Continuation of Lower Nushagak River Fecal Coliform and Water Quality Assessment

August 2007 – June 2008

Final Report to the Alaska Department of Environmental Conservation

and

The Bristol Bay Native Association

prepared by

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October 2008

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Acknowledgements

This project was made possible by a grant from an Alaska Clean Water Actions (ACWA) grant from the Alaska Department of Environmental Conservation. This project built upon previous work that was led by Lisa Ferber at Zender Environmental Science and Planning Services with support from the Nushagak Mulchatna Watershed Council.

Sue Flensburg, at the Bristol Bay Native Association, conducted the grant administration and logistical planning for this project. She generously provided housing and hospitality for field crew while they were in Dillingham and filled in to do fieldwork herself on one occasion. Daniel Chythlook and Tina Carr provided fieldwork assistance for this project. Luki Akelkok, Sr. provided transportation to study sites and housing, food and steams for the fieldcrew in Ekwok.

Introduction

Background
The Nushagak River is one of the premier salmon-producing systems in Southwest Alaska. Originating in the Taylor Mountains and the Alaska Range, the Nushagak watershed drains an extensive area of tundra, wetlands, and forested lowlands and eventually empties into Bristol Bay. The Nature Conservancy, working with local residents, has identified the Nushagak River watershed as one of the most important areas in the region for biodiversity conservation, producing five species of Pacific salmon and several species of freshwater fish, as well as providing extensive habitat for waterfowl, moose, and caribou (NMWC, 2007). Seven predominately Native communities and approximately 250 Native allotments depend on the Nushagak River and its tributaries for subsistence harvesting, commercial fisheries, and renewable resource-based economic activities.

People in local communities are concerned about water quality in the river and possible impacts caused by increasing development of state and Native lands and threats from non-point source pollution associated with community growth. Local residents are also concerned about the impacts of increased recreational use and the growing number of sport fishing and hunting lodges on the river, and the solid waste and waste water associated with these facilities.

The discovery of one of the largest gold-copper deposits in North America at the headwaters of the Koktuli River, an important salmon-bearing tributary of the Mulchatna River, poses an additional threat to the water quality of the lower Nushagak River. If developed, the Pebble Mine could alter water quality conditions in the Nushagak River with potential impacts to the river's aquatic biodiversity and subsistence resources that sustain communities and their cultural identity. The Pebble Project is currently in the early development stages but has an aggressive timeline for moving forward. Promising exploration results have also spurred a staking rush and renewed interest in other mineral deposits in the upper watershed, such as the Shotgun Hills gold deposit in the King Salmon River, another key tributary in the upper Nushagak. Mining developments in the Nushagak River watershed would also lead to increased population base, putting additional pressure on water, fish, and wildlife resources.

Previous Water Quality Assessments
The U.S. Geological Survey collected stream discharge on the Nushagak River at Ekwok from 1975 to 1993 (USGS site 15302500). Water quality data was collected by the USGS at Ekwok in 1956 and from 1979 to 1986, and at New Stuyahok and Portage Creek from 1970 to 1971 (USGS, 2008). Currently, the National Weather Service is collecting stage data from observers in Ekwok. The Nushagak-Mulchatna Watershed Council (NMWC) sampled tributaries of the Nushagak River for water quality and benthic macroinvertebrates approximately twice per year from 1999 to 2003 (data sheets on file at BBNA). The University of Alaska Anchorage (ANHP and ENRI) and BBNA identified environmental indicators for the Nushagak/Mulchatna River watershed (Boggs et al., 1999). The Nushagak River Watershed Traditional Use and Conservation Plan (NMWC, 2007) was prepared under the direction of the NMWC to guide conservation related activities within the watershed. This report documented local knowledge of important ecological and subsistence areas within the watershed and discussed potential threats to

these resources. BBNA has been conducting an instream flow reservation project on the Koktuli River, and are planning to begin another one on the Stuyahok River in the fall of 2008.

This study builds on work that was conducted through BBNA and the Alaska Soil and Water Conservation District (ASWCD) in 2006 and 2007. That study looked at fecal coliform concentrations and other basic water quality parameters at eight sites in the Lower Nushagak River. Three of those sites showed periodic elevated levels of fecal coliform bacteria in the river and are the foci of this study.

Study Area

The lower Nushagak River winds its way through the Bristol Bay Lowlands ecoregion before emptying into Bristol Bay at Dillingham, Alaska. The 4780 square mile basin of the lower Nushagak River has a predominantly maritime climate, but is influenced by the continental climate further inland. The average annual precipitation is 20-35 inches and average summer temperatures range from 37-66 degrees Fahrenheit; average winter temperatures range from 4 to 30 degrees.

The NMWC has identified the lower Nushagak River its highest priority sub-basin due to its heavy use, both by local residents and recreational visitors. This is the part of the larger watershed that is home to the five communities on the river: Koliganek, New Stuyahok, Ekwok, Portage Creek, and Dillingham.

This study focuses on three locations in the lower Nushagak River that have had episodic elevated fecal coliform levels: near the community of Koliganek, at the confluence with the Mulchatna River, and near the community of New Stuyahok (Figure 1).

Figure 1. The three main study sites on the Lower Nushagak River.

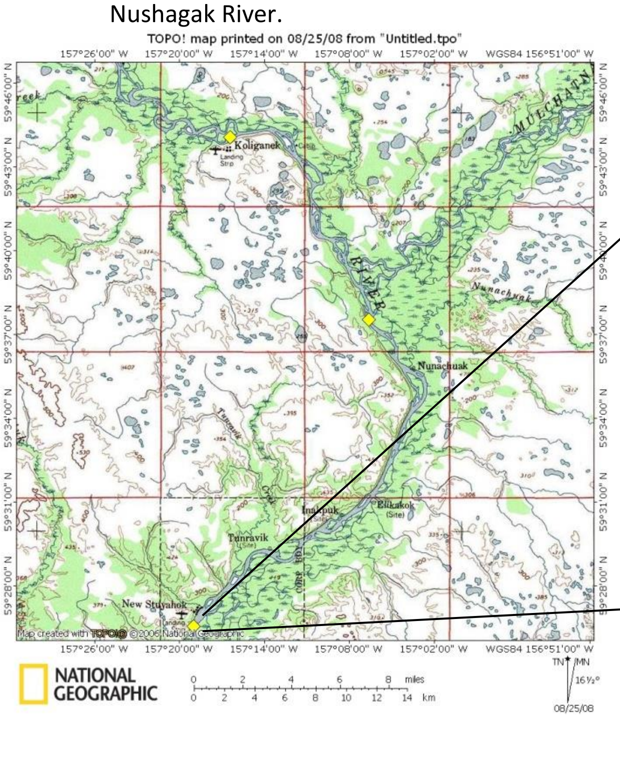
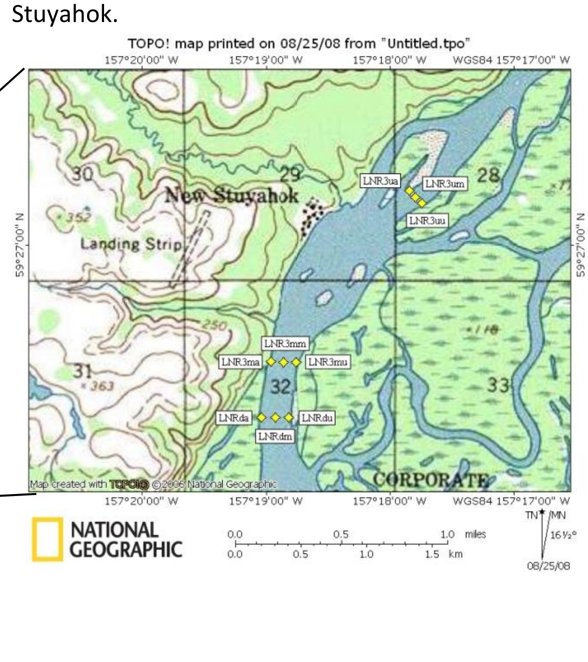


