Technical Report No. 06-03

Aquatic Biomonitoring at Red Dog Mine, 2005
National Pollution Discharge Elimination System
Permit No. AK-003865-2

by Alvin G. Ott and William A. Morris

Tailing Impoundment, Red Dog
Photograph by Al Ott 2005

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Alaska Department of Natural Resources
Office of Habitat Management and Permitting

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Table of Contents

Table of Contents (continued).

List of Tables

List of Figures

List of Figures (continued).

List of Figures (continued).

List of Figures (continued).

List of Figures (continued).

List of Figures (concluded).

Acknowledgements

We thank Teck Cominco Alaska Inc. (TCAK) for financial and logistic support enabling us to conduct biomonitoring work at the Red Dog Mine in summer 2005. We specifically acknowledge the support given by Mr. Jim Kulas, Mr. Mark Thompson, and Mr. John Martinisko of TCAK.

We thank Mr. Alan Townsend, Ms. Lisa Whitman, Mr. Jack Winters, Ms. Nancy Ihlenfeldt, and Ms. Laura Jacobs, with the Alaska Department of Natural Resources (ADNR), who assisted with field and laboratory work. Mr. Fred DeCicco, Alaska Department of Fish and Game (ADF&G), conducted the fall Dolly Varden (*Salvelinus malma*) aerial surveys and collected the fall sample of adult Dolly Varden from the Wulik River. The University of Alaska Fairbanks allowed us to use their equipment for chlorophyll analyses. Special thanks again to Dr. Phyllis Weber Scannell for providing substantial input in the preparation of the Red Dog technical report.

We have and will continue to work cooperatively with the ADF&G. It should be recognized that the biomonitoring project at the Red Dog Mine was initiated by the ADF&G via agreement with TCAK. Biomonitoring work was transferred to the Office of Habitat Management and Permitting in the ADNR in May of 2003, when the Habitat and Restoration Division of the ADF&G was transferred to the ADNR as the Office of Habitat Management and Permitting.

Executive Summary

- Concentrations of Cd and Zn are lower at sample stations located downstream of the Red Dog Mine when compared with premining data. However, both Cd and Zn increased from baseline concentrations from 1999 through 2001 at Station 9 (Ikalukrok Creek upstream of Mainstem Red Dog Creek), but have shown a decreasing trend from 2002 through 2005. The most likely cause of these changes from baseline conditions is the very active mineral seep at Cub Creek. Peak Pb concentrations often are higher than seen in baseline data at all sample sites. At Station 10 (Mainstem Red Dog Creek) below the mine and wastewater treatment facility discharge, the pH is higher and median concentrations of Zn, Cd, and Pb are lower.

- Chlorophyll-a concentrations are lowest for all sample years at Station 20 in Middle Fork Red Dog Creek. Generally, chlorophyll-a concentrations are highest in North Fork Red Dog Creek with the exception of 2004. A trend towards increasing chlorophyll-a concentrations is seen from 2002 through 2004 at Stations 8, 9, and 10. Improvements in water quality (decrease in metals loading from upper Ikalukrok Creek) coincide with the trend toward increasing chlorophyll-a concentrations at Stations 8 and 9. Overall, chlorophyll-a results seem to accurately represent the sample sites and serve as a valid indicator of basic biological productivity.

- Aquatic invertebrates from the NPDES sample sites demonstrate a high degree of variability among sites and years. Generally the % Ephemoptera, Plecoptera, and Tricoptera (EPT) is lowest at Station 20 in Middle Fork Red Dog Creek and highest at Stations 8 and 9 located below and upstream of Mainstem Red Dog Creek. Total aquatic taxa are similar for all sites with the greatest number of aquatic taxa occurring in the uppermost sample sites at Stations 20 (Middle Fork Red Dog Creek) and 12 (North Fork Red Dog Creek). Densities of aquatic invertebrates also show high variation among years, but overall densities are highest in North Fork Red Dog Creek. Overall, aquatic invertebrate data appear to be representative of productivity at individual sample sites.

- The volume of the discharge from the water treatment plant is regulated to control the TDS during Arctic grayling spawning. Arctic grayling spawning began on May 27 (determined by the first day that peak water temperature exceeded 3°C) and was determined to be complete June 6, 2005. TDS concentrations at Station 10 did not exceed 500 mg/L during the time period of Arctic grayling spawning.

- Concentrations of TDS at Station 160 (Ikalukrok Creek below Dudd Creek) during summer 2005 never exceeded 500 mg/L. The highest TDS concentration measured was 460 mg/L on October 5, 2005. The wastewater discharge is regulated from July 25 through the end of the discharge season to ensure that TDS concentrations do not exceed 500 mg/L at Station 160.

Executive Summary (continued).

- Adult Dolly Varden from the Wulik River have been sampled for metals concentrations (Al, Cd, Cu, Pb, and Zn) in gill, kidney, liver, and muscle tissues since 1990. In 1997, we added Se and in 1998 we started sampling reproductive tissues, when available. In 2003, we added Hg and Ca to the analytes being measured. None of the analytes measured have been found to concentrate in muscle tissue. The various analytes concentrate in specific tissues: Al concentrates in gill tissue; Cd in kidney tissue; Cu in liver tissue; Pb in gill tissue; Se in kidney and ovarian tissue; and Zn in ovarian tissue. In these tissues, there is no evidence of any trends for increases or decreases since 1999. Median Cd concentrations in kidney tissue are lower than baseline data, but median Cu concentrations in liver tissue are higher. Al and Pb in gill tissue exhibit high variability among individual fish and may be related to soil particles trapped within the gill structure.
- The number of overwintering Dolly Varden is estimated each fall in the Wulik River and the estimates vary annually. There is no indication, based on surveys conducted before and after mining, that the estimated number of fish overwintering in the Wulik River has increased or decreased. Aerial surveys before mine development found that 90% of the Dolly Varden in the Wulik River in the fall are located below the mouth of Ikalukrok Creek. Surveys, post mining, have continued to find that over 90% of the Dolly Varden are seen downstream of Ikalukrok Creek.
- Annual aerial surveys to assess the distribution of adult chum salmon in Ikalukrok Creek from its mouth (i.e., confluence with Wulik River) upstream to Dudd Creek are made. Counts of chum salmon in Ikalukrok Creek after mine development in 1990 and 1991 were lower than reported in baseline studies. Surveys began again in 1995, with the highest return of chum salmon seen in fall 2001 and the highest number of chinook salmon found in fall 2004. Large runs of chum salmon in recent years, particularly 2001 and 2002, are good indications that the population has recovered from the low counts seen in the early 1990s.
- Juvenile Dolly Varden were caught in all sample reaches including Mainstem Red Dog Creek. Use of Mainstem Red Dog Creek by juvenile Dolly Varden, based on minnow trap catches, has remained low since 2000. Reduced presence of juvenile Dolly Varden in Mainstem Red Dog Creek may be related to improvements in water quality in upper Ikalukrok Creek. Improved water quality in upper Ikalukrok Creek may be resulting in increased distribution and use of portions of the drainage upstream of Mainstem Red Dog Creek. Presence of resident Dolly Varden using North Fork Red Dog Creek in spring continues to be confirmed by fyke net catches. Highest use by rearing Dolly Varden occurs in Anxiety Ridge and Buddy creeks.

Executive Summary (concluded).

- Adult chinook salmon (several pairs) are observed in some years in Ikalukrok Creek, but it was not until July 2004 that we caught a juvenile chinook salmon in minnow buckets fished at the NPDES sample sites. In 2004, we caught 1 juvenile chinook salmon in Ikalukrok Creek just below Dudd Creek and 5 in Anxiety Ridge Creek in August 2004. This is the only year since sampling began in 1990 that we have captured juvenile chinook salmon at the NPDES sample sites.
- Arctic grayling spawn in North Fork Red Dog and Mainstem Red Dog creeks each year. We estimated the Arctic grayling population in North Fork Red Dog and Mainstem Red Dog creeks at 870 fish in spring 2001. Relative abundance of fry varies annually and recruitment to the population does not occur each year. Movement of adult fish after spawning is highly variable – in some years the majority of fish remain in North Fork Red Dog Creek to rear until fall when they outmigrate to overwintering habitats. Generally, adults move out of North Fork Red Dog and Mainstem Red Dog creeks immediately following spawning, and then move up Ikalukrok Creek to rear in East Fork Ikalukrok and Grayling Junior creeks. In some years, we have not been able to find the adult fish in the Ikalukrok Creek drainage after spawning. The Arctic grayling population in the Ikalukrok Creek drainage is a stable population of predominantly large fish (>300 mm) with low overall recruitment. The population structure is very different from the Arctic grayling (transplanted population) population in Bons Pond.
- Slimy sculpin abundance premining is not known, but baseline data reports indicate that this species was numerous in the Ikalukrok Creek drainage. Catches of slimy sculpin in the Ikalukrok Creek drainage NPDES sample sites indicate an increasing trend from 2000 through 2005. Slimy sculpin may have been impacted by water quality changes in 1989 and 1990 (prior to construction of the clean water bypass) and again in the late 1990s (the Cub Creek seep). Slimy sculpin are long lived, do not make extensive migrations, and considered to be indicative of good water quality. Increasing numbers of slimy sculpin in recent years may reflect general improvement in water quality due to mine operations and water treatment and natural decreases in the Cub Creek seep located in the upper Ikalukrok Creek drainage.

Introduction

The Red Dog zinc (Zn) and lead (Pb) deposit is located in northwestern Alaska, about 130 km north of Kotzebue and 75 km inland from the Chukchi Sea coast (Figure 1). The mine operation and facilities and surrounding vegetation and wildlife are described in Weber Scannell and Ott (1998). A chronology of development and operations at the Red Dog Mine is presented in Appendix 1. Aquatic resources in the Wulik River drainage are described in Weber Scannell et al. (2000).

In July 1998, the US Environmental Protection Agency (EPA) issued a draft National Pollution Discharge Elimination System Permit No. AK-003865-2 (NPDES Permit) to Teck Cominco Alaska Inc. (TCAK) to allow discharge of up to 2.418 billion gallons of treated effluent per year. The Alaska Department of Environmental Conservation (ADEC) issued a Certificate of Reasonable Assurance and the NPDES Permit became effective August 28, 1998. The NPDES Permit was modified effective August 23, 2003, to include ADEC's authorization of two mixing zones for total dissolved solids in Mainstem Red Dog and Ikalukrok creeks.

The NPDES Permit requires biomonitoring of fish, aquatic invertebrates, and periphyton in streams downstream and adjacent to the Red Dog Mine. Although the NPDES Permit expired August 28, 2003, it was administratively extended until such time as a new permit is issued. This report contains the results of biomonitoring studies conducted by the Alaska Department of Natural Resources (ADNR) in 2005 and comparisons of the 2005 data with previous years.

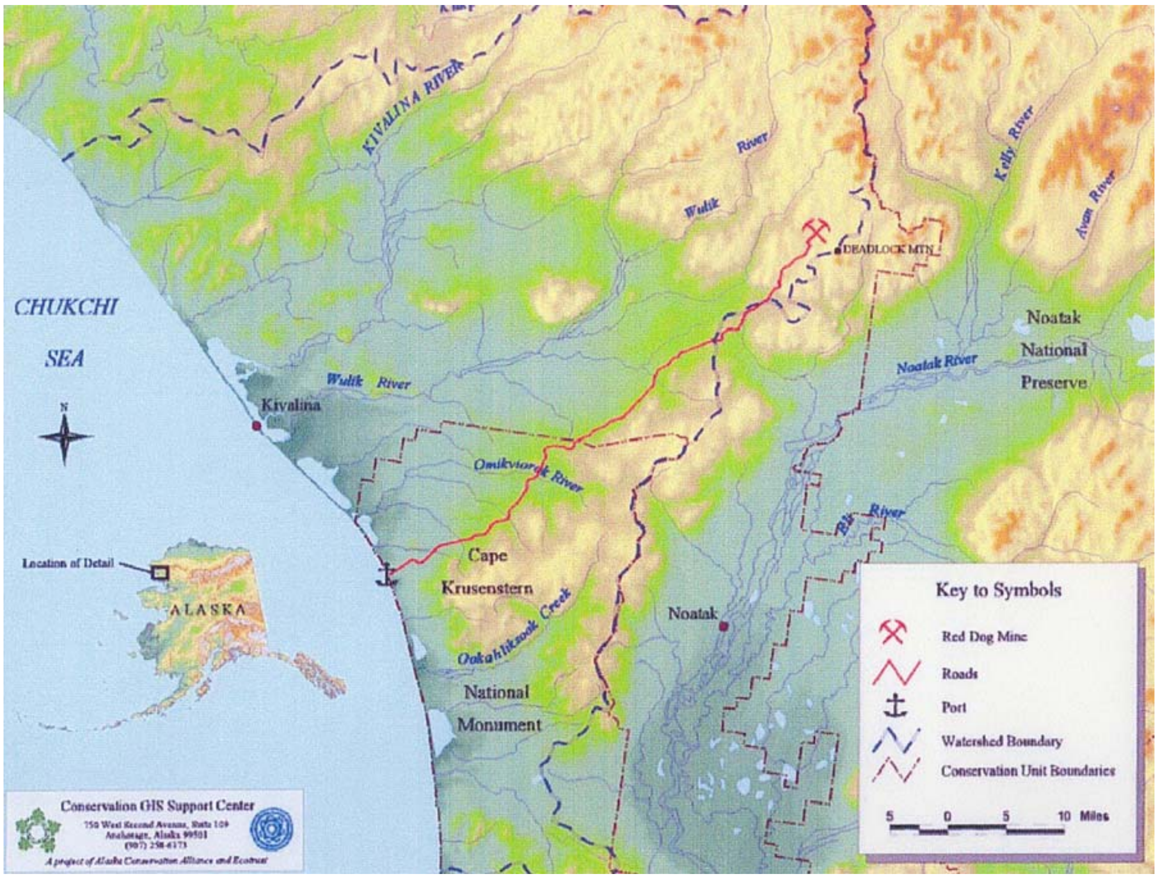

Figure 1. Location of the Red Dog Mine in northwestern Alaska. Map used with permission of Conservation GIS Support Center, Anchorage, Alaska.

Structure of Report

Results of water quality monitoring, aquatic invertebrate sampling, and estimates of periphyton standing crop are given for each site for the years sampled (1999 to 2005). Following presentation of these results by individual site is a table summarizing changes in biotic communities and water quality conditions. Metals concentration data for adult Dolly Varden (*Salvelinus malma*) collected from the Wulik River are then presented followed by aerial survey counts of overwintering Dolly Varden in the Wulik River and chum salmon (*Oncorhynchus keta*) spawners in Ikalukrok Creek. Biological monitoring information for Dolly Varden juveniles, Arctic grayling (*Thymallus arcticus*), and slimy sculpin (*Cottus cognatus*) in streams near the Red Dog Mine are discussed in the last sections of this report.

Location of Sample Sites

Biomonitoring is conducted in streams adjacent to and downstream of the Red Dog Mine as required under the EPA NPDES Permit No. AK-003865-2 (Table 1, Figure 2). A description of the site location and the Station Number identification, where available, is presented in Table 1.

Table 1. Location of sample sites for NPDES biomonitoring.

Stream or Site Name	Station Number
Ikalukrok Creek downstream of Dudd Creek	Station 7
Ikalukrok Creek upstream of Dudd Creek	no station #
Ikalukrok Creek downstream of Mainstem Red Dog Creek	Station 8
Ikalukrok Creek upstream of Mainstem Red Dog Creek	Station 9
Mainstem Red Dog Creek	Station 10
North Fork Red Dog Creek	Station 12
Middle Fork Red Dog Creek	Station 20

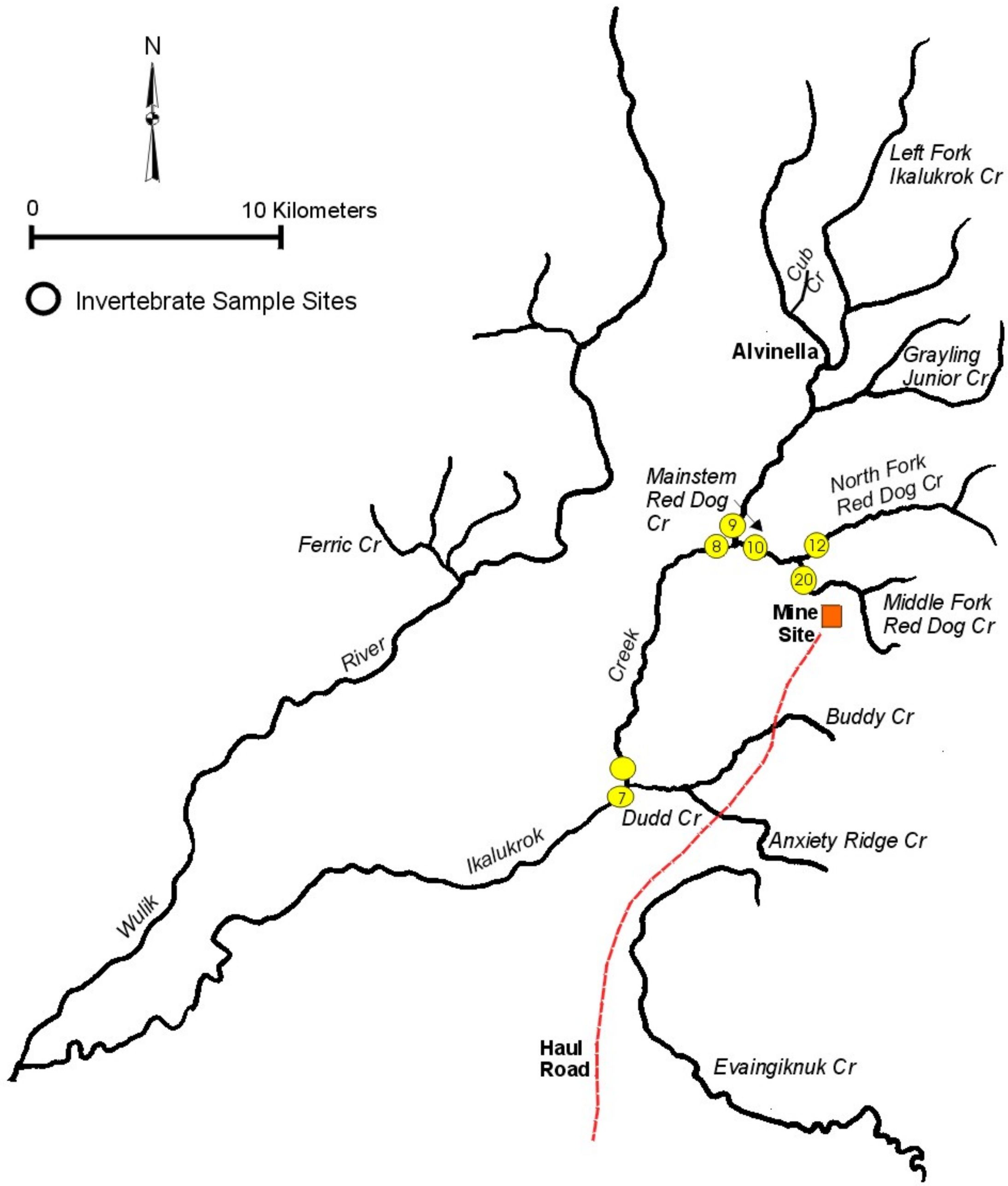

Figure 2. Location of sample sites in the Ikalukrok Creek drainage for aquatic invertebrate and periphyton sampling. The Ikalukrok Creek site upstream of Dudd Creek does not have a numerical description.

Description of Streams

All streams in this study are in the Wulik River drainage, except for Evaingiknuk Creek which is in the Noatak River drainage. Station Numbers correspond either to those used by Dames and Moore (1983) during baseline studies or to the current water quality program being conducted by TCAK. Water quality and fish data collected during baseline studies (1979 to 1982) represent pre-mining conditions. Each component and location listed in Table 2 is required by NPDES Permit No. AK-003865-2. ADNR and ADEC conduct additional sampling that is supplemental to the requirements under the NPDES Permit to further our understanding of the aquatic communities (Table 3). Supplemental sampling is not done annually, but opportunistically based on need, time, and logistical support.

Table 2. Locations and components of studies required by NPDES Permit.

Ikalukrok Creek Stations 7, 8, 9, and upstream of Dudd Creek	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates (taxa richness and abundance) Fish presence and use
Mainstem Red Dog Creek Station 10	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates (taxa richness and abundance) Fish presence and use
North Fork Red Dog Creek Station 12	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates (taxa richness and abundance) Fish presence and use
Middle Fork Red Dog Creek Station 20	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates (taxa richness and abundance) Fish presence and use
Ikalukrok Creek	Fall aerial survey, chum salmon
Wulik River	Fall aerial survey, Dolly Varden Metals concentrations in adult Dolly Varden tissues (gill, liver, muscle, kidney) in spring and fall
Anxiety Ridge Creek	Fish presence and use
Evaingiknuk Creek	Fish presence and use
Buddy Creek	Fish presence and use

Table 3. Locations and components of supplemental biomonitoring studies in 2005.

Ikalukrok Creek	Aerial Arctic grayling surveys, headwaters Fish presence and use downstream of Station 160[1]
Mainstem Red Dog Creek	Juvenile Dolly Varden, whole body metal analyses Fish presence and use at Station 151[2] Spawning condition of Arctic grayling (spent, ripe) Mark-recapture Arctic grayling
North Fork Red Dog Creek	Spawning condition of Arctic grayling (spent, ripe) Mark-recapture Arctic grayling
Buddy Creek, below falls	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates (taxa richness and abundance) Juvenile Dolly Varden, whole body metal analyses
Buddy Creek, above Haul Road	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates (taxa richness and abundance) Fish presence and use
Bons Creek, below Bons Pond	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates (taxa richness and abundance) Fish presence and use
Bons Pond	Fish presence and use Mark-recapture Arctic grayling Arctic grayling population estimate
Bons Creek, above Bons Pond	Periphyton (as chlorophyll-a concentration) Aquatic invertebrates (taxa richness and abundance) Fish presence and use

[1]Station 160 is located on Ikalukrok Creek about 6 km downstream of Station 7
[2]Station 151 is located on Middle Fork Red Dog Creek about 1 km downstream of Station 20.

Methods Used for NPDES Biomonitoring

All methods used for the NPDES biomonitoring study were described by ADF&G (1998) and submitted to EPA for their approval and comment. Only minor modifications, as described by Ott and Weber Scannell (2003), have been made.

The method detection limits (MDL) in 2000 for copper (Cu), lead (Pb) and selenium (Se) were 50, 20, and 50 *u*g/L, respectively, for some of the early samples. MDL's were changed part way through the 2000 summer for Cu, Pb, and Se to 1, 2, and 1 *u*g/L. Because of the high MDLs used in early 2000, water quality data for these analytes are not presented in our report.

All water quality concentrations in this report are shown as "total recoverable." All water quality data contained in this report are from TCAK.

Results and Discussion

Ikalukrok Creek at Station 7

Site Description

Ikalukrok Creek below Dudd Creek (Station 7, Figure 3) is about 10 to 40 m wide with depths from 0.3 to 1.2 m. The substrate consists of small to medium sized gravel with prevalent gravel bars at low flows. Ikalukrok and Dudd creeks are not completely mixed at Station 7; complete mixing of the two creeks under various flow conditions does not occur until about 8 km downstream.

Figure 3. Ikalukrok Creek downstream of Dudd Creek, Station 7.

Water Quality

In May 1999, the stream gauge and monitoring station were moved from Station 7 near Dudd Creek downstream to Station 160. The new sampling location is below complete mixing of Dudd and Ikalukrok creeks and in a more stable stream reach. Baseline water quality data are from Station 7, but water quality are from Station 160 for 1999 through 2005.

Concentrations of TDS at Station 160 are shown in Figure 4. During summer 2005, TDS concentrations never exceeded 500 mg/L. The highest TDS concentration measured was 460 mg/L on October 5, 2005. The wastewater discharge is regulated from July 25 through the end of the discharge season to ensure that TDS concentrations do not exceed 500 mg/L at Station 160. Dolly Varden and chinook and chum salmon spawn in Ikalukrok Creek downstream of Station 160.

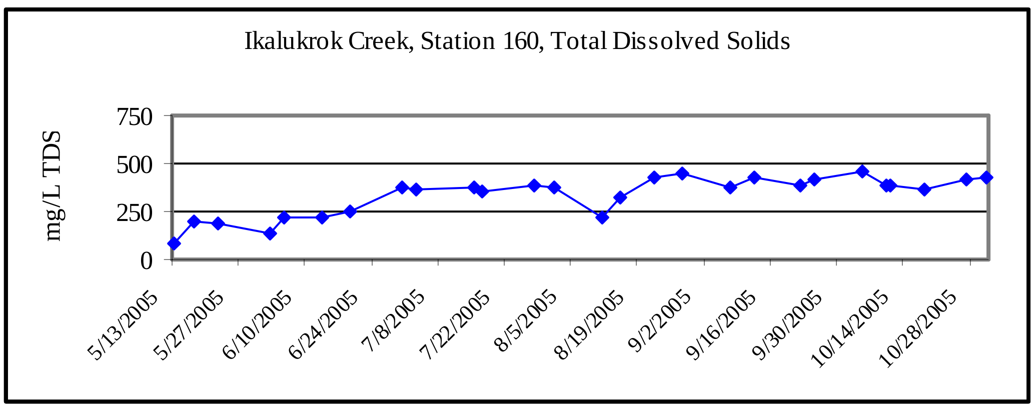

Figure 4. TDS concentrations in Ikalukrok Creek at Station 160.

Concentrations of aluminum (Al), cadmium (Cd), copper (Cu), lead (Pb), selenium (Se), and zinc (Zn) are presented in Figures 5 through 10. Baseline data are only available for Cd, Pb, and Zn. Median Cd and Zn concentrations from 1999 through 2005 are lower than baseline data. Median Pb concentrations vary with respect to baseline data, but maximum concentrations are higher than pre-mining.

