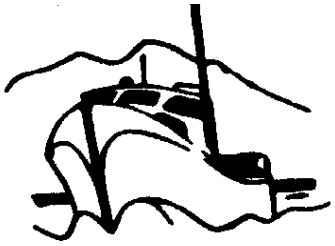
Bristol Bay Native Association



Continuation of Fecal Coliform and Water Quality Assessment of the Lower Nushagak River (Year 2: Data Collection, Analysis, & Report)

State of Alaska Department of Environmental Conservation
Project ACWA 07-03

Final Report

July 2006 to June 2007

Bristol Bay Native Association

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Final report

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We wish to thank Susan Flensburg who managed BBNA's ACWA grant and coordinated all logistics for this project. We also thank Pauline and Luki Akelkok, Sr. (Maaluq's Lodge, NMWC), Tina Carr (NMWC), Daniel Chythlook (NMWC), and Lisa Ferber (Zender Environmental) for completing two successful water quality sampling trips during this grant period. Bill Rice, U.S. Fish and Wildlife Service (USFWS), again provided helpful guidance and feedback on the sample design and results as Project QA Officer. Tim Stevens and Laura Eldred (ADEC) also provided project guidance, particularly regarding best Coliscan method to use. Tom Cappiello and Joe Klein (both ADF&G), and Ben Balk and Dave Streubel (both NOAA) provided stream discharge measurements for the August and June samplings, respectively.

The technical advisory committee (TAC) for this project convened in November 2007 and provided helpful feedback regarding bioassessment options for the Lower Nushagak River. The TAC included: Bill Rice, Tim Stevens, Bob Ourso (USGS), Cindy Anderson (ADNR), Michael Wiedmer (ADF&G), Daniel Chythlook, Natalia Ishnook (NMWC), and Susan Flensburg (BBNA).

We appreciate the support of all who have helped to make this project successful and the opportunity to gather data necessary to help us make planning decisions for the Lower Nushagak River.

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Introduction

Background

The Nushagak River is a large, productive salmon-producing system in Southwest Alaska. Originating on the southwest flanks of the Alaska Range, the Nushagak watershed drains an extensive area of tundra, wetlands, and forested lowlands and eventually empties into Bristol Bay. The Nushagak River is one of the most important areas in the region for biodiversity conservation and is a priority water body for protection in the Alaska Clean Water Actions (ACWA) program. It is a key producer of five species of Pacific salmon and several species of freshwater fish. The Nushagak also provides extensive habitat for waterfowl and shorebirds, as well as terrestrial birds and mammals. Seven predominately Alaska 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.

Concerns about declining water quality due to increasing pressures to develop state, federal, and Native lands have grown in recent years, as have threats from non-point source pollution associated with community growth. Proposed revisions to the Alaska Department of Natural Resources (ADNR) Bristol Bay Area Plan and Nushagak Mulchatna Rivers Recreation Management Plan increase the potential for access to and development of state lands in the watershed. The number of Native allotments on the market has risen dramatically in recent years, and parcels are typically purchased for large sport fishing and hunting operations. These changes in land use practices create concerns about solid and human waste and waste water disposal methods at these remote sites. Most of the state-owned and state-selected land in the watershed is managed by ADNR. The Bureau of Land Management manages federal land, as well as ANCSA Corporation selected land and some state-selected land (NMWC, 2001).

In addition to local development concerns, deposits of copper, gold, molybdenum, and silver have been identified near the headwaters of the Koktuli River, within the Nushagak-Mulchatna watershed. Known as the Pebble Project, extensive drilling, environmental, socio-economic, and cultural studies are being conducted by consultants of Northern Dynasty Minerals, Inc. to develop plans for an open pit mine (NDM, 2006). Exploration results from Pebble have also spurred renewed interest in other mineral deposits in the upper Nushagak watershed, such as the Shotgun Hills gold deposit near the King Salmon River, a key tributary of the upper watershed. Concerns about potential impacts from the mine and increased development have been expressed by many people living in the Bristol Bay region.

Objectives of this project were two-fold. We continued the fecal coliform and water quality assessment that commenced in FY06 with a few modifications from lessons we learned. In addition, in August, we assessed several locations on the river for suitability for future bioassessment studies.

Previous Water Quality Assessments

The Alaska Soil and Water Conservation District and Bristol Bay Native Association partnered to complete the FY06 ACWA Fecal Coliform and Water Quality Assessment of the Lower Nushagak River. This study found the water quality of the river to be generally excellent and meet ADEC and USEPA water quality standards. The few exceptions to this statement include fecal coliform exceedances at three sites (one exceedance per site), dissolved iron exceedances at four sites, and one instance of elevated dissolved oxygen content. Petroleum sheens were searched for during the two sampling excursions, but none were found (AKSWCD, 2006).

Other studies previously conducted in the region include the U.S. Geological Survey stream discharge collection on the Nushagak River at Ekwok from 1975 to 1993 (USGS site 15302500). Water quality data was collected by the USGS at Ekwok from 1956 to 1986, and at New Stuyahok and Portage Creek from 1970 to 1971 (USGS, 2006). The Nushagak-Mulchatna Watershed Council sampled tributaries of the Nushagak for water quality and benthic macroinvertebrates approximately twice per year from 1999 to 2003 (data sheets on file at BBNA). A recent study (1999-2000) through the University of Alaska Fairbanks investigated mercury concentrations in surface water and muscle and liver tissues of salmon at several locations in Alaska including the Nushagak River at Portage Creek (Duffy and Zhang, 2001). Also in 1999, The University of Alaska Anchorage (ANHP and ENRI) and the Bristol Bay Native Association identified environmental indicators for the Nushagak/Mulchatna River watershed (Boggs et al., 1999). The bulk of the surface water quality indicators recommended were included in the current study. In addition, two current projects being conducted through the Bristol Bay Native Association include an instream flow reservation project on the Koktuli River, and a Traditional Use Area Conservation Planning Project, which will provide local knowledge on ecological observations and habitat values.

Study Area

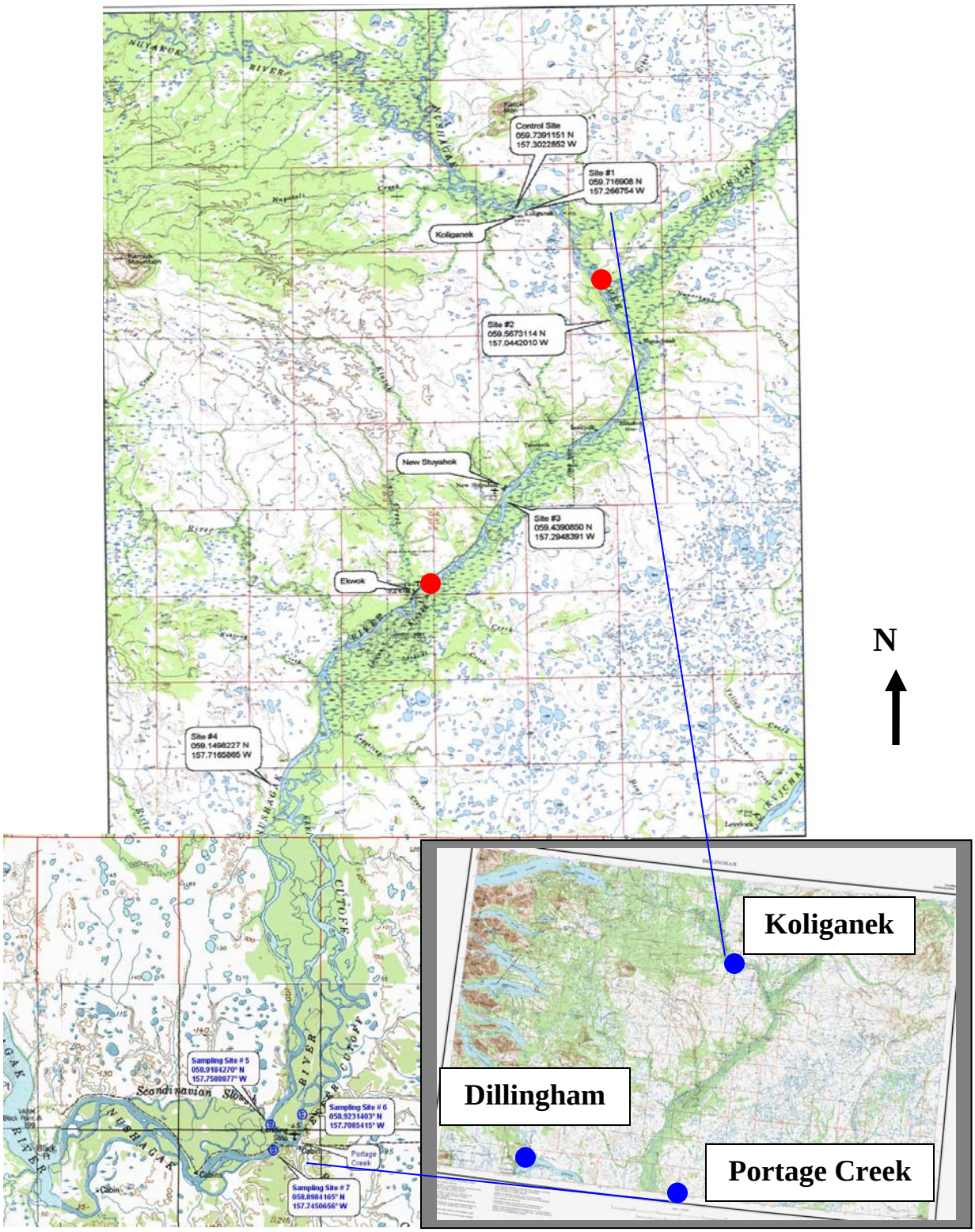
The climate of the Nushagak River is predominantly maritime, with average summer temperatures ranging from 37 to 66 ºF and winter temperatures from 4 to 30 ºF. Annual precipitation is approximately 20-35 inches. The river is generally ice-free from May/June until mid-November. Elevation of the sampling sites ranged from 200 feet near Koliganek to 30 feet at Portage Creek. The people living in the four Alaska Native villages within the study area are principally southern Yup'ik Eskimo who live a predominantly subsistence lifestyle (ACIS, 2006).

