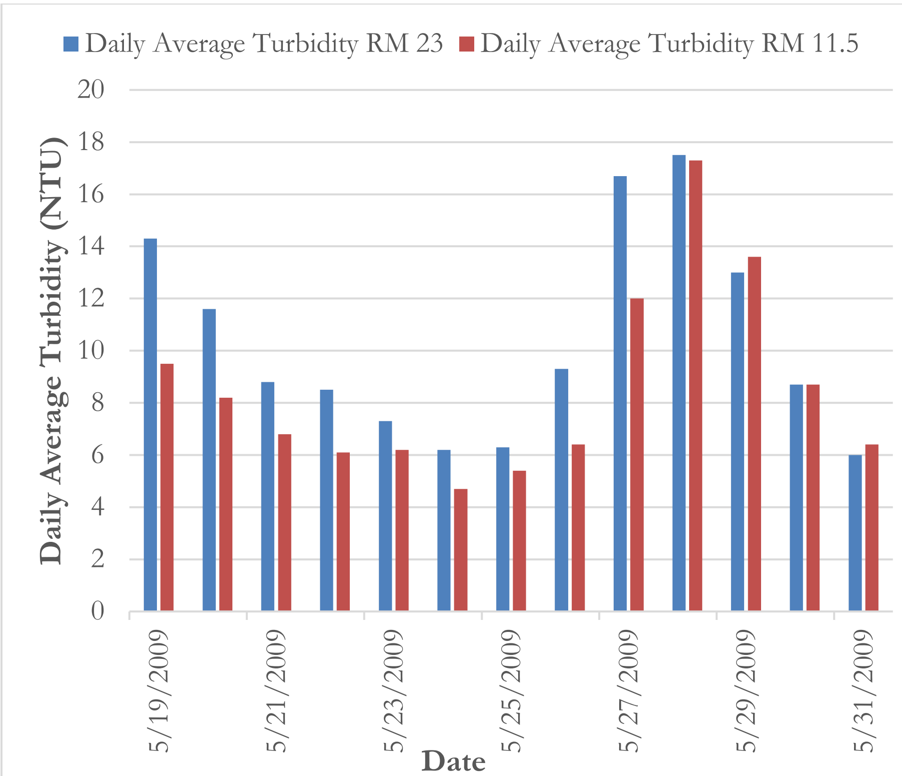


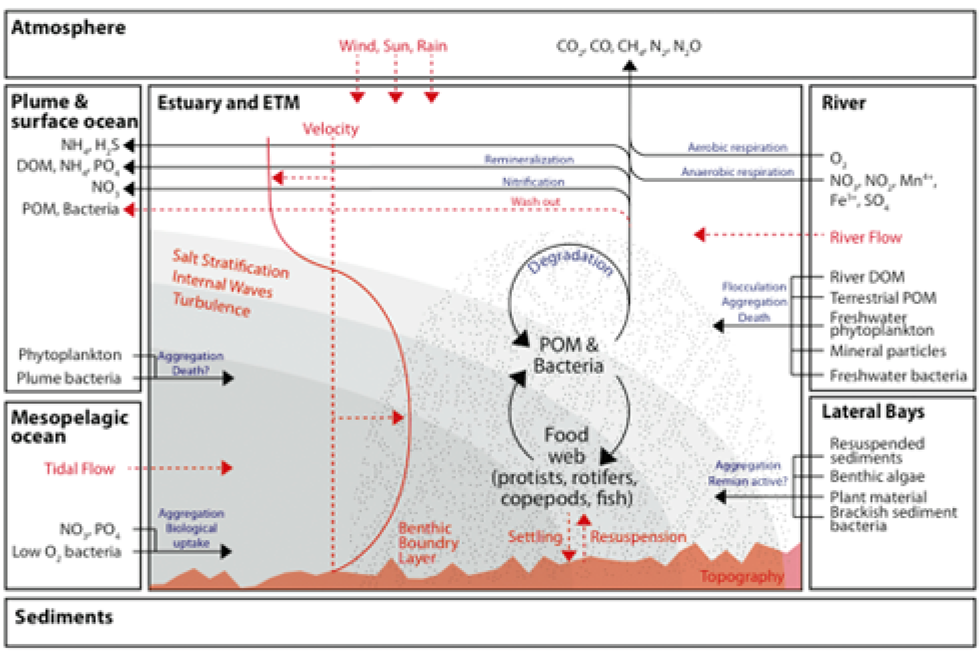
Figure A3. Time series plot of average daily turbidity criteria (natural conditions site: RM 23) and at the impacted site (RM 11.5) from May 19 through May 31, 2009. Time period is outside the July salmon fisheries when little motorized boat activity occurs.

Appendix B - Source Assessment

A conceptual model (Figure B1) for turbidity in the lower Kenai River, including the reach (RM 5 to RM 12.5), and the natural conditions site (RM 23), evaluates the sources of turbidity by providing an understanding the possible physical, chemical and biological influences. Since sediment is often a major factor in turbidity, the conceptual model includes an evaluation of sediment transport.