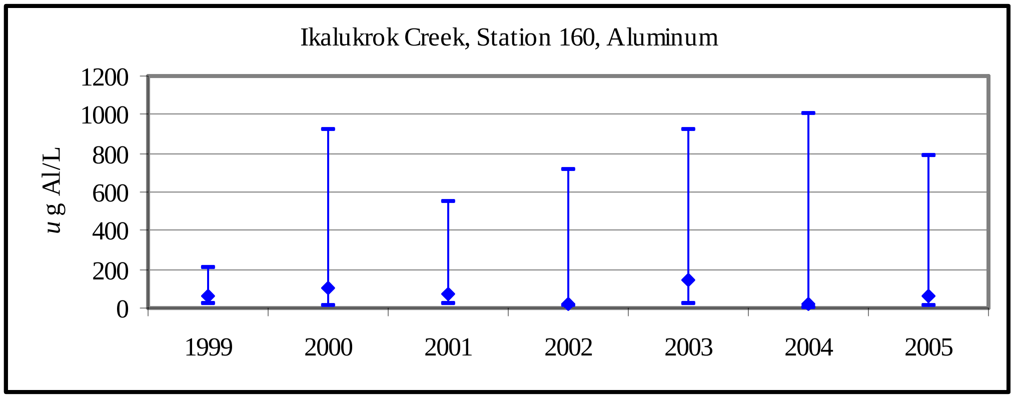

Figure 5. Median, maximum, and minimum concentrations of Al at Station 160.

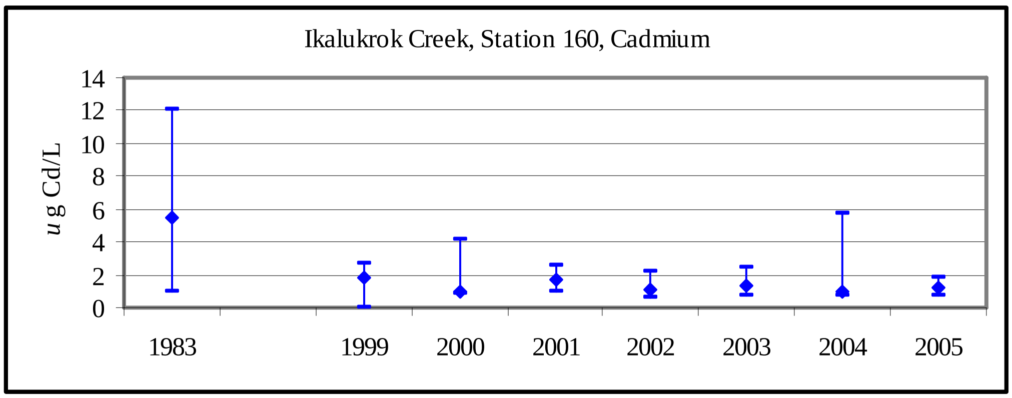

Figure 6. Median, maximum, and minimum concentrations of Cd at Station 160.

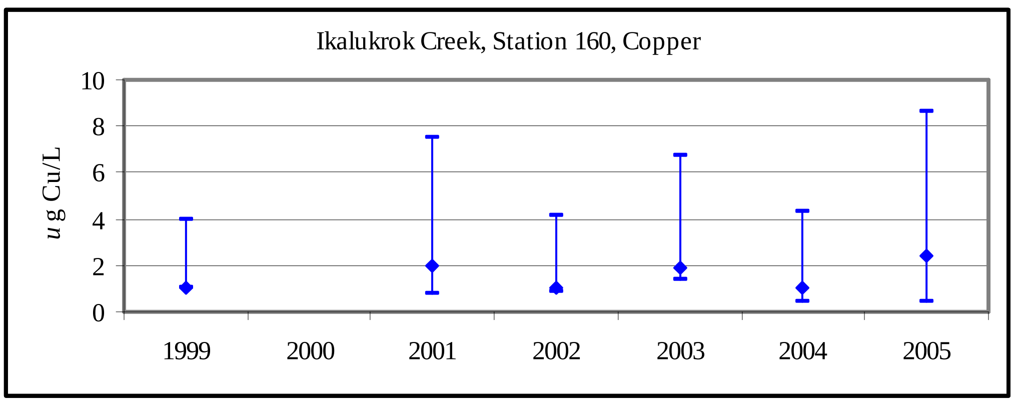

Figure 7. Median, maximum, and minimum concentrations of Cu at Station 160.

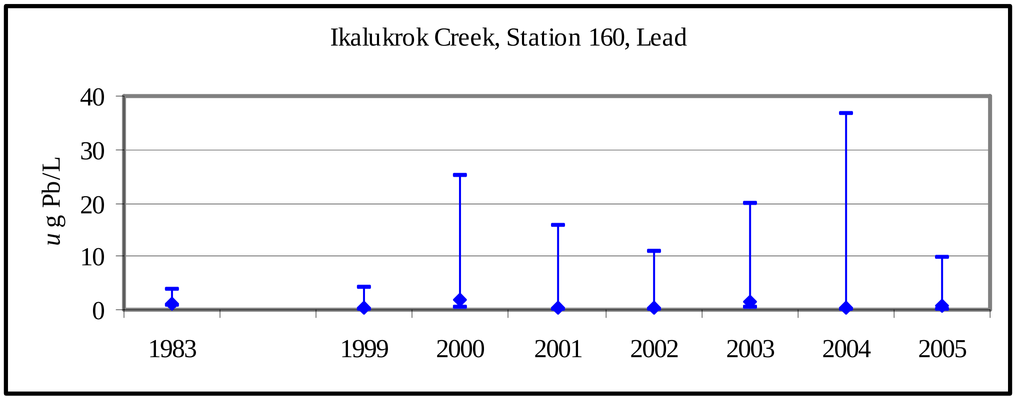

Figure 8. Median, maximum, and minimum concentrations of Pb at Station 160.

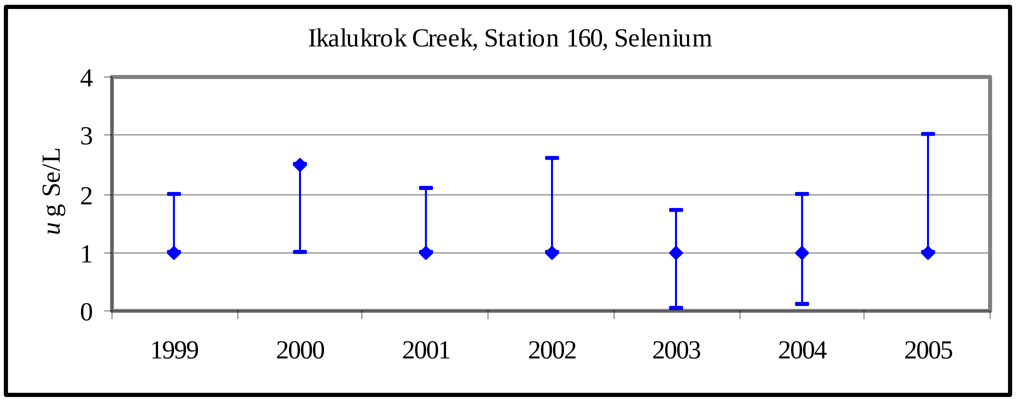

Figure 9. Median, maximum, and minimum concentrations of Se at Station 160.

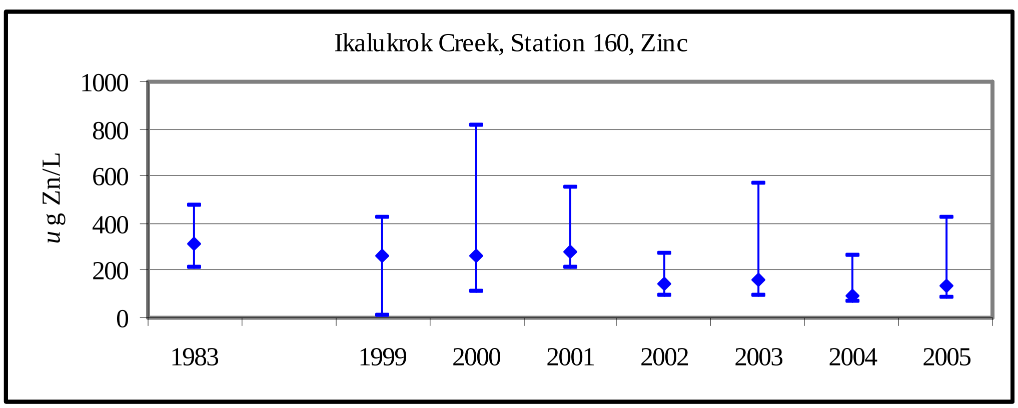

Figure 10. Median, maximum, and minimum concentrations of Zn at Station 160.

Invertebrate Community (Abundance, Density, Taxa Richness, and Structure)

Aquatic invertebrate abundance, density, taxa richness, and structure are presented in Figures 11 through 15. Considerable variability in aquatic invertebrate abundance is shown in Figure 11.

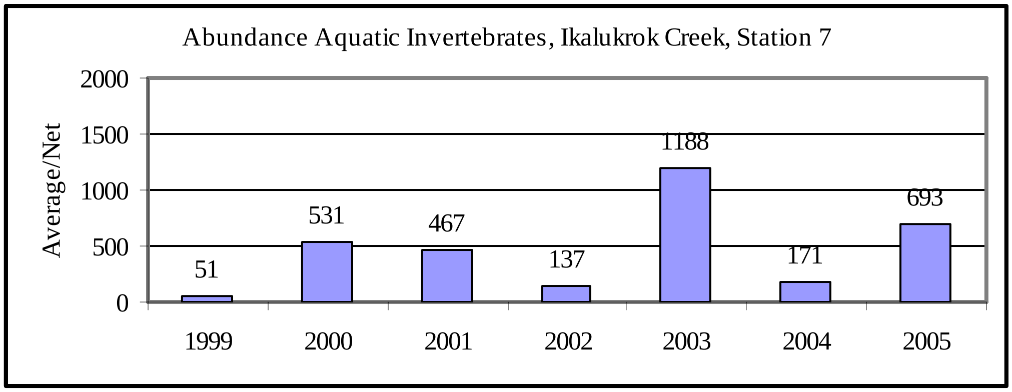

Figure 11. Aquatic invertebrate abundance, Ikalukrok Creek at Station 7.

Variability in the density of aquatic invertebrates was also high ranging from a low of 0.7/m^3 to a high of 11.4/m^3 (Figure 12).

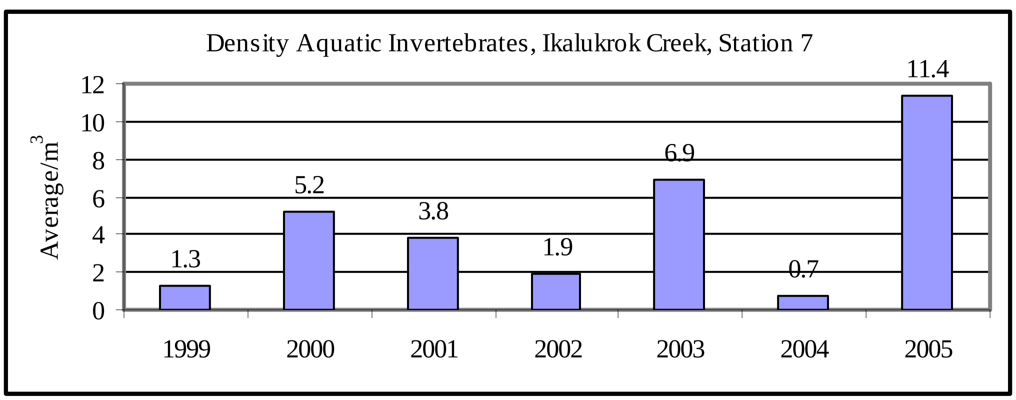

Figure 12. Aquatic invertebrate density, Ikalukrok Creek at Station 7.

Total aquatic taxa in Ikalukrok Creek, downstream of Dudd Creek, varied from a low of 10 to a high of 24 (Figure 13). The proportion of Ephemoptera, Plecoptera, and Tricoptera (EPT) in the aquatic invertebrate samples from Ikalukrok Creek were similar in four out of the six years and ranged from a high of 39% to a low of 8% (Figure 14). Aquatic invertebrate data from Ikalukrok Creek at Station 7 indicate a productive community with high variability.

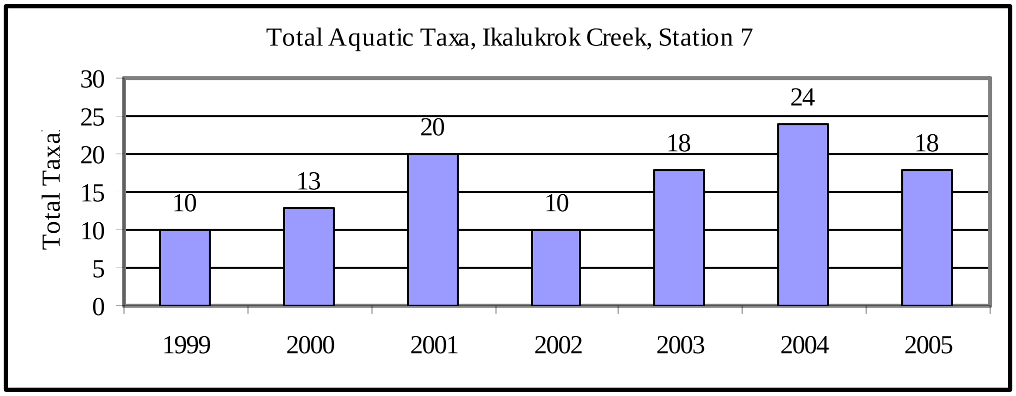

Figure 13. Aquatic invertebrate taxa richness, Ikalukrok Creek at Station 7.

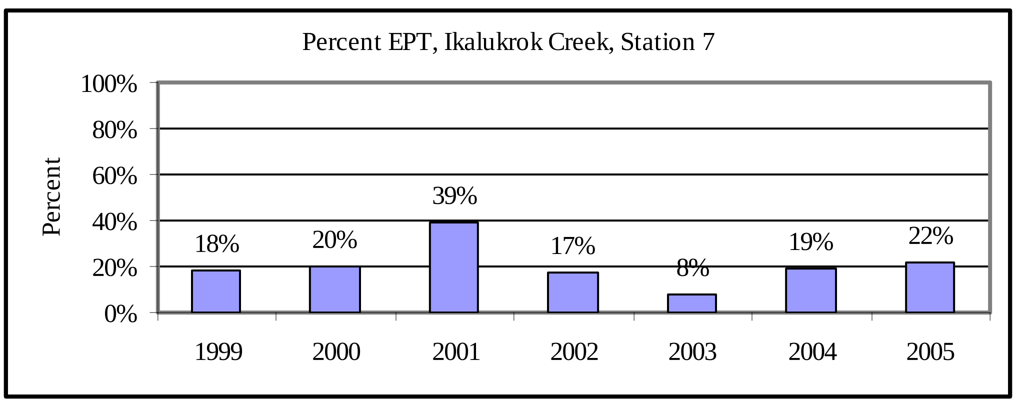

Figure 14. Proportion of EPT in aquatic invertebrate samples, Ikalukrok Creek at Station 7.

Periphyton Standing Crop

Algal biomass, as estimated by chlorophyll-a concentrations has been fairly consistent over the sample years at Station 7 (Figure 15).

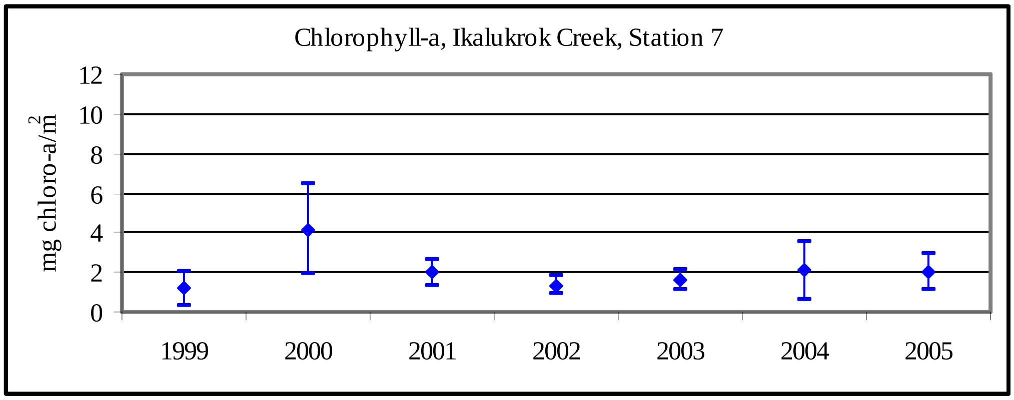

Figure 15. Average concentration of chlorophyll-a, plus and minus one standard deviation, in Ikalukrok Creek at Station 7.

Biomonitoring Summary

Changes in water quality, aquatic invertebrates, periphyton, and larval fish that have been documented over time in Ikalukrok Creek at Station 7 are summarized in Table 4.

Table 4. Ikalukrok Creek, Station 7, 1999 to 2005

Factor	Changes Observed
Water Quality	TDS concentrations below 500 mg/L Median Cd and Zn concentrations lower than baseline Maximum Pb concentrations higher than baseline
Invertebrates	Abundance, highly variable among sample years Density, highly variable among sample years Taxa Richness, low of 10 and a high of 24 % EPT, low of 8% and a high of 39%
Periphyton	Fairly consistent in all sample years
Larval Fish	Arctic grayling in 2000, 2002, and 2003

Ikalukrok Creek Upstream of Dudd Creek

Site Description

Ikalukrok Creek, upstream of Dudd Creek, is a wide, fairly shallow stream up to 40 m wide and 0.5 to 1.5 m deep during summer low flows (Figure 16). Pools along cut banks or adjacent to rock bluffs are 2 to 4 m deep. The substrate consists of mostly small cobble mixed with medium sized gravel. Streambanks are thickly vegetated with willows, herbaceous plants, and grasses.

Figure 16. Ikalukrok Creek upstream of Dudd Creek.

Water Quality

Water is not sampled in Ikalukrok Creek at our biomonitoring site. Water samples in 1999 and 2000 were collected at Station 73 and from 2001 to 2005 at Station 150. Stations 73 and 150 are both located upstream of Dudd Creek, but below the mouth of Mainstem Red Dog Creek. Only a few minor tributaries enter Ikalukrok Creek between the mouths of Mainstem Red Dog and Dudd creeks. Station 150 is a new station located about 9 km upstream of our biomonitoring site and is below the end of the mixing zone in Ikalukrok Creek. Concentrations of TDS in Ikalukrok Creek are not to exceed 1,000 mg/L at the end of the mixing zone. TDS concentrations have not exceeded the limit placed in ADEC's authorized mixing zone (Figure 17).

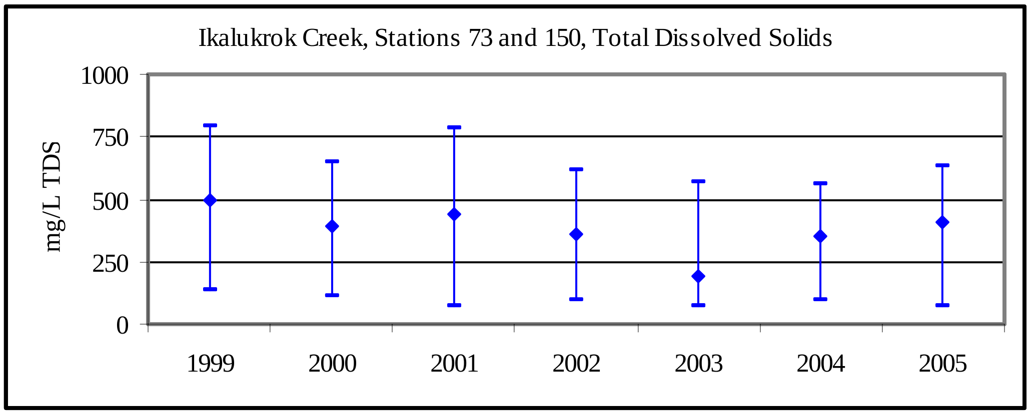

Figure 17. TDS in Ikalukrok Creek at Station 73. Both sites are located below complete mixing of Mainstem Red Dog Creek with waters from Ikalukrok Creek.

Concentrations of Al, Cd, Cu, Pb, Se, and Zn are presented in Figures 18 through 23. Baseline data only are available for Cd, Pb, and Zn. Median Cd and Zn concentrations from 1999 through 2005 are lower than baseline data. Median Pb concentrations vary with respect to baseline data, but in several years post-mining the maximum Pb concentrations are higher.

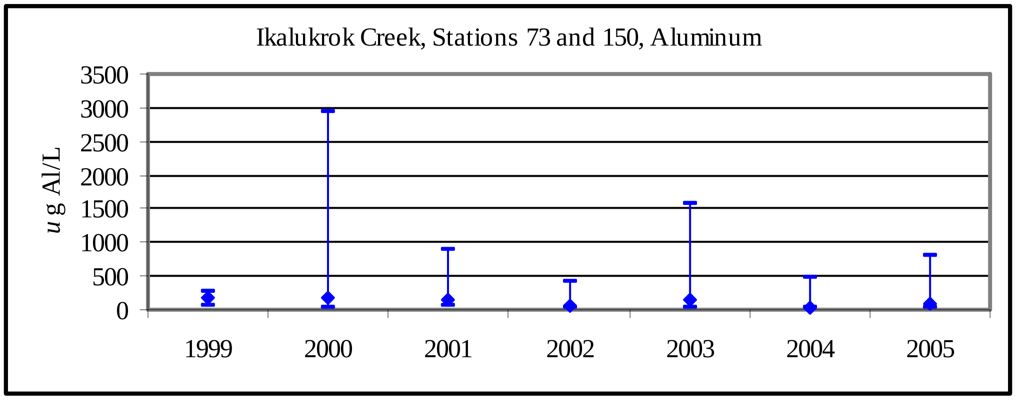

Figure 18. Median, maximum, and minimum concentrations of Al at Station 150.

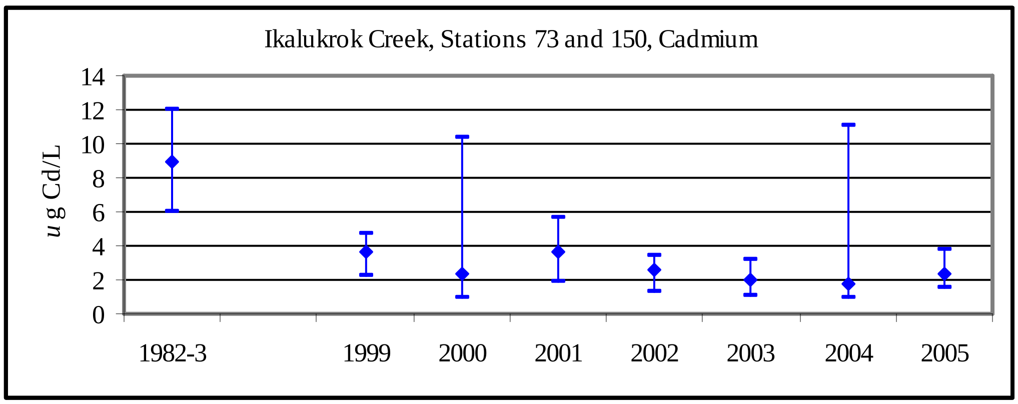

Figure 19. Median, maximum, and minimum concentrations of Cd at Station 150.

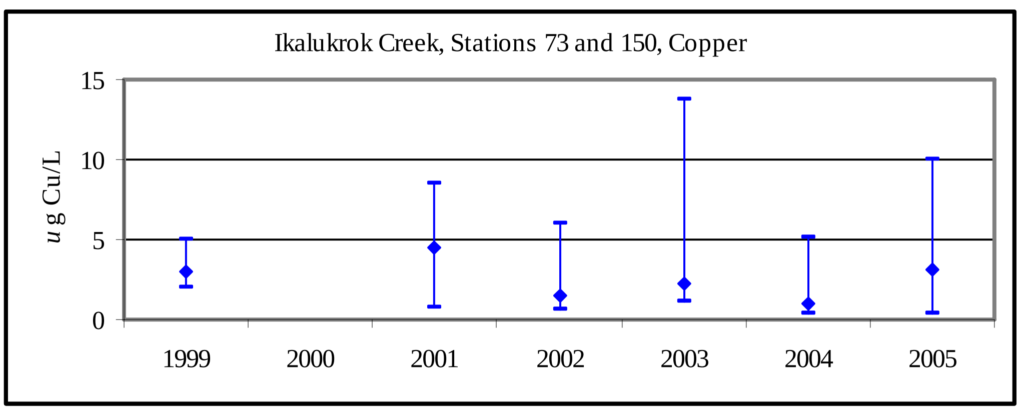

Figure 20. Median, maximum, and minimum concentrations of Cu at Station 150. Data from 2000 are not presented due to use of high detection limits.

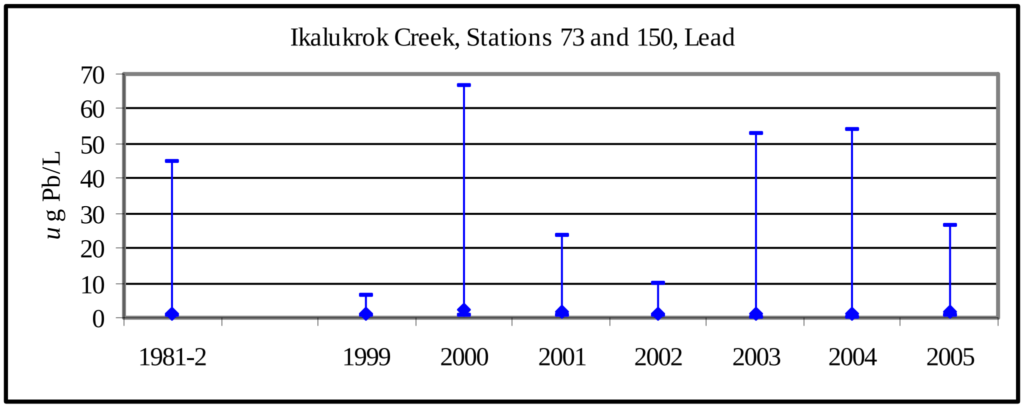

Figure 21. Median, maximum, and minimum concentrations of Pb at Station 150.