Figure 2. Sampling locations at study site LNR3 near New Stuyahok.



Methods

Sampling design

Fecal coliform and water quality measurements were taken at three sites on the lower Nushagak River between Koliganek and just downstream from New Stuyahok five times during FY08: in August, September and October 2007, and in May and June 2008. GPS Coordinates are listed in Table 1:

Table 1. GPS Coordinates of Lower Nushagak River Sampling Locations

Sample Site	Location Description	Latitude (º)	Longitude (º)
Site 1	Below Koliganek	59.73053	-157.27261
Site 2	Below mouth of Mulchatna River	59.62221	-157.10503
Site 3	Below New Stuyahok	59.44092	-157.31445

The sampling crew consisted of the project officer, one to two local monitors, and the boat operator. Each of the three sample sites had a total of 9 sampling locations located along three transects. The main site transect was located based on the information in Table 1. Three samples were taken at the main transect—two located two feet from each bank and one "main" site at the main flow of the river. Sample sites were located on a straight reach of the river, with a uniform channel cross section. A GPS waypoint (minimum 20 feet accuracy) was taken at the main flow/midpoint of the stream. The distance below/above the ordinary high water (OHW) mark was estimated at the affected bank of each site.

Per site, there were also two additional sampling transects—one located upstream, above all suspected local human caused inputs of fecal coliform, and one located about 300 meters downstream from the main site transect. Three sites were sampled along each of these transects— two located two feet from each bank and one "main" site at the main flow of the river (see Figure 2).

In addition to the nine fecal coliform samples collected at each of the three sites, three sterile Deionized water "blanks" were poured into sample bottles, for a total of 30 fecal coliform samples that were sent to the laboratory after each of the five sampling events.

Field measurements

- Water temperature
- Dissolved oxygen
- pH
- Specific conductance
- Turbidity
- Barometric pressure

Laboratory samples

- Fecal coliform

Our rationale for this design is that human waste and pollutants are likely be greatest near the stream bank at the three sites where elevated levels of fecal coliform have been detected in the past, and diluted toward the midpoint of the stream. In addition, by collecting fecal coliform samples both above and below the main sample site, we would be able to determine a more precise location of the source of the bacteria and gain some understanding of its downstream fate.

Assumptions for this design include:

- The main flow/midpoint of the stream is the most representative of the stream channel.
- Fecal coliform bacteria concentrations will be greatest nearest the affected bank.
- The first two sampling events in the fall 2007 will occur during peak use periods by hunting camps on the river, while the third fall sampling event will occur after the hunting peak. The spring 2008 sampling events will coincide with peak fishing guide camp activity.

After lab samples were collected, they were immediately put on gel ice and delivered to the laboratory the following morning to meet the 30 hours holding time. The only mishap that we encountered during our fecal coliform sampling was the loss of a sample bottle cap during our May 2008 sampling trip, which resulted in only two DI blanks being sent to the lab for that sampling trip.

Sampling methods

The YSI 556 multi-meter and turbidimeter were calibrated the night before each of the sampling trips while in Ekwok. All measurements and sample water were collected from the upstream side of the boat at elbow depth. Water temperature, dissolved oxygen, pH, specific conductance, and barometric pressure readings were taken with the YSI 556 multi-meter. Turbidity tubes were filled at elbow depth and analyzed with the Hach 2100 turbidimeter. All field measurements were made in at least duplicate with 10% distilled water blanks for turbidity measurements. The YSI multi-meter probes and turbidity tubes were rinsed thoroughly with distilled water after each use and with sample water before recording measurements/collecting samples. Digital photographs were taken.

Laboratory sample bottles were filled at elbow depth below the water surface. The sampler collected the sample by submerging the inverted sample jar into the water while facing upriver. Once the bottle reached elbow depth, the sampler turned the bottle opening into the current and upright, allowing it to fill, before pulling it from the water and capping. Samples were immediately labeled and collection times were logged. Samples were placed on gel ice and remained there until delivered to the lab on the following morning.

The same measurements and samples were collected at an upstream transect, located upriver from the main site transect, above all suspected human bacteria influences in the immediate area. The same measurements and samples were collected at a downstream transect, located approximately 300 meters downstream from the main site transect.

Measurements and analysis techniques

Field measurements and laboratory analysis followed ADEC-approved methods to insure data quality and to provide continuity with previous studies. Additional details about sampling procedures and parameters can be found in the ADEC-approved QAPP for this project. Analytica Group, an ADEC-approved lab, was the laboratory selected to perform the analysis of the fecal coliform samples for this project.

Data management

Field data sheets were printed on Rite in the Rain paper and used to record field measurements and observations. Data sheets were reviewed in the field to insure completeness before moving on to the next site. Once back in Anchorage, data and observations were entered into an Excel spreadsheet. The project coordinator reviewed all the data to insure its accuracy. Data not meeting data quality objectives outlined in the QAPP were flagged in the spreadsheet. Laboratory data were reviewed upon receipt from the lab and also entered into an Excel spreadsheet for data analysis.