The components of the model include the following potential sources:

- Background suspended sediment
- Discharges
- Tides
- Physical processes (including motor boat resuspension)
- Other chemical and biological processes



Conceptual diagram of an estuarine turbidity maximum (ETM) in the estuary illustrating the geographic origin of materials and microbes to the ETM, biological and chemical processes affecting those materials and microbes (in blue), and physical features and processes that influence. Not represented is the seasonal variability of the sources of sediments to the ETM.

reproduced by permission of Dr. Byron Crump and the Center for Coastal Margin Observation & Prediction. (CMOP)

Figure B1. Conceptual diagram of an estuarine turbidity maximum (ETM).

B.1 Background Suspended Sediment

One of the major sources of suspended sediment in the lower Kenai River is the suspended solids load from upstream. The drainage area of the Kenai River watershed is over 2,200 square miles. There is a USGS gage, #15266300, on the Kenai River at Soldotna (USGS 2017) which has a contributing drainage area of 2,020 square miles and is located close to RM 21 where the Sterling Highway crosses the river. The suspended solids concentrations at this site are shown in Table B1, using daily data from October 1978 to September 2001, showing the following monthly average concentrations, based on daily mean values:

Table B1. Monthly average sediment concentrations and daily loads from 1978 to 2001 in Kenai River near RM 21.

Month	SS Concentration, mg/L	SS Loading tons/day
May	17.6	207
June	55.8	1,738
July	31.7	1,538
August	15.5	692
September	15.1	596
October	12.1	351
November	9.8	188

B.2 Discharges

The Soldotna Wastewater Treatment Plant (WWTP) has a 1.2 million gallons per day (MGD) capacity and is a secondary treatment wastewater facility with no nutrient removal. The outfall of the Soldotna WWTP is at about RM 21; downstream from the natural conditions site (RM 23) and upstream from the impacted site (RM 11.5). The average flow at the plant in the month of July is around 0.62 MGD which when compared to the Kenai River flow (13,600 cubic feet per second (cfs), mean of monthly discharge, 1965-2016, [USGS 2017]) represents on a small contribution to the lower river, roughly 0.01% of the river flow. Discharge monitoring reports (Soldotna 2008, 2009, 2010) from July 2008, 2009 and 2010 show the suspended solids concentrations vary around 5 to 10 milligrams/Liter (mg/L) or 26 to 64 pounds (lbs)/day of solids (Table B2). This is much lower than the background suspended solids concentrations on the Kenai River, as is shown in Table B1. Therefore, wastewater suspended solids are not a significant source of turbidity.

Table B2. Weekly sediment concentrations and daily loads data from 2008, 2009, and 2010 from Soldotna WWTP.

July, Year	SS Concentration, mg/L	SS Loading, tons/day
2008	6-10	0.017-0.032
2009	5-7	0.013-0.018
2010	5-8	0.015-0.025

Other discharges which may result in turbidity in the river include stormwater runoff from the City of Soldotna, which may include suspended solids and associated nutrients, dissolved organic matter, and bacteria loads. Development along the banks of the river, especially the lower river where both banks are mostly developed, would have increased runoff from these properties, though all of the stormwater contributions to the river would be relatively small and perhaps localized.

There are several larger tributaries which contribute flow to the lower Kenai River: Soldotna Creek, Slikok Creek, and Beaver Creek. These creeks have much smaller drainage areas relative to the Kenai River and their longitudinal gradients are not very steep so they are not likely to contribute much suspended solids to the lower Kenai River. For example, the only tributary of the Kenai River where the USGS maintains a gaging station is on Beaver Creek. Beaver Creek watershed drainage area is 42.7 square miles and the elevation is 48 feet. The USGS gage, #15266500, is sited about 1.5 miles from the confluence of Beaver Creek with the Kenai River near the point where the Kenai Spur Highway crosses Beaver Creek. The average flow rate of Beaver Creek in July from 1967 to 1978 is 19 cfs. The suspended solids concentration at this site, using daily data from August 9, 1970, the only date when this data was available, showed the following daily average concentration in Table B3:

Table B3. Daily average sediment concentrations and daily loads on August 9, 1970 in Beaver Creek near confluence with the Kenai River.

Month, Day	SS Concentration, mg/L	SS Loading tons/day
August 9	6	0.32

While atmospheric deposition of pollen, leaf litter, dust and other particulates may also influence the kinds of suspended solids in the water column, their influence on turbidity may be limited since many of these particles tend to be larger and settle out.

B.3. Tides

In estuarine systems, tidal fluctuations can influence turbidity through a number of factors. These include suspension of bed sediments through turbulent mixing of freshwater and saltwater, ocean derived inputs of nutrients and macrophytes, and flocculation of dissolved solids in saltwater. The Kenai River exhibits strong tidal influences from Cook Inlet. The zone of tidal influence extends upstream from the mouth of the river to about RM 13, including the impacted site (RM 11.5) in the 2012 KWF study, but not the natural conditions site (RM 23).

Because physical processes that influence turbidity are complex and are often interrelated, it can be challenging to determine whether elevated turbidity is caused by the tides or from other sources. One way to estimate the effect is to evaluate the timing of turbidity spikes at the impact site to see if they correspond with tidal cycles. With some exceptions, tidal cycles are 24 hours and 50 minutes long, while boat use on the Kenai roughly corresponds to a 24-hour cycle. Guide boats are allowed on the Kenai from 6:00 am to 6:00 pm during the summer months.