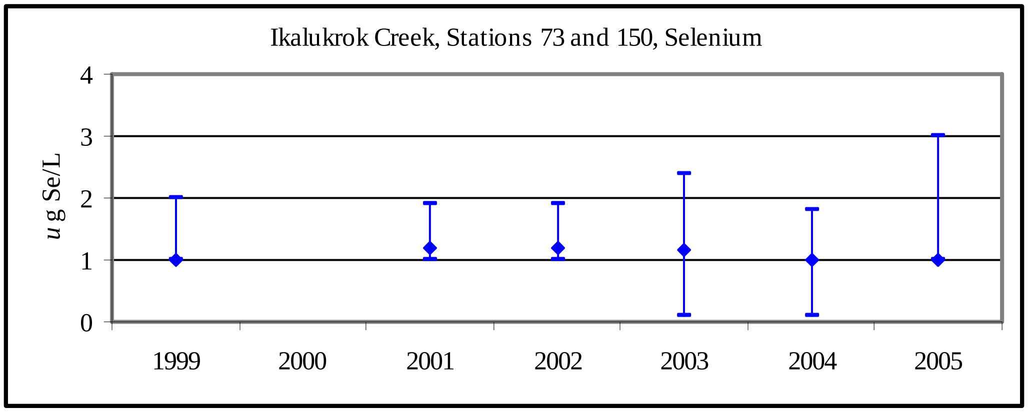

Figure 22. Median, maximum, and minimum concentrations of Se at Station 150.

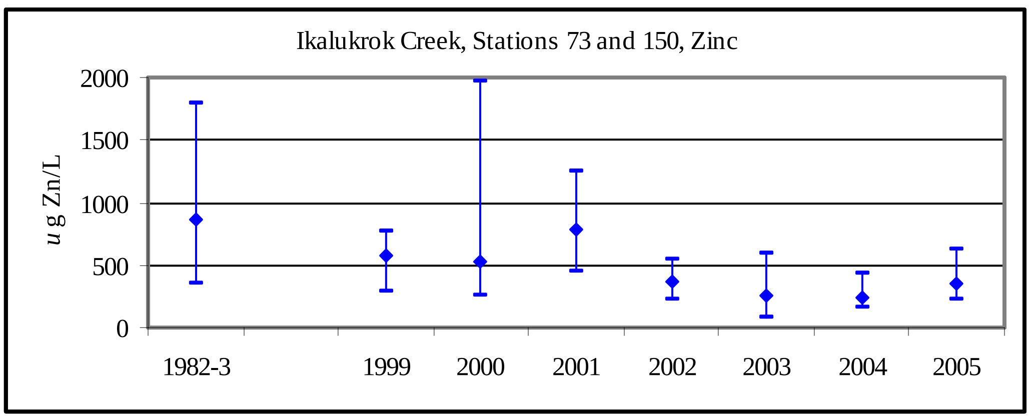

Figure 23. Median, maximum, and minimum concentrations of Zn at Station 150.

Invertebrate Community (Abundance, Density, Taxa Richness, and Structure)

Aquatic invertebrate abundance, density, taxa richness, and structure are presented in Figures 24 through 27. Considerable variability in aquatic invertebrate abundance is shown in Figure 24, but the pattern (higher abundance) by year is similar to that found at Station 7 in Ikalukrok Creek with fewer organisms found in 1999, 2002, and 2004 at both sites (Figures 11 and 24).

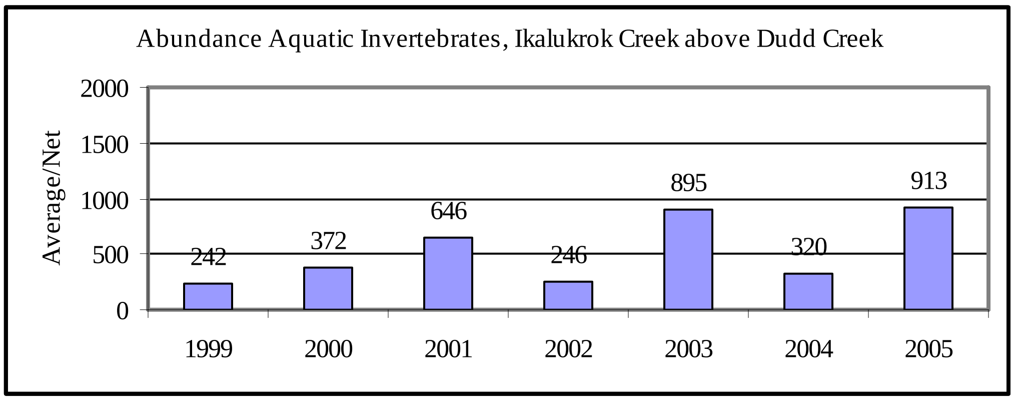

Figure 24. Aquatic invertebrate abundance, Ikalukrok Creek above Dudd Creek.

Density of aquatic invertebrates varied from a low of 0.6 organisms/m^3 to a high of 7.3/m^3 (Figure 25). Lower densities in 1999, 2002, and 2004 correspond closely with

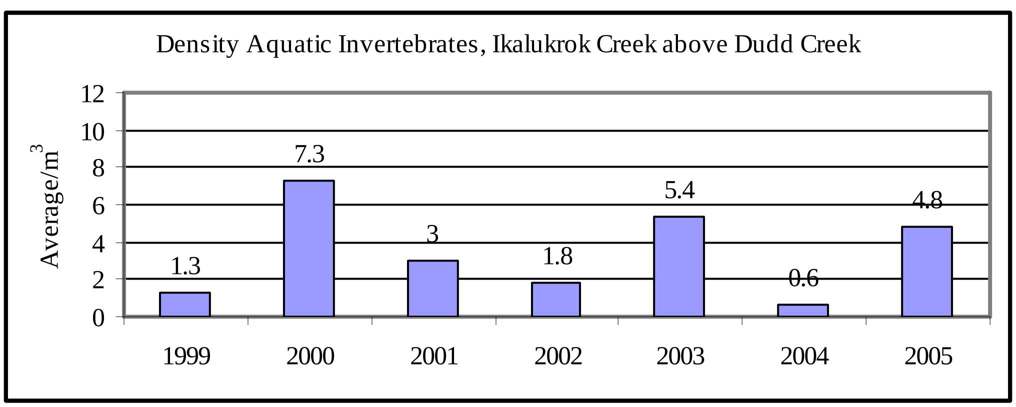

Figure 25. Aquatic invertebrate density, Ikalukrok Creek above Dudd Creek.

aquatic invertebrate densities found in Ikalukrok Creek at Station 7. Total aquatic taxa in Ikalukrok Creek upstream of Dudd Creek are reported in Figure 26. Taxa richness is fairly consistent among the sample years ranging from a low of 13 to a high of 21.

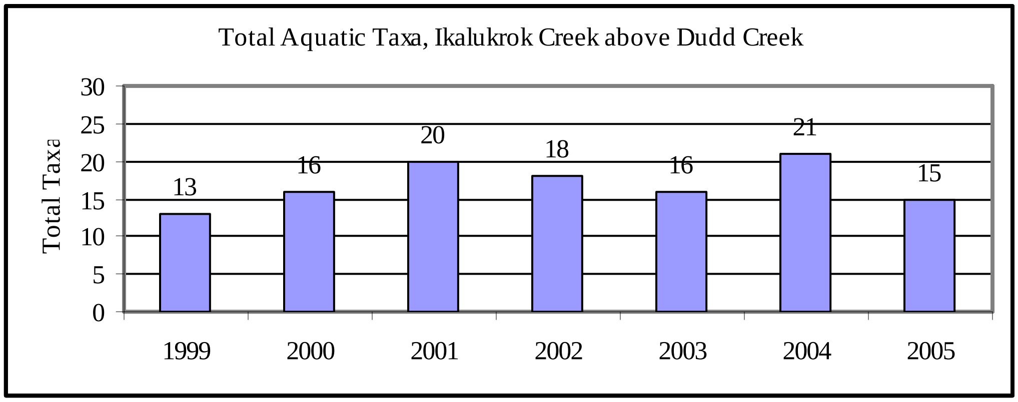

Figure 26. Aquatic invertebrate taxa richness, Ikalukrok Creek above Dudd Creek.

The proportion of EPT in the aquatic invertebrate samples from Ikalukrok Creek, upstream of Dudd Creek, peaked in 2001 at 53% (Figure 27). It is worth noting that the peak percentage of EPT for Ikalukrok Creek, downstream of Dudd Creek, also occurred in 2001 at 39%.

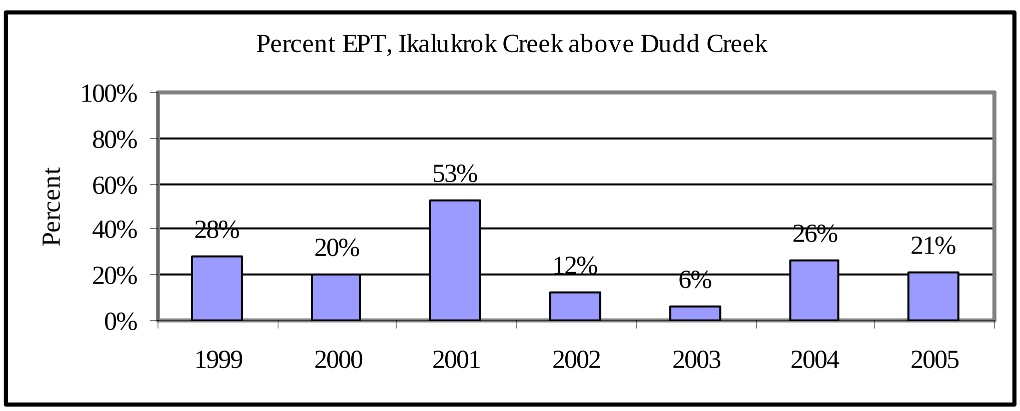

Figure 27. Proportion of EPT in aquatic invertebrate samples, Ikalukrok Creek above Dudd Creek.

Periphyton Standing Crop

Algae biomass, as estimated by chlorophyll-a concentrations has been fairly consistent over the sample years in Ikalukrok Creek upstream of Dudd Creek (Figure 28).

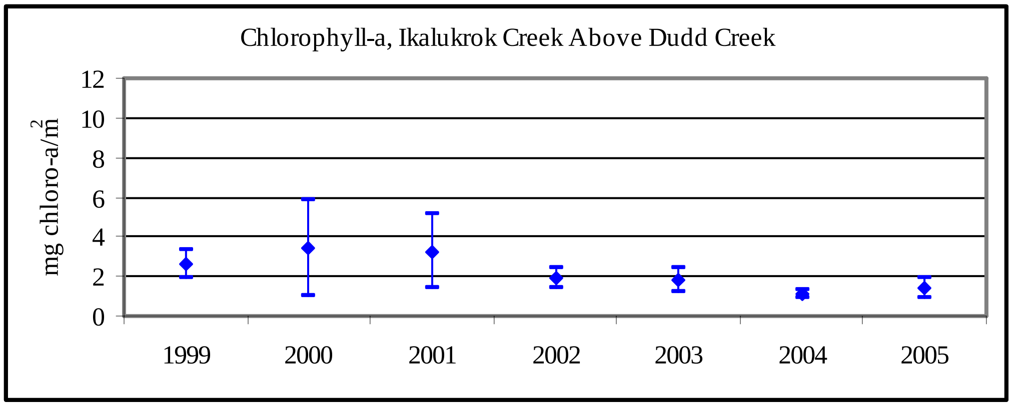

Figure 28. Average concentration of chlorophyll-a, plus and minus one standard deviation, in Ikalukrok Creek above Dudd Creek.

Biomonitoring Summary

Changes in water quality, aquatic invertebrates, periphyton, and larval fish that have been documented over time in Ikalukrok Creek, immediately upstream of Dudd Creek, are summarized in Table 5.

Table 5. Ikalukrok Creek, Upstream of Dudd Creek, 1999 to 2005

Factor	Changes Observed
Water Quality	TDS concentrations below 1,000 mg/L Median Cd and Zn concentrations lower than baseline Some maximum Pb concentrations higher than baseline
Invertebrates	Abundance, highly variable among sample years Density, highly variable among sample years Taxa Richness, low of 13 and a high of 21 % EPT, low of 6% and a high of 53%
Periphyton	Fairly consistent in all sample years
Larval Fish	Arctic grayling in 2000, 2002, and 2003 Slimy sculpin in 2005

Ikalukrok Creek at Station 8

Site Description

Ikalukrok Creek, downstream of Mainstem Red Dog Creek, is a relatively fast-flowing stream with medium sized gravel to small cobble substrate (Figure 29). Streambanks are vegetated with various species of willow and gravel bars are exposed at lower flows. During the summer months, the stream bottom is frequently covered with filamentous algae.

Figure 29. Ikalukrok Creek downstream of Mainstem Red Dog Creek, Station 8.

Water samples have not been collected from Station 8 in recent years because water from Mainstem Red Dog Creek and Ikalukrok Creek is not mixed until further downstream. Water samples are now collected at Station 150 about 0.5 km below Station 8 and downstream of complete mixing of Mainstem Red Dog and Ikalukrok creeks.

Invertebrate Community (Abundance, Density, Taxa Richness, and Structure)

Aquatic invertebrate abundance, density, taxa richness, and structure are presented in Figures 30 through 34. Considerable variability in aquatic invertebrate abundance is shown among years in Figure 30.

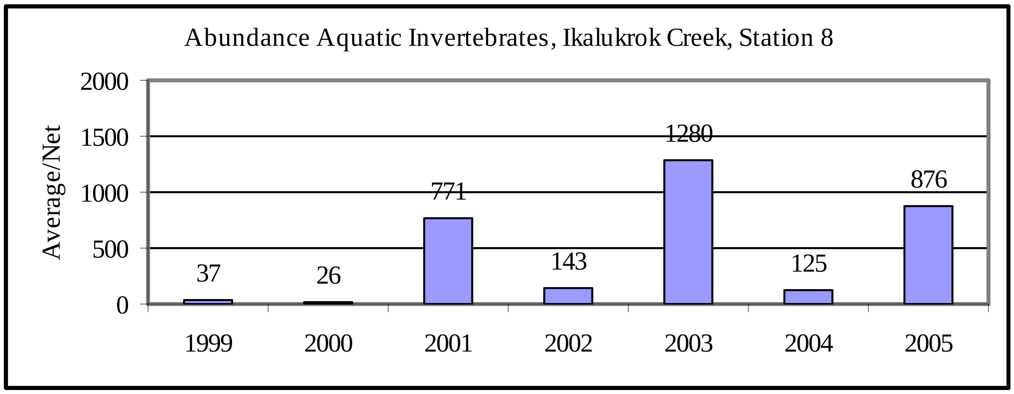

Figure 30. Aquatic invertebrate abundance, Ikalukrok Creek at Station 8.

Variability in the density of aquatic invertebrates also was high ranging from a low of $0.7/m^3$ to a high of $9.9/m^3$ (Figure 31).

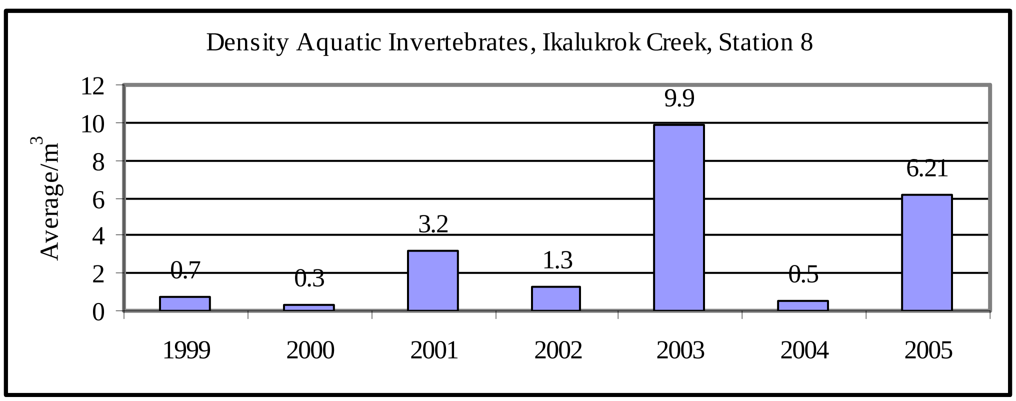

Figure 31. Aquatic invertebrate density, Ikalukrok Creek at Station 8.

Total aquatic taxa in Ikalukrok Creek, downstream of Mainstem Red Dog Creek, varied from a low of 10 to a high of 24 (Figure 32).

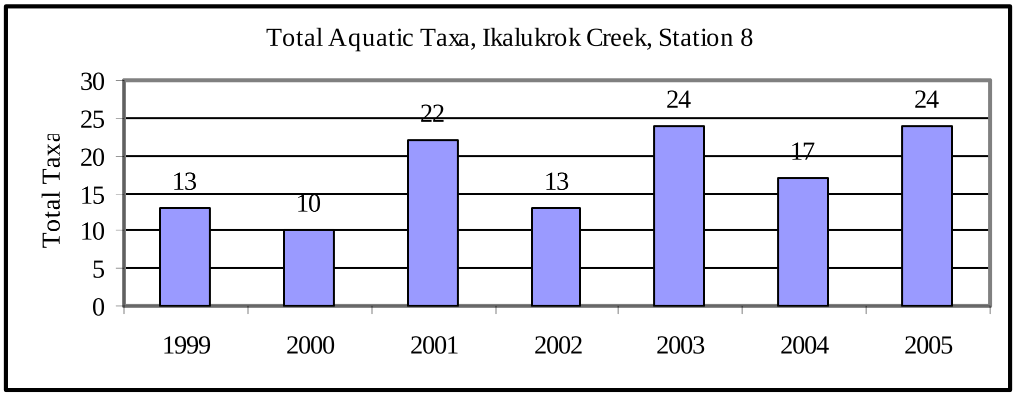

Figure 32. Aquatic invertebrate taxa richness, Ikalukrok Creek at Station 8.

The proportion of EPT in the aquatic invertebrate samples from Ikalukrok Creek varied from a low of 23% to a high of 60% (Figure 33). Aquatic invertebrate data from Station 8 in Ikalukrok Creek clearly indicate a healthy, productive community present high variability among years.

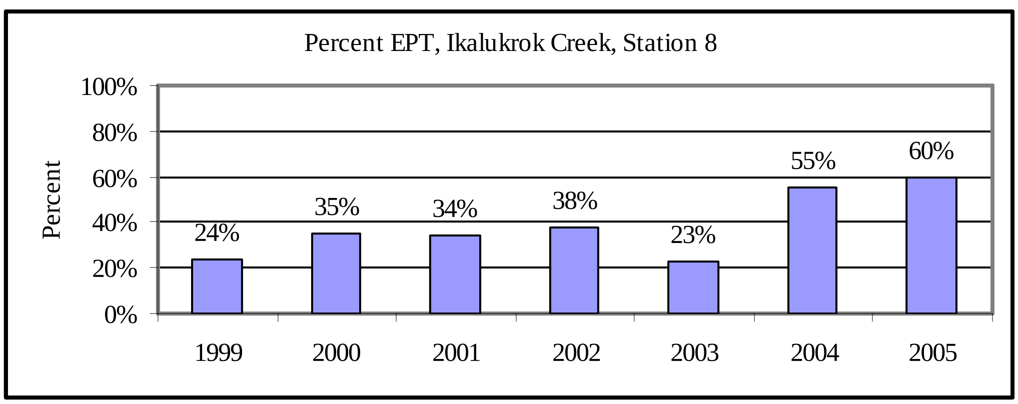

Figure 33. Proportion of EPT in aquatic invertebrate samples, Ikalukrok Creek at Station 8.

Periphyton Standing Crop

Algal biomass, as estimated by chlorophyll-a concentrations was fairly consistent from 1999 through 2003, but higher in both 2004 and 2005 (Figure 34).

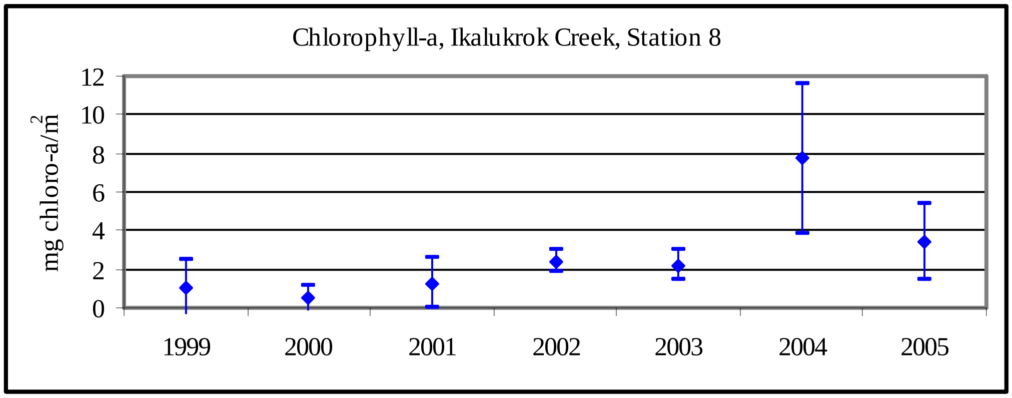

Figure 34. Average concentration of chlorophyll-a, plus and minus one standard deviation, in Ikalukrok Creek at Station 8.

Biomonitoring Summary

Changes in water quality, aquatic invertebrates, periphyton, and larval fish that have been documented over time in Ikalukrok Creek, immediately below Mainstem Red Dog Creek, are summarized in Table 6.

Table 6. Ikalukrok Creek, Station 8, 1999 to 2005

Factor	Changes Observed
Water Quality	Ikalukrok Creek and Mainstem Red Dog Creek not mixed
Invertebrates	Abundance, highly variable among sample years Density, highly variable among sample years Taxa Richness, low of 10 and a high of 24 % EPT, low of 23% and a high of 60%
Periphyton	Fairly consistent from 1999 to 2003, but higher in both 2004 and 2005
Larval Fish	Arctic grayling in 2000 and 2002

Ikalukrok Creek at Station 9

Site Description

Station 9 is located in Ikalukrok Creek upstream of the confluence with Mainstem Red Dog Creek and near the US Geological Survey gauging station (Figure 35). The creek at this site, divides around a large partially vegetated gravel bar; the right channel facing downstream contains most of the flow. Periphyton and aquatic invertebrate samples were collected in the right channel.

Figure 35. Ikalukrok Creek upstream of Mainstem Red Dog Creek, Station 9.

Water Quality

Water quality at Station 9 is not affected by water discharged from the Red Dog water treatment facility, but is affected by natural mineral seeps located upstream. The first year since our fieldwork began in 1990 that we noticed visible effects to water clarity was in summer 1997. Mineralized seeps are visible along Ikalukrok Creek upstream of Mainstem Red Dog Creek at Moil, Noa, Cub, and West Fork Ikalukrok creeks. All of these seeps are located along Ikalukrok Creek; none have been observed on East Fork Ikalukrok Creek. The pH at Station 9 during the ice-free season is shown in Figure 36. Note the low pH values recorded in 1999 and 2003, in comparison with baseline premining data.

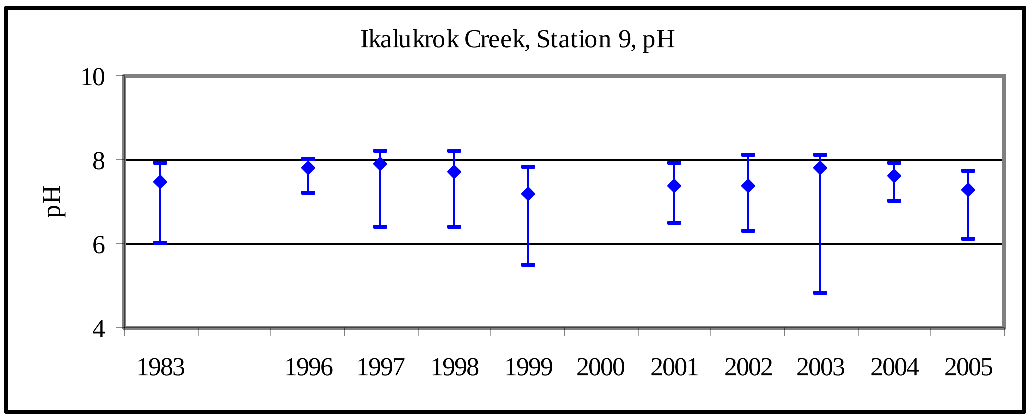

Figure 36. Median, maximum, and minimum pH at Station 9 in Ikalukrok Creek.

Concentrations of Al, Cd, Cu, Pb, Se, and Zn are presented in Figures 37 through 42. Baseline data are available for Al, Cd, Cu, Pb, and Zn. Both Cd and Zn increased from baseline concentrations from 1999 through 2001, but have shown a decreasing trend from 2002 through 2005. Al concentrations are higher than baseline conditions measured for all sample years from 1999 through 2005. Although Zn concentrations have shown a decrease from 2002 to 2005, they are still higher than baseline data. The most likely cause of these changes from baseline conditions is the very active mineral seep at Cub Creek where the pH was measured at 3.3 in early July 2005.