The lower Nushagak River sub-watershed (3,059,000 acres) was identified as the highest priority basin in the Nushagak Mulchatna watershed by the Nushagak Mulchatna Watershed Council (NMWC, 2001). The Council named the lower Nushagak the highest priority because of several reasons including 1) locals use this sub-watershed the most heavily compared to other sub-watersheds, 2) Alaska Native Claims Settlement Act (ANCSA) corporation lands and the majority of Native allotments in the watershed are located along this river corridor, 3) all five communities (Koliganek, New Stuyahok, Ekwok, Portage Creek, and Dillingham) are located in the lower Nushagak sub-watershed, 4) community development and inadequate infrastructures

have lead to increased pollution, and 5) the lower Nushagak receives the greatest amount of commercial recreation use, both in the number of permitted camp operations and client user days (NMWC, 2001).

This study sampled eight sites from Koliganek to Portage creek, which covered approximately 80 river miles of the lower Nushagak River.

Figure 1: Maps of Study Area



Methods

Study design

As in FY06, the study design of this project was again driven by the relatively short hold time for fecal coliform samples to reach the laboratory and be prepared for analysis (30 hours). All other laboratory-analyzed parameters had hold times of at least 48 hours. Samples were collected in the mornings between approximately 8 a.m. and 3 p.m. and then shipped immediately from Ekwok to Dillingham. From Dillingham, samples were shipped to the Anchorage laboratory (SGS Environmental) on the evening flight, and the samples transported via courier the following morning to SGS. A second method to determine fecal coliform bacteria concentrations was employed with samples being incubated and enumerated in Ekwok. All data were entered into BBNA's DASLER-X database (modified from the AKSWCD's database) and uploaded into STORET.

Sample site selection

In summer 2005, Bristol Bay Native Association Environmental Program staff worked with Choggiung Limited and the Nushagak Mulchatna Watershed Council to identify appropriate sample sites on Native lands on the lower Nushagak River for the FY06 study. Additionally, Alaska SWCD staff worked with ADNR personnel and resources to identify potential sampling locations on State-owned lands. With this information, eight sample sites were identified. Three sites were selected in the vicinity of Portage Creek, which hosts relatively high concentrations of guide camps for both fishing and hunting. One site was chosen as a control site above the village of Koliganek, and two sites located downstream of villages (Koliganek and New Stuyahok) were selected for comparison with the sites downstream of guide camps. Two additional sites were chosen, the mouth of the Mulchatna River, and Keeper's Cutoff, where the main stem of the Nushagak breaks into two distinct channels until re-joining in Portage Creek.

A ninth site (Site 8) was established in June 2006 near the old USGS gage in Ekwok, and stream discharge was estimated at this time. Site 8 was only sampled for discharge once because the river is so wide that more sophisticated equipment is needed to gain an accurate measurement. Based on feedback from the February 2006 TAC meeting, a tenth site (Site 9) was added to the current study. Site 9 is located about one-half mile up the Mulchatna River from its mouth (near Site 2) and allows us to assess the Mulchatna's chemical inputs into the Nushagak before the two rivers merge.

A summary of the sample site locations is found in Table 1:

Table 1: Lower Nushagak River Sample Site Descriptions and GPS Coordinates

Sample Site	Location Description	Latitude (º)	Longitude (º)
Control	Above Koliganek	59.73209	-157.29866
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
Site 4	Above Keeper's Cutoff	59.15601	-157.72077
Site 5	Above Portage Creek, West channel	58.91524	-157.75339
Site 6	Above Portage Creek, East channel	58.91774	-157.72197
Site 7	Below Portage Creek, confluence of W. & E channels	58.90524	-157.74316
Site 8	Above Ekwok, old USGS gage (not sampled in FY07)	59.34866	-157.47411
Site 9	Mulchatna River (one-half mile upriver from Nushagak)	59.66745	-157.06916

At each of the eight sites, four sub-sites were identified (labeled subsites A-D). The main site was located at the place of highest stream flow, generally at its mid-point. Water two feet from the "affected" bank, meaning the side of the river that was most likely to be affected by a guide camp or village, was labeled subsite A. Subsite D was located two feet from the "unaffected" bank, and subsites B and C were half-way from the main site to the un/affected banks. Whenever possible, we tried to sample all subsites at each site. However, because transport times between sites were fairly lengthy and flights often depart Ekwok in early- to mid-afternoon, samples were often collected at only the main site and subsites A and D to reduce the risk of missing the outbound flight.

Monitoring frequency

Two two-day sampling events occurred during this project, each sampling day lasting approximately eight hours. Sampling events occurred on August 29-30, 2006 and June 5-6, 2007.

Parameter selection

Water quality parameters were selected to effectively assess fecal coliform concentrations for comparison to ADEC water quality standards per the ACWA identified actions. In addition, parameters common to most baseline water quality studies were also included in the study to document current conditions and screen for any exceedances. Selected parameters for surface water included:

Field

- Total coliform (Coliscan MF)
- *E. Coli* bacteria (Coliscan MF)
- Air Temperature (thermometer)
- Water Temperature (YSI 556)
- Dissolved oxygen (YSI 556)
- pH (YSI 556)
- Specific conductance (YSI 556)

- Oxidation-reduction potential (YSI 556)
- Turbidity (Hach 2100 P)

Laboratory
- Fecal coliform (SM 9222D)
- E. Coli & Total Coliform bacteria (SM 9223B "Quanti-tray")
- Total Nitrate-nitrogen (EPA 300.0)
- Alkalinity (SM 2320 B)
- Dissolved metals (EPA 200.8)
- Dissolved Hardness (calculation)

Measurement and Analytical Techniques

Field measurements and laboratory analyses followed ADEC- and/or EPA-approved methods whenever possible for credibility and continuity. The list of selected parameter above briefly identifies the methods used; additional details can be found in BBNA's quality assurance plan for this project. SGS Environmental Services, an ADEC-approved lab, was selected to perform the lab analysis for this project. The Coliscan MF method for *E. Coli* and Total Coliform analysis is EPA-approved and allows us to collect up to 30 mL of sample water instead of up to 5 mL as with the Coliscan Easygel. This greater sample volume reduces the chance of "false negative" results, generates less extrapolation error, and is suitable for the bacteria concentrations generally encountered on the Lower Nushagak River. Field and lab sample results are in Appendix A.

Data Management

Field data sheets printed on Rite in the Rain paper were used to record field measurements and observations. Data sheets were checked to ensure complete-ness before departing each sample site. Data from field sheets were entered into a Microsoft Excel spreadsheet upon return to Anchorage, where precision and accuracy checks were made. Any data that did not meet data quality objectives were flagged in the Excel spreadsheet. Laboratory data were reviewed upon receipt and also entered into the Excel spreadsheet using SGS Environmental's "Data View" Access-based data retrieval program. Data were next checked by the project QA officer and then qualified data were entered into BBNA's DASLER-X database which is included with this report.