The one-hour moving average of turbidity was calculated from the 15-minute collected data at RM 11.5 in order to smooth out noise in the data. Next, peaks were identified through a trend analysis. An example of the data for 2008 is shown in Figure B2.

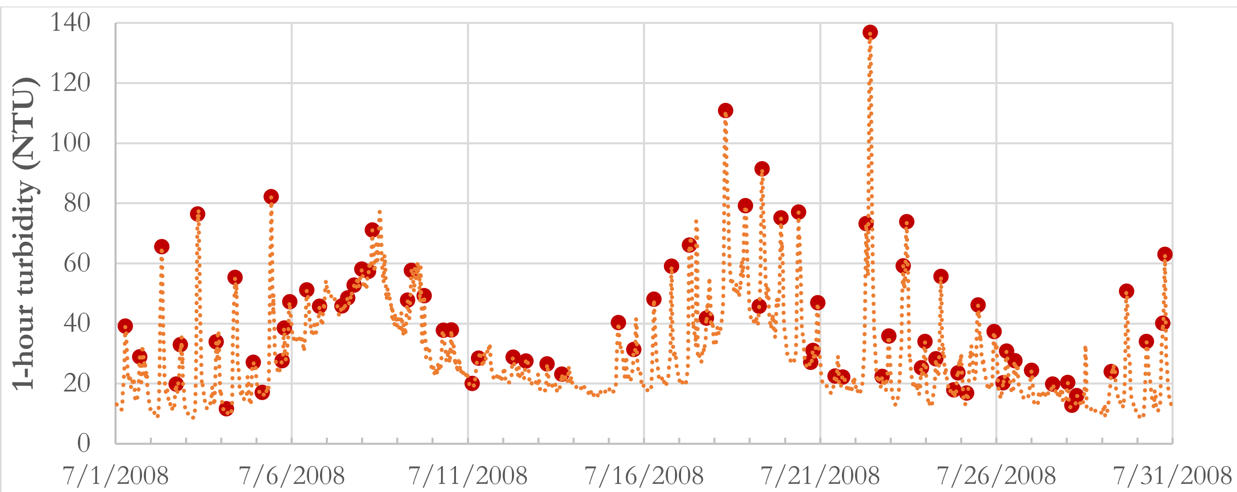


Figure B2. One-hour moving average of 2008 turbidity data at RM 11.5. Local peaks are designated by red dots.

Next, frequency of the timing of these peaks was analyzed. A histogram of the hour of occurrence of peak turbidity at RM 11.5 is shown in Figure B3 for data from 2008, 2009, and 2010. The histogram shows the most frequent hour of turbidity peaks is between 6:00 and 7:00 am. This corresponds to the time of day when guide boats are first allowed on the Kenai River. In order to further investigate whether turbidity peaks can be explained by tidal influences, the timing of tidal ranges was investigated. Historical tidal data was retrieved for the nearest harmonic tidal station, Seldovia, AK (NOAA Station No. 9455500) and transformed using NOAA specified offset parameters to reflect conditions at the Kenai City Pier. The frequency of the timing of both low tide and high tide were investigated. Histograms showing the timing of low tide and high tide are shown in Figures B4 and B5. As expected with a non-24 hour cycle, there is no apparent correlation between time of day and tidal data, and therefore tidal activity is not expected to be the source of turbidity spikes observed regularly in the 6:00 am to 7:00 am timeframe at RM 11.5, which leaves boat traffic as the likely main source of suspended sediment and elevated turbidity in the river.