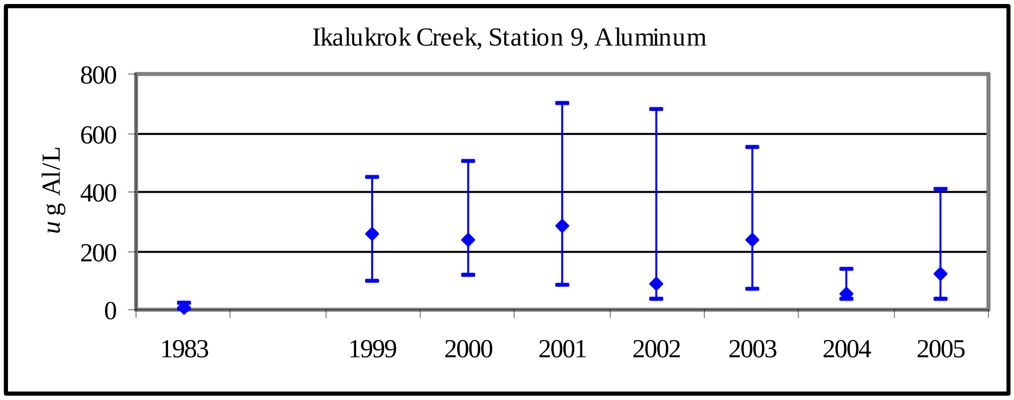

Figure 37. Median, maximum, and minimum concentrations of Al at Station 9.

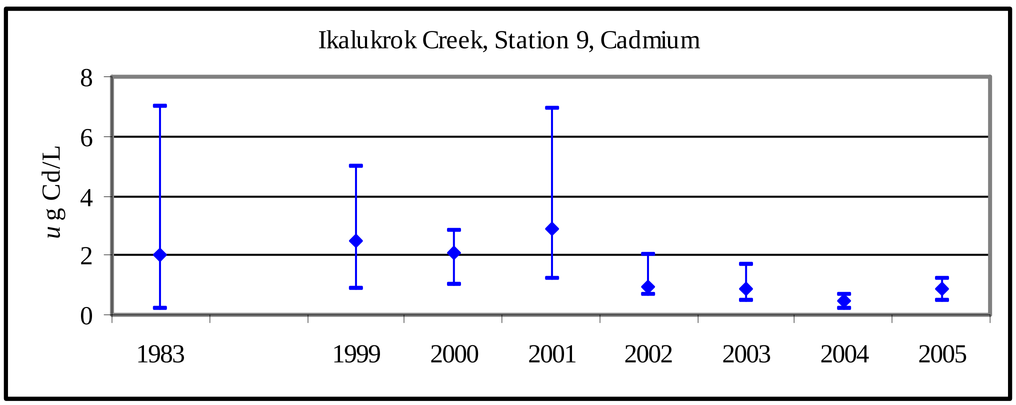

Figure 38. Median, maximum, and minimum concentrations of Cd at Station 9.

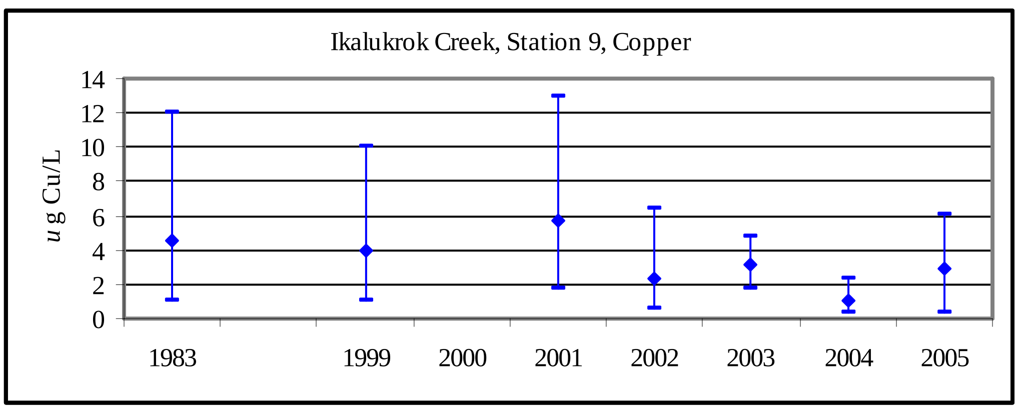

Figure 39. Median, maximum, and minimum concentrations of Cu at Station 9.

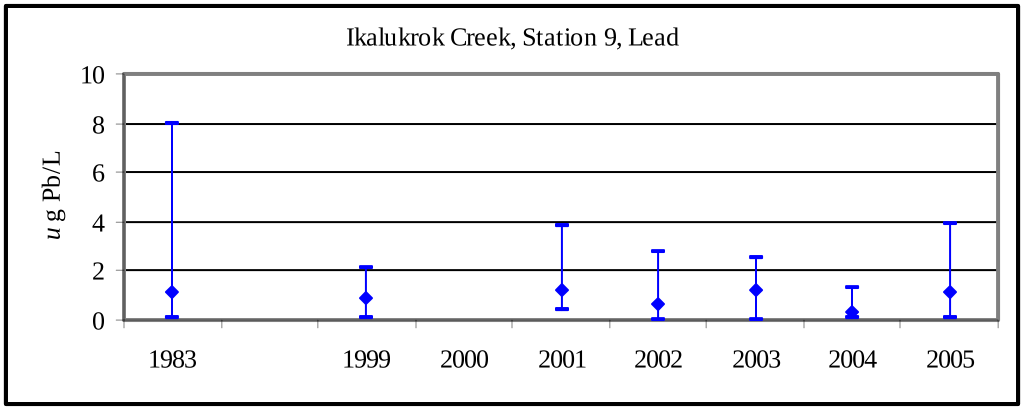

Figure 40. Median, maximum, and minimum concentrations of Pb at Station 9.

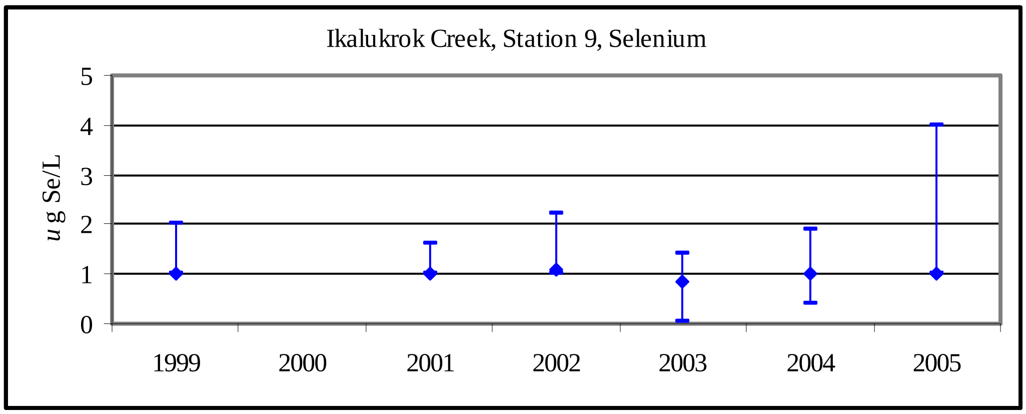

Figure 41. Median, maximum, and minimum concentrations of Se at Station 9.

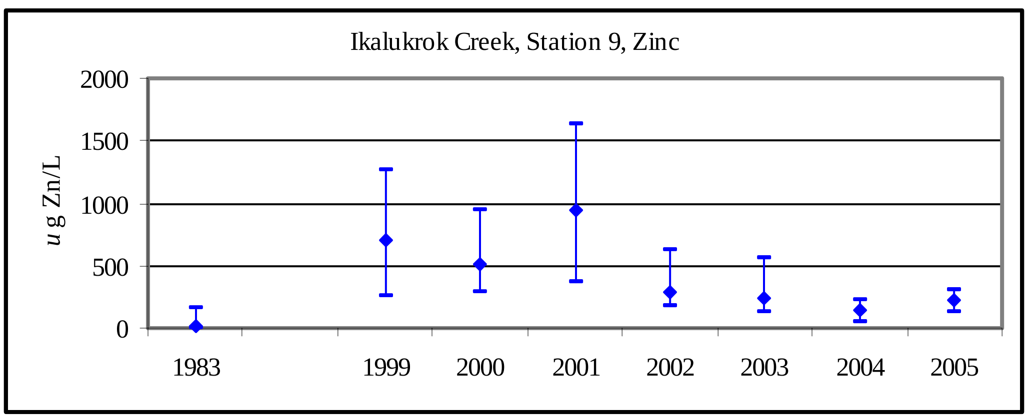

Figure 42. Median, maximum, and minimum concentrations of Zn at Station 9.

Invertebrate Community (Abundance, Density, Taxa Richness, and Structure)

Aquatic invertebrate abundance, density, taxa richness, and structure are presented in Figures 43 through 46. Abundance and density of aquatic invertebrates was highly variable among sample years (Figures 43 and 44). Although highly variable, there are similarities between Stations 8 and 9, both on Ikalukrok Creek just above and below the mouth of Mainstem Red Dog Creek, with lower overall aquatic invertebrates in 1999, 2000, 2002, and 2004 at both sites.

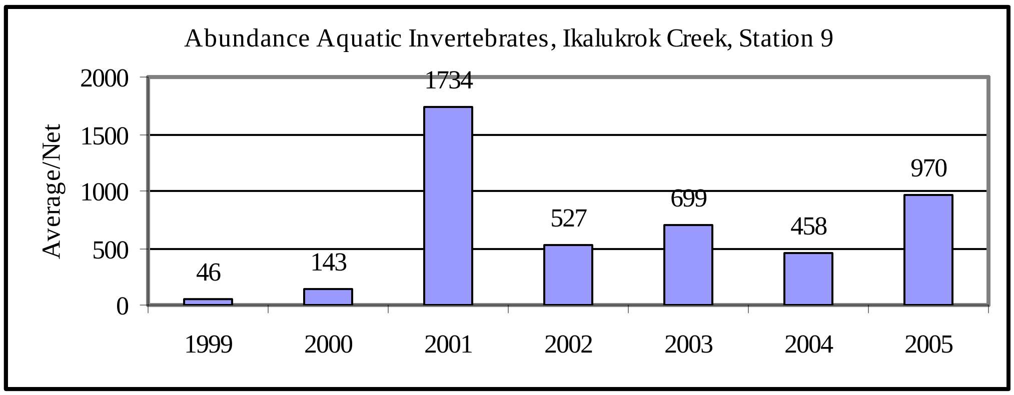

Figure 43. Aquatic invertebrate abundance, Ikalukrok Creek at Station 9.

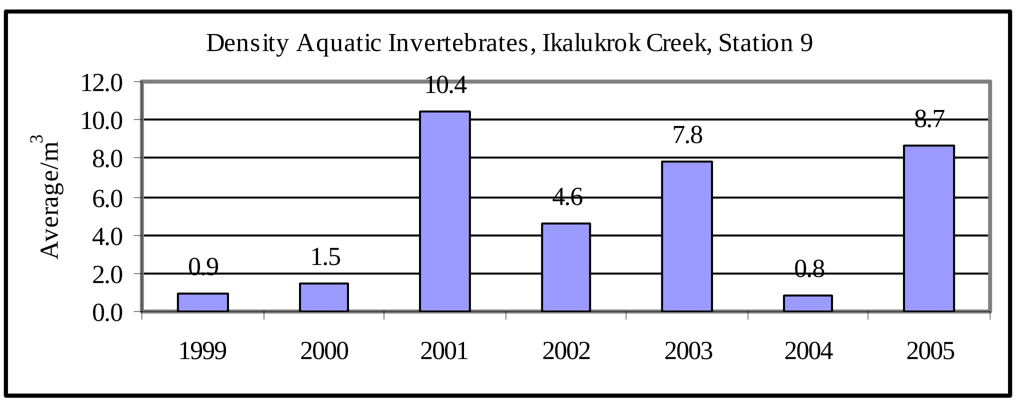

Figure 44. Aquatic invertebrate density, Ikalukrok Creek at Station 9.

Total aquatic taxa in Ikalukrok Creek, upstream of Mainstem Red Dog Creek, varied from a low of 8 to a high of 20 (Figure 45). The proportion of EPT in the aquatic invertebrate samples was the highest at 79% in 2005 (Figure 46). Overall, the EPT proportions at Stations 8 and 9 are higher than at the two Ikalukrok Creek sites located further downstream near the mouth of Dudd Creek.

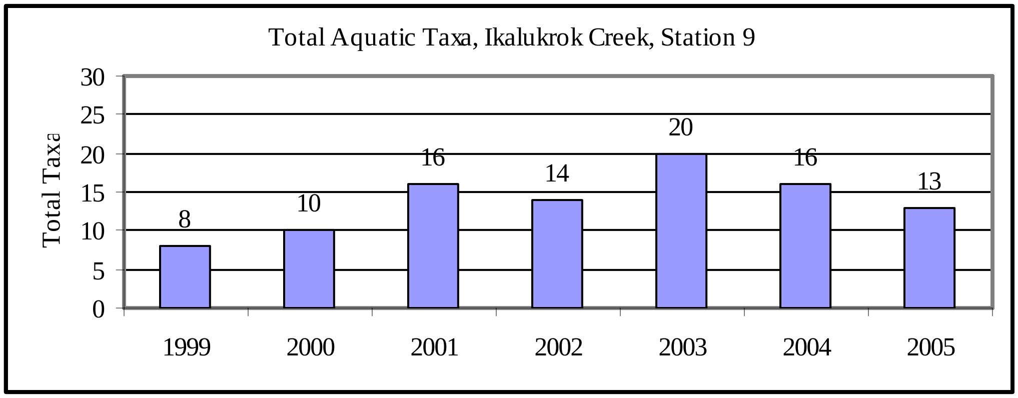

Figure 45. Aquatic invertebrate taxa richness, Ikalukrok Creek at Station 9.

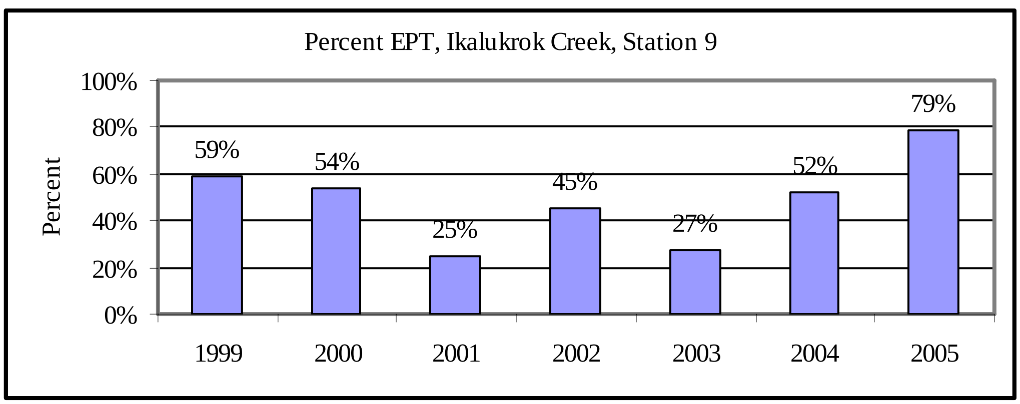

Figure 46. Proportion of EPT in aquatic invertebrate samples, Ikalukrok Creek at Station 9.

Periphyton Standing Crop

Algal biomass, as estimated by chlorophyll-a concentrations was lower from 1999 to 2001 than from 2002 through 2005 (Figure 47). Higher chlorophyll-a concentrations from 2002 through 2005 may be related to decreases in certain metals such as Zn and Cd, and perhaps Nickel (Ni). Nickel concentrations have decreased substantially since 1999 and 2000 (Figure 48).

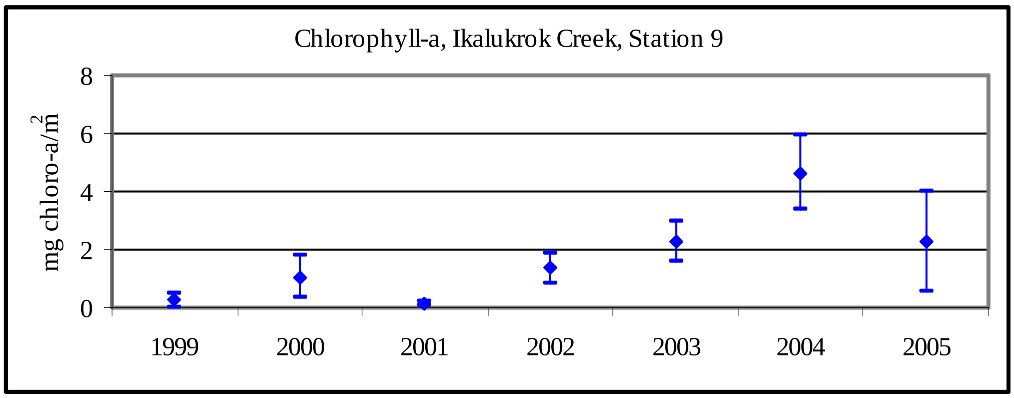

Figure 47. Average concentration of chlorophyll-a, plus and minus one standard deviation, in Ikalukrok Creek at Station 9.

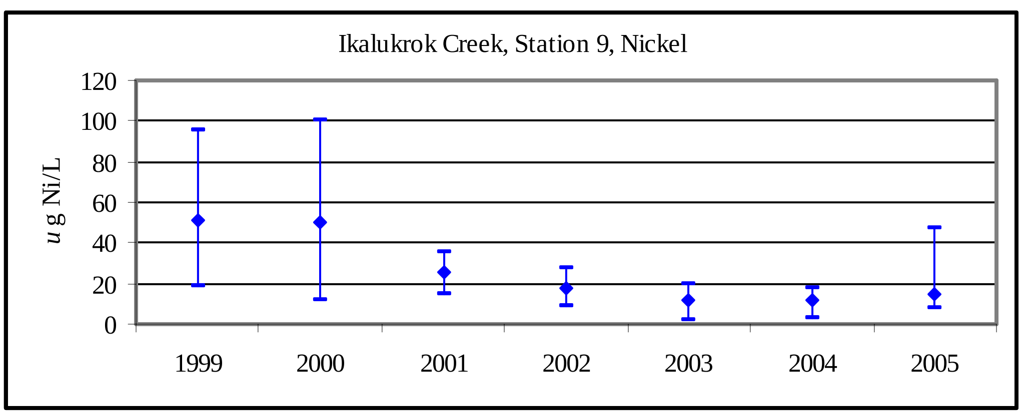

Figure 48. Median, maximum, and minimum concentrations of Ni at Station 9.

Biomonitoring Summary

Changes in water quality, aquatic invertebrates, periphyton, and larval fish that have been documented over time in Ikalukrok Creek at Station 9 are summarized in Table 7.

Table 7. Ikalukrok Creek, Station 9, 1999 to 2005

Factor	Changes Observed
Water Quality	Cd and Zn concentrations decreased in 2002 to 2005 Zn and Al concentrations higher than baseline data Ni concentrations deceasing with time since 1999
Invertebrates	Abundance, highly variable among sample years Density, highly variable among sample years Taxa Richness, low of 8 and a high of 20 % EPT, low of 25% and a high of 79%
Periphyton	Fairly consistent and low from 1999 to 2001, but higher from 2002 through 2005
Larval Fish	Arctic grayling in 2000 and 2002

Mainstem Red Dog Creek at Station 10

Site Description

Mainstem Red Dog Creek varies in width from 3.5 to 18 m and water depths range from 0.06 to 2.5 m. The streambed consists mostly of gravel, small cobbles, and boulders. The creek has some meanders and areas where the channel has shifted location. Deep pools are found along cut banks with rock outcroppings. Dense mats of filamentous green algae are common along reaches of Mainstem Red Dog Creek.

Figure 49. Mainstem Red Dog Creek, Station 10.

Water Quality

Discharge volume from the water treatment plant is regulated to control the TDS concentrations in Mainstem Red Dog Creek. Concentrations of TDS are limited by permit condition to less than 500 mg/L during Arctic grayling spawning in spring. Arctic grayling are sampled, depending upon flow and ice conditions, with fyke nets and by angling and visual observation in both Mainstem Red Dog and North Fork Red Dog creeks. After Arctic grayling spawning has been completed in Mainstem Red Dog Creek, the TDS concentrations are increased to not exceed 1,500 mg/L at Station 10 (Figure 50). Arctic grayling spawning began on May 27 (determined by the first day that peak water temperature exceeded 3°C) and was determined to be complete June 6, 2005 (McLean 2005). TDS concentrations at Station 10 did not exceed 500 mg/L during the time period of Arctic grayling spawning (Figure 50).

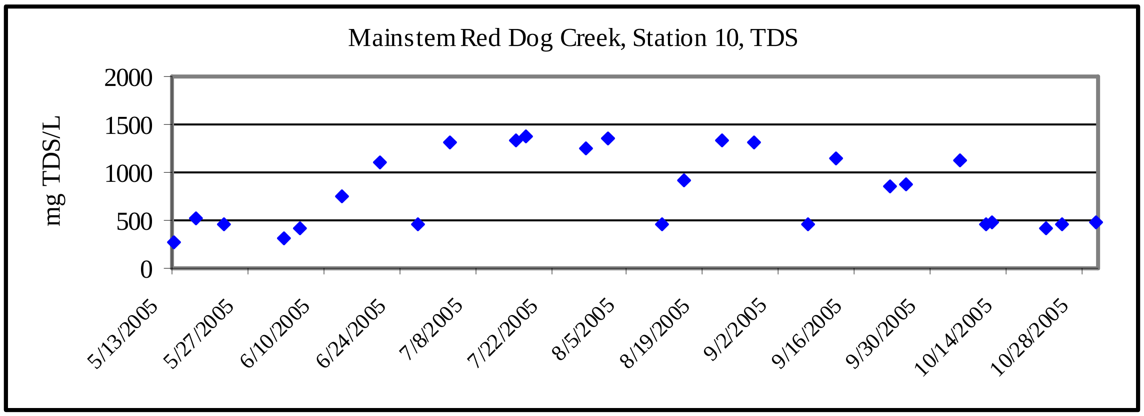

Figure 50. TDS concentrations in Mainstem Red Dog Creek, Station 10.

McLean (2005) presented a summary of data gathered on Arctic grayling spawning in Mainstem Red Dog and North Fork Red Dog creeks for spring 2001 through 2005 (Table 8). Using all five years of data on water temperature and spawning in Mainstem Red Dog Creek, Arctic grayling spawning was judged to be complete after peak daily water temperatures exceeded 4°C for 4 to 9 cumulative days within the sample year. In those years, when the magnitude of the peak temperature was highest, the cumulative days needed to complete spawning were the fewest. Our recommendation for using temperature to determine start and finish of Arctic grayling spawning in Mainstem Red Dog Creek follows:

THE START OF ARCTIC GRAYLING SPAWNING IN ANY GIVEN YEAR IN MAINSTEM RED DOG CREEK OCCURS WHEN THE PEAK WATER TEMPERATURE REACHES 3°C AT STATION 10. ARCTIC GRAYLING SPAWNING WILL BE CONSIDERED COMPLETE WHEN PEAK WATER TEMPERATURES AT STATION 10 EXCEED 4°C FOR NINE (9) CUMULATIVE DAYS.

Following this recommendation would be conservative based on both the beginning of spawning and the fact that in four out of five years spawning was judged to be complete in less than nine days.

Table 8. A summary of Arctic grayling spawning in Mainstem Red Dog Creek from 2001 to 2005 using water temperature to indicate the beginning of spawning and condition of captured Arctic grayling to determine when spawning was complete.

Year	Date When Limited Spawning Started (3°C)	Date When Spawning Complete (Condition of Females)	Number of Days Peak Temperatures Exceeded 4°C[1]
2001	June 6	June 15	6
2002	May 29	June 8	8
2003	June 7	June 14	6
2004	May 25	May 31	4
2005	May 27	June 6	9

[1]Does not include the day spawning was judged to be complete since the fyke net is worked in the early morning prior to peak water temperatures on that day.

Concentrations of specific metals in Mainstem Red Dog Creek at Station 10 were high before mining, highest in 1989 and 1990, and lower after construction of the clean water bypass in March/April 1991. Improvements to the clean water bypass system have occurred periodically since 1991 (Appendix 1). The pH values reflect these conditions with the lowest pH measured in 1990 and higher pH reported from 1999 through 2005 as compared with either premining or 1990 (Figure 51).

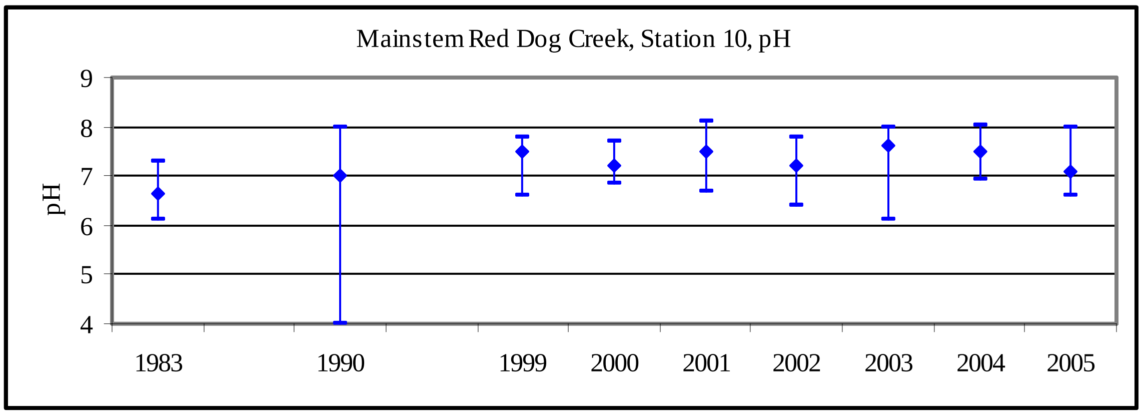

Figure 51. Median, maximum, and minimum pH values in Mainstem Red Dog Creek at Station 10.