Quality Assurance

The quality assurance plan for this project was approved by ADEC prior to any data collection. The project QA officer and Technical Advisory Committee made recommendations to the study design of this project to ensure its quality and success. An ADEC-laboratory was contracted for this project. All field measurements made with the YSI 556 multi-probe instrument (dissolved oxygen, water temperature, pH, specific conductance, and ORP) were made in duplicate with 10% distilled water blanks. An exception to this occurred in the June sampling, when only 3.5% blanks were collected due to a miscalculation. Ten percent blanks and duplicates were made for all turbidity and Coliscan MF measurements/samples. One site was duplicated for all laboratory analyses for both sample excursions. Duplicate measurements are included in Appendix A with the water quality data. Quality assurance distilled water blank results and instrument calibration

logs are included in Appendix B. BBNA's quality assurance plan for this study outlines data management and quality assurance protocols for this study in further detail.

Water Quality Data Results

Selected water quality data are presented here, and all data are available in Appendix A. Data presented in Appendix A were entered into the DASLER-X database accompanying this report unless struck. Results from the FY06 ACWA Nushagak project as well as historic data collected by USGS at Ekwok (May to through September samples only; USGS, 2006) will be used for comparison to this study's results whenever comparable analytical methods were used.

Fecal Coliform

Fecal coliform concentrations met ADEC drinking water quality standards (geometric mean of < 20 CFU/100 mL in a 30 day period) at all sample locations during this study. In FY06, three sites had fecal coliform concentrations that exceeded the standards once at each site. Historic USGS fecal coliform data collected between May 1979 to August 1986 showed a range of 1 to 40 CFU/100 mL. All samples collected in the current study also fall within this range. Note that all fecal coliform lab samples were collected at subsite A at each site (nearest the "affected" bank).

Table 2: Laboratory Fecal Coliform Results

Laboratory Fecal Coliform Results		
	Fecal Coliform forming units per 100 mL	
Site	Aug-06	Jun-07
Control a	3	0
1a	13	1
2a	11	13
3a	15	0
4a[1]	12	0
5a	6	1
6a[2]	6	2
7a	8	0

Notes:
1) August 2006 Site 4a value is an average of two samples: 14 and 10 CFU/100 mL
2) June 2007 Site 6a value is an average of two samples: 2 and 2 CFU/100 mL

Laboratory and Coliscan MF *E. Coli* tests showed better correlation in the June samples than in August (Figures 2a & 2b). Concentrations of *E. Coli* were generally higher than the laboratory fecal coliform results. One distilled water blank from Site 6 in August 2006 had contamination. Because it was the only contaminated blank in the study, we believe it was not caused by systematic error.

Figure 2a: Laboratory and Coliscan MF *E. Coli* concentrations at subsites A, August 2006

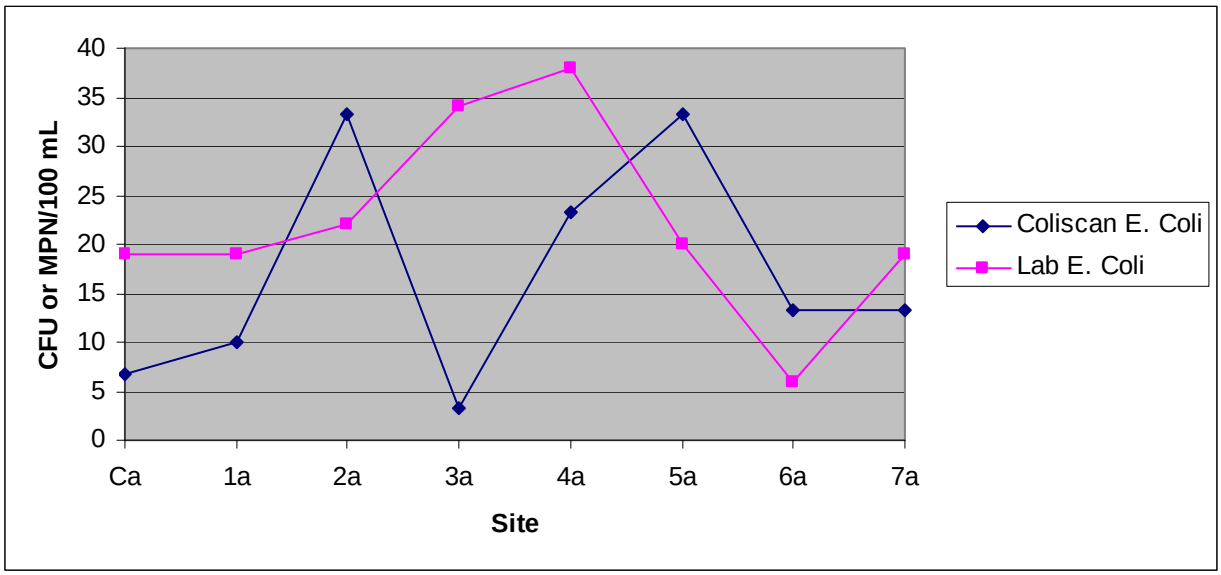
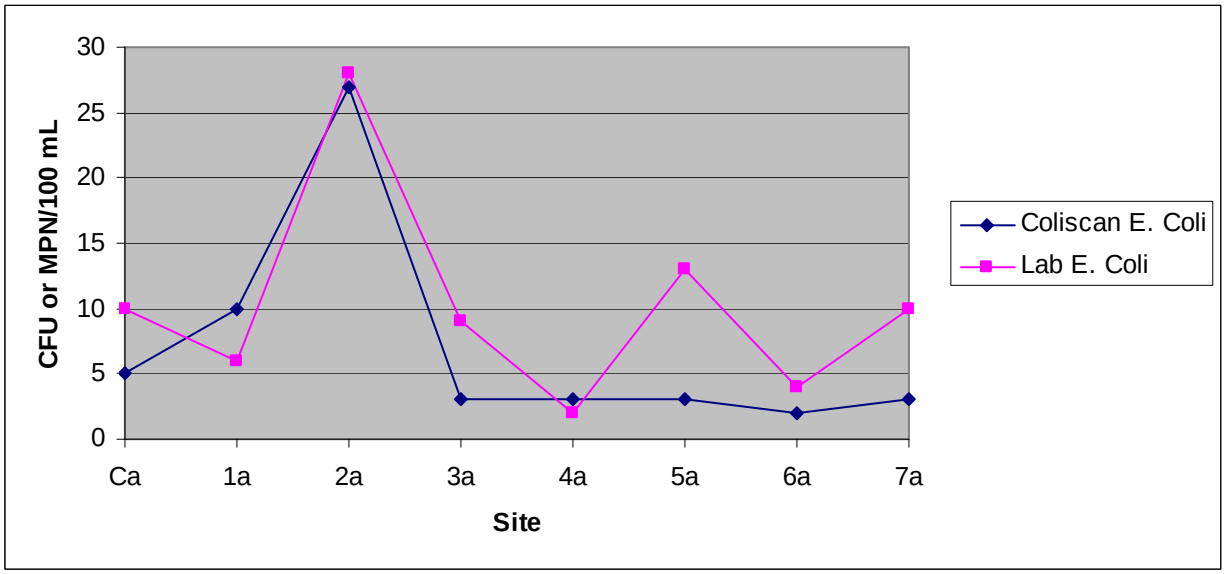


Figure 2b: Laboratory and Coliscan MF *E. Coli* concentrations at subsites A, June 2007



Water Quality Assessment

Additional water quality parameters measured from the lower Nushagak River met almost all ADEC water quality standards for drinking water, drinking water maximum contaminants levels, and chronic aquatic life criteria. See Appendix C for further details on the relevance of each water quality parameter.

Field

Water Temperature: Water temperature of the Nushagak River ranged from an average of 10.6 to 11.8 in ºC August 2006, and from 5.5 to 9.2 ºC in June 2007. Average air temperatures during the sampling events were 11.7 and 9.7 ºC, respectively. All results therefore meet the ADEC water quality standard for drinking water (15ºC), as well as the more strict water supply aquaculture standard of 13ºC for spawning areas and egg and fry incubation. FY06 water temperatures ranged from 11.6 to 12.3 ºC in August, and from 6.0 to 9.1 ºC in June, and so were very similar to results of the current study. Historic USGS water temperature data ranged from 1.5 to 16.5 ºC (May through September, 1956 to 1986), and data from this study fall within this temperature range.