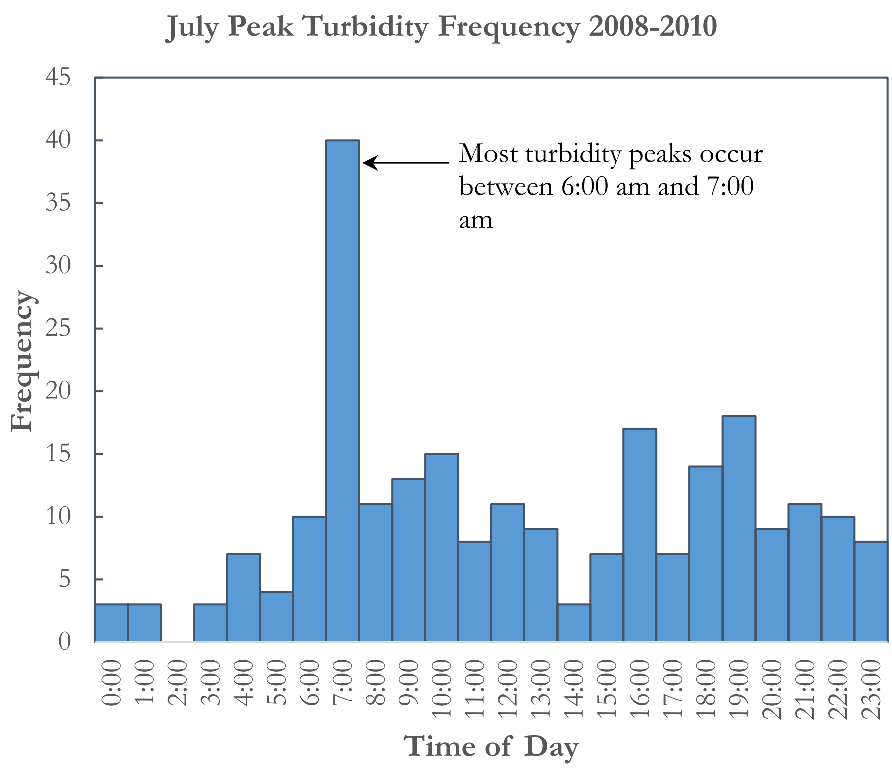


Figure B3. July Peak Turbidity Frequency 2008-2010 at RM 11.5.

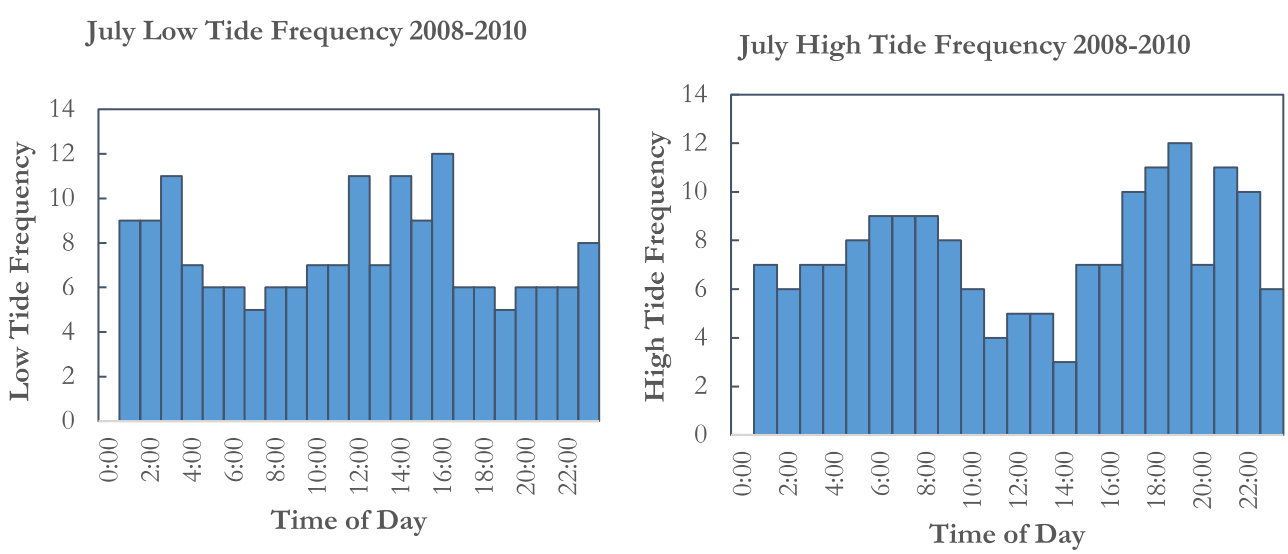


Figure B4-B5. Histograms showing the timing of the low and high tides in July 2008 to 2010 for the Kenai River.

The tidal cycle can often be a source of suspended materials that can lead to turbidity in the river, which can include bacteria, phytoplankton, nutrients, and sediment. If these sources were significant, we would expect to find additional side effects captured in water quality monitoring and field observations, such as localized algal blooms or clouds of suspended sediment during each tidal cycle, independent of human uses on the river. The studies did not document any water quality abnormalities that would indicate tide-related turbidity sources.

Tidal Summary

The Kenai River exhibits strong tidal influences from Cook Inlet that could increase erosion. The zone of tidal influence extends upstream from the mouth of the river to about RM 13, including the impacted site (RM 11.5), but not the natural conditions site (RM 23). The conceptual model evaluation shows that, while it is probable that tidal influence plays a role in the overall turbidity of the impacted part of the Kenai River, tidal influence is not the primary cause of high turbidity conditions observed at the impacted site.

B.4 Motorized Boats

5.4.1 Literature Findings

Boats may resuspend sediment by two major actions; (1) wave action along the banks and shallow waters and (2) the mechanical action of boat propellers (Mosisch and Arthington, 1998). Wave action resulting from recreational power boating is considered a form of mechanical disturbance, causing far-reaching problems due to bank damage by erosion. (Kuss et al.,1990) reported that power boat operation causes more shoreline damage than other types of boating (e.g. sailing, rowing) and several studies have discussed these effects (e.g. Tanner, 1973; Garrad and Hey, 1988; Pressey and Harris, 1988; Ward and Andrews, 1993) and the physical damage to both emergent and floating water plants due to power boating activity (e.g., Cragg et al., 1980; Vermaat and Bruyne, 1993; Murphy, et al., 1995). Mechanical disturbance is created by turbulence in the area immediately surrounding an outboard motor propeller leading to bed sediment resuspension, especially in shallow waters, which can then reduce the productivity of a water body (Kirk, 1985). (Smart, et al., 1985) demonstrated that almost every recreational vessel has the capacity to resuspend sediments.