Concentrations of Al, Cd, Cu, Pb, Se, and Zn are presented in Figures 52 through 57. Median concentrations for Al, Cd, Pb, and Zn have consistently been lower since 1999 than those reported premining. However, we still see peaks during the ice-free season for Al and Pb that are comparable or higher than baseline data. A high peak concentration of Se was noted at Station 10, but also was seen at other stations including Station 9 that is not affected by waters from the Red Dog Mine facility.

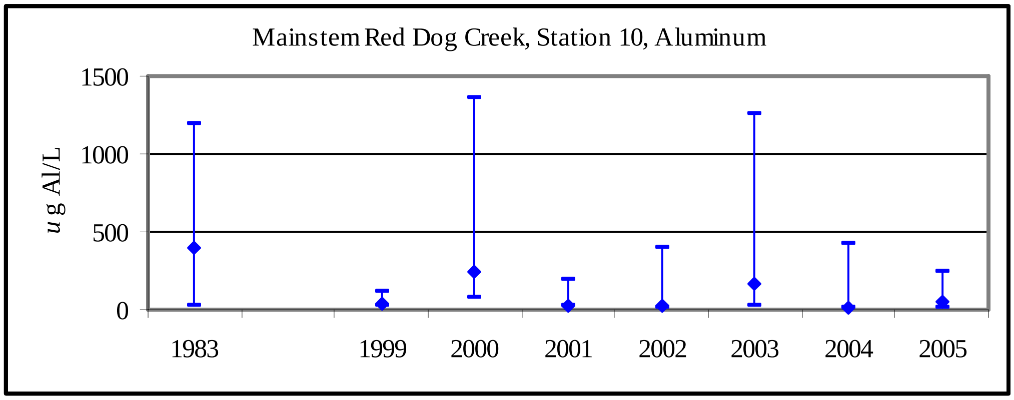

Figure 52. Median, maximum, and minimum concentrations of Al at Station 10.

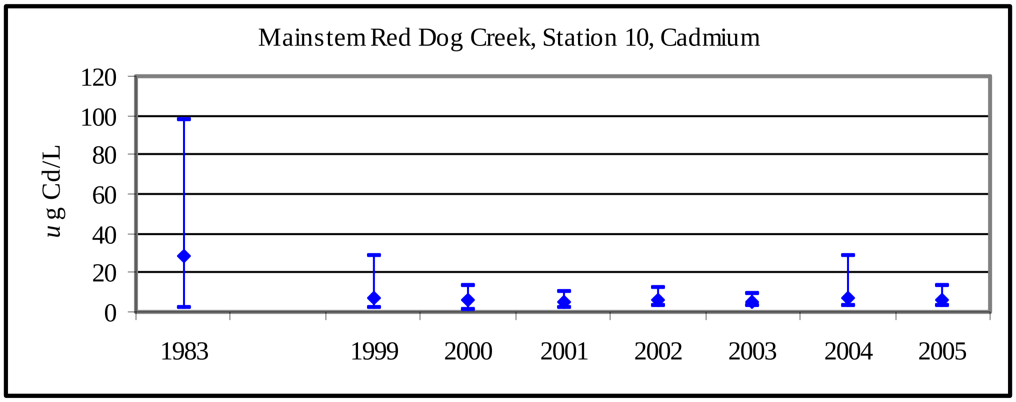

Figure 53. Median, maximum, and minimum concentrations of Cd at Station 10.

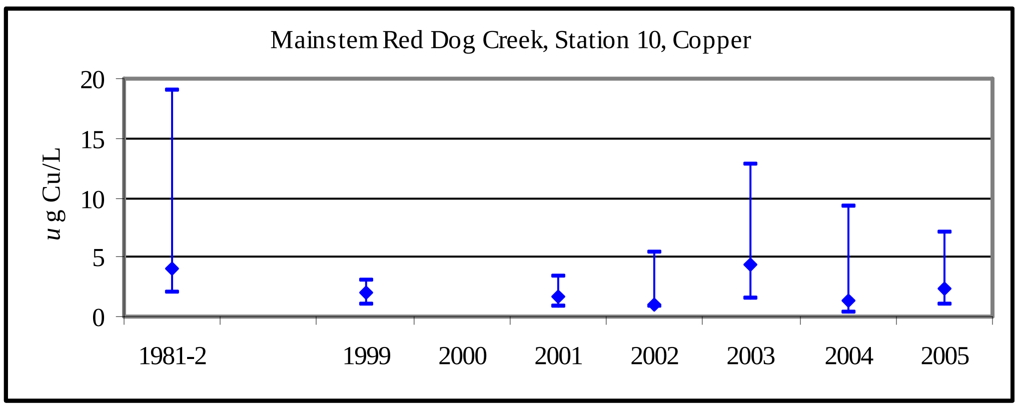

Figure 54. Median, maximum, and minimum concentrations of Cu at Station 10.

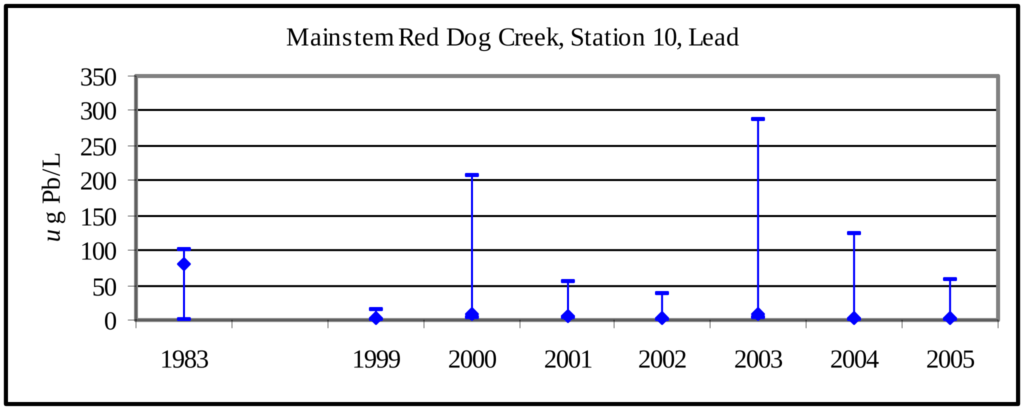

Figure 55. Median, maximum, and minimum concentrations of Pb at Station 10.

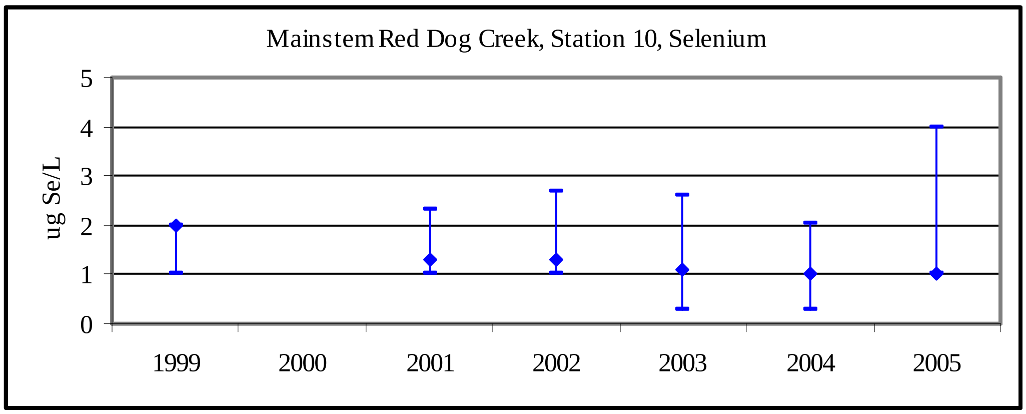

Figure 56. Median, maximum, and minimum concentrations of Se at Station 10.

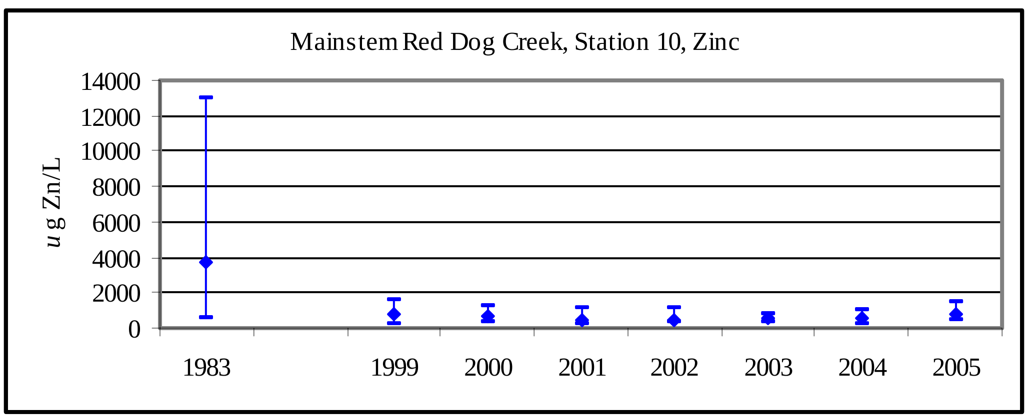

Figure 57. Median, maximum, and minimum concentrations of Zn at Station 10.

Invertebrate Community (Abundance, Density, Taxa Richness, and Structure)

Aquatic invertebrate abundance, density, taxa richness, and structure are presented in Figures 58 through 61. High variability among years in both abundance and density of aquatic invertebrates is shown in Figures 58 and 59. Abundance and density of aquatic invertebrates was higher in 2001, 2003 and 2005 at Station 10 and this pattern seems to be similar at the three sample stations located downstream in Ikalukrok Creek. These results indicate that variability among years is due to background environmental differences (e.g., flow and water temperature).

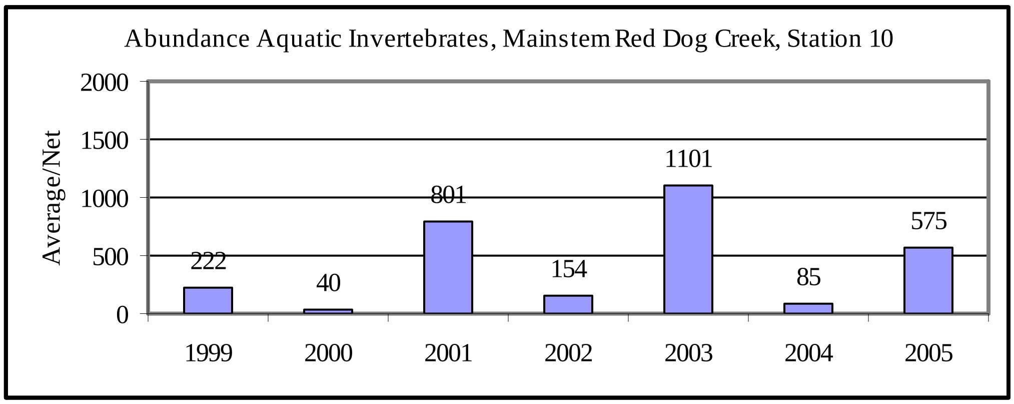

Figure 58. Aquatic invertebrate abundance, Mainstem Red Dog Creek, Station 10.

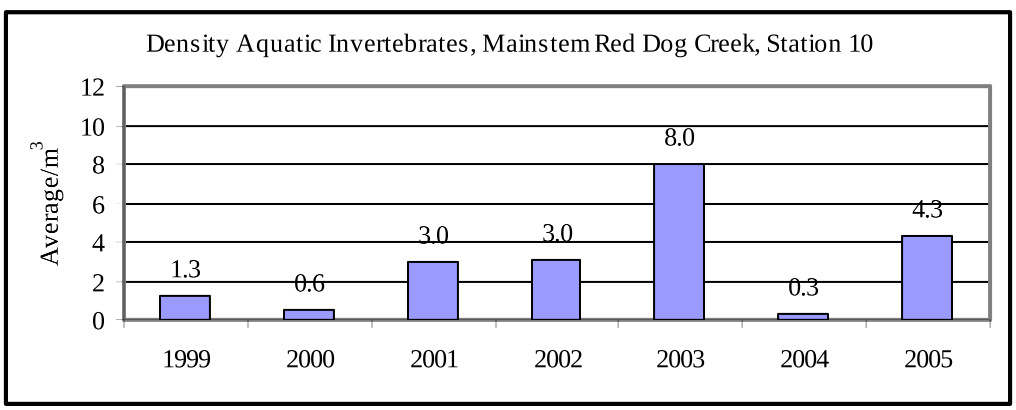

Figure 59. Aquatic invertebrate density, Mainstem Red Dog Creek, Station 10.

Total aquatic taxa in Mainstem Red Dog Creek, varied from a low of 10 in 2000 to a high of 20 in both 2001 and 2003 (Figure 61). The proportion of EPT in the aquatic invertebrate samples was lower in 2005 than it had been in the previous two years (Figure 61).

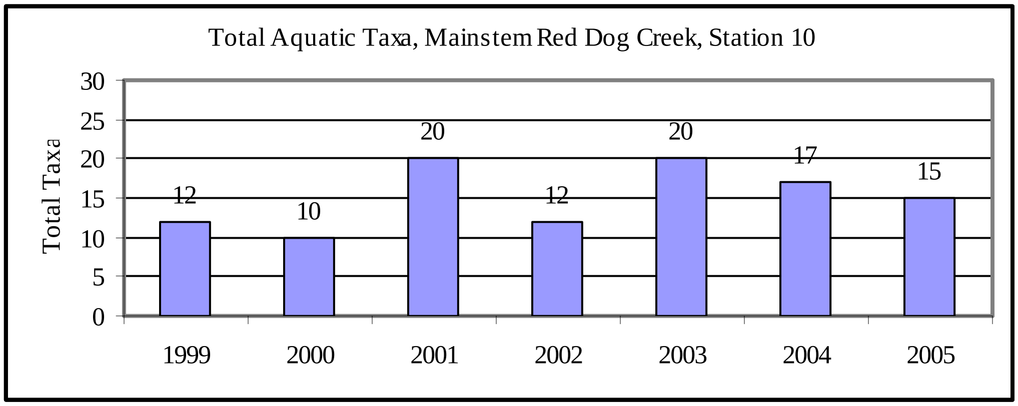

Figure 60. Aquatic invertebrate taxa richness, Mainstem Red Dog Creek, Station 10.

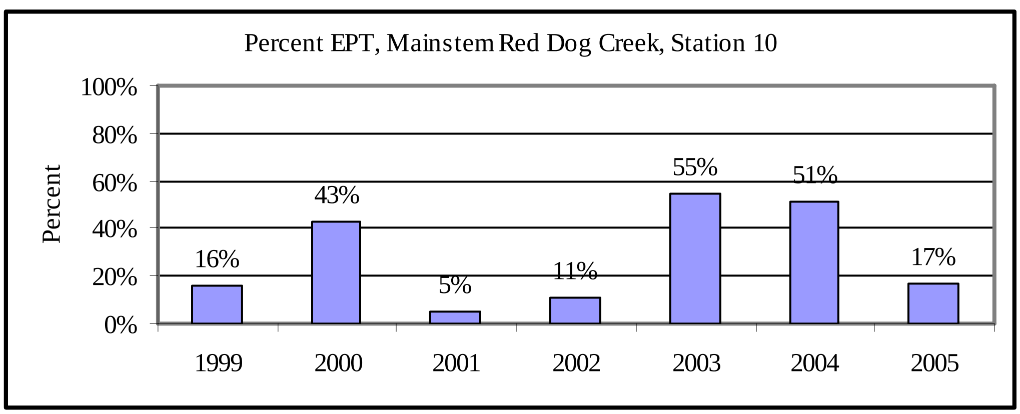

Figure 61. Proportion of EPT in aquatic invertebrate samples, Mainstem Red Dog Creek, Station 10.

Periphyton Standing Crop

Algal biomass, as estimated by chlorophyll-a concentrations has been fairly consistent over the sample years. Highest chlorophyll-a concentrations were measured in samples collected in 2004 and the lowest were found in 2000 (Figure 62). Chlorophyll-a concentrations also were the highest measured in 2004 at both Stations 9 (Ikalukrok Creek upstream of Mainstem Red Dog Creek) and 8 (Ikalukrok Creek just downstream of the mouth of Mainstem Red Dog Creek).

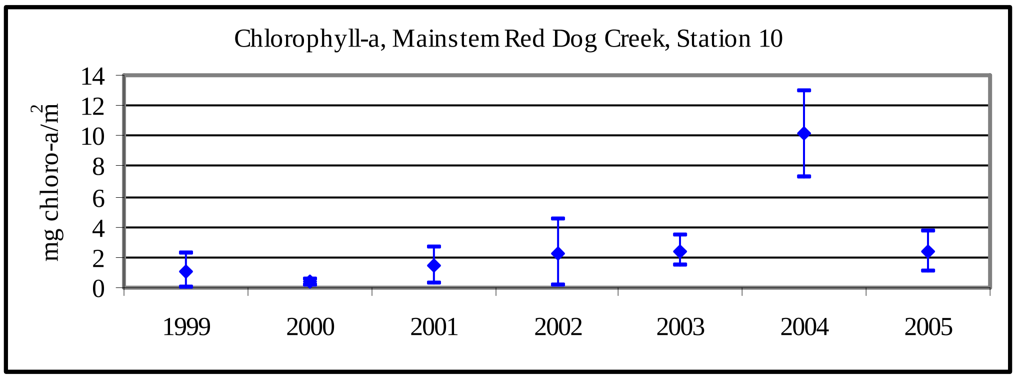

Figure 62. Average concentration of chlorophyll-a, plus and minus one standard deviation, in Mainstem Red Dog Creek at Station 10.

Biomonitoring Summary

Changes in water quality, aquatic invertebrates, periphyton, and larval fish that have been documented over time in Mainstem Red Dog Creek at Station 10 are summarized in Table 9.

Table 9. Mainstem Red Dog Creek, Station 10, 1999 to 2005.

Factor	Changes Observed
Water Quality	TDS concentrations below 500 mg/L during grayling spawning TDS concentrations below 1,500 mg/L at all other times Median concentrations Al, Cd, Pb, and Zn consistently lower
Invertebrates	Abundance, highly variable among sample years Density, highly variable among sample years Taxa Richness, low of 10 and a high of 20 % EPT, low of 5% and a high of 55%
Periphyton	Fairly consistent in most years, high in 2004
Larval Fish	Arctic grayling in 1999, 2000, 2002, and 2003

North Fork Red Dog Creek at Station 12

Site Description

North Fork Red Dog and Middle Fork Red Dog creeks merge to form Mainstem Red Dog Creek. North Fork Red Dog Creek has a drainage area of 41 km^2, abundant streamside vegetation, deep pool, and wide riffle areas (Figure 63). Channel widths range from 7 to 15 m and depths range from 0.1 to 2 m. Arctic grayling spawn in North Fork Red Dog Creek. Juvenile and resident Dolly Varden and juvenile and adult Arctic grayling rear in the creek during the ice-free season.

Figure 63. North Fork Red Dog Creek, Station 12.

Water Quality

North Fork Red Dog Creek is a clearwater stream that drains areas containing ice-rich soils. Thermal degradation in the upper part of the drainage has caused periodic increases in turbidity. Our first observation of increased sediments in North Fork Red

Dog Creek was made in summer 2000. Prior to that time we had not seen noticeable increases in turbidity. Turbid water conditions have been observed each year since 2000, but most times North Fork Red Dog Creek flows clear. Several years of total suspended solids (TSS) data are available. TSS concentrations generally are low, except for peaks above 100 mg/L seen in 2001 and 2003 (Figure 64).

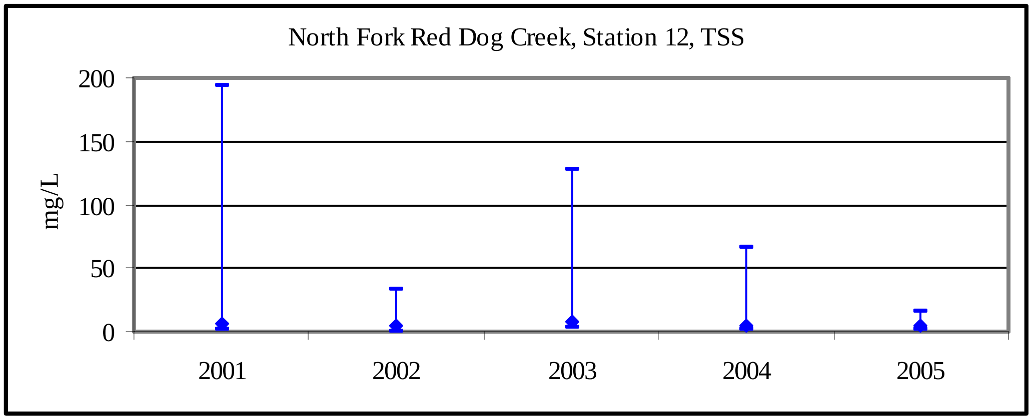

Figure 64. Total suspended sediments in North Fork Red Dog Creek.

Concentrations of Al, Cd, Cu, Pb, Se, and Zn are presented in Figures 65 through 70. Maximum concentrations of Al and Pb in some years from 1999 through 2005 have exceeded baseline data, but may be related to input of sediments in the upper part of North Fork Red Dog Creek drainage. Median concentrations of Cd, Cu, and Pb appear to be slightly lower than those reported for pre-mining conditions. These changes in water quality reflect natural variation in the system. The effluent from the Red Dog Mine water treatment facility does not affect North Fork Red Dog Creek.

Invertebrate Community (Abundance, Density, Taxa Richness, and Structure)

Aquatic invertebrate abundance, density, taxa richness, and structure are presented in Figures 71 through 74. Invertebrate abundance in North Fork Red Dog Creek has ranged from a low of 87 in 2004 to a high of 1,502 in 2001 (Figure 71). Densities of aquatic

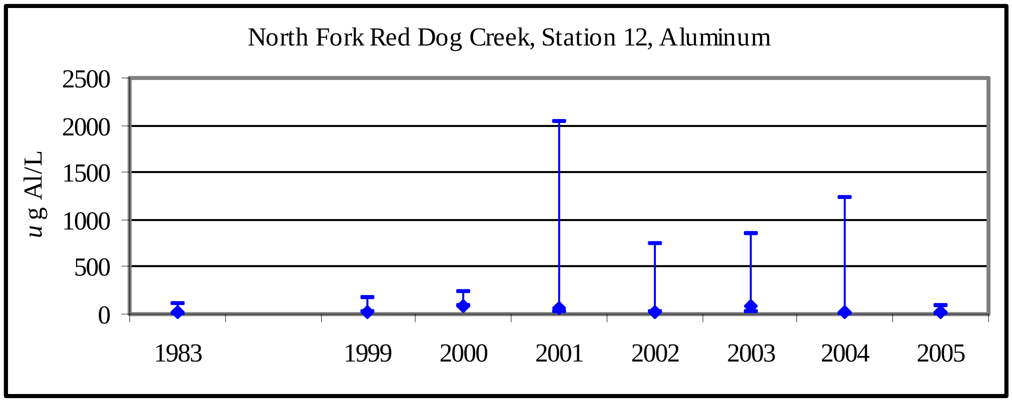

Figure 65. Median, maximum, and minimum concentrations of Al at Station 12.

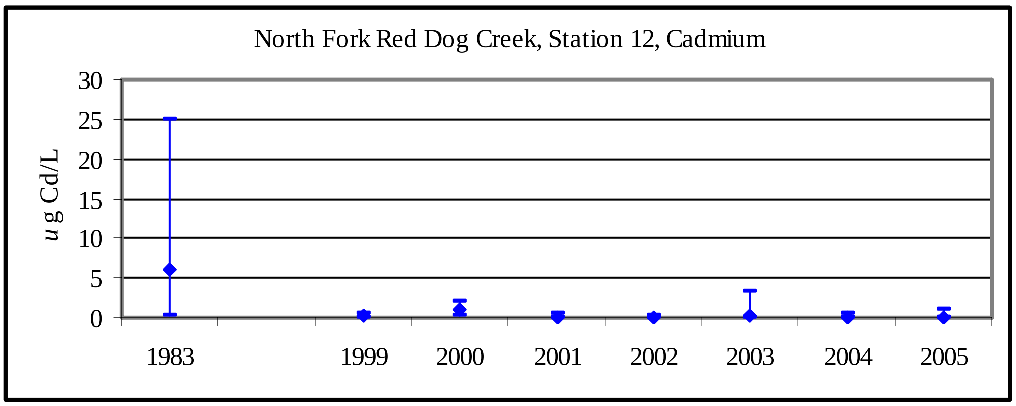

Figure 66. Median, maximum, and minimum concentrations of Cd at Station 12.

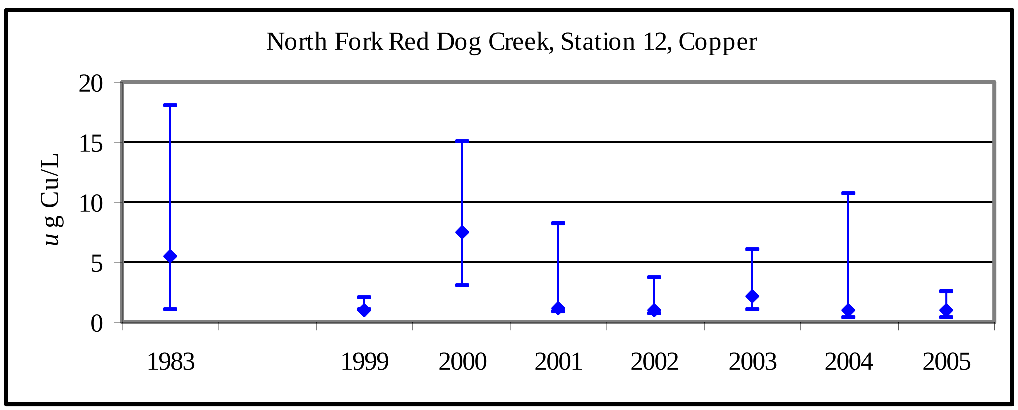

Figure 67. Median, maximum, and minimum concentrations of Cu at Station 12.