Dissolved oxygen: Dissolved oxygen ranged from 9.9 mg/L (90.5 % saturation) to 10.9 mg/L (99.6 % saturation) in August 2006, and from 11.3 mg/L (93.9 % saturation) to 13.3 mg/L (96.1 % saturation) in June 2007. ADEC water quality standards for growth of fish, shellfish, other aquatic life, and wildlife state that waters that are home to anadromous or resident fish should be between 7 -17 mg/L and should never exceed 110% of saturation. Therefore, all dissolved oxygen levels in this study meet these standards. In FY06, dissolved oxygen ranged from 9.9 mg/L (91.2 % saturation) to 12.3 mg/L (115.2 % saturation) in August, and from 11.2 mg/L (90.4 % saturation) to 12.9 mg/L (109.9 % saturation) in June. Historic USGS dissolved oxygen data ranged from 9.8 to 13.0 mg/L and 88 to 104% saturation (May through September, 1979 to 1986).

pH: The pH ranged from 6.2 to 7.1 in August 2006, and from 6.1 to 7.2 in June 2007. ADEC drinking water quality standards' acceptable range is pH 6.0 to 8.5, so all results of the current study fall within this range. In FY06, pH ranged from 6.9 to 7.4 in August, and from 5.7 to 6.6 in June. Historic USGS pH data ranged from 6.1 to 7.6 (May through September, 1956 to 1986). Note that the distilled water blank samples in August 2006 for the control site and Site 2 were too low because a container other than the YSI calibration cup was used in calibration. Upon realizing this, all distilled water blank measurements were taken using only the calibration cup.

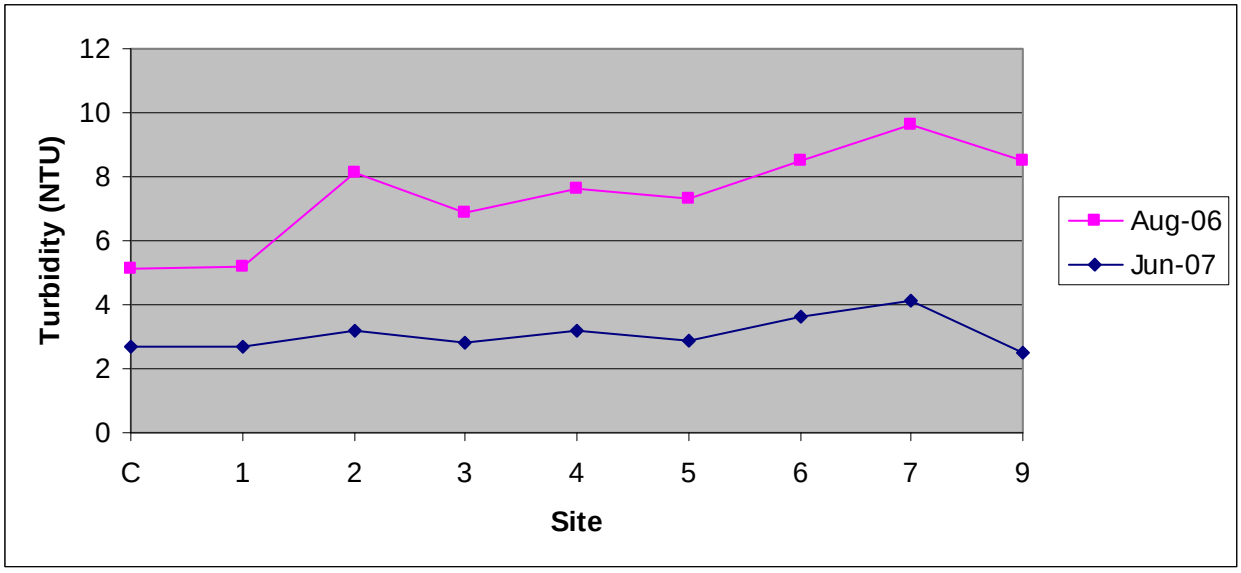
Specific Conductance: Specific conductance results ranged from 59 to 73 µS/cm in August 2006, and from 34 to 43 µS/cm in June 2007. There are no ADEC water quality standards for specific conductance. In FY06, specific conductance results varied little, from 63 to 64 µS/cm in August, and from 34 to 43 µS/cm in June. Historic USGS data for specific conductance ranged from 24 to 65 µS/cm (May through September, 1956 to 1986).

Oxidation-Reduction Potential (ORP): ORP ranged from 77 to 238 mV in August 2006 and from 201 to 300 mV in June 2007. There are no ADEC water quality standards for ORP. In

FY06, measurements for ORP were lower in August, ranging from 167 to 209 mV, compared to 292 to 626 in June. There are no historic USGS data for oxidation-reduction potential.

Turbidity: Turbidity values were generally low, ranging from 2.2 to 6.8 NTU (average 4.3 NTU) in August 2006, and in June 2007 from 2.1 to 6.7 NTU (average 3.1 NTU). Figure 3 shows a general trend of increasing turbidity from upriver (control site) to downriver (Site 7) with slight increases at Site 2 near the mouth of the Mulchatna River. ADEC standards for turbidity stipulate that drinking water is to be no more than 5 NTU above natural conditions when natural turbidity is < 50 NTU. In FY06, turbidity values were also low, ranging from 2.3 to 10.5 NTU (average 3.9 NTU) in August, and in June from 3.9 to 8.1 NTU (average 6.0 NTU). Historic USGS data for turbidity ranged from 0 to 8.1 NTU (average 2.9; May through September 1979 to 1986). Therefore, turbidity values found in the current study fall within FY06 and historic USGS ranges. Note that August 2006 Site 4, replicate 1 turbidity value exceeded the precision objective as stated in BBNA's QAPP, so the average value for this site (4.4 NTU) does not include this value.

Figure 3: Turbidity of the Lower Nushagak River.
(Note that Site 9 is located on the Mulchatna River, approximately one-half mile upstream of its mouth.)



Stream Discharge: No stream discharge measurements were taken in the current study, and there are no ADEC standards for discharge. In FY06, stream discharge was estimated to be 33.361 CFS at the old USGS gage site at Ekwok using a Global Flow meter. Historic USGS data show that measurements were made at this site several times per year from 1978 to 1993. The average of the 16 measurements made during this time that were closest to June 13 was 40,919 CFS (range 23,600 to 74,000 CFS).

Stream stage data, measured daily by a National Oceanic and Atmospheric Administration (NOAA) volunteer at Ekwok, was obtained from NOAA staff (NOAA, 2007). Figures 4a and 4b

show relative stage data for 2006 and 2007 (flood stage is 16 feet) with discharge measurements made by ADF&G (August) and NOAA-NWS (June) noted in the captions.

Figure 4a: NOAA Nushagak River Stage Data at Ekwok (2006).
On August 6, 2006, ADF&G measured stream discharge using ADCP to be 21,690 cfs, correlating to a stage of 5.58 ft. The current study sampled August 29-30. Though stream stage was not recorded on these dates, it was likely approximately 6 ft.