Outward and downward forces created by the passage of power boats resuspend nutrient and mineral-containing bed sediments and erode the shoreline (Fallen, 1985). It has been shown that power boat activity can cause resuspension of sediments and associated turbidity due to the turbulence created by the propeller (e.g. Pressey and Harris, 1988), and, in the case of water storages, may lead to "premature siltation" (Fallen, 1985). Shallow areas are particularly affected by the stirring actions of boat propellers (Kuss et al., 1990). The magnitude of sediment resuspension will depend on the origin and composition of the sediment itself, for example its clay content (Liddle and Scorgie, 1980; (Smart, et al., 1985). Clay suspensoids can stay in the water column for days and up to weeks (Kirk, 1985).

(Williamson, et al., 1989) found that power boating may increase turbidity in a water body for only a relatively short period. This was also observed by (Horsfall, et al., 1988), who researched the impacts of recreational power boating on lakes and noted that power boat-generated turbulence resulted only in a temporary increase in turbidity. (Hilton and Phillips, 1982) examined the effects of motorized recreational boating on turbidity in a shallow English river. They noted that turbidity due to re-suspended bed sediments can affect the growth of submerged macrophytes and that boats were responsible for most of the turbidity present in the water. However, turbidity levels returned to normal approximately five and a half hours after boating activities had stopped. It is important to note that in the case of rivers, re-suspended sediments would be carried downstream continuously with the flow and thus turbidity would be expected to clear faster than in lakes (Mosisch and Arthington 1998). (Moss, 1977) stated that suspended sediments would sink back to the bottom quite rapidly, unless the water is continuously re-agitated by further boating activity.

There is extensive evidence that power boat operation is responsible for disturbance of sediments and resultant turbidity increases (Cragg, et al., 1980; Garman and Geering, 1985a; Smart, et al., 1985; Garrad and Hey, 1988; Williamson, et al., 1989), and that reduced boat operation can improve water quality by controlling turbidity (Garrad and Hey, 1988).

Kenai Data Analysis

In addition to the literature findings on the impacts of boats on turbidity, KWF examined boat counts collected on the Kenai River to see if boating impacts could be demonstrated. As the DEC-funded studies did not focus on boat counts, limited data is available. Table B4 presents boat count available in July 2008. Even using the limited amount of data, a weak correlation is shown.

Although boat count data is limited, patterns of boating are well known. By regulation, Sunday is a non-guided only day and by nature of the fishing patterns, Tuesday prior to 06:00 is a very heavy use morning by local private anglers, followed by a busy guide day. July Tuesdays are known locally as Super Tuesday, because of the perceived or real improved fishing opportunity resulting from the relatively low fishing pressure currently experienced during the regulatory non-motorized Monday fishing.

Assuming the boat count distribution presented in Table B4 is typical, the data provides a rationale for the spikes in turbidity noticeable in the morning hours at the impacted site (RM 11.5) in Figures B7-B9. The impacted reach (RM 5-13) makes up about 16% of the Middle and lower Kenai River, but the boat counts showed the percentage of boat in this reach in 2008 in the morning hours as being typically around 25%. This concentrated motorized activity could account for the turbidity spikes seen in Figures A1 and B2.

Table B4. Boat Count Information (Ruffner, 2009).

Day of Week/Date	Time of Day	Section of River	Total Power Boats in use	Percentage of Boats in Impacted Reach of River (RM 5-13)
Saturday/ 7/19/2008	8:00	RM 0-5	185	25%
		RM 5-13	148	
		RM 13-20	188	
		RM 20-50	55	
Saturday/ 7/19/2008	8:45	RM 0-5	199	28%
		RM 5-13	154	
		RM 13-20	193	
		RM 20-50	None	
Saturday/ 7/19/2008	14:00	RM 0-5	212	21%
		RM 5-13	129	
		RM 13-2	173	
		RM 20- 50	89	
Saturday/ 7/19/2008	20:00	RM 0-5	201	16%
		RM 5-13	65	
		RM 13-20	99	
		RM 20- 50	44	
Sunday/ 7/20/2008	8:00	RM 0-5	107	32%
		RM 5-13	132	
		RM 13-20	142	
		RM 20- 50	33	

Day of Week/Date	Time of Day	Section of River	Total Power Boats in use	Percentage of Boats in Impacted Reach of River (RM 5-13)
Sunday/ 7/20/2008	8:45	RM 0-5	120	9%
		RM 5-13	15	
		RM 13-20	36	
		RM 20- 50	None	
Sunday/ 7/20/2008	14:00	RM 0-5	106	25%
		RM 5-13	98	
		RM 13-20	123	
		RM 20- 50	64	
Tuesday/ 7/22/2008	8:45	RM 0-5	77	43%
		RM 5-13	259	
		RM 13-20	260	
		RM 20- 50	None	
Tuesday/ 7/22/2008	14:00	RM 0-5	76	28%
		RM 5-13	138	
		RM 13-20	220	
		RM 20- 50	56	
Tuesday/ 7/22/2008	20:00	RM 0-5	53	0%
		RM 5-13	None	
		RM 13-20	None	
		RM 20- 50	None	