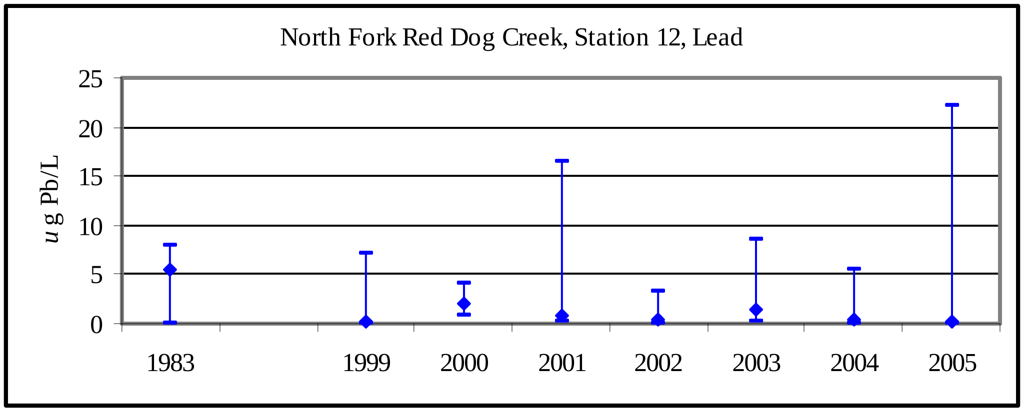

Figure 68. Median, maximum, and minimum concentrations of Pb at Station 12.

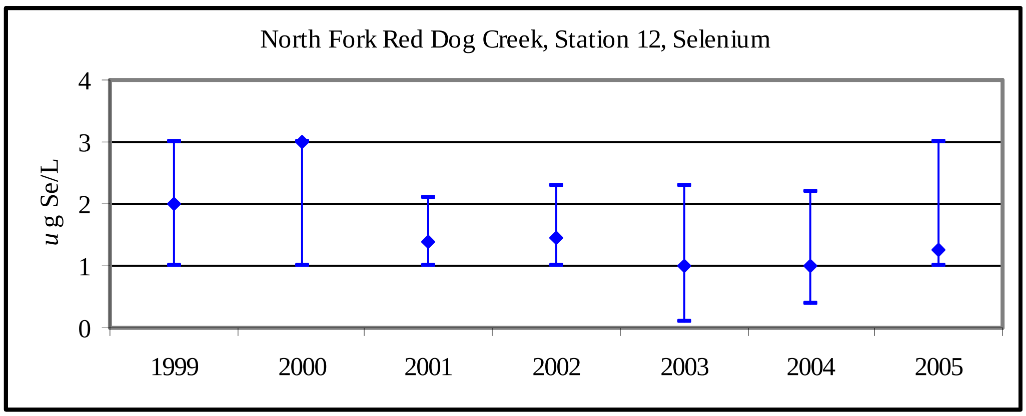

Figure 69. Median, maximum, and minimum concentrations of Se at Station 12.

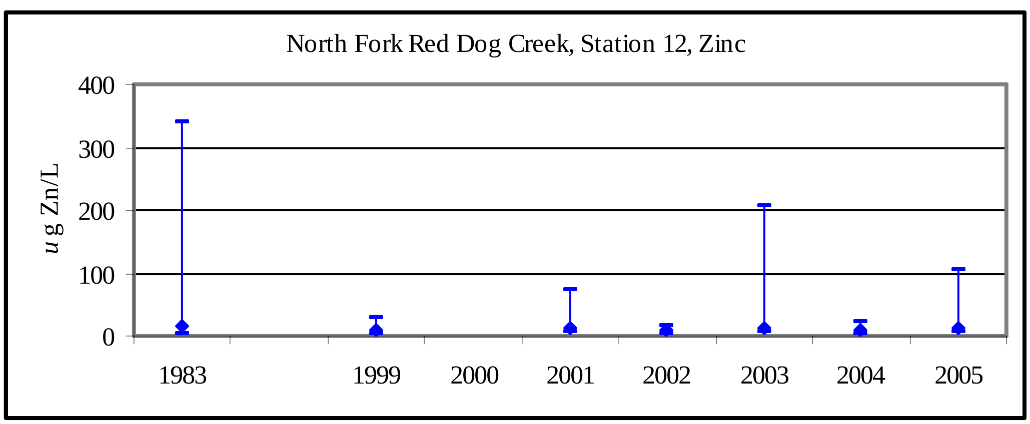

Figure 70. Median, maximum, and minimum concentrations of Zn at Station 12.

invertebrates were fairly consistent and high by comparison with other sample sites from 1999 through 2003, but very low in 2004 (Figure 72). The pattern of abundance of aquatic invertebrates at Stations 12 (North Fork Red Dog Creek) and 10 (Mainstem Red Dog Creek) is similar. Lower numbers of aquatic invertebrates were found at both sites in 2000, 2002, and 2004 (Figures 58 and 71). Overall, the density of aquatic invertebrates is higher in North Fork Red Dog Creek than in Mainstem Red Dog Creek (Figures 59 and 72).

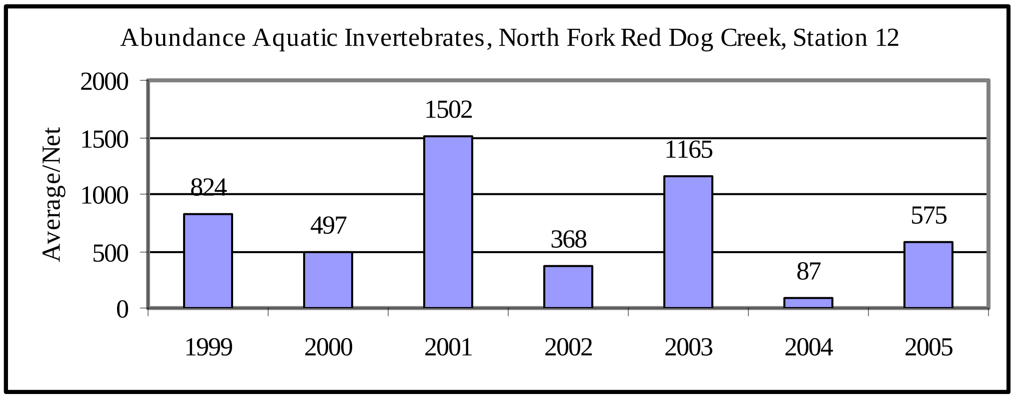

Figure 71. Aquatic invertebrate abundance, North Fork Red Dog Creek, Station 12.

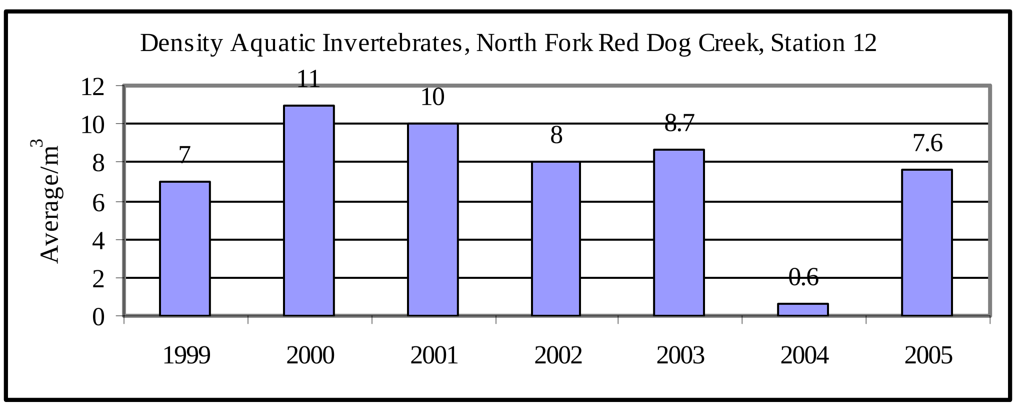

Figure 72. Aquatic invertebrate density, North Fork Red Dog Creek, Station 12.

Taxa richness has been fairly consistent among sample years in North Fork Red Dog Creek (Figure 73). Proportion of EPT varied from a low of 9% in 2001 to a high of 57% in 2002. In 3 of the 7 sample events, the %EPT is virtually the same in Mainstem Red Dog and North Fork Red Dog creeks (Figures 61 and 74). In 2 of the 7 sample years, the %EPT is higher in Mainstem Red Dog Creek. Assuming EPT is an indicator of a productive community and good water quality, then we can conclude that water quality conditions at Station 10 are sufficient to support the most sensitive aquatic invertebrates present.

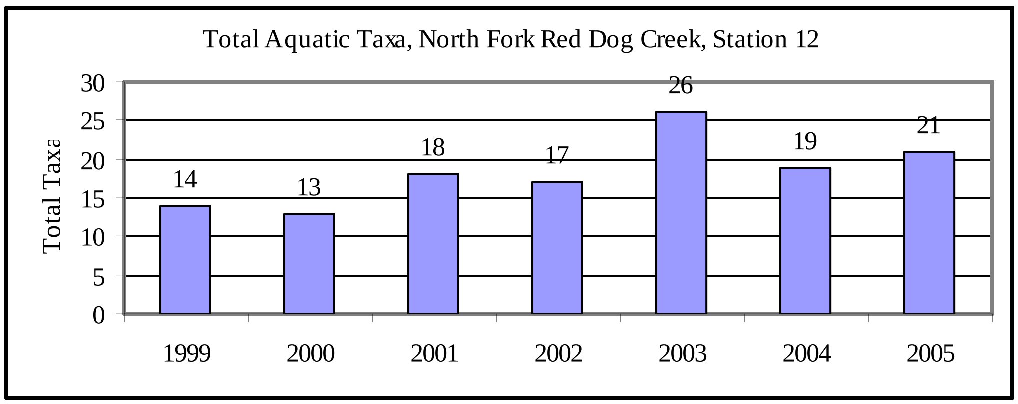

Figure 73. Aquatic invertebrate taxa richness, North Fork Red Dog Creek, Station 12.

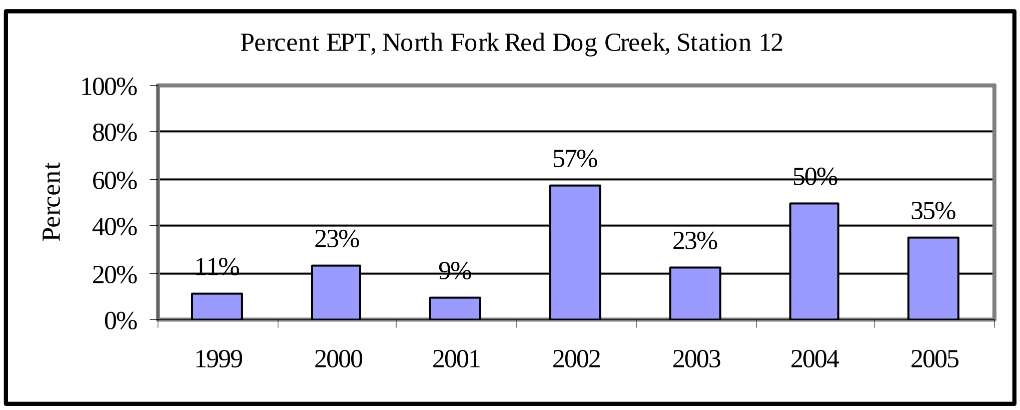

Figure 74. Proportion of EPT in aquatic invertebrate samples, North Fork Red Dog Creek, Station 12.

Periphyton Standing Crop

Algal biomass, as estimated by chlorophyll-a concentrations is presented in Figure 75. Abundant algae were present each year, except for 2004. The lowest abundance and diversity of aquatic invertebrates also was found in summer 2004. During our 2004 field sampling, streambed materials were more heavily covered with sediments. By contrast, the highest chlorophyll-a concentrations in Mainstem Red Dog Creek were found in 2004. Generally, chlorophyll-a concentrations in North Fork Red Dog Creek are higher than those found in Mainstem Red Dog Creek.

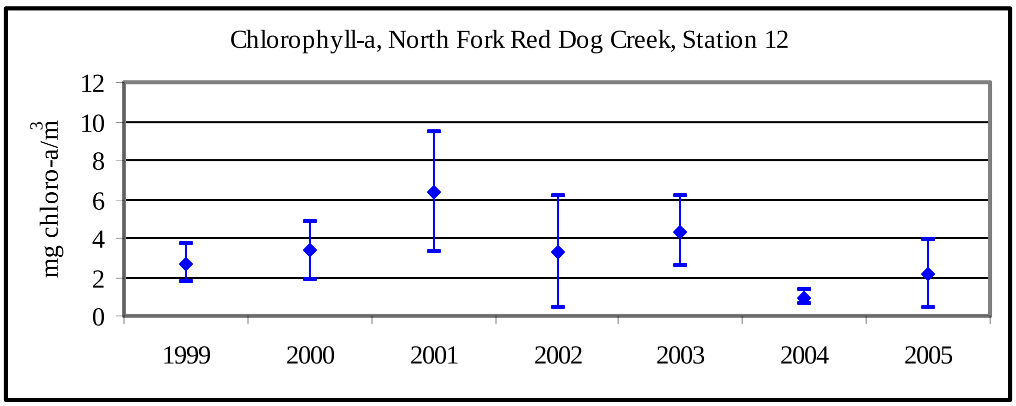

Figure 75. Average concentration of chlorophyll-a, plus and minus one standard deviation, in North Fork Red Dog Creek at Station 12.

Biomonitoring Summary

Changes in water quality, aquatic invertebrates, periphyton, and larval fish that have been documented over time in North Fork Red Dog Creek at Station 12 are summarized in Table 10.

Table 10. North Fork Red Dog Creek, Station 12, 1999 to 2005.

Factor	Changes Observed
Water Quality	Turbid water conditions first observed in 2000 Peak Al and Pb concentrations higher than baseline data Median concentrations of Cd, Cu, and Pb slightly lower than baseline data
Invertebrates	Abundance, highly variable among sample years Density, higher than other sites except for one year, 2004 Taxa Richness, low of 13 and a high of 26 % EPT, low of 9% and a high of 57%
Periphyton	Fairly consistent in most years, low in 2004
Larval Fish	Arctic grayling in 1997, 1999, 2000, and 2001

Middle Fork Red Dog Creek

Site Description

Water at Station 20 in Middle Fork Red Dog Creek consists of water from the clean water bypass and the treated mine effluent. Upper Middle Fork Red Dog Creek and tributaries (Rachael, Connie, Shelly, and Sulfur creeks) flow into the clean water bypass system. Middle Fork Red Dog Creek has wide meanders with channel widths from 3 to 10 m and depths from 0.3 to 0.45 m (Figure 76). A gabion basket weir blocks migration of fish into Middle Fork Red Dog Creek. The weir is located immediately upstream of the confluence of Middle Fork Red Dog and North Fork Red Dog creeks.

Figure 76. Middle Fork Red Dog Creek, Station 20.

Water Quality

Before mining, the pH ranged from 5.7 to 6.9 (Figure 77). The pH values from 2000 through 2005 are higher than pre-mining. The higher pH values are directly related to a higher pH in the wastewater mine effluent and higher pH values in the clean water bypass due to interception of highly acidic water by the dirty water collection system.

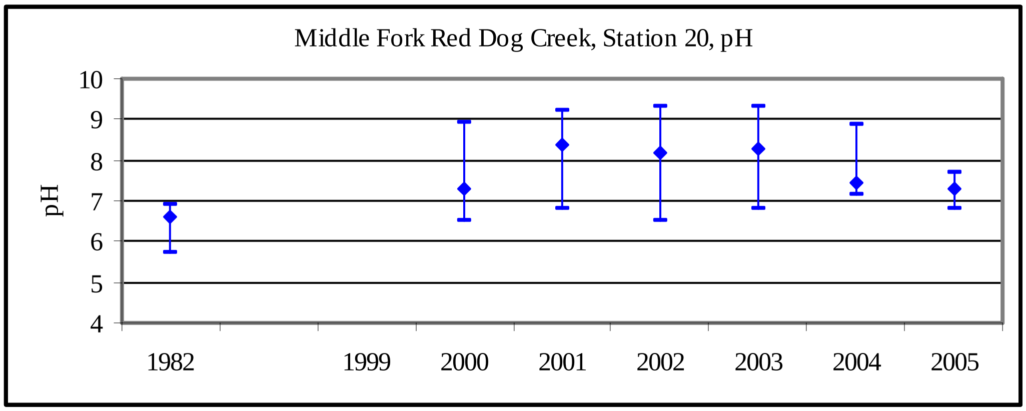

Figure 77. Median, maximum, and minimum pH values in Middle Fork Red Dog Creek, Station 20.

During our July 2005 field trip to Red Dog, we observed a substantial amount of precipitate (white/gray color) and the water clarity was opaque (Figure 78). The gray/white precipitate began at the end of the outfall and extended downstream about 1 km. The precipitate was most likely amorphous gypsum ($CaSO_4$).

Concentrations of Al, Cd, Cu, Pb, Se, and Zn are presented in Figures 79 through 84. Concentrations of Cd and Zn are consistently lower than those reported from baseline studies (Figures 80 and 84). Median Pb concentrations from 1999 through 2005 are lower than baseline data, but peak concentrations exceeding baseline data have occurred (Figure 82). The lowest Pb concentrations occurred in 2005 (Figure 82).

Figure 78. Middle Fork Red Dog Creek immediately downstream of the wastewater discharge (Outfall 001).

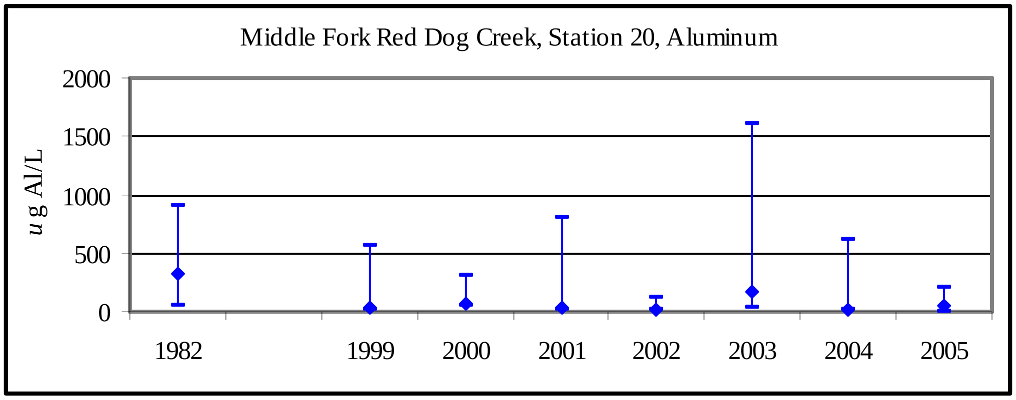

Figure 79. Median, maximum, and minimum concentrations of Al at Station 20.

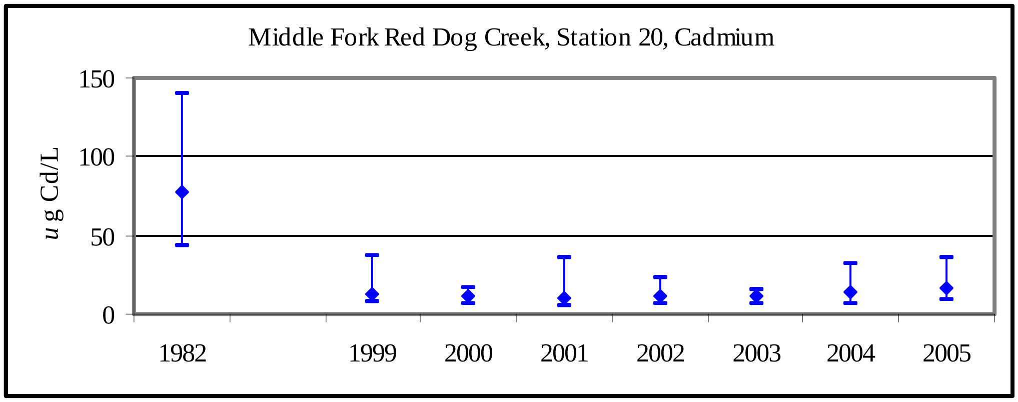

Figure 80. Median, maximum, and minimum concentrations of Cd at Station 20.

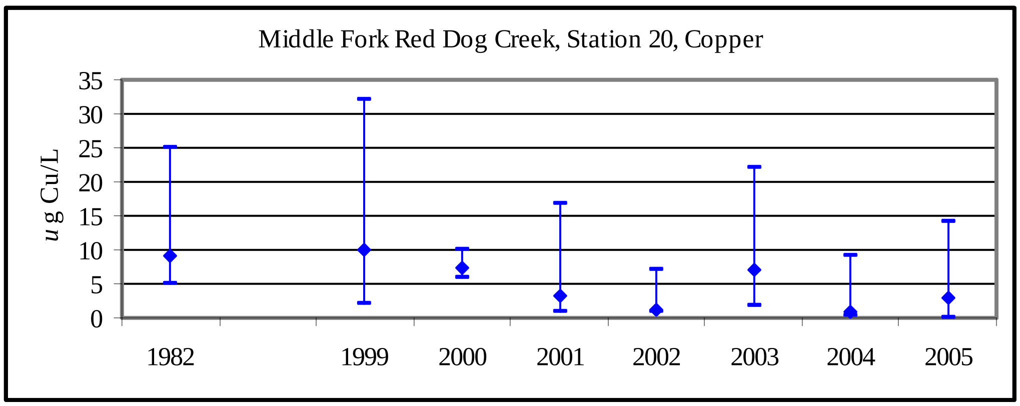

Figure 81. Median, maximum, and minimum concentrations of Cu at Station 20.

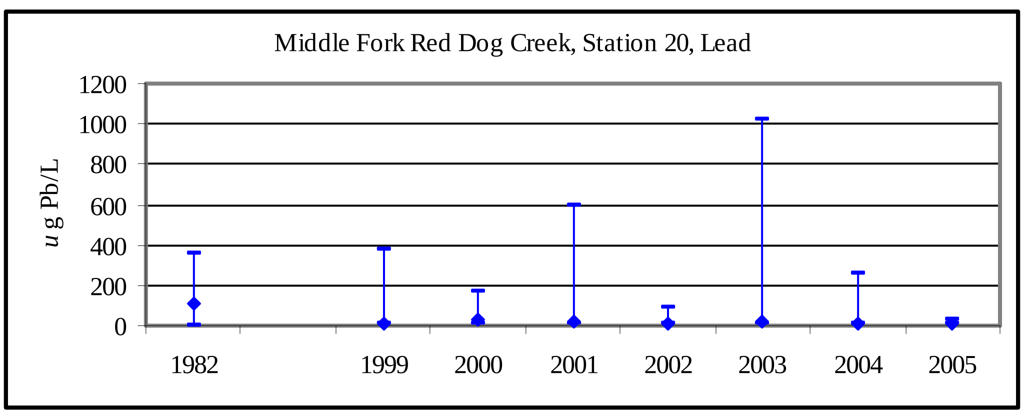

Figure 82. Median, maximum, and minimum concentrations of Pb at Station 20.

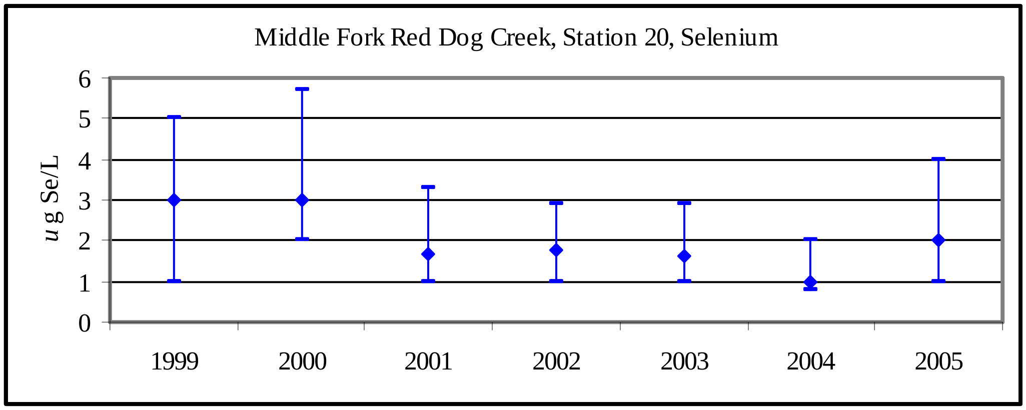

Figure 83. Median, maximum, and minimum concentrations of Se at Station 20.

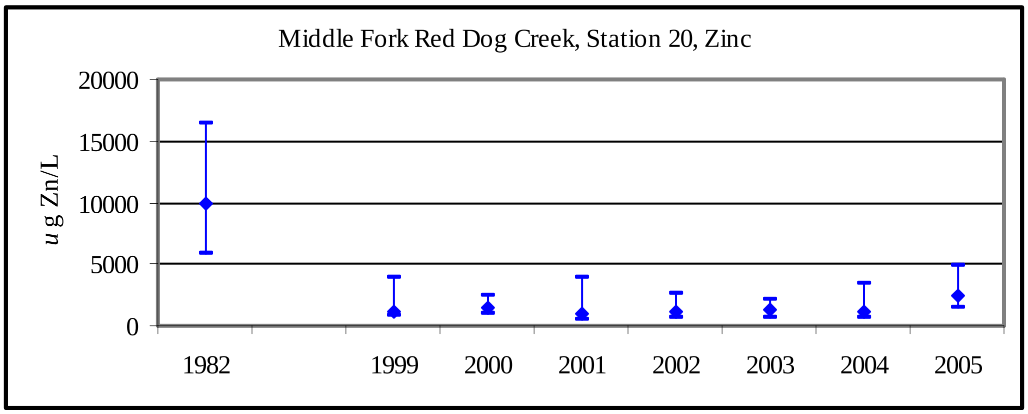

Figure 84. Median, maximum, and minimum concentrations of Zn at Station 20.