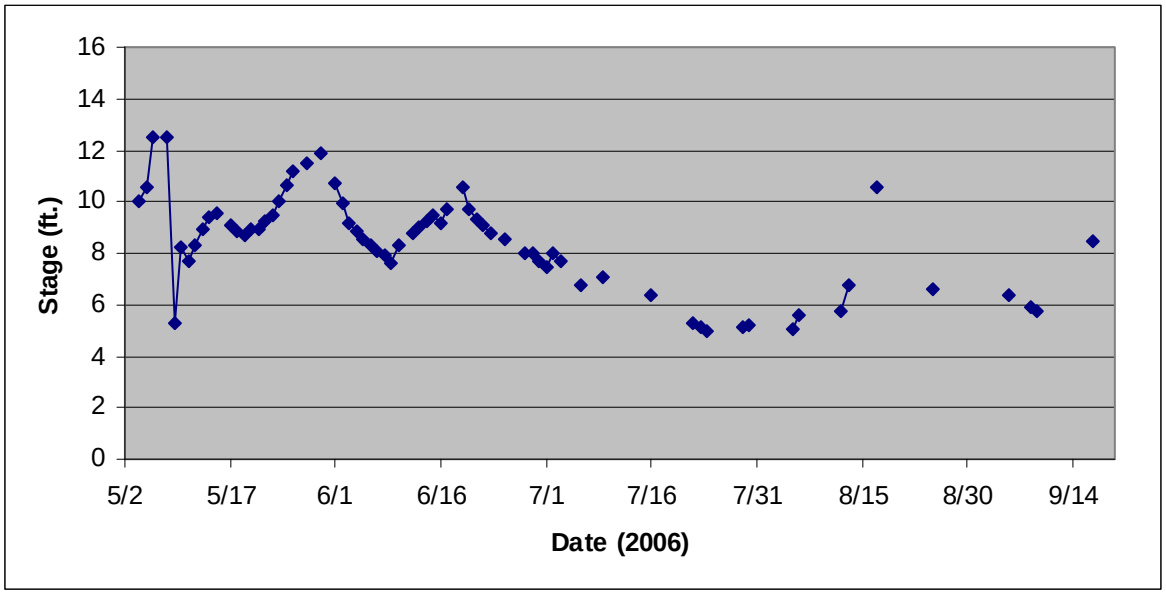
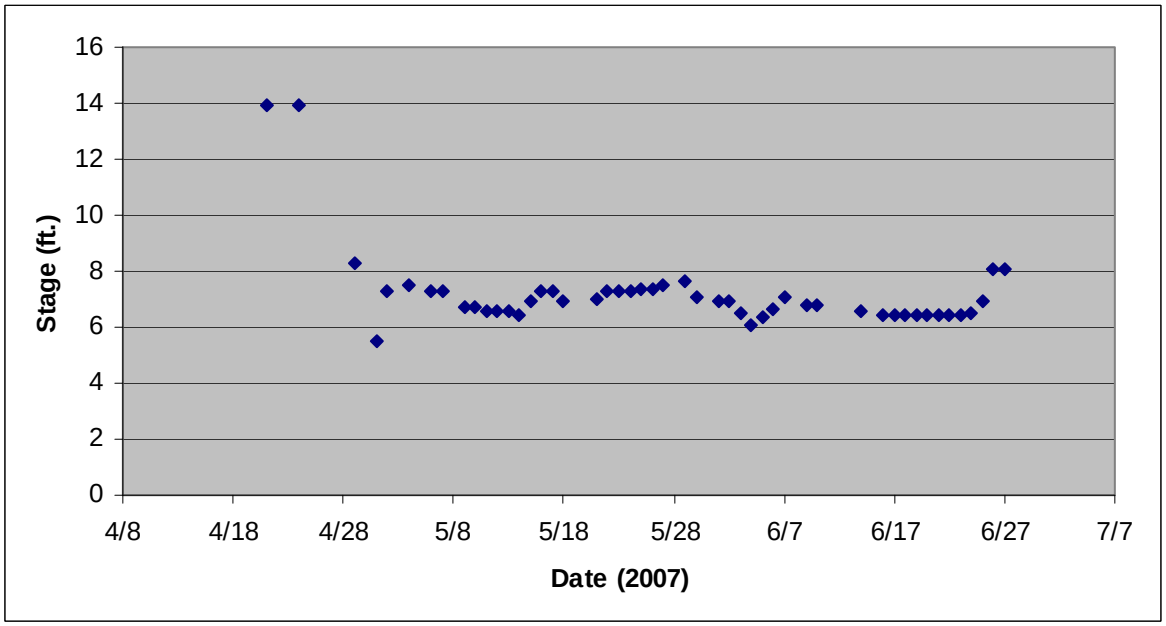


Figure 4b: NOAA Nushagak River Stage Data at Ekwok (2007).
On June 4, 2007, NOAA-NWS personnel measured stream discharge to be 30,914 cfs, correlating to a stage of 6.1 ft. The current study sampled June 5-6.



Laboratory

Total Nitrate-nitrogen: Total nitrate-nitrogen values were below or barely above the laboratory detection limit of 0.100 mg/L in both August 2006 and June 2007. The highest level was found in June at Site 2, 0.249 mg/L. These values are well below the ADEC drinking water MCL of 10 mg/L. In FY06, total nitrate-nitrogen values were also lower in August than in June, ranging from < 0.100 to 0.201 mg/L and 0.128 to 0.197 mg/L, respectively. Historic USGS unfiltered Total Nitrogen as Nitrate ranged from 0.9 to 4 mg/L (May through September 1979 to 1981). Total nitrate-nitrogen data collected in the current study and in FY06 were clearly lower than the USGS data in Ekwok. It is possible that the USGS collection site at Ekwok was simply higher in nitrate-nitrogen, perhaps from groundwater inputs, or that the analytical techniques are not comparable.

Total Alkalinity: Total alkalinity values ranged from 24.0 to 28.0 mg/L in August 2006, and from 22.0 to 24.0 mg/L in June 2007. In FY06, total alkalinity values ranged from 25.0 to 26.5 mg/L in August, and from 22.0 to 24.0 mg/L in June. These data meet the chronic aquatic life criteria of a *minimum* of 20 mg/L (20,000 µg/L) for total alkalinity. Historic USGS unfiltered alkalinity as calcium carbonate ranged from 18 to 20 mg/L (June through August 1979 to 1986). The current study and FY06 results found higher total alkalinity values than the USGS data at Ekwok, assuming that methods are comparable.

Total Hardness: Total hardness ranged from 26.3 to 28.0 mg/L in August 2006, and from 22.9 to 25.8 mg/L in June 2007. There are no ADEC standards for total hardness. In FY06, total hardness ranged from 24.4 to 27.5 mg/L in August, and from 20.0 to 22.4 mg/L in. Hardness values were calculated by the laboratory. Historic USGS data at Ekwok found hardness as mg/L calcium carbonate to range from 15 to 31 mg/L (May through September, 1956 to 1986). Therefore, total hardness data from the current study and from FY06 fall within this range.

Dissolved Metals: Results of the 27 dissolved metals and other elements are listed in Appendix A with corresponding maximum drinking water contaminant levels (MCL) and aquatic life criteria when available. Most of the analytes were undetectable at the practical quantitation limit (PQL) used by the laboratory. None of the 27 analytes exceeded ADEC drinking water MCLs nor aquatic life criteria, though one dissolved iron sample exceeded the national secondary drinking water standard, which is unenforceable. The secondary standard for iron is 300 µg/L, and the value that exceeded this standard was 328 µg/L (Site 7, August 2006). In FY06, four August samples were found to exceed the 300 µg/L standard; the highest level was 397 µg/L. Historic USGS data at Ekwok for filtered iron ranged from 74 to 230 µg/L (May through September, 1979 to 1986), which is below the PQL of the method used in the current study. Thus, the current study and FY06 results found a few dissolved iron values that were higher than historic USGS data, which may be an artifact of different analytical methods.

Benthic Macroinvertebrates

Two potential benthic macroinvertebrate sample sites were investigated during the August 2006 sampling trip. Sites were photographed, approximate measurements taken, and their streambed substrates examined for suitability for future benthic macroinvertebrate sampling. These sites are indicated by red dots on Figure 1, and GPS coordinates (WGS84) are as follows:

Table 3: GPS Coordinates of Potential Macroinvertebrate Sample Sites

Site	Latitude	Longitude
Between Koliganek and mouth of Mulchatna River	N 59.64178	W 157.12231
Just above Ekwok. Gravel bar on East side of channel	N 59.34866	W 157.47411

A technical advisory committee (TAC) meeting was held in November 2006 to discuss findings of the investigation and to give feedback regarding suitability of benthic macroinvertebrate sampling on the Lower Nushagak River. The TAC concluded that because of the depth of the main stem of the Nushagak River, a benthic macroinvertebrate assessment could only be performed in shallow (wade-able) areas using the standard protocols for Alaska. Alternative methods (such as a bucket dredge) could be used to collect benthic macroinvertebrates in the deep portions of the river. However, it would be difficult to perform a truly representative assessment of the Nushagak River using benthic macroinvertebrates as an indicator of water quality. Therefore, the TAC considered several other methods that could alternatively be used as water quality indicators. Several options were discussed, and diatom sampling was determined to be the best alternative for bioassessment of the Lower Nushagak River.

Summary

Water quality on the Lower Nushagak River was found to be excellent in the current study. None of the sites sampled in August 2006 or June 2007 exceeded ADEC water quality standards for the parameters sampled. Dissolved iron exceeded its secondary (unenforceable) water quality on one occasion, but its level is still relatively low and does not pose a health risk.

The current study followed most of the recommendations for future monitoring outlined in the FY06 final report. The sampling was divided into two days, and laboratory samples were shipped to Anchorage from our base in Ekwok. Coliscan MF samples were also processed and incubated in Ekwok. Lengthening the sampling period worked well, though the need to meet the scheduled mid-afternoon flight still caused the sampling team to need to work expediently. Tina Carr and Daniel Chythlook continued their involvement as local monitors and are able to operate the field equipment (YSI 566, turbidimeter, etc.), collect and ship laboratory samples, and process Coliscan MF samples with minimal (if any) oversight.

E. Coli laboratory samples were collected in the current study, though results from these samples did not always correlate well with Coliscan MF *E. Coli* or laboratory fecal coliform samples. The Coliscan MF method for measuring *E. Coli* and total coliform concentrations worked better than the Coliscan Easygel method used in FY06. Because 30 mL of sample water can be assayed with the MF method (versus 5 mL can be used with the Easygel method), we achieved greater accuracy with the MF method.

Recommendations for future sampling include 1) to continue monitoring of sample sites that had exceedances for fecal coliform in FY06, and 2) to continue to increase the responsibilities of local monitors to carry out this study.