Data quality assurance

The Quality Assurance Project Plan (QAPP) for this project was approved by ADEC prior to any data collection. The QAPP for this project outlines data quality assurance measures in more detail, and is available from ENRI upon request. Both YSI 556 multi-meter and Hach 2100 turbidimeter were calibrated prior to sampling events. All field measurements for this project were collected in *at least* duplicate, with 10% DI blanks measured for turbidity. The YSI 556 multi-meter was checked periodically during sampling to check for drift. We had problems with the pH probe on the multi-meter during the October sampling event, after which the multi-meter was sent to TTT Environmental, Inc. for maintenance and repairs. Ten percent of all fecal coliform samples were filled with sterile deionized water and submitted to the lab blind. All of these samples were found to be below the detection limit in the lab.

Results

Water quality data

Water quality data collected for this project in FY08 included field measurements of water temperature, pH, specific conductance, and dissolved oxygen and collection and analysis of water samples for fecal coliform bacteria. These data were collected at three major sites, each consisting of nine sampling sites, in the lower Nushagak River. These data will contribute to the baseline data collection effort to date on the lower Nushagak River. All data are presented in Appendix A—Water Quality Data.

Water temperature

The temperature of the water influences both the chemistry and biology in any aquatic system. Water temperature, along with barometric pressure, determines the amount of dissolved oxygen the water can hold in solution when at equilibrium with the atmosphere. The colder the water, the more dissolved oxygen it can hold in solution. Water temperature also affects the metabolic and growth rates of fish. The state of Alaska sets the upper limit for water temperature in waters that are migration routes and rearing areas for anadromous fish at 15 degrees Celsius.

At no time during our sampling did the water temperature exceed 12 degrees Celsius, and was therefore within the acceptable limits set by the state of Alaska. The warmest temperatures were measured in our August and September sampling events, with water temperatures of 10.8 to 11.4°C near Koliganek, and water temperatures of 11.3 to 11.8°C near New Stuyahok. The coldest water temperatures were measured in our May sampling event, where water temperatures near Koliganek ranged from 1.6 to 1.8°C, and water temperatures near New Stuyahok ranged from 2.6 to 3.3°C. Historic USGS water temperature data ranged from 1.5 to 16.5°C (May through September, 1956, and 1979 to 1986); data from this study fall within this temperature range.

Dissolved oxygen

The dissolved oxygen content in a river is controlled by several factors, including water temperature, atmospheric pressure, hydraulics, and rates of photosynthesis and respiration. All fish living in the Nushagak River, and especially salmon, require well-oxygenated water throughout their entire life cycle. Dissolved oxygen was measured as a concentration (mg/L) and as a percentage of its maximum value (% saturation). Alaska state water quality standards set a lower limit of 7 mg/L of dissolved oxygen for waters that support anadromous fish.

At no time during our sampling did the dissolved oxygen levels approach the lower limit of 7mg/L; in fact, dissolved oxygen at no time was measured below 10 mg/L. With the exception of the May sampling event, dissolved oxygen was measured near 100% saturation, indicating healthy levels of dissolved oxygen for the river. During the May sampling event, dissolved oxygen measurements ranged from 86 to 95% saturated. In August 2005, dissolved oxygen levels were detected at 115.2% saturated (Zender, 2006). At no time during our sampling did percent saturation approach the upper limit as defined by the Alaska State water quality standards of 110% saturated.

pH

The pH of water is a measure of the hydrogen ion activity, or more commonly, the acidity or alkalinity of the water. Neutral waters have a value of pH 7; pH values below 7 indicate acidic conditions, while values above 7 indicate alkaline conditions. Natural waters typically have a pH between 6.5 and 8.5. Alaska state water quality standards use this range as the acceptable pH range for natural waters, and also state that they should not vary more than 0.5 pH units from their natural background condition.

Most of the pH values were below 7, indicating slightly acidic conditions in the lower Nushagak River. Measured pH values were ranged from 6.2 to 7.3, within the typical range for healthy fish. Measured pH values on the Nushagak tended to increase downriver from its confluence with the Mulchatna River.

Specific Conductance

Specific conductance is a measure of the water's ability to conduct an electric current. Specific conductance values increase with increasing concentrations of ions dissolved in the water. During low flow conditions, the river's specific conductance will typically be at its highest, indicating a larger proportion of groundwater I the river's makeup. Conversely, during high flow periods, specific conductance values tend to be lower, indicating a higher proportion of runoff (from rainfall or snowmelt) which typically has smaller ion concentrations. Specific conductance measured values tended to follow this pattern, with values dropping from near 60µS/cm in the summer and fall months to around 20µS/cm during the May sampling event, when the river stage was at its highest during our five sampling events. As the river level dropped in June, the specific conductance came back up to near 50µS/cm.

Turbidity

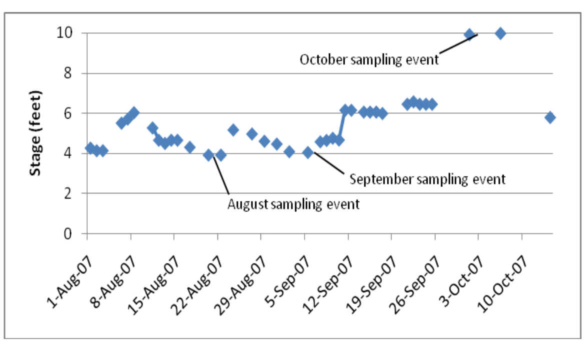
Turbidity is a measure of water's cloudiness due to suspended particles that are generally difficult to see with the unaided eye. Turbidity tends to increase during high flow conditions, due to the runoff from rainfall or snowmelt carrying particles from the land into the river. Turbidity levels were generally low in the months of August, September, and October, with average turbidity measurements of 1.9, 2.0 and 4.1 NTUs respectively. During the May sampling event, the average turbidity measurement was 25.0 NTUs, a six-fold increase over the readings in October. As the river level dropped in June, so did the turbidity, with an average measurement of 4.8 NTUs. The Alaska state water quality standard for turbidity requires natural running waters not exceed an increase of 25 NTUs above natural conditions.

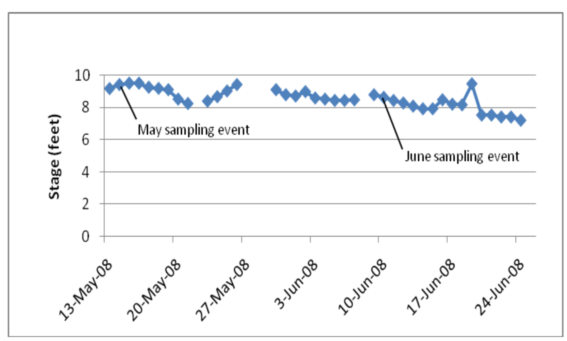
Fecal coliform bacteria

Fecal coliform bacteria are used as indicators of possible sewage contamination, as they are commonly found in human and other animal feces. The Alaska state water quality standards for fecal coliform (drinking water) state that the geometric mean for a 30-day period should not exceed 20 fecal colonies/100mL, with no more than 10% of the samples exceeding 40 fecal colonies/100mL. At least five samples should be collected over the 30-day period for the calculation of the geometric mean; our study design didn't allow for such a calculation.