Using the limited data a correlation between turbidity and boat counts does show a relationship, although the relationship is not strong (R^2=.2552)

Figures B6, B7, and B8 further illustrate the impact of boats. The figures are time series plots for three days (i.e., Saturday, Sunday and Monday) in each of the years of the 2008-2010 KWF study. These figures demonstrate that at the impacted site (RM 11.5), turbidity patterns change throughout a 24-hour period on non-Mondays. An increase in turbidity starts early in the morning at the start of boating activity, with continuing turbidity spikes throughout the day. The turbidity spikes decline during the night as boat traffic drops. On Mondays, when fishing is prohibited from motorized boats, the pattern of reduced turbidity during the day is not observed at the impacted site (RM 11.5). This pattern of turbidity changes each day was not observed at the upstream natural conditions site (RM 23).

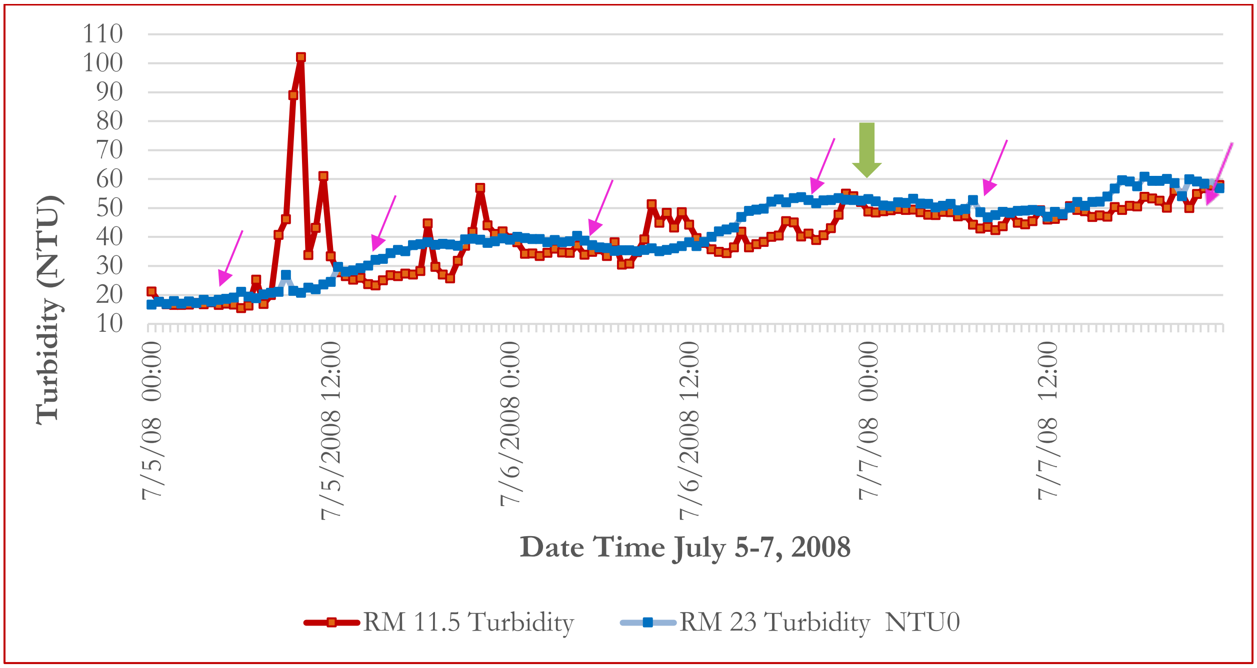


Figure B6. Turbidity during the king salmon fishery in July, 2008 at the natural conditions site, RM 23, and the impacted site, RM 11.5. Green arrow designates Monday; pink arrows designate high tide.