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US Geological Survey (USGS), 2006. Water quality database visited 7/15-28/06. http://waterdata.usgs.gov/ak/nwis/qw and http://nwis.waterdata.usgs.gov/ak/nwis

Appendix A--Water Quality Data

Appendix B--Calibration logs and Quality Assurance Blanks

Appendix C--Information on Water Quality Parameters

Sources:

EPA Volunteer Stream Monitoring Manual
(http://www.epa.gov/volunteer/stream/index.html)

USGS Water Quality Information News website
(http://water.usgs.gov/owq/Explanation.html)

Russell Mainstream Supply Ltd., Technical Area (United Kingdom)
(http://www.rmprocesscontrol.co.uk/Technical.htm#ORP)

Lenntech—Metals in Aquatic Freshwater
(http://www.lenntech.com/aquatic/metals.htm)

Information below was taken from the EPA Volunteer Stream Monitoring Manual
(http://www.epa.gov/volunteer/stream/index.html)

DISSOLVED OXYGEN

What is dissolved oxygen and why is it important?

The stream system both produces and consumes oxygen. It gains oxygen from the atmosphere and from plants as a result of photosynthesis. Running water, because of its churning, dissolves more oxygen than still water, such as that in a reservoir behind a dam. Respiration by aquatic animals, decomposition, and various chemical reactions consume oxygen.

Wastewater from sewage treatment plants often contains organic materials that are decomposed by microorganisms, which use oxygen in the process. (The amount of oxygen consumed by these organisms in breaking down the waste is known as the biochemical oxygen demand or BOD. A discussion of BOD and how to monitor it is included at the end of this section.) Other sources of oxygen-consuming waste include stormwater runoff from farmland or urban streets, feedlots, and failing septic systems.

Oxygen is measured in its dissolved form as dissolved oxygen (DO). If more oxygen is consumed than is produced, dissolved oxygen levels decline and some sensitive animals may move away, weaken, or die.

DO levels fluctuate seasonally and over a 24-hour period. They vary with water temperature and altitude. Cold water holds more oxygen than warm water (Table 5.3) and water holds less oxygen at higher altitudes. Thermal discharges, such as water used to cool machinery in a manufacturing plant or a power plant, raise the temperature of water and lower its oxygen content. Aquatic animals are most vulnerable to lowered DO levels in the early morning on hot summer days when stream flows are low, water temperatures are high, and aquatic plants have not been producing oxygen since sunset.

NITRATES

What are nitrates and why are they important?

Nitrates are a form of nitrogen, which is found in several different forms in terrestrial and aquatic ecosystems. These forms of nitrogen include ammonia (NH3), nitrates (NO3), and nitrites (NO2). Nitrates are essential plant nutrients, but in excess amounts they can cause significant water quality problems. Together with phosphorus, nitrates in excess amounts can accelerate eutrophication, causing dramatic increases in aquatic plant growth and changes in the types of plants and animals that live in the stream. This, in turn, affects dissolved oxygen, temperature, and other indicators. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations (10 mg/L) or higher) under certain conditions. The natural level of ammonia or nitrate in surface water is typically low (less than 1 mg/L); in the effluent of wastewater treatment plants, it can range up to 30 mg/L.
Sources of nitrates include wastewater treatment plants, runoff from fertilized lawns and cropland, failing on-site septic systems, runoff from animal manure storage areas, and industrial discharges that contain corrosion inhibitors.

TEMPERATURE

Why is temperature important?

The rates of biological and chemical processes depend on temperature. Aquatic organisms from microbes to fish are dependent on certain temperature ranges for their optimal health. Optimal temperatures for fish depend on the species: some survive best in colder water, whereas others prefer warmer water. Benthic macroinvertebrates are also sensitive to temperature and will move in the stream to find their optimal temperature. If temperatures are outside this optimal range for a prolonged period of time, organisms are stressed and can die. Temperature is measured in de-grees Fahrenheit (F) or degrees Celsius (C).

For fish, there are two kinds of limiting temperatures the maximum temperature for short exposures and a weekly average temperature that varies according to the time of year and the life cycle stage of the fish species. Reproductive stages (spawning and embryo development) are the most sensitive stages.

Table 5.5 provides temperature criteria for some species.

Temperature affects the oxygen content of the water (oxygen levels become lower as temperature increases); the rate of photosynthesis by aquatic plants; the metabolic rates of aquatic organisms; and the sensitivity of organisms to toxic wastes, parasites, and diseases.

Causes of temperature change include weather, removal of shading streambank vegetation, impoundments (a body of water confined by a barrier, such as a dam), dis-charge of cooling water, urban storm water, and groundwater inflows to the stream.

Table 5.5

Maximum average temperatures for growth and short-term maximum temperatures for selected fish (°C and ° F)

Species	Max. weekly average temp. for growth (juveniles)	Max. temp. for survival of short exposure (juveniles)	Max. weekly average temp. for spawning [a]	Max. temp. for embryo spawning [b]
Atlantic salmon	20 °C (68 °F)	23 °C (73 °F)	5 °C (41 °F)	11 °C (52 °F)
Bluegill	32 °C (90 °F)	35 °C (95 °F)	25 °C (77 °F)	34 °C (93 °F)
Brook trout	19 °C (66 °F)	24 °C (75 °F)	9 °C (48 °F)	13 °C (55 °F)
Common carp	---	---	21 °C (70 °F)	33 °C (91 °F)
Channel catfish	32 °C (90 °F)	35 °C (95 °F)	27 °C (81 °F)	29 °C (84 °F)
Largemouth bass	32 °C (90 °F)	34 °C (93 °F)	21 °C (70 °F)	27 °C (81 °F)
Rainbow trout	19 °C (66 °F)	24 °C (75 °F)	9 °C (48 °F)	13 °C (55 °F)
Smallmouth bass	29 °C (84 °F)	---	17 °C (63 °F)	23 °C (73 °F)
Sockeye salmon	18 °C (64 °F)	22 °C (72 °F)	10 °C (50 °F)	13 °C (55 °F)

a - Optimum or mean of the range of spawning temperatures reported for the species
b - Upper temperature for successful incubation and hatching reported for the species
c - Upper temperature for spawning

(Brungs and Jones 1977)

pH

What Is pH and why is it important?

pH is a term used to indicate the alkalinity or acidity of a substance as ranked on a scale from 1.0 to 14.0. Acidity increases as the pH gets lower. Fig. 5.9 present the pH of some common liquids.

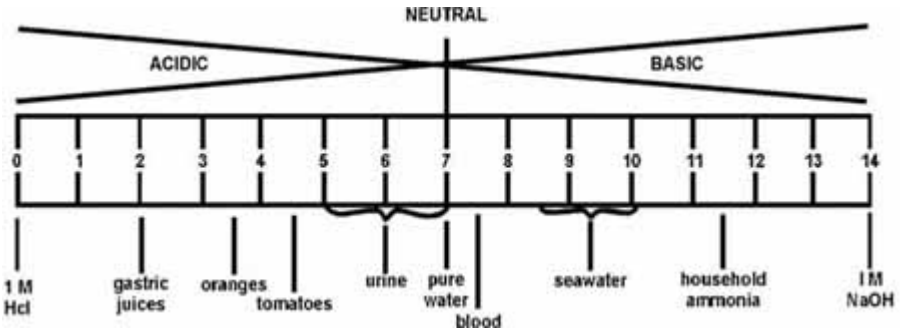


Figure 5.9

pH of selected liquids

pH affects many chemical and biological processes in the water. For example, different organisms flourish within different ranges of pH. The largest variety of aquatic animals prefer a range of 6.5-8.0. pH outside this range reduces the diversity in the stream because it stresses the physiological systems of most organisms and can reduce reproduction. Low pH can also allow toxic elements and compounds to become mobile and "available" for uptake by aquatic plants and animals. This can produce conditions that are toxic to aquatic life, particularly to sensitive species like rainbow trout. Changes in acidity can be caused by atmospheric deposition (acid rain), surrounding rock, and certain wastewater discharges.

The pH scale measures the logarithmic concentration of hydrogen (H+) and hydroxide (OH-) ions, which make up water (H+ + OH- = H2O). When both types of ions are in equal concentration, the pH is 7.0 or neutral. Below 7.0, the water is acidic (there are more hydrogen ions than hydroxide ions). When the pH is above 7.0, the water is alkaline, or basic (there are more hydroxide ions than hydrogen ions). Since the scale is logarithmic, a drop in the pH by 1.0 unit is equivalent to a 10-fold increase in acidity. So, a water sample with a pH of 5.0 is 10 times as acidic as one with a pH of 6.0, and pH 4.0 is 100 times as acidic as pH 6.0.

TURBIDITY

What is turbidity and why is it important?

Turbidity is a measure of water clarity how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. These materials are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand). Turbidity can affect the color of the water.