The May 2008 sampling event showed a spike in fecal coliform concentrations throughout the lower Nushagak River. Fecal coliform bacteria concentrations ranged from a low of 36 fc/100ml near Koliganek to 91 fc/100ml above Koliganek near the opposite bank. River levels during that sampling event were relatively high (Figure 3). River levels were also relatively high during the October 2007 sampling event, yet fecal coliform concentrations were lowest throughout the river at that time, ranging from a low of 1 fc/100ml near the Mulchatna River mouth to a high of 18 fc/100ml along the affected bank downstream from the Mulchatna River mouth.

Figure 3. River Stage (observational) data for the Nushagak River at Ekwok.





Discussion

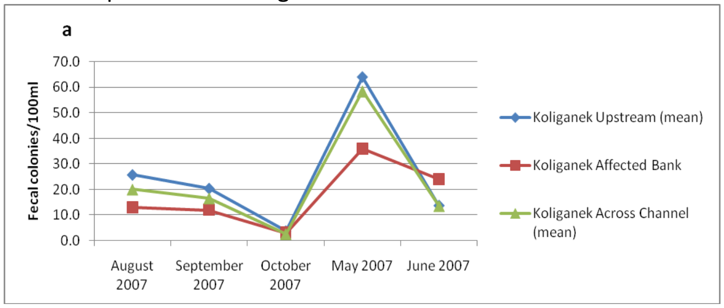
Fecal coliform bacteria results showed no pattern with relation to the three suspected sources: the village of Koliganek, the Mulchatna River, and the village of New Stuyahok. The study design for this project allowed for comparison of fecal coliform concentrations between both upriver and across channel control sites and the site just below the suspected input at the affected bank. At each of the three sites, fecal coliform bacteria concentrations were more abundant at the upriver and cross channel control sites than the affected bank site on at least three of the five collection dates (Figure 4). At the Koliganek site, the mean (from the five sampling events) at the affected bank downstream from the village (LNR-1a) was 17.6 fc/100ml, which was lower than the means from the upstream and across channel sampling locations at the Koliganek site (Table 2). The affected bank below the Mulchatna River site (LNR-2a) had a mean of 23.0 fc/100ml, compared to a mean of 22.8 fc/100ml at its upstream control sites and a mean of 22.0 fc/100ml at its across channel control sites. The affected bank site below New Stuyahok had a mean of 22.1 fc/100ml, compared to a mean of 22.5 fc/100ml at the upstream control sites and 20.2 fc/100ml at the across channel control sites. Sites that were located downstream from the affected bank sites showed similar patterns, with no significant differences between upstream and downstream sites. A complete list of the fecal coliform data can be found in Table A2.

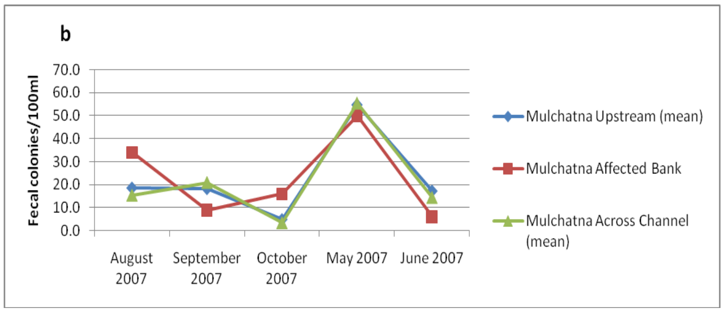
When viewing the fecal coliform data in relation to river gage data, the August and September 2007 sampling events occurred when river stage was relatively low (Figure 3). The river stage during the October 2007 and May and June 2008 sampling events was considerably higher. River stage was similarly high in both the October 2007 sampling event, when fecal coliform concentrations were at their lowest, and the May 2008 sampling event when fecal coliform concentrations were at their highest (on average, almost eight times higher).

Downstream sites were set up across channel to attempt to understand the downriver fate of bacteria. Since elevated fecal coliform levels were not detected at the three potential sources, an analysis of the downstream fate of the bacteria is unwarranted. When viewed with the other fecal coliform data, no meaningful trends emerge.

The data did not suggest that the three possible sources of fecal coliform identified in previous studies were contributing to the overall fecal coliform bacteria load in the river. Other potential sources of fecal coliform include wildlife, recreationists, and sport fishers and hunters. During the May 2008 sampling event when fecal coliform levels were at their highest, dozens of moose and waterfowl were seen by the sampling crew along the river. During the October 2007 sampling event, when fecal coliform levels were at their lowest, the sampling crew spotted no wildlife along the river (Appendix B). The May 2008 spike in fecal coliform concentrations was accompanied by a spike in turbidity (Table A1) and a three-fold drop in specific conductance (Table A4), suggesting that overland flow during spring break up may have been contributing to these spikes.

Figure 4. Fecal coliform bacteria concentrations at the three sites on the Nushagak River: a) near Koliganek, b) near the mouth of the Mulchatna River, and c) near New Stuyahok. FC concentrations from three upstream samples (affected bank, mid-channel and unaffected bank) were averaged and the mid-channel and unaffected bank samples were averaged for the across channel sites.





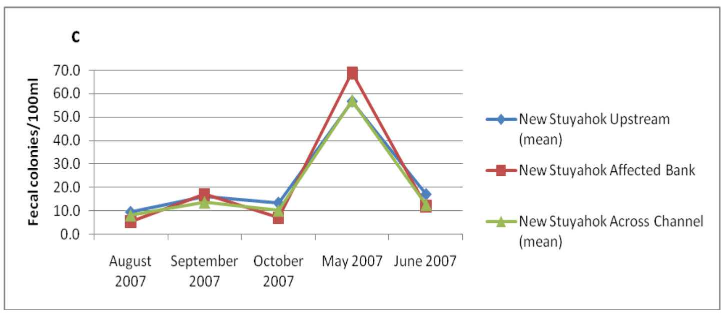


Table 2. Fecal coliform bacteria concentrations in fc/100ml by site as compared to upriver and cross channel control sites. The affected bank site is directly downriver from a potential input of fecal coliform. Upstream sites are upriver of the potential input; across channel sites are across the channel from potential inputs.