Invertebrate Community (Abundance, Density, Taxa Richness, and Structure)

Aquatic invertebrate abundance, density, taxa richness, and structure are presented in Figures 85 through 88). Abundance and density of aquatic invertebrates exhibits high variability among sample years (Figures 85 and 86). Densities of aquatic invertebrates are lower than North Fork Red Dog Creek but are comparable with Station 10 in Mainstem Red Dog Creek. Highest densities of aquatic invertebrates in 2003 and 2005 were found at both Stations 10 and 20 while the lowest densities at both sites occurred in 2000 and 2004.

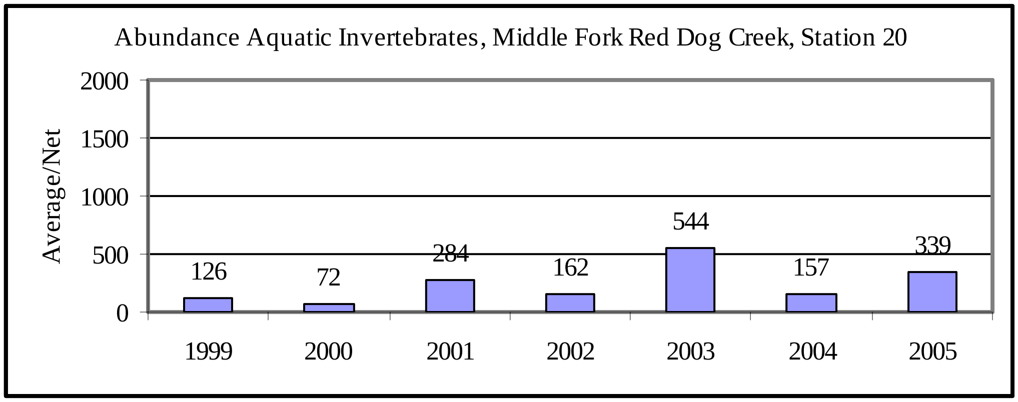

Figure 85. Aquatic invertebrate abundance, Middle Fork Red Dog Creek, Station 20.

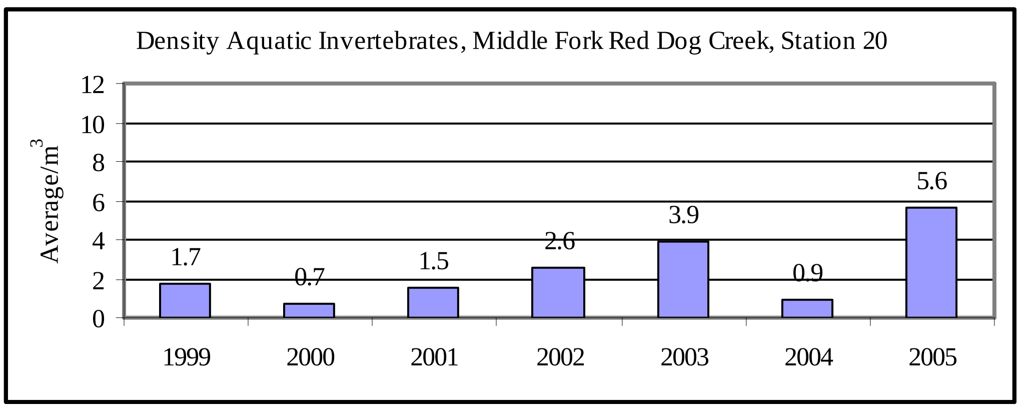

Figure 86. Aquatic invertebrate density, Middle Fork Red Dog Creek, Station 20.

Total aquatic taxa in invertebrate samples ranged from 14 to 28 from 1999 to 2005 (Figure 87). The percent EPT in the aquatic invertebrate samples was highest in 2004 and lowest in 2000 and 2003 (Figure 88). In most years (6 out of 7), EPT only varied from 7 to 21% (Figure 88). There is no indication from the EPT data, that conditions for these invertebrates has changed dramatically in the last 7 years.

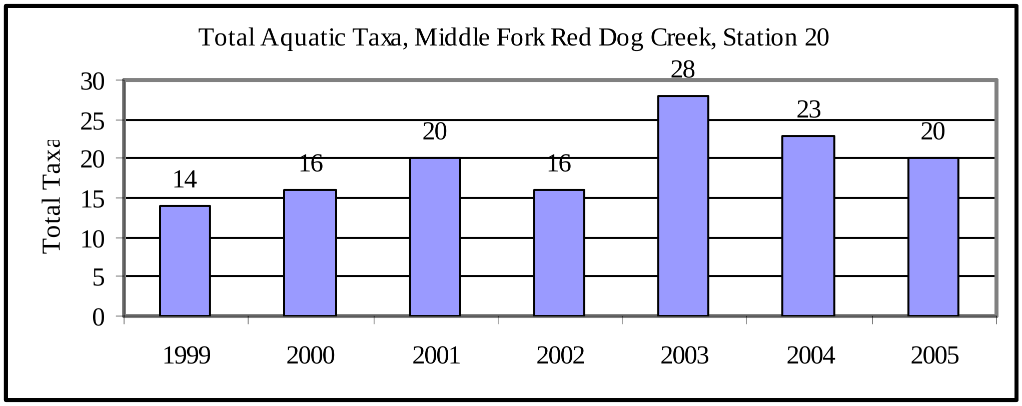

Figure 87. Total aquatic taxa, Middle Fork Red Dog Creek, Station 20.

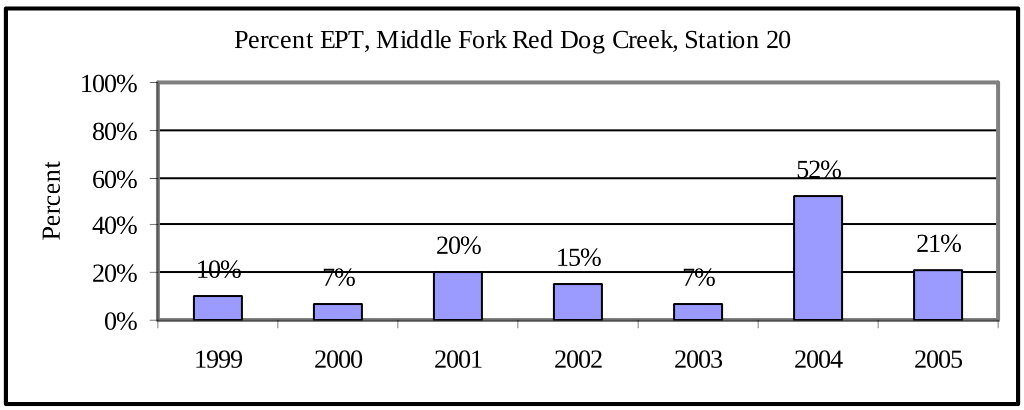

Figure 88. Proportion of EPT in aquatic invertebrate samples, Middle Fork Red Dog Creek, Station 20.

Periphyton Standing Crop

Algal biomass, as estimated by chlorophyll-a concentrations has been consistently low in Middle Fork Red Dog Creek. Chlorophyll-a concentrations at Station 20 are lower than those measured at any of the other NPDES sample sites. Generally, chlorophyll-a concentrations are below detection.

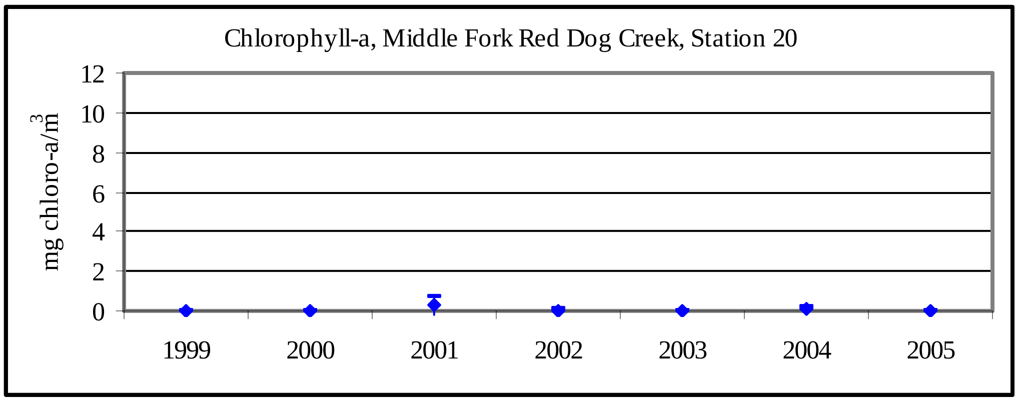

Figure 89. Average concentration of chlorophyll-a, plus and minus one standard deviation, in Middle Fork Red Dog Creek at Station 20.

Biomonitoring Summary

Changes in water quality, aquatic invertebrates, periphyton, and larval fish that have been documented over time in Middle Fork Red Dog Creek at Station 20 are summarized in Table 11.

Table 11. Middle Fork Red Dog Creek, Station 20, 1999 to 2005.

Factor	Changes Observed
Water Quality	pH values higher than pre-mining Cd and Zn concentrations lower than baseline data Median Pb concentrations lower 1999 through 2005 Peak Pb concentrations have exceeded baseline data
Invertebrates	Abundance, variable among sample years Density, generally lower than other sites Taxa Richness, low of 14 and a high of 28 % EPT, low of 7% and a high of 52%
Periphyton	Very low all years
Larval Fish	none

Middle Fork Red Dog Creek at Station 140

Site Description

Station 140 is located in Middle Fork Red Dog Creek downstream of the clean water bypass and upstream of the discharge point from the wastewater treatment plant. Fish, invertebrate, and periphyton sampling is not done at Station 140, but water quality data are collected. The pH for Middle Fork Red Dog Creek is presented in Figure 90. The pH values are consistently higher at Station 140 as compared to pre-mining conditions.

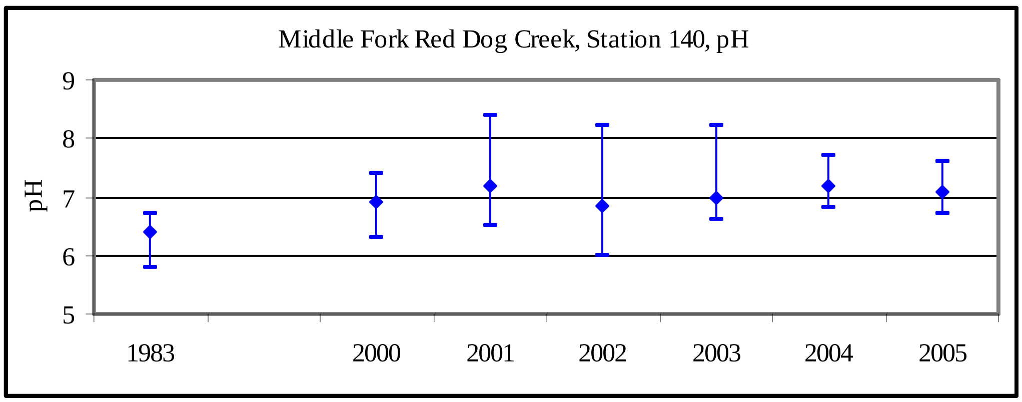

Figure 90. Median, maximum, and minimum pH values in Middle Fork Red Dog Creek at Station 140.

Concentrations of Cd, Pb, and Zn are presented in Figures 91 through 93. These analytes were selected because pre-mining data are available. Median concentrations of Cd, Pb, and Zn at Station 140 are consistently lower (1999 through 2005) than pre-mining (Figures 91 to 93), indicating that the clean water bypass is working to minimize downstream loading of metals. Immediately adjacent to the clean water bypass and at a lower elevation is the dirty water collection system that takes water to a pump-back site where it is transferred to the tailing impoundment for treatment.

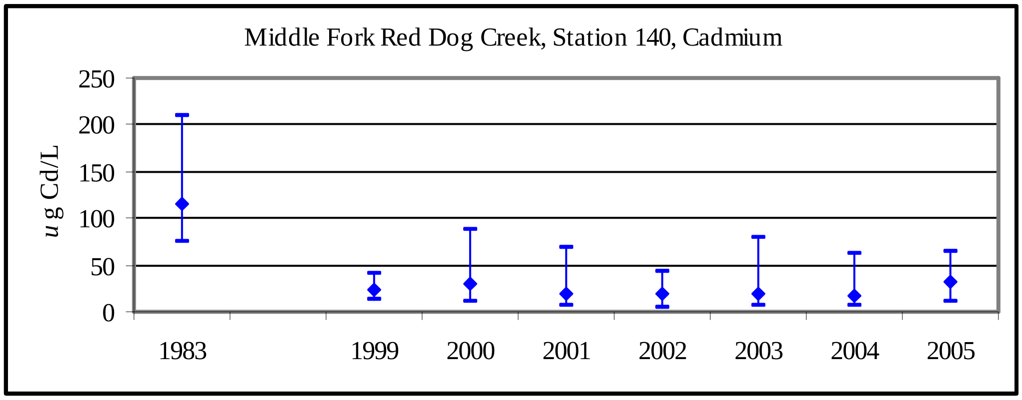

Figure 91. Median, maximum, and minimum concentrations of Cd at Station 140.

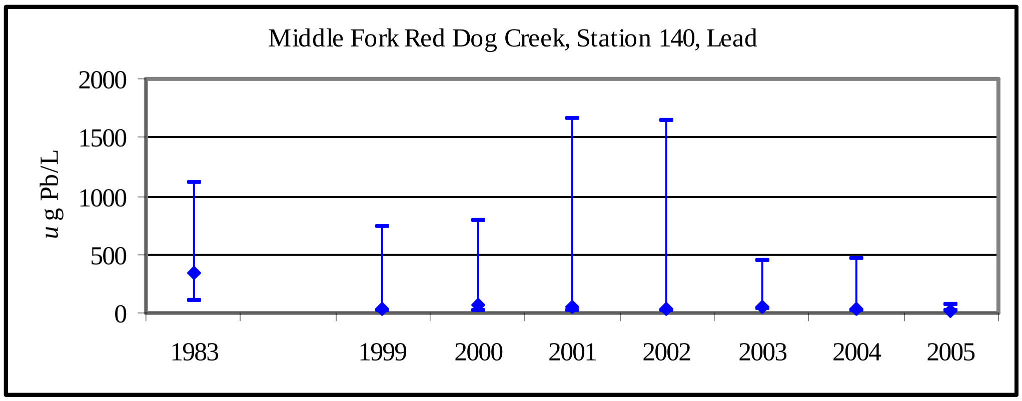

Figure 92. Median, maximum, and minimum concentrations of Pb at Station 140.

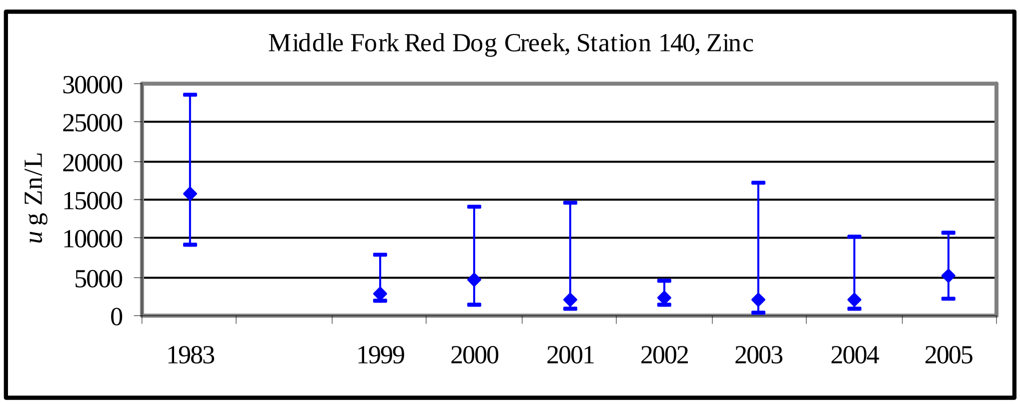

Figure 93. Median, maximum, and minimum concentrations of Zn at Station 140.

Metals Concentrations in Adult Dolly Varden, Wulik River

Since 1990, we have sampled adult Dolly Varden from the Wulik River at Station 2 near Tutak Creek for metals concentrations (Al, Cd, Cu, Pb, and Zn) in gill, kidney, liver, and muscle tissues (Weber Scannell et al. 2000). In 1997, we added Se and in 1998 we started sampling reproductive tissues, when available. In 2003, we added Hg and Ca to the analytes being tested. In 2004 and 2005, Dolly Varden tissues were analyzed for Al, Cd, Cu, Pb, Se, Zn, and Hg. The number of fish in each sample period is 6, except for fall 2002 when only 5 fish were caught.

The purpose of sampling adult Dolly Varden for metals concentrations is to monitor long-term condition over the life of the Red Dog Mine and to identify changes in metals concentrations that may be related to mining activities. All laboratory work to date has been done with Level III Quality Assurance.

Metals are known to concentrate preferentially in certain organs; however, the relationship of organ concentration of metals to ambient environmental concentrations is unknown. Concentrations of metals vary with season, age, size, weight, and feeding habits of fish (Jenkins 1980) and in the case of anadromous Dolly Varden, the metals vary with exposure to freshwater and marine environments. Our data from the Wulik River Dolly Varden suggest the following:

- Al concentrates in gill tissue (Figure 94);
- Cd concentrates in kidney tissue (Figure 95);
- Cu concentrates in liver tissue (Figure 96);
- Pb concentrates in gill tissue (Figure 97);
- Se concentrates in kidney and ovarian tissue (Figure 98);
- Zn concentrates in ovarian tissue (Figure 99); and
- Hg concentrates in kidney tissue (Figure 100).
- None of the analytes concentrate in muscle tissue.

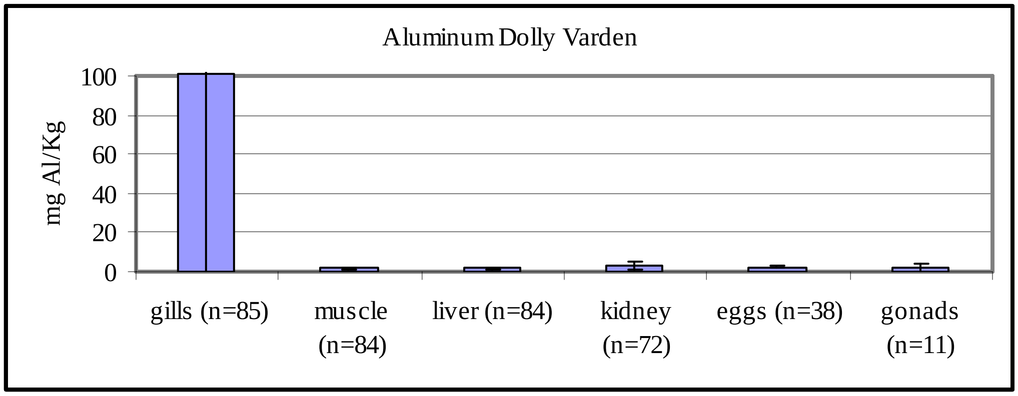

Figure 94. Al concentrations are the average of all fish collected during the NPDES sample period (1999 to 2005) plus and minus one standard deviation.

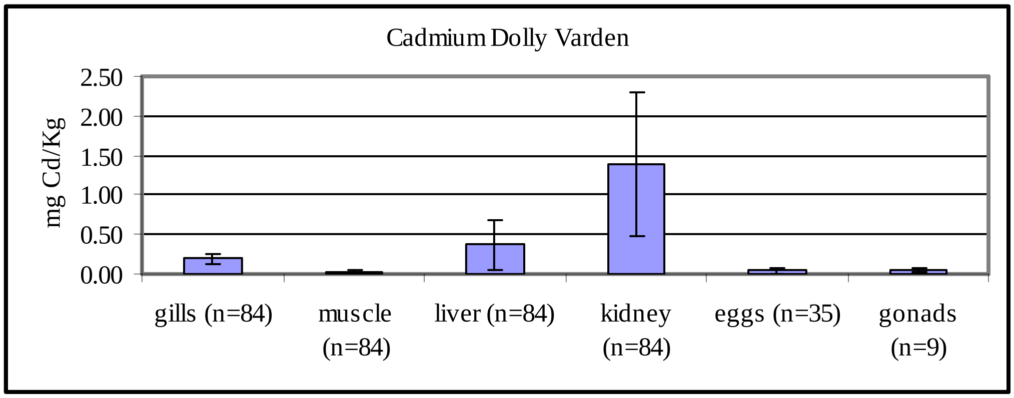

Figure 95. Cd concentrations are the average of all fish collected during the NPDES sample period (1999 to 2005) plus and minus one standard deviation.

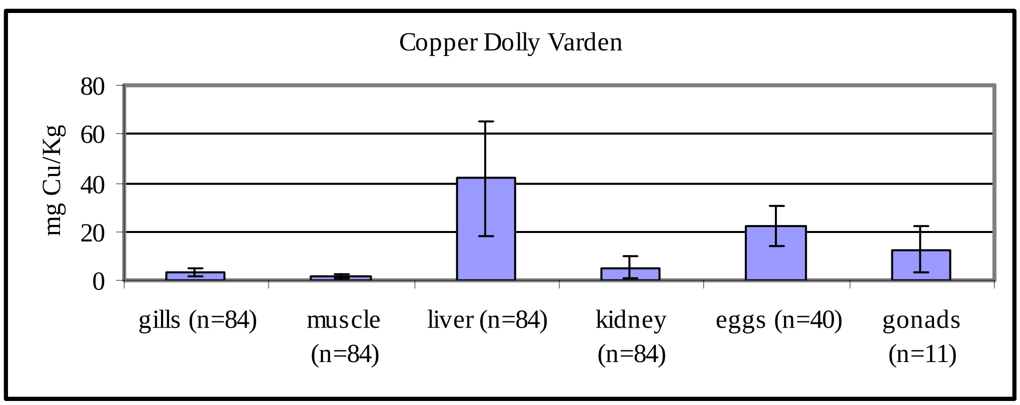

Figure 96. Cu concentrations are the average of all fish collected during the NPDES sample period (1999 to 2005) plus and minus one standard deviation.

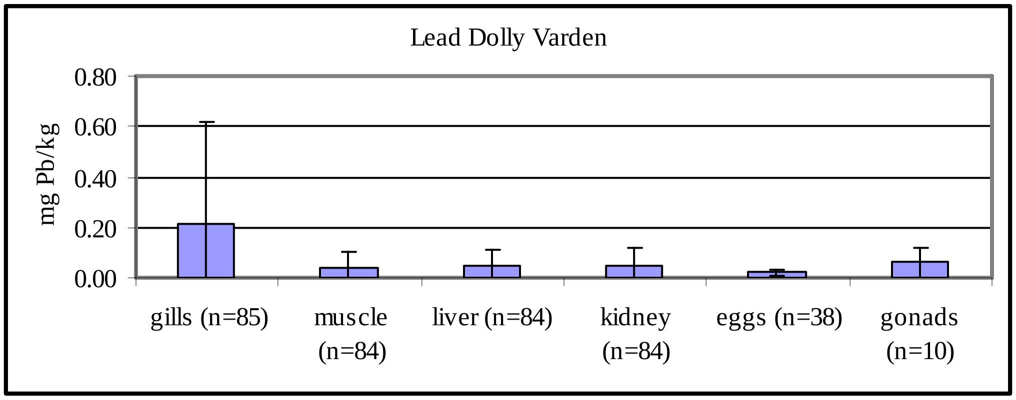

Figure 97. Pb concentrations are the average of all fish collected during the NPDES sample period (1999 to 2005) plus and minus one standard deviation.

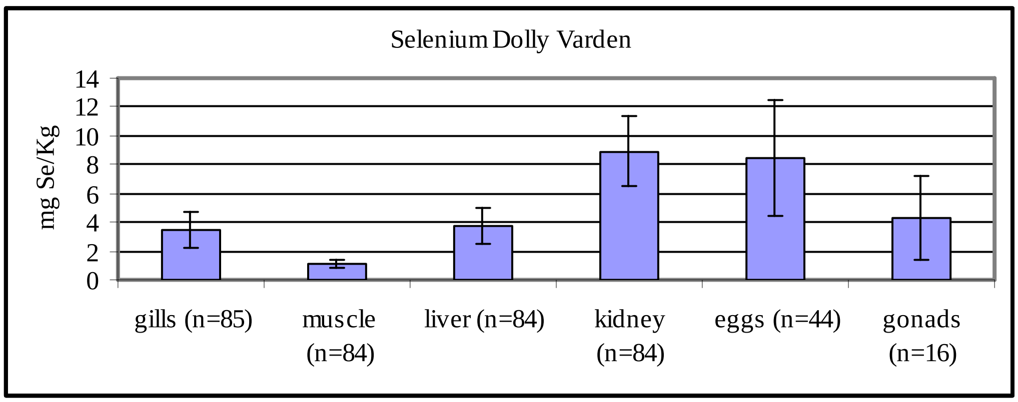

Figure 98. Se concentrations are the average of all fish collected during the NPDES sample period (1999 to 2005) plus and minus one standard deviation.