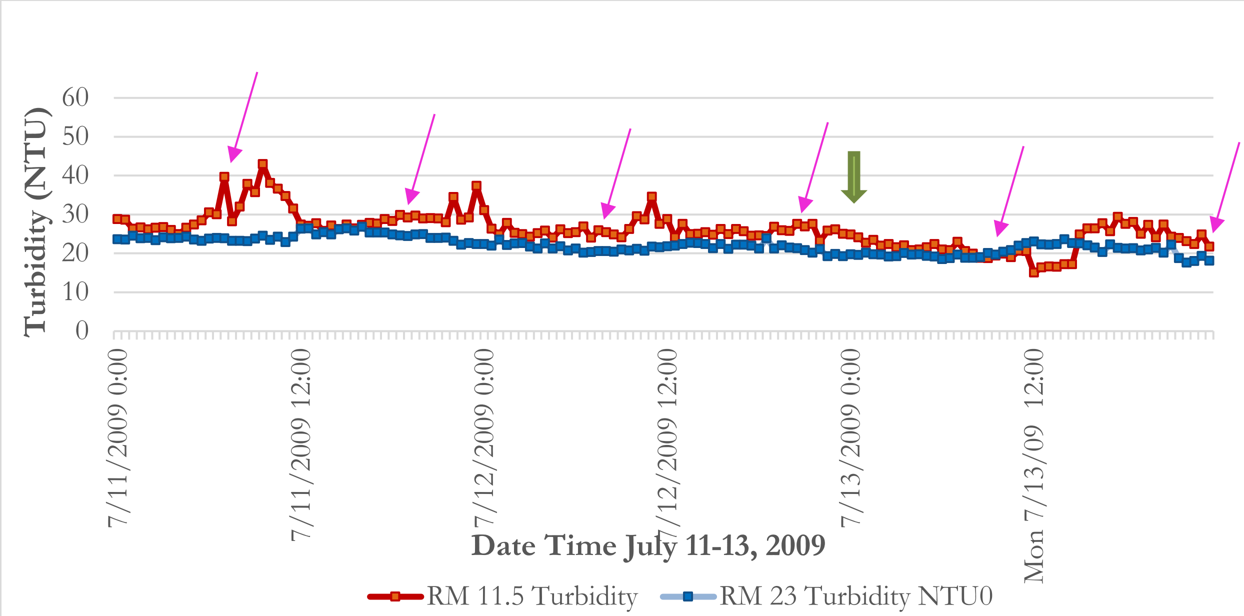


Figure B7. Turbidity during the king salmon fishery in July 2009 at the natural conditions site, RM 23, and the impacted site, RM 11.5. Green arrow designates Monday; pink arrows designate high tide.

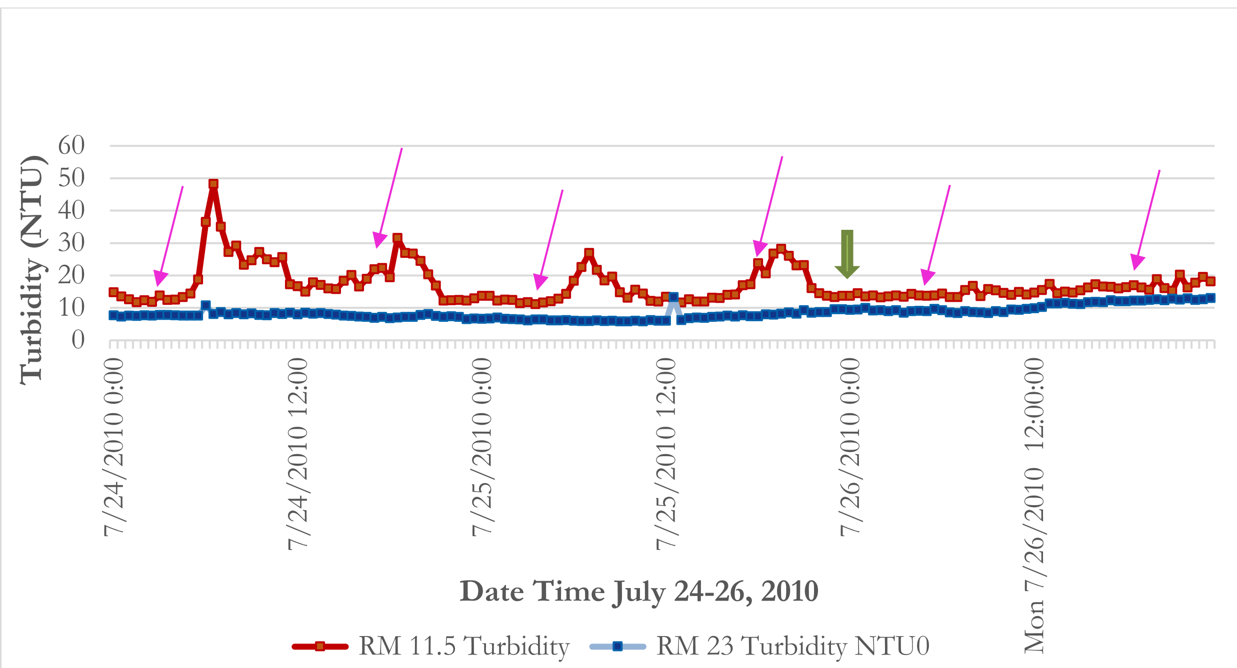


Figure B8. Turbidity during the king salmon fishery in July 2010 at the natural conditions site, RM 23, and the impacted site, RM 11.5. Green arrow designates Monday; pink arrows designate high tide.

B.5 Physical Processes

There are several physical processes that influence the turbidity in the water column, some of which are natural processes of reworking of streambed sediments within the river channel and others from external sources acting on the river.

Flocculation of dissolved sediments in salt water mixing zones.

The degree of flocculation of dissolved sediments in the salt water mixing zone is unknown but is probably low. (Orejuela, 2015) reports low salinity values downstream of the impacted site (RM 11.5) to the mouth of the Kenai River. The area between river mile 5 and river mile 12.5 is tidally influenced by the rise and fall of water levels, conductivity readings indicate that the saltwater does not intrude past river mile 5. Therefore, the freshwater criteria apply. In low salinity environments, there is a decrease in flocculation of dissolved sediments.

Natural Stream Processes

Remobilization of deposited sediments is usually the primary source of sediments within streams. The frequency and extent of sediment remobilization is dependent on the erosivity of flows and the stability of the channel bed (Woodward and Foster, 1997). As described in the background (geomorphology), given the longitudinal slope of the stream bed and the sediment bed characteristics in the impacted reach the sediments that settle out are fine grained particles such as silt and clays. These fine grain size particles are easily eroded by higher velocities caused by storm events or anthropogenic activities, such as boat traffic.