Sample date **Location**	**21 Aug 2007**	**6 Sept 2007**	**2 Oct 2007**	**14 May 2008**	**10 June 2008**	**Mean**
Koliganek Upstream (mean)	25.7	20.3	3.7	64.0	13.7	25.5
Koliganek Affected Bank	13.0	12.0	3.0	36.0	24.0	17.6
Koliganek Across Channel (mean)	20.0	16.5	2.5	58.5	13.5	22.2
Mulchatna Upstream (mean)	18.7	18.3	5.0	54.7	17.3	22.8
Mulchatna Affected Bank	34.0	9.0	16.0	50.0	6.0	23.0
Mulchatna Across Channel (mean)	15.5	21.0	3.5	55.5	14.5	22.0
New Stuyahok Upstream (mean)	9.4	16.0	13.3	56.7	17.0	22.5
New Stuyahok Affected Bank	5.4	17.0	7.0	69.0	12.0	22.1
New Stuyahok Across Channel (mean)	8.0	13.5	10.0	57.0	12.5	20.2

Between 1979 and 1986, the USGS recorded turbidity in the lower Nushagak River at Ekwok on 36 separate occasions (USGS, 2008). The May 2008 turbidity levels in the lower Nushagak River, on average, showed a three-fold increase from the highest turbidity reading of 8.1 NTUs on June 6, 1985 by the USGS over that time period (Table A1). The elevated turbidity in the river in May, accompanied with the spike in fecal coliform concentrations suggest that more intensive monitoring of the river immediately following breakup may be warranted.

It is also interesting to note that the sampling period when water quality was at its lowest did not correspond with one of the assumptions in our study design, which was that water quality would decline during peak human activity on the river (in August, September and June). During those times, fecal coliform concentrations in the lower Nushagak were relatively low as compared to the May sampling event, although they were not as low as they were in October, when recreational activities on the river had waned for the year. Again, the magnitude of the May spike in turbidity and corresponding spike in fecal coliform concentrations may warrant further investigation.

Recommendations for future monitoring

The results of this study add additional data to a growing water quality data set on the lower Nushagak River. In light of the results of this latest study, we make the following recommendations for future monitoring efforts:

1) Investigate the duration and intensity of the spike in turbidity and fecal coliform concentrations in the lower Nushagak River after breakup. Infrequent sampling to date has painted a hazy picture of the temporal changes in water quality in the river. More concentrated sampling efforts during times when conditions are most degraded may help to determine the causes of degradation.
2) Continue to involve local monitors and guides in water quality monitoring. These folks have developed expertise in collecting data and have invaluable knowledge of the region. They have the largest vested interest in monitoring Nushagak River water quality, as the river is the lifeblood of their communities.
3) Collection of bacteriological information, in addition to fecal coliform, to help determine the source(s) of the fecal bacteria in the river. Fecal coliform has many sources, including all warm-blooded wildlife, whereas *E. coli* may prove to be a better estimator of human sources of fecal bacteria in a waterbody.

Citations

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Appendix A—Water quality data

Table A1. Lower Nushagak River turbidity data (in NTUs). The affected bank on sites near Koliganek and New Stuyahok is the right bank (facing downstream); the affected bank for the sites near the mouth of the Mulchatna River is the left bank.

Site Description	Station ID	21Aug07	6Sept07	2Oct07	14May08	10Jun09	Mean
Above Koliganek	LNR-Ca	1.7	**1.7**	1.9	25.1	3.1	6.7
	LNR-C	1.1	**1.5**	2.2	20.6	4.5	6.0
	LNR-Cd	1.2	1.8	2.1	22.8	4.8	6.5
Below Koliganek	LNR-1a	2.0	1.7	4.7	26.0	3.4	7.6
	LNR-1	1.2	1.6	2.6	20.6	3.9	6.0
	LNR-1d	1.8	2.0	2.5	25.2	6.1	7.5
Downstream below Koliganek	LNR-d1a	1.9	1.5	2.4	27.2	3.1	7.2
	LNR-d1	1.4	2.0	2.1	23.9	5.6	7.0
	LNR-d1d	1.8	2.1	2.4	21.7	5.1	6.6
Above Mulchatna River mouth	LNR-u2a	2.2	2.4	3.3	27.3	6.0	8.2
	LNR-u2	1.6	1.9	2.2	25.8	5.2	7.3
	LNR-u2d	2.2	1.8	2.2	28.5	5.0	7.9
Below Mulchatna River mouth	LNR-2a	2.6	2.0	9.2	28.3	6.0	9.6
	LNR-2	2.9	1.7	3.1	21.8	5.1	6.9
	LNR-2d	1.4	1.6	2.4	24.6	4.1	6.8
Downstream below Mulchatna R mouth	LNR-d2a	2.6	2.1	8.5	21.1	4.0	7.7
	LNR-d2	1.6	1.6	6.5	24.9	5.0	7.9
	LNR-d2d	1.7	1.8	3.0	25.2	3.9	7.1
Above New Stuyahok	LNR-u3a	1.8	2.5	4.4	24.6	5.8	7.8
	LNR-u3	1.8	2.2	5.7	27.4	5.3	8.5
	LNR-u3d	2.1	2.1	6.2	28.2	4.9	8.7
Below New Stuyahok	LNR-3a	1.6	2.0	3.9	21.9	4.8	6.8
	LNR-3	2.1	2.0	4.9	28.4	5.6	8.6
	LNR-3d	2.1	2.1	6.1	28.1	5.1	8.7
Downstream below New Stuyahok	LNR-d3a	1.6	2.1	3.9	22.4	5.0	7.0
	LNR-d3	2.2	2.7	5.7	26.7	5.5	8.6
	LNR-d3d	2.6	2.4	6.1	28.1	4.7	8.8

Table A2. Fecal coliform data for the lower Nushagak River. Site codes ending in "a" are two feet from the affected bank; site codes ending in "d" are two feet from the unaffected bank; site codes ending in C, 1, or2 are mid-channel.