Higher turbidity increases water temperatures because suspended particles absorb more heat. This, in turn, reduces the concentration of dissolved oxygen (DO) because warm water holds less DO than cold. Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of DO. Suspended materials can clog fish gills, reducing resistance to disease in fish, lowering growth rates, and affecting egg and larval development. As the particles settle, they can blanket the stream bottom, especially in slower waters, and smother fish eggs and benthic macroinvertebrates. Sources of turbidity include:

- Soil erosion
- Waste discharge
- Urban runoff
- Eroding stream banks
- Large numbers of bottom feeders (such as carp), which stir up bottom sediments
- Excessive algal growth.

CONDUCTIVITY

What is conductivity and why is it important?

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius (25 C). Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through.

Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate; an oil spill would lower the conductivity.

The basic unit of measurement of conductivity is the mho or siemens. Conductivity is measured in micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µs/cm). Distilled water has a conductivity in the range of 0.5 to 3 µmhos/cm. The conductivity of rivers in the United States generally ranges from 50 to 1500 µmhos/cm. Studies of inland fresh waters indicate that streams supporting good mixed fisheries have a range between 150 and 500 µhos/cm. Conductivity outside this range could indicate that the water is not suitable for certain species of fish or macroinvertebrates. Industrial waters can range as high as 10,000 µmhos/cm.

TOTAL ALKALINITY

What is total alkalinity and why is it important?

Alkalinity is a measure of the capacity of water to neutralize acids (see pH description). Alkaline compounds in the water such as bicarbonates (baking soda is one type), carbonates, and hydroxides remove H+ ions and lower the acidity of the water (which means increased pH). They usually do this by combining with the H+ ions to make new compounds. Without this acid-neutralizing capacity, any acid added to a stream would cause an immediate change in the pH. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. It's one of the best measures of the sensitivity of the stream to acid inputs.

Alkalinity in streams is influenced by rocks and soils, salts, certain plant activities, and certain industrial wastewater discharges.

Total alkalinity is measured by measuring the amount of acid (e.g., sulfuric acid) needed to bring the sample to a pH of 4.2. At this pH all the alkaline compounds in the sample are "used up." The result is reported as milligrams per liter of calcium carbonate (mg/L $CaCO_3$).

FECAL BACTERIA

What are fecal bacteria and why are they important?

Members of two bacteria groups, coliforms and fecal streptococci, are used as indicators of possible sewage contamination because they are commonly found in human and animal feces. Although they are generally not harmful themselves, they indicate the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Therefore, their presence in streams suggests that pathogenic microorganisms might also be present and that swimming and eating shellfish might be a health risk. Since it is difficult, time-consuming, and expensive to test directly for the presence of a large variety of pathogens, water is usually tested for coliforms and fecal streptococci instead. Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff.

In addition to the possible health risk associated with the presence of elevated levels of fecal bacteria, they can also cause cloudy water, unpleasant odors, and an increased oxygen demand. (Refer to the section on dissolved oxygen.)

Indicator bacteria types and what they can tell you

The most commonly tested fecal bacteria indicators are total coliforms, fecal coliforms, *Escherichia coli*, fecal streptococci, and enterococci. All but *E. coli* are composed of a number of species of bacteria that share common characteristics such as shape, habitat, or behavior; *E. coli* is a single species in the fecal coliform group.

Total coliforms are a group of bacteria that are widespread in nature. All members of the total coliform group can occur in human feces, but some can also be present in animal manure, soil, and submerged wood and in other places outside the human body. Thus, the usefulness of total coliforms as an indicator of fecal contamination depends on the extent to which the bacteria species found are fecal and human in origin. For recreational waters, total coliforms are no longer recommended as an indicator. For drinking water, total coliforms are still the standard test because their presence indicates contamination of a water supply by an outside source.

Fecal coliforms, a subset of total coliform bacteria, are more fecal-specific in origin. However, even this group contains a genus, *Klebsiella*, with species that are not necessarily fecal in origin. *Klebsiella* are commonly associated with textile and pulp and paper mill wastes. Therefore, if these sources discharge to your stream, you might wish to consider monitoring more fecal and human-specific bacteria. For recreational waters, this group was the primary bacteria indicator until relatively recently, when EPA began recommending *E. coli* and enterococci as better indicators of health risk from water contact. Fecal coliforms are still being used in many states as the indicator bacteria.

E. coli is a species of fecal coliform bacteria that is specific to fecal material from humans and other warm-blooded animals. EPA recommends E. coli as the best indicator of health risk from water contact in recreational waters; some states have changed their water quality standards and are monitoring accordingly.

Fecal streptococci generally occur in the digestive systems of humans and other warm-blooded animals. In the past, fecal streptococci were monitored together with fecal coliforms and a ratio of fecal coliforms to streptococci was calculated. This ratio was used to determine whether the contamination was of human or nonhuman origin. However, this is no longer recommended as a reliable test.

Enterococci are a subgroup within the fecal streptococcus group. Enterococci are distinguished by their ability to survive in salt water, and in this respect they more closely mimic many pathogens than do the other indicators.

Enterococci are typically more human-specific than the larger fecal streptococcus group. EPA recommends enterococci as the best indicator of health risk in salt water used for recreation and as a useful indicator in fresh water as well.

Which Bacteria Should You Monitor?

Which bacteria you test for depends on what you want to know. Do you want to know whether swimming in your stream poses a health risk? Do you want to know whether your stream is meeting state water quality standards? Studies conducted by EPA to determine the correlation between different bacterial indicators and the occurrence of digestive system illness at swimming beaches suggest that the best indicators of health risk from recreational water contact in fresh water are *E. coli* and enterococci. For salt water, enterococci are the best. Interestingly, fecal coliforms as a group were determined to be a poor indicator of the risk of digestive system illness. However, many states continue to use fecal coliforms as their primary health risk indicator.

If your state is still using total or fecal coliforms as the indicator bacteria and you want to know whether the water meets state water quality standards, you should monitor fecal coliforms. However, if you want to know the health risk from recreational water contact, the results of EPA studies suggest that you should consider switching to the *E. coli* or enterococci method for testing fresh water. In any case, it is best to consult with the water quality division of your state's environmental agency, especially if you expect them to use your data.

Information below was taken from Russell Mainstream Supply Ltd., Technical Area (United Kingdom) (http://www.rmprocesscontrol.co.uk/Technical.htm#ORP)

OXIDATION-REDUCTION POTENTIAL (ORP)

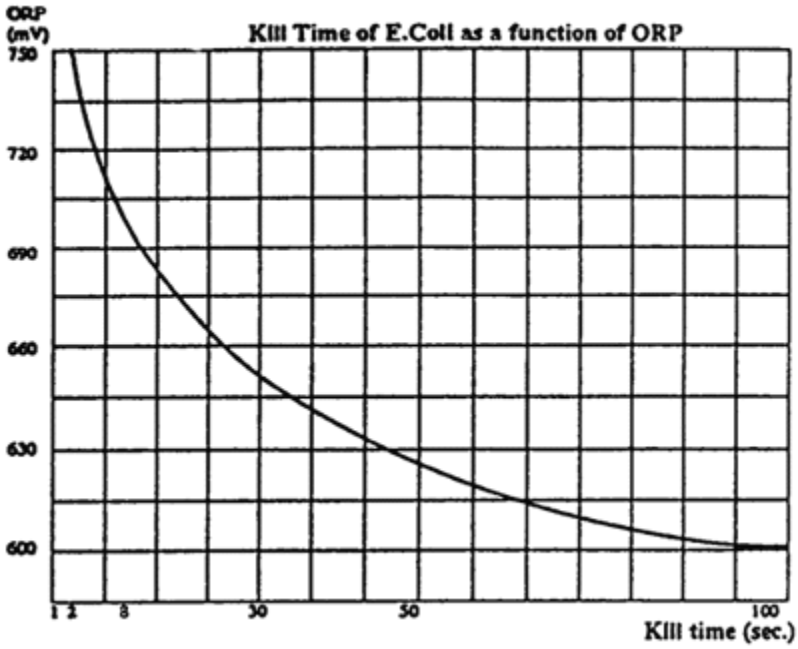
Oxidation-Reduction Potential (ORP) or Redox potential measurements are used to monitor chemical reactions, to quantify ion activity, or to determine the oxidizing or reducing properties of a solution. ORP is a measurement of the electrical potential of a redox reaction and serves as a yardstick to judge how much oxidation or reduction takes place under existing conditions.

ORP electrodes measure the voltage across a circuit formed by the measuring metal half cell and the reference half cell. When the ORP electrode is placed in the presence of oxidizing or reducing agents, electrons are constantly transferred back and forth on its measuring surface, generating a tiny voltage. The ORP measurement can be made using the millivolt mode of a pH meter.