River bank erosion is a source of sediments present in the water column. The rate of erosion at a specific streambank is controlled by numerous natural properties of the river environment, which can vary over time and along the river. These properties include the depth, velocity, approach angle, and sediment content of the river; the type and density of vegetation; the height and slope of the banks; the soil type; and the size of particles making up the potentially eroded material. (Dorava and Moore, 1997). Streambanks respond to river currents differently depending on their configuration, geometry, and orientation. Additionally, the type and size of material composing the bank will affect its resistance to erosion. For example, if the bank is vertical and oriented perpendicular to the river flow, and is composed of material that is loose, unconsolidated, fine-grained, and unvegetated, it would erode more readily than a gently sloping bank that is oriented parallel to the river flow, and composed of consolidated, coarse-grained materials that are covered with thick vegetation.

Because study sites along the Kenai River depict a variety of these characteristics, natural erosion rates also varied among the sites. (Dorava and Moore, 1997). Table B5 summarizes the differences in bank erosion susceptibility in different segments of the Lower Kenai River.

Table B5. Summary of channel characteristics pertinent to determining sensitivity of the Kenai River to development. (Dorava and Moore, 1997).

Segment of channel (river miles)	Pattern and degree of entrenchment	Underfit conditions	Degree of armoring	Rate of bank erosion under present regime (ft/yr)	Relative sensitivity to development
34.8 to 21.8	Sinuous to straight; entrenched within Soldotna terrace	Most underfit section of entire river	Mainly armored	<1.0	Low
21.8 to 17.6	Meandering; entrenched within Soldotna terrace	Underfit	Mainly armored	<1.0	Low
17.6 to 13.4	Meandering; Partially entrenched but meanders are migrating.	Slightly underfit	Parts may be slightly armored	2.0	High
13.4 to 9.0	Sinuous and anabranching	Channel is product of present flow regime	None	5.0	High
9.0 to mouth	Meandering in tidal regime; channel is free to migrate	Channel is mainly product of present flow regime	None	2.0	Moderate

(Dorava and Moore, 1997) stated that accounting for all the natural erosional forces is impractical and because river currents act continuously, the rate of all the natural erosion processes on the Kenai River is assumed to be proportional to the tractive force of the river currents.

Human-Caused Stream Processes

Natural erosion caused by river currents and human-induced erosion are very different mechanisms. River currents flow generally parallel to the riverbank and move sediment towards and away from the bank as well as transport it downstream. In addition to watershed and river characteristics, human factors—such as bank alterations and river use—affect erosion rates. (Scott, 1982) reported that an unknown but probably significant amount of the suspended-sediment load in the Kenai River is presently derived from bank erosion. (Scott, 1982) also predicted that future increases in suspended sediment will be caused by any type of development or river use that increases bank erosion. In a stream the size and type of the Kenai River, increased suspended-sediment transport will be the first general effect of development with the potential to be deleterious to the physical stream system, chiefly through deposition of fine sediment in the pores of the streambed gravel.

Human-caused bank erosion activities include land use changes, boatwakes, and bank trampling. Boatwakes travel essentially perpendicular to the bank and move sediment by dislodging it upon impact, by splashing up and down the bank, and by causing a rapid inflow and outflow of water from permeable banks. (Dorava and Moore, 1982). Bank trampling occurs from anglers fishing for salmon from the river. Shore anglers may negatively affect riparian and fish habitat by trampling and denuding vegetation, accelerating erosion of riverbanks. (King and Hansen, 2015).

Chemical and Biological Processes

Turbidity in some waterbodies may be caused by organic matter, such as blooms of phytoplankton and benthic algae. In a glacially-derived, fast-flowing stream like the Kenai River, the presence of algae and decaying organic matter is likely a minor source of turbidity. KWF conducted water quality sampling for fourteen years of along the length of the Kenai River, and found very low levels of nitrate and phosphorus, parameters sometimes associated with algal growth, in the main stem of the Kenai River, including the Lower Kenai River. Levels of fecal coliform, another potential biological component of turbidity, were also in very low concentrations in the main stem of the Kenai River, above RM 6.5; with few exceptions. (Orejuela, 2015).

B.6 Summary of Turbidity Conceptual Model

The following conclusions can be drawn by summarizing information from Section 5. Figure B1 illustrates some of these features in an estuarine system:

- Point sources (including stormwater inputs, sediment contributions from tributaries in the impacted section of the Lower Kenai River and the Soldotna Wastewater Treatment Plant effluent probably contribute low amount of turbidity compared to background/upstream.
- Tidally induced erosion does not appear to be a significant factor.
- The largest sources of particles that can contribute to turbidity are the watershed itself, i.e. the main stem of the Kenai River for bringing sediment to the impacted reach – though this may settle out on a regular tidal cycle resulting in a well- established range of turbidity values.
- The largest source of disturbance to the impacted reach that causes the turbidity values to exceeded water quality criteria is the human activity.