Fecal coliform data in fc/100ml							
Station ID	**21 Aug 07**	**6 Sept 07**	**2 Oct 07**	**14 May 08**	**10 June 08**	**Mean**	**Geometric Mean**
Sites near Koliganek							
LNR-Ca	20	21	6.0	42	15	20.8	17.4
LNR-C	27	17	3.0	59	14	24.0	16.3
LNR-Cd	30	23	2.0	91	12	31.6	17.2
LNR-1a	13	12	3.0	36	24	17.6	13.2
LNR-1	20	17	2.0	48	14	20.2	13.6
LNR-1d	20	16	3.0	69	13	24.2	15.4
LNR-d1a	27	13	2.0	52	14	21.6	13.9
LNR-d1	14	30	4.0	78	8	26.8	16.0
LNR-d1d	25	23	4.0	72	14	27.6	18.8
Sites near the mouth of the Mulchatna River							
LNR-u2a	13	20	6.0	62	18	23.8	17.7
LNR-u2	20	19	5.0	60	19	24.6	18.5
LNR-u2d	23	16	4.0	42	15	20.0	15.6
LNR-2a	34	9	16	50	6	23.0	17.1
LNR-2	20	30	6.0	55	18	25.8	20.4
LNR-2d	11	12	1.0	56	11	18.2	9.6
LNR-d2a	14	10	18	72	5	23.8	15.5
LNR-d2	29	11	14	56	20	26.0	21.9
LNR-d2d	16	20	6.0	61	10	22.6	16.4
Sites near New Stuyahok							
LNR-u3a	7	19	8.0	50	12	19.2	14.5
LNR-u3	14	17	17	58	14	24.0	20.1
LNR-u3d	7	12	15	62	25	24.2	18.2
LNR-3a	5	17	7.0	69	12	22.1	14.0
LNR-3	7	13	7.0	62	12	20.2	13.7
LNR-3d	9	14	13	52	13	20.2	16.1
LNR-d3a	5	25	11	52	10	20.7	15.1
LNR-d3	9	19	7.0	50	8	18.6	13.6
LNR-d3d	7	20	10	66	11	22.8	15.9

Table A3. Lower Nushagak River water temperature data (°C). The affected bank on sites near Koliganek and New Stuyahok is the right bank (facing downstream); the affected bank for the sites near the mouth of the Mulchatna River is the left bank.

Site Description	Station ID	21Aug07	Time	6Sept07	Time	2Oct07	Time	14May08	Time	10Jun09	Time
Above Koliganek	LNR-Ca	10.8	9:45	11.5	9:49	7.2	10:05	1.6	9:57	6.4	9:22
	LNR-C	10.8	9:55	11.4	9:54	7.1	10:17	1.7	10:10	6.7	9:30
	LNR-Cd	10.8	10:02	11.3	10:08	6.8	10:31	1.7	10:25	7.0	9:36
Below Koliganek	LNR-1a	10.8	10:12	11.4	10:18	7.0	10:42	1.7	10:39	6.4	9:44
	LNR-1	10.8	10:21	11.4	10:30	7.1	11:10	1.7	10:49	6.6	9:49
	LNR-1d	10.9	10:27	11.3	10:33	6.9	11:22	1.7	10:56	6.9	9:53
Downstream below Koliganek	LNR-d1a	10.9	10:33	11.5	10:51	7.1	11:33	1.7	11:04	6.5	9:59
	LNR-d1	10.9	10:39	11.4	10:58	7.1	11:41	1.7	11:13	6.7	10:03
	LNR-d1d	10.9	10:44	11.4	11:04	7.0	11:55	1.8	11:21	6.9	10:08
Above Mulchatna River mouth	LNR-u2a	11.0	11:19	11.4	11:28	7.0	12:47	2.1	11:45	7.1	10:40
	LNR-u2	10.9	11:30	11.5	11:40	7.2	12:53	1.9	11:56	6.9	10:48
	LNR-u2d	10.9	11:34	11.5	11:45	7.2	12:59	2.0	12:04	6.8	10:52
Below Mulchatna River mouth	LNR-2a	11.9	11:43	11.0	11:53	6.2	13:12	3.5	12:11	8.3	11:00
	LNR-2	11.1	11:50	11.5	12:00	7.0	13:19	2.4	12:20	7.0	11:07
	LNR-2d	10.9	11:56	11.5	12:09	7.3	13:31	2.1	12:26	6.9	11:11
Downstream below Mulchatna R mouth	LNR-d2a	11.9	12:03	11.0	12:16	6.3	13:42	3.6	12:40	8.3	11:20
	LNR-d2	11.4	12:09	11.2	12:24	7.1	13:55	2.3	12:46	7.4	11:24
	LNR-d2d	11.0	12:15	11.6	12:29	7.3	14:04	2.2	12:49	6.9	11:28
Above New Stuyahok	LNR-u3a	11.3	13:00	11.6	13:04	7.1	14:47	2.6	13:29	7.3	12:11
	LNR-u3	11.3	13:10	11.5	13:14	6.8	14:55	2.8	13:34	7.5	12:15
	LNR-u3d	11.7	13:17	11.5	13:24	6.6	15:02	3.3	13:42	8.0	12:21
Below New Stuyahok	LNR-3a	11.3	13:26	11.4	13:31	7.0	15:10	2.8	13:50	7.5	12:27
	LNR-3	11.3	13:31	11.5	13:36	6.9	15:19	2.8	13:55	7.5	12:32
	LNR-3d	11.6	13:38	11.5	13:45	6.7	15:26	3.3	14:02	8.0	12:37
Downstream below New Stuyahok	LNR-d3a	11.4	13:45	11.5	13:54	7.0	15:33	2.8	14:08	7.5	12:43
	LNR-d3	11.4	13:53	11.4	13:59	6.7	15:43	2.8	14:12	7.6	12:47
	LNR-d3d	11.8	14:01	11.7	14:10	6.7	15:53	3.3	14:22	8.0	12:52

Table A4. Lower Nushagak River pH data. NA=not available. The affected bank on sites near Koliganek and New Stuyahok is the right bank (facing downstream); the affected bank for the sites near the mouth of the Mulchatna River is the left bank.