ORP measurement may be utilized very successfully in many commercial and industrial applications. These include:

- Cyanide Oxidation
- Aquarium Monitoring
- Chromate Reduction
- Drinking Water
- Swimming Pool Water
- Pulp Bleaching
- Cooling Tower
- Ozone Monitoring
- Water Pollution Monitoring

ORP technology has been gaining recognition worldwide and is found to be a reliable indicator of bacteriological water quality for sanitation - determine free chlorine parameter. In swimming pool application, the ideal ORP value is approximately 700 mV where the Kill Time of E.Coli bacteria is the fastest to ensure good water quality. However ORP value also depends on the pH of pool water, which is typically between 7.2 and 7.6 pH.



The pH of pool water has to be maintained at optimum level by dosing appropriate chemicals. If the pH of swimming pool is acceptable and ORP value is below 700 mV, then hypochlorite or other oxidizing chemicals need to be added.

Information below was taken from the USGS Water Quality Information—News website
(http://water.usgs.gov/owq/Explanation.html)

HARDNESS

Many industrial and domestic water users are concerned about the hardness of their water. Hard water requires more soap and synthetic detergents for home laundry and washing, and contributes to scaling in boilers and industrial equipment. Hardness is caused by compounds of calcium and magnesium, and by a variety of other metals. General guidelines for classification of waters are: 0 to 60 mg/L (milligrams per liter) as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard.

Mean values of hardness at 344 stations during the 1975 water year are represented by the chart. The highest 7 values, those over 1,120 mg/L, are lumped in the last bar of the chart in order to maintain the scale. About half of the mean hardness values for the stations are in the soft to moderately hard categories, and about half can be classified as hard to very hard.

Patterns of hardness in the United States are shown on the map of accounting units at the bottom of the figure. Softest waters were in parts of the New England, South Atlantic-Gulf, Pacific Northwest, and Hawaii regions. Moderately hard waters were common in many of the rivers of the Tennessee, Great Lakes, Pacific Northwest, and Alaska regions. Hard and very hard waters were found in some of the streams in most of the regions throughout the country. Hardest waters (greater than 1,000 mg/L) were measured in streams in Texas, New Mexico, Kansas, Arizona, and southern California.

(From Briggs, J.C., and Ficke, J.F., 1977, Quality of Rivers of the United States, 1975 Water Year--Based on the National Stream Quality Accounting Network (NASQAN): U.S. Geological Survey Open-File Report 78-200, 436 p.)

Note to Readers: Water hardness is based on major-ion chemistry concentrations. Major-ion chemistry in ground water is relatively stable and generally does not change over time. Although the map illustrates data from 1975, these data have been found to be accurate and useful in current assessments.

There are, however, several caveats about the nature, use, and interpretations of these data: (1) the data illustrated represent water hardness on a national and regional scale and must be so interpreted; (2) the 1975 data are not designed to be used to make local decisions or decisions on the scale of individual homeowner property; and (3) information that is directly relevant to water hardness and other chemical properties at a home or immediate locale should be provided by the local health agency, local water utility, or by the vendor of a local water-softening system.

METALS

Information below was taken from Lenntech—metals in aquatic freshwater (http://www.lenntech.com/aquatic/metals.htm)

How metals get into freshwater

Metals are introduced in aquatic systems as a result of the weathering of soils and rocks, from volcanic eruptions, and from a variety of human activities involving the mining, processing, or use of metals and/or substances that contain metal pollutants. The most common heavy metal pollutants are arsenic, cadmium, chromium, copper, nickel, lead and mercury. There are different types of sources of pollutants: point sources (localized pollution), where pollutants come from single, identifiable sources. The second type of pollutant sources are nonpoint sources, where pollutants come from dispersed (and often difficult to identify) sources. There are only a few examples of localized metal pollution, like the natural weathering of ore bodies and the little metal particles coming from coal-burning power plants via smokestacks in air, water and soils around the factory.
The most common metal pollution in freshwater comes from mining companies. They usually use an acid mine drainage system to release heavy metals from ores, because metals are very soluble in an acid solution. After the drainage process, they disperse the acid solution in the groundwater, containing high levels of metals. See also acids & alkalis.

The term 'heavy metal' is somewhat imprecise, but includes most metals with an atomic number greater than 20, and excludes alkali metals, alkaline earths, lanthanides and actinides.

What happens when an excess of metals enters freshwater ecosystems?

When the pH in water falls, metal solubility increases and the metal particles become more mobile. That is why metals are more toxic in soft waters. Metals can become 'locked up' in bottom sediments, where they remain for many years. Streams coming from draining mining areas are often very acidic and contain high concentrations of dissolved metals with little aquatic life. Both localized and dispersed metal pollution cause environmental damage because metals are non-biodegradable. Unlike some organic pesticides, metals cannot be broken down into less harmful components in the environment.
Campbell and Stokes (1985) described two contrasting responses of an organism to a metal toxicity with declining pH:
- If there is little change in speciation and the metal binding is weak at the biological surface, a decrease in pH will decrease owning to competition for binding sites from hydrogen ions.
- Where there is a marked effect on speciation and strong binding of the metal at the biological surface, the dominant effect of a decrease in pH will be to increase the metal availability.

Generally the ionic form of a metal is more toxic, because it can form toxic compounds with other ions. Electron transfer reactions that are connected with oxygen can lead to the production of toxic oxyradicals, a toxicity mechanism now known to be of considerable importance in both animals and plants. Some oxyradicals, such as superoxide anion (O_2^-) and the hydroxyl radical (OH^-), can cause serious cellular damage.

Some inorganic pollutants are assimilated by organisms to a greater extent than others. This is reflected in the Bioconcentration Factor (BCF), which can be expressed as follows:
BCF = concentration of the chemical in the organism / concentration of the chemical in the ambient environment.

The ambient environment for aquatic organisms is usually the water or sediments. With inorganic chemicals, the extent of long-term bioaccumulation depends on the rate of excretion. Toxic chemicals can be stored into tissues of species, especially fat tissues. Bioaccumulation of cadmium in animals is high compared to most of the other metals, as it is assimilated rapidly and excreted slowly. Also the sensitivity of individuals of a particular species to a pollutant may be influenced by factors such as sex, age, or size. In general the concentrations of metals in invertebrates is inversely related to their body mass. In fish, the embryonic and larval stages are usually the most sensitive to pollutants.
Benthic organisms are likely to be the most directly affected by metal concentrations in the sediments, because the benthos is the ultimate repository of the particulate materials that are washed into aquatic systems.

Metal tolerance

Some metals, such as manganese, iron, copper, and zinc are essential micronutrients. They are essential to life in the right concentrations, but in excess, these chemicals can be poisonous. At the same time, chronic low exposures to heavy metals can have serious health effects in the long run.
Tolerance to metals has also been recorded in invertebrates and in fish. After exposure for 24 hours to a copper concentration of 0.55

mg/l, rainbow trout showed a 55 per cent inhibition of sodium uptake and a 4 per cent reduction in affinity for sodium, which resulted in an overall decrease in total sodium concentration of sulphydryl-rich protein (Lauren and McDonald 1987a,b). The protein was considered to be a metallothionein. These low molecular weight proteins contain many sulphur-rich amino acids which bind and detoxify some metals. The pretreatment of an organism with low doses of a metal may stimulate metallothionein synthesis and provide tolerance during a subsequent exposure (Pascoe and Beattie, 1979).

Many rivers are polluted with heavy metals from old mine workings and some species of algae become very tolerant to polluted conditions. A survey of 47 sites with different concentration of zinc found the filamentous green alga 'Hormidium rivulare' to be abundant everywhere, tolerating zinc concentrations as high as 30.2 mg Zn/l.

Toxicity of metals

For the protection of human health, the maximum permissible concentrations for metals in natural waters that are recommended by the Environmental Protection Agency (EPA), are listed below:

Maximum Permissible Concentrations (MPC) of Various Metals in Natural Waters For the Protection of Human Health

Metal	*Chemical Symbol*	*mg m^{-3}*
Mercury	Hg	0.144
Lead	Pb	5
Cadmium	Cd	10
Selenium	Se	10
Thallium	Tl	13
Nickel	Ni	13.4
Silver	Ag	50
Manganese	Mn	50
Chromium	Cr	50
Iron	Fe	300
Barium	Ba	1000

Source: EPA (1987); Federal Register *56* (110): 26460-26564 (1991).

This table gives an idea of the relative toxicity of various metals. Mercury, lead and cadmium are not required even in small amounts by any organism.

Because metals are rather insoluble in neutral or basic pH, pHs of 7 or above give a highly misleading picture of the degree of metal pollution. So in some cases it may underestimate significantly the total of metal concentrations in natural waters.