Site Description	Station ID	21Aug07	Time	6Sept07	Time	2Oct07	Time	14May08	Time	10Jun09	Time
Above Koliganek	LNR-Ca	6.4	9:45	6.5	9:49	6.7	10:05	6.4	9:57	6.5	9:22
	LNR-C	6.4	9:55	6.2	9:54	6.5	10:17	6.4	10:10	6.7	9:30
	LNR-Cd	6.5	10:02	6.3	10:08	6.8	10:31	6.3	10:25	6.7	9:36
Below Koliganek	LNR-1a	6.5	10:12	6.4	10:18	NA	10:42	6.8	10:39	6.7	9:44
	LNR-1	6.4	10:21	6.2	10:30	7.1	11:10	6.5	10:49	6.6	9:49
	LNR-1d	6.5	10:27	6.2	10:33	6.5	11:22	6.4	10:56	6.6	9:53
Downstream below Koliganek	LNR-d1a	6.5	10:33	6.4	10:51	6.8	11:33	6.3	11:04	6.6	9:59
	LNR-d1	6.4	10:39	6.4	10:58	6.7	11:41	6.4	11:13	6.7	10:03
	LNR-d1d	6.6	10:44	6.5	11:04	6.6	11:55	6.4	11:21	6.6	10:08
Above Mulchatna River mouth	LNR-u2a	6.6	11:19	6.6	11:28	NA	12:47	6.7	11:45	6.6	10:40
	LNR-u2	6.5	11:30	6.4	11:40	NA	12:53	6.6	11:56	6.7	10:48
	LNR-u2d	6.6	11:34	6.6	11:45	NA	12:59	6.6	12:04	6.7	10:52
Below Mulchatna River mouth	LNR-2a	6.8	11:43	6.5	11:53	NA	13:12	6.8	12:11	6.9	11:00
	LNR-2	6.6	11:50	6.5	12:00	NA	13:19	6.6	12:20	7.0	11:07
	LNR-2d	6.6	11:56	6.7	12:09	NA	13:31	6.6	12:26	6.8	11:11
Downstream below Mulchatna R mouth	LNR-d2a	6.9	12:03	6.7	12:16	NA	13:42	6.8	12:40	6.9	11:20
	LNR-d2	6.6	12:09	6.5	12:24	NA	13:55	6.8	12:46	6.9	11:24
	LNR-d2d	6.7	12:15	6.7	12:29	NA	14:04	6.7	12:49	6.8	11:28
Above New Stuyahok	LNR-u3a	6.7	13:00	6.8	13:04	NA	14:47	6.7	13:29	6.8	12:11
	LNR-u3	6.7	13:10	6.6	13:14	NA	14:55	6.7	13:34	6.8	12:15
	LNR-u3d	6.9	13:17	7.0	13:24	NA	15:02	6.8	13:42	6.8	12:21
Below New Stuyahok	LNR-3a	6.9	13:26	6.9	13:31	NA	15:10	6.6	13:50	6.8	12:27
	LNR-3	6.7	13:31	6.7	13:36	NA	15:19	6.7	13:55	6.8	12:32
	LNR-3d	6.9	13:38	6.9	13:45	NA	15:26	6.7	14:02	6.8	12:37
Downstream below New Stuyahok	LNR-d3a	6.8	13:45	7.1	13:54	NA	15:33	6.7	14:08	6.9	12:43
	LNR-d3	6.7	13:53	6.7	13:59	NA	15:43	NA	14:12	6.8	12:47
	LNR-d3d	7.0	14:01	7.3	14:10	NA	15:53	6.7	14:22	6.8	12:52

Table A5. Lower Nushagak River specific conductance data (µS/cm). NA=not available. The affected bank on sites near Koliganek and New Stuyahok is the right bank (facing downstream); the affected bank for the sites near the mouth of the Mulchatna River is the left bank.

Site Description	Station ID	21Aug07	Time	6Sept07	Time	2Oct07	Time	14May08	Time	10Jun09	Time
Above Koliganek	LNR-Ca	62	9:45	63	9:49	62	10:05	15	9:57	51	9:22
	LNR-C	63	9:55	62	9:54	62	10:17	18	10:10	NA	9:30
	LNR-Cd	63	10:02	62	10:08	61	10:31	18	10:25	49	9:36
Below Koliganek	LNR-1a	62	10:12	62	10:18	59	10:42	15	10:39	51	9:44
	LNR-1	63	10:21	63	10:30	62	11:10	18	10:49	50	9:49
	LNR-1d	63	10:27	62	10:33	62	11:22	18	10:56	49	9:53
Downstream below Koliganek	LNR-d1a	63	10:33	63	10:51	60	11:33	15	11:04	51	9:59
	LNR-d1	63	10:39	63	10:58	62	11:41	18	11:13	50	10:03
	LNR-d1d	63	10:44	62	11:04	62	11:55	18	11:21	49	10:08
Above Mulchatna River mouth	LNR-u2a	63	11:19	62	11:28	60	12:47	18	11:45	49	10:40
	LNR-u2	63	11:30	63	11:40	62	12:53	17	11:56	50	10:48
	LNR-u2d	62	11:34	63	11:45	61	12:59	17	12:04	50	10:52
Below Mulchatna River mouth	LNR-2a	70	11:43	67	11:53	61	13:12	21	12:11	58	11:00
	LNR-2	65	11:50	63	12:00	60	13:19	19	12:20	50	11:07
	LNR-2d	62	11:56	63	12:09	62	13:31	17	12:26	50	11:11
Downstream below Mulchatna R mouth	LNR-d2a	70	12:03	67	12:16	61	13:42	21	12:40	58	11:20
	LNR-d2	66	12:09	65	12:24	61	13:55	18	12:46	51	11:24
	LNR-d2d	62	12:15	63	12:29	62	14:04	17	12:49	50	11:28
Above New Stuyahok	LNR-u3a	64	13:00	NA	13:04	61	14:47	16	13:29	50	12:11
	LNR-u3	65	13:10	64	13:14	58	14:55	18	13:34	51	12:15
	LNR-u3d	66	13:17	64	13:24	61	15:02	20	13:42	53	12:21
Below New Stuyahok	LNR-3a	65	13:26	64	13:31	59	15:10	18	13:50	51	12:27
	LNR-3	65	13:31	64	13:36	61	15:19	17	13:55	51	12:32
	LNR-3d	66	13:38	64	13:45	61	15:26	20	14:02	53	12:37
Downstream below New Stuyahok	LNR-d3a	65	13:45	64	13:54	60	15:33	18	14:08	51	12:43
	LNR-d3	66	13:53	64	13:59	61	15:43	19	14:12	51	12:47
	LNR-d3d	66	14:01	65	14:10	61	15:53	20	14:22	53	12:52

Table A6. Lower Nushagak River dissolved oxygen data (milligrams per liter/percent saturation). The affected bank on sites near Koliganek and New Stuyahok is the right bank (facing downstream); the affected bank for the sites near the mouth of the Mulchatna River is the left bank.

Site Description	Station ID	21Aug07	Time	6Sept07	Time	2Oct07	Time	14May08	Time	10Jun09	Time
Above Koliganek	LNR-Ca	10.7/97	9:45	10.6/97	9:49	10.9/91	10:05	12.3/88	9:57	12.3/100	9:22
	LNR-C	10.7/97	9:55	10.6/97	9:54	11.1/92	10:17	12.5/89	10:10	12.1/99	9:30
	LNR-Cd	10.8/97	10:02	10.7/97	10:08	11.3/93	10:31	12.3/88	10:25	12.0/98	9:36
Below Koliganek	LNR-1a	10.8/97	10:12	10.6/98	10:18	11.0/91	10:42	12.1/87	10:39	12.3/100	9:44
	LNR-1	10.8/97	10:21	10.7/98	10:30	11.1/92	11:10	12.2/88	10:49	12.6/103	9:49
	LNR-1d	10.7/97	10:27	10.8/98	10:33	11.2/92	11:22	12.2/88	10:56	12.2/100	9:53
Downstream below Koliganek	LNR-d1a	10.8/98	10:33	10.8/99	10:51	11.2/93	11:33	12.0/86	11:04	12.3/100	9:59
	LNR-d1	10.7/97	10:39	10.5/96	10:58	11.2/93	11:41	12.6/90	11:13	12.2/100	10:03
	LNR-d1d	10.7/97	10:44	10.5/96	11:04	11.4/94	11:55	12.4/90	11:21	12.1/100	10:08
Above Mulchatna River mouth	LNR-u2a	10.8/98	11:19	10.9/100	11:28	11.6/95	12:47	12.5/91	11:45	12.1/100	10:40
	LNR-u2	10.7/97	11:30	10.7/98	11:40	11.3/93	12:53	12.6/91	11:56	12.1/100	10:48
	LNR-u2d	10.8/98	11:34	10.3/99	11:45	11.5/95	12:59	12.2/88	12:04	12.2/100	10:52
Below Mulchatna River mouth	LNR-2a	10.3/96	11:43	10.6/96	11:53	11.6/94	13:12	12.0/90	12:11	11.5/98	11:00
	LNR-2	10.7/98	11:50	10.8/99	12:00	11.4/94	13:19	12.5/92	12:20	12.0/99	11:07
	LNR-2d	10.8/97	11:56	10.8/99	12:09	11.5/96	13:31	12.1/88	12:26	12.4/102	11:11
Downstream below Mulchatna R mouth	LNR-d2a	10.3/95	12:03	10.8/98	12:16	11.6/94	13:42	12.0/91	12:40	11.5/98	11:20
	LNR-d2	10.6/97	12:09	10.8/99	12:24	11.5/95	13:55	12.4/91	12:46	12.0/100	11:24
	LNR-d2d	10.8/98	12:15	10.9/100	12:29	11.6/96	14:04	12.2/89	12:49	12.2/100	11:28
Above New Stuyahok	LNR-u3a	11.0/100	13:00	11.3/103	13:04	11.9/98	14:47	12.9/95	13:29	12.3/102	12:11
	LNR-u3	10.7/98	13:10	10.7/98	13:14	11.6/95	14:55	12.4/91	13:34	12.0/100	12:15
	LNR-u3d	10.9/101	13:17	11.4/104	13:24	11.7/95	15:02	12.3/91	13:42	11.8/100	12:21
Below New Stuyahok	LNR-3a	11.0/101	13:26	11.4/105	13:31	11.9/98	15:10	12.3/91	13:50	12.2/102	12:27
	LNR-3	10.7/98	13:31	10.8/99	13:36	11.6/95	15:19	12.7/93	13:55	12.1/101	12:32
	LNR-3d	10.9/100	13:38	11.2/103	13:45	11.7/95	15:26	12.2/91	14:02	11.8/100	12:37
Downstream below New Stuyahok	LNR-d3a	11.1/102	13:45	11.6/106	13:54	11.8/98	15:33	12.3/91	14:08	12.6/104	12:43
	LNR-d3	10.8/99	13:53	10.9/100	13:59	11.6/95	15:43	12.2/90	14:12	12.0/100	12:47
	LNR-d3d	11.0/102	14:01	11.5/106	14:10	11.7/96	15:53	12.2/92	14:22	11.8/100	12:52

Appendix B—Wildlife and other observations

Site	Date	Wildlife and other Observations
LNR-1	21Aug07	Osprey
LNR-1a	21Aug07	Surface scum at this site
LNR-d1a	21Aug07	Small creek coming in ~20 meters below sample site. Small pieces of foam and surface scum at site.
LNR-d1	21Aug07	Foam drifting on port side of boat
LNR-2	21Aug07	Belted kingfisher
LNR-u2d	21Aug07	Scum floating by at site
LNR-d2	21Aug07	Scum going down river
LNR-d2d	21Aug07	scum/foam at this site
LNR-3	21Aug07	No wildlife observed
LNR-u3d	21Aug07	Trash on bank
LNR-d3a	21Aug07	Scum/foam buildup along upstream side of the boat
LNR-1	6Sept07	No wildlife observed. When leaving Ekwok the Nushagak River had a lot of foam due to lots of rainy weather the last few days
LNR-2	6Sept07	No wildlife observed.
LNR-3	6Sept07	Osprey
LNR-1	2Oct07	No wildlife observed. River higher than last two trips (average for this time of year, per Luki). Little bits of foam coming down the river.
LNR-1a	2Oct07	pH readings here highly variable. pH higher here than in the middle channel. Variable pH may be a result of fluxuating flows between water near the bank and the main river. Traveled upriver along the bank about 100 meters and measured pH at 7.00.
LNR-2	2Oct07	No wildlife observed. No foam coming down river here. Temperature reading on YSI meter is fluxuating (probably due to the mixing of the Mulchatna River into the Nushagak River).
LNR-3	2Oct07	No wildlife observed. No foam, no debris.
LNR-3a	2Oct07	Surface film visible on water.
LNR-d3a	2Oct07	Surface film still present. Some (minimal) bubbles/foam.
LNR-d3d	2Oct07	Couldn't access bank due to sandbar. Took sample at the edge of sandbar. Sandbar extends about 75 feet.
LNR-1	14May08	Saw 16 moose on our way upriver from Ekwok. Saw dozens of ducks, one swan and several geese. Foam on the water; water really high.
LNR-2	14May08	On the way down from Koliganek we saw dozens of ducks and a pair of swans.
LNR-u2a	14May08	A bald eagle flew overhead.
LNR-d3a	14May08	A moose on the bank just down river.

LNR-3	14May08	Saw a pair of eagles and dozens of ducks on trip downriver from the Mulchatna. Eight moose also spotted.
LNR-u3a	14May08	Sample collected 35 feet from bank due to shallow water.
LNR-1	10Jun09	Saw dozens of ducks on our way upriver. Also saw 8 moose.
LNR-2	10Jun09	Saw ducks, terns, swallows and one moose between Koliganek and Mulchatna.
LNR-m2m	10Jun09	Kingfishers flying by.
LNR-d2a	10Jun09	We collected sample 45 feet downstream from site due to shallow water at site.
LNR-3	10Jun09	Saw ducks, one moose, and shorebirds on the way downriver to New Stuyahok.
LNR-u3a	10Jun09	Sample collected 15 feet from bank because there is a sandbar almost exposed.
LNR-d3a	10Jun09	Noticeable scum on water