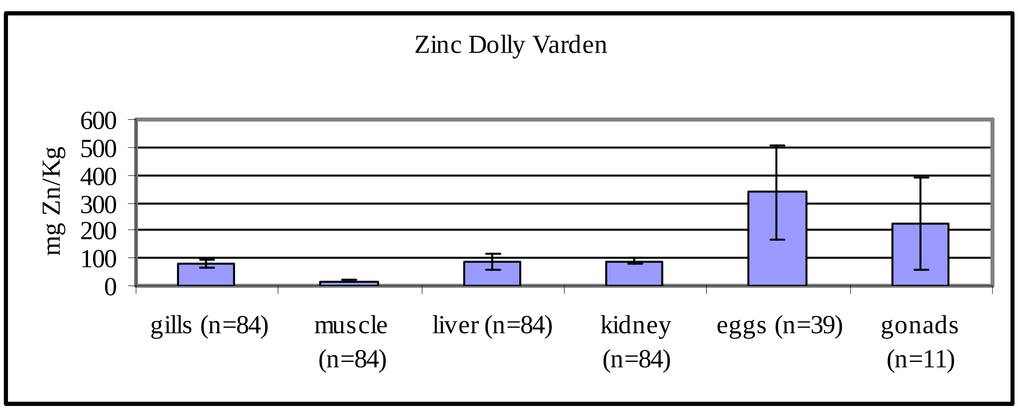

Figure 99. Zn concentrations are the average of all fish collected during the NPDES sample period (1999 to 2005) plus and minus one standard deviation.

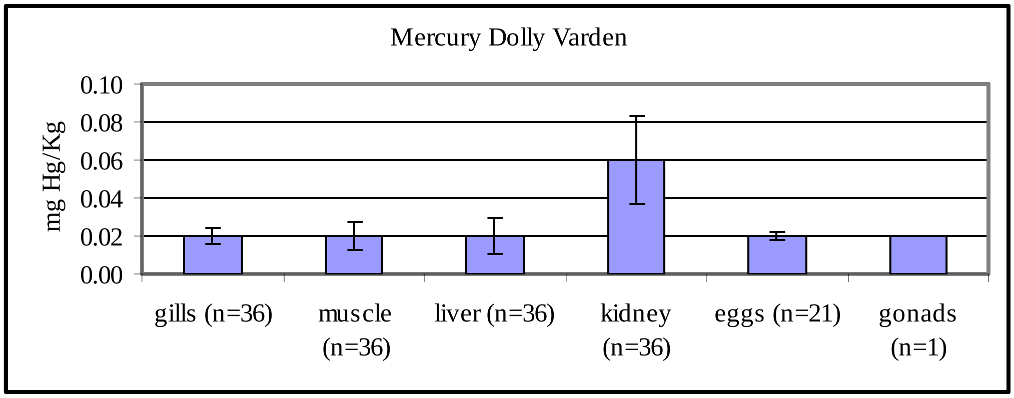

Figure 100. Hg concentrations are the average of all fish collected during the NPDES sample period (1999 to 2005) plus and minus one standard deviation. Detection limit for Hg is 0.02 mg/Kg.

Aluminum

Median concentrations of Al in gill tissue are highly variable within samples and between the spring and fall sample events (Figure 101). No real pattern or trend appears to exist for Al in gill tissue, other than the fact that it is highly variable.

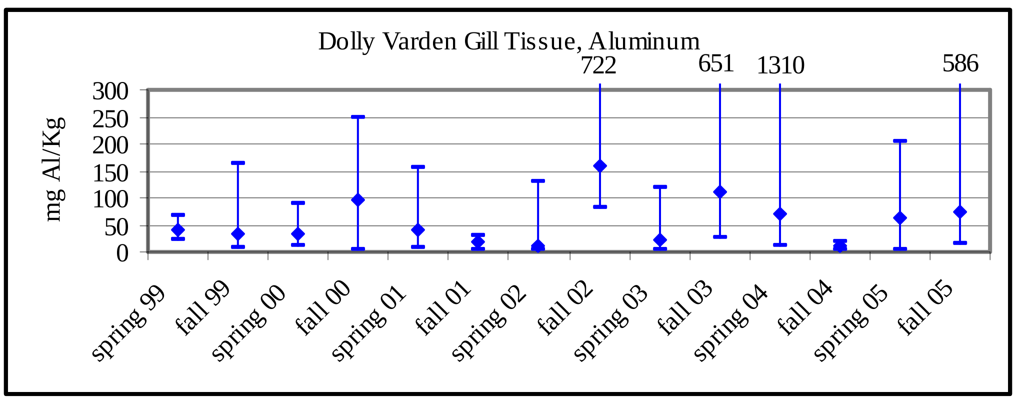

Figure 101. Median, maximum, and minimum concentrations of Al (dry weight) in Dolly Varden gill tissue (1999 to 2005). No baseline data for Al exists.

Cadmium

Median Cd concentrations in Dolly Varden kidney tissue from 1999 through 2005, both spring and fall, are lower than baseline data (Figure 102). Fall-caught fish generally have lower Cd concentrations than spring-caught fish.

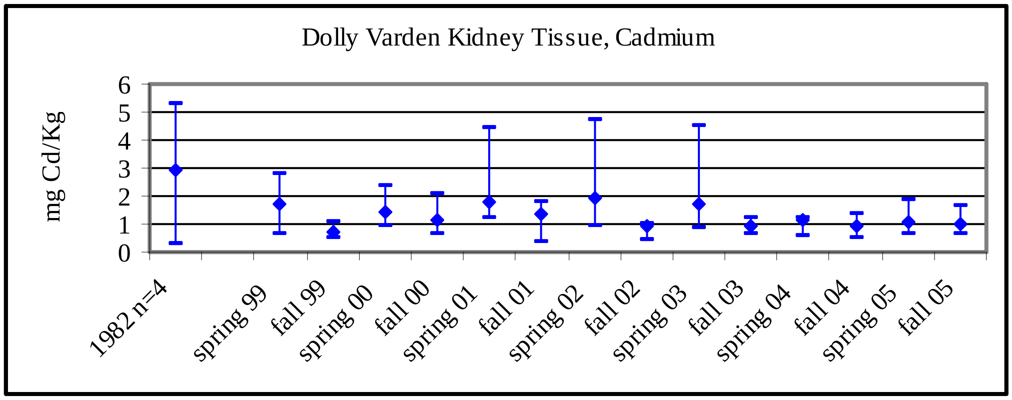

Figure 102. Median, maximum, and minimum concentrations of Cd (dry weight) in Dolly Varden kidney tissue (1982 and 1999 to 2005).

Copper

Median copper concentrations in liver tissue are consistently higher than baseline data (Figure 103). Spring-caught fish generally are higher in Cu than fall-caught fish.

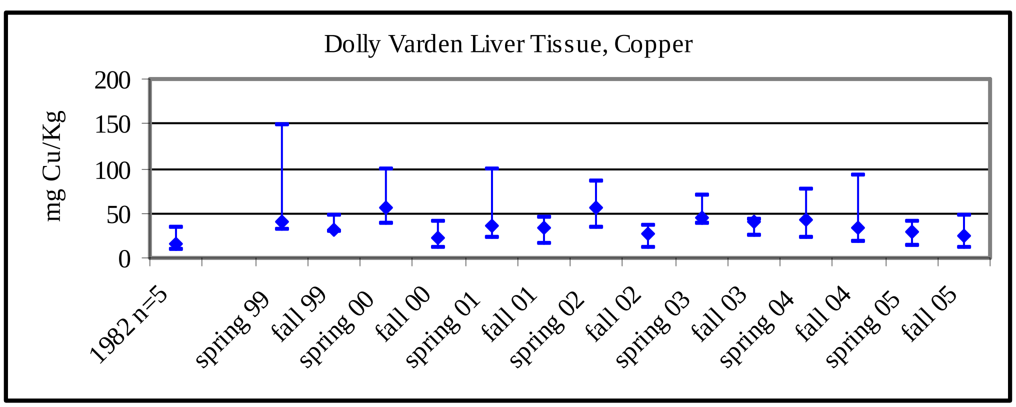

Figure 103. Median, maximum, and minimum concentrations of Cu (dry weight) in Dolly Varden liver tissue (1982 and 1999 to 2005).

Lead

The concentration of Pb in Dolly Varden gill tissue from fish collected prior to mining was below the detection limits (0.03 or 0.04 mg/Kg). Median concentrations of Pb in gill tissue from 1999 through 2005 are higher than baseline data (Figure 104).

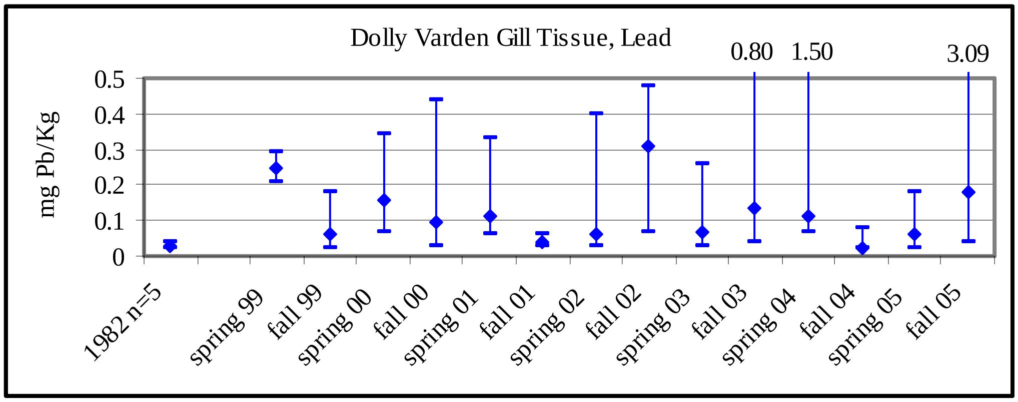

Figure 104. Median, maximum, and minimum concentrations of Pb (dry weight) in Dolly Varden gill tissue (1982 and 1999 to 2005).

Selenium

Median Se concentrations are consistently higher in fall-caught fish (Figure 105). Highest Se concentrations occurred in fall 2002 and fall 2005 (Figure 105).

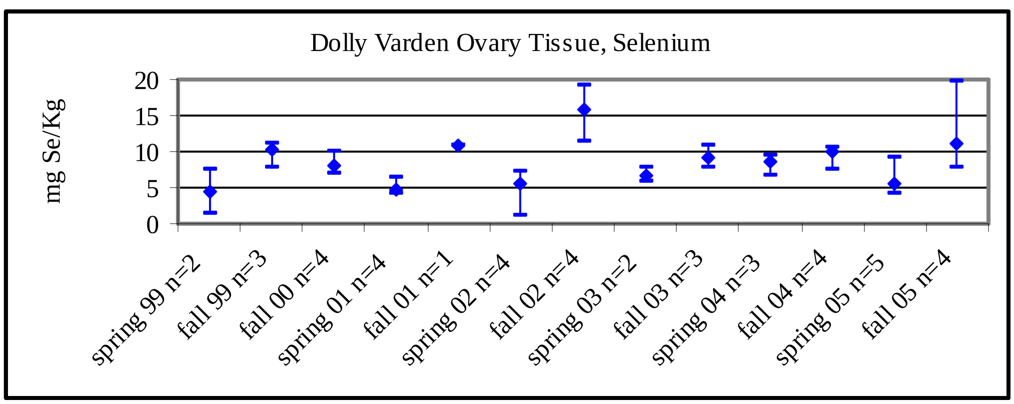

Figure 105. Median, maximum, and minimum concentrations of Se (dry weight) in Dolly Varden ovary tissue (1999 to 2005). No baseline data for Se exists.

Zinc

Median Zn concentrations in ovarian tissue have remained fairly consistent during the sample period (Figure 106). Generally, Zn concentrations are higher in fall-caught fish.

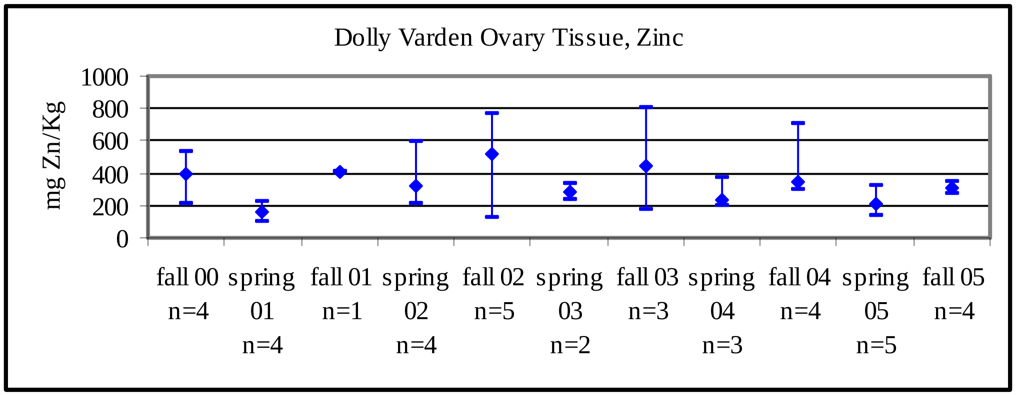

Figure 106. Median, maximum, and minimum concentrations of Zn (dry weight) in Dolly Varden ovary tissue (1999 to 2005). No baseline data for Zn exists.

Mercury

Concentrations of Hg in all tissues, except kidney, generally are below the detection limit (0.02 mg/Kg). Hg concentrations in kidney are similar from 2003 to 2005 (Figure 107).

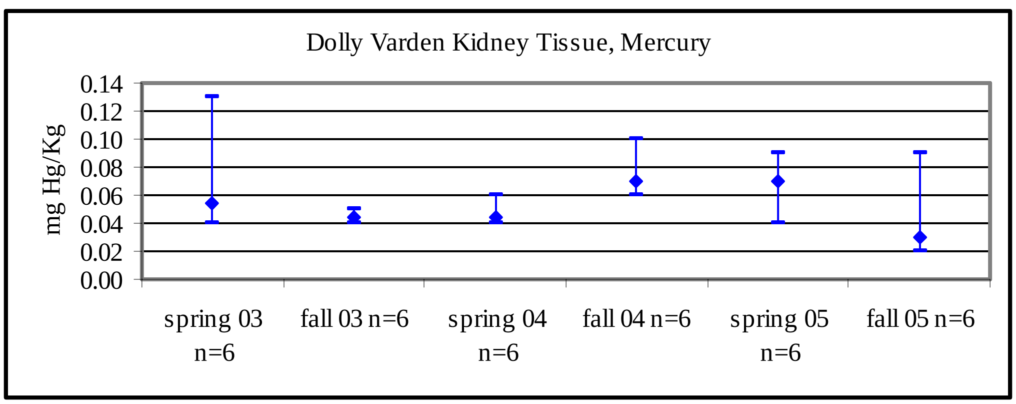

Figure 107. Median, maximum, and minimum concentrations of Hg (dry weight) in Dolly Varden kidney tissue (2003 to 2005). No baseline data for Hg exists.

Distribution of Fish

Overwintering Dolly Varden

The Dolly Varden fall aerial survey in the Wulik River was conducted on October 6, 2005. Survey conditions in fall 2005 were nearly ideal with clear sky, clear water, and good visibility (DeCicco 2005). There were several large groups of Dolly Varden in the Wulik River just upstream of the lagoon to about 1 mi above Ikalukrok Creek. In general, there were some fairly large groups of mixed size fish in the lower 2/3 of the river, and more smaller fish upstream. There were more Dolly Varden upstream of Ikalukrok Creek than normal. Upstream dispersal of Dolly Varden is likely due to high water events in late August and early September. The estimated number of Dolly Varden is an underestimate of actual number present (DeCicco 2005).

Number of Dolly Varden estimated in fall in the Wulik River varies annually (Figure 108, Appendix 2). Surveys conducted through fall 2005, suggest that over 90% of the Dolly Varden are seen downstream of Ikalukrok Creek. Only in 2004 was the percent of fish below Ikalukrok less than 90% and as DeCicco (2004) stated, conditions for aerial observations in the lower river in fall 2004 were poor due to overcast skies.

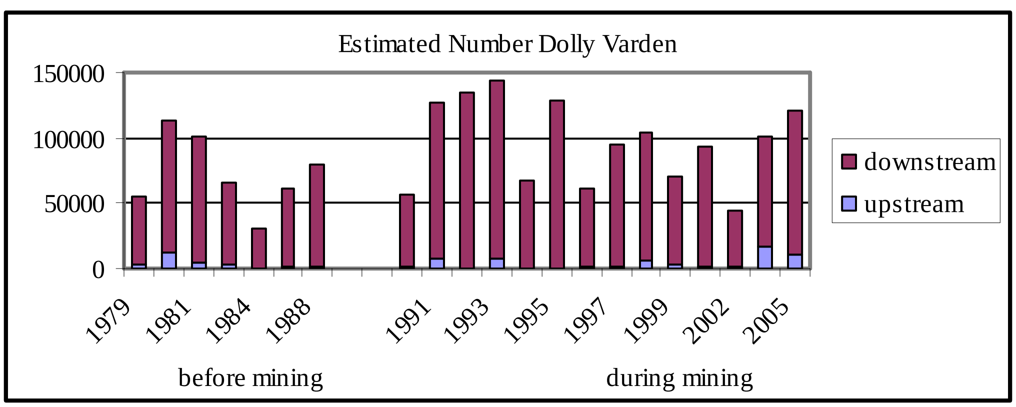

Figure 108. The number of Dolly Varden estimated in the Wulik River.

Chum Salmon

ADNR conducts annual surveys to assess the distribution of adult chum salmon in Ikalukrok Creek from its mouth (i.e., confluence with Wulik River) upstream to Dudd Creek (Table 12 and Appendix 3). In fall 2005, TCAK flew two helicopter surveys (Thompson 2005). On August 26, 2005, they estimated 210 live chum salmon and about 30 to 50 dead spawned out fish. They estimated about 350 adult chum salmon on August 29, 2005, under fairly good survey conditions. No chinook salmon were observed in Ikalukrok Creek or in a slough (N 67.56.45 W 163.24.91) of Ikalukrok Creek where 56 spawners were seen in fall 2004. Minnow traps were fished in Ikalukrok Creek near and in the slough, and one juvenile chinook salmon was caught and released.

Counts of chum salmon in Ikalukrok Creek after mine development in 1990 and 1991 were lower than reported in baseline studies. Surveys began again in 1995, with the highest return of chum salmon seen in fall 2001 and the highest number of chinook salmon found in fall 2004. Large runs of chum salmon in recent years, particularly 2001 and 2002, are good indications that the population has recovered from the low counts made in the early 1990s.

Table 12. Number of chum salmon adults in Ikalukrok Creek.

Survey Time	Number of Chum Salmon	Reference
September 1981	3,520 to 6,960	Houghton and Hilgert 1983
August September 1982	353 to 1,400	Houghton and Hilgert 1983
August 1984	994	DeCicco 1990b
August 1986	1,985	DeCicco 1990b
August 1990	<70	Ott et al. 1992
August 1991	<70	Ott et al. 1992
August 16, 1995	49	Townsend and Lunderstadt 1995
August 1995	300 to 400	DeCicco 1995
August 11, 1996	180	Townsend and Hemming 1996
August 12, 1997	730 to 780	Ott and Simpers 1997
1998	no survey	
August 9, 1999	75	Ott and Morris 1999
2000	no survey	
August 7, 2001	850	Morris and Ott 2001
August 28, 2001	2,250	DeCicco 2001b
August 29, 2001	1,836	DeCicco 2001b
September 23, 2001	500	DeCicco 2001c
October 8, 2001	232	DeCicco 2001a
August 5, 2002	890	Ott and Townsend 2002
August 11, 2003	218	Townsend and Ingalls 2003
August 26, 2004	405	Townsend and Conley 2004
August 29, 2005	350	Thompson 2005

Dolly Varden

Limited pre-mining juvenile Dolly Varden distribution and use data are available for most of the streams in the vicinity of the Red Dog Mine, including Ikalukrok, Evaingiknuk, Buddy, Mainstem Red Dog, and North Fork Red Dog creeks. In the early 1990s, we found the highest use by juvenile Dolly Varden was in Anxiety Ridge Creek, also identified as the most productive stream system in the project area by Houghton and Hilgert (1983). However, Buddy Creek below the falls and downstream of the haul road was never sampled until 1996.

We have conducted annual sampling of juvenile Dolly Varden in Evaingiknuk, Anxiety Ridge, and Ikalukrok creeks since 1990 to assess seasonal patterns of fish use. Since 1990, we have added new sample sites and increased the number of minnow traps per sample site. Currently, we sample ten sites as listed in Table 13 (Appendix 4) using ten minnow traps per sample reach.

Table 13. Location of juvenile Dolly Varden sample sites.

Site Name	Station No.	Year First Sampled
Evaingiknuk Creek		1990
Anxiety Ridge Creek		1990
Buddy Creek		1996
North Fork Red Dog Creek	12	1993
Mainstem Red Dog Creek, below North Fork	11	1995
Mainstem Red Dog Creek, at Ikalukrok	10	1996
Ikalukrok Creek above Mainstem	9	1996
Ikalukrok Creek below Mainstem	8	1996
Ikalukrok Creek above Dudd Creek		1990
Ikalukrok Creek below Dudd Creek	7	1990

Relative abundance (i.e., catches) of juvenile Dolly Varden varies among years. Natural environmental conditions such as the duration of breakup, patterns and magnitude of rainfall events, and ambient temperature affect distribution of juveniles during the ice-free season. Perhaps the most substantial variable affecting abundance is the number of adult spawners and survival of age-0 fish.

Juvenile Dolly Varden are most abundant in our Red Dog sample sites from late July to mid-August. Generally, abundance is higher in the upper portion of each stream and peak usage continues until the onset of freezing conditions when most fish outmigrate to overwintering areas. Catches of juvenile Dolly Varden in the early 1990s, when sampling occurred from spring through late fall, were very low in the spring and decreased as freezeup approached in the fall. Sampling suggests that a few juvenile Dolly Varden overwinter in these streams, but that overwintering is limited to Anxiety Ridge and Evaingiknuk creeks.

Sampling of the 10 NPDES sites in July and August has been conducted each year since 1997. Our highest catches were in 1999 and the lowest in 2000 and 2001 (Appendix 5). Late summer catches of Dolly Varden for Anxiety Ridge and Buddy creeks are presented in Figure 109. Highest catches of juvenile Dolly Varden are consistently found in

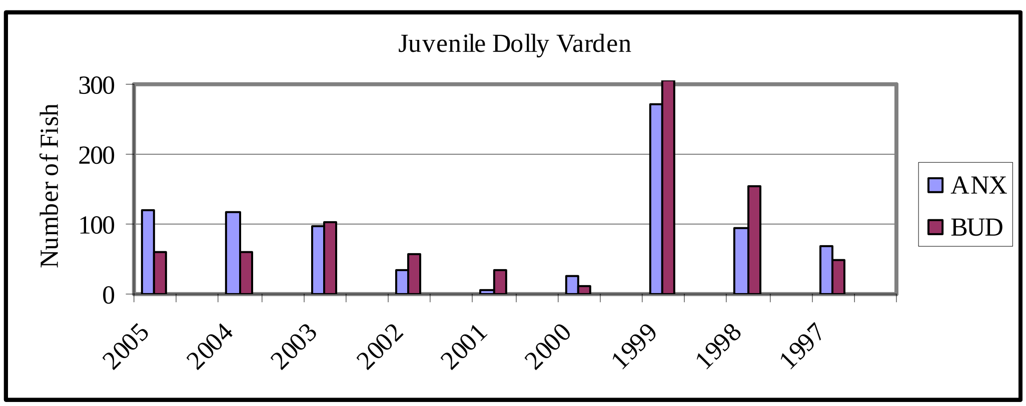

Figure 109. Catches of juvenile Dolly Varden in Anxiety Ridge (ANX) and Buddy (BUD) Creeks, 1997 to 2005.

Anxiety Ridge and Buddy creeks. Catches in Mainstem Red Dog Creek (upper and lower sample reaches) are presented in Figure 110. From 1997 to 2001, catches followed a similar pattern: when higher in Anxiety Ridge and Buddy creeks, catches also were higher in Mainstem Red Dog Creek. However, lower catches in Mainstem Red Dog Creek have now been seen in four consecutive years (2002 to 2005).

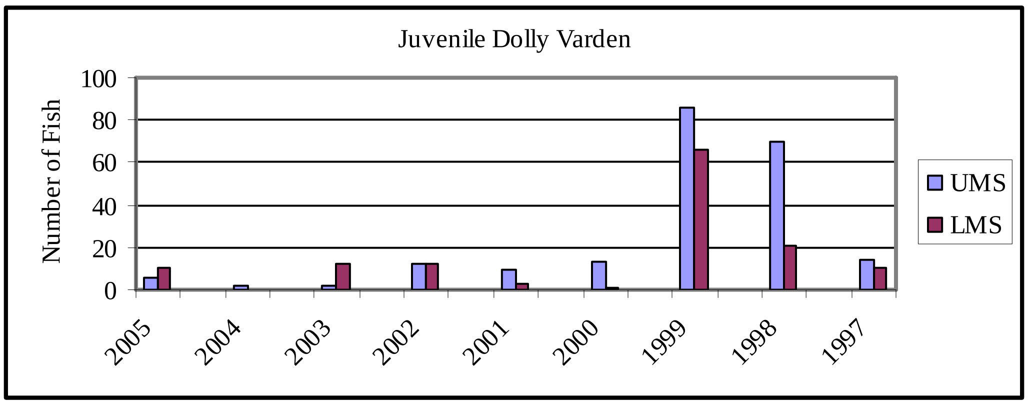

Figure 110. Catches of juvenile Dolly Varden in upper Mainstem Red Dog (UMS) and lower Mainstem Red Dog (LMS) creeks, 1997 to 2005.

A natural seep located on Cub Creek in upper Ikalukrok Creek has affected water quality in Ikalukrok Creek. The Cub Creek seep is located upstream of Mainstem Red Dog Creek. Visible effects to water clarity were first noted in 1997 and water quality data (1999 through 2005) indicate generally improving conditions from 2001 through 2005. One possible explanation for the continued low catches of Dolly Varden juveniles in Mainstem Red Dog Creek is that with improved water quality since 2001, more Dolly Varden moved upstream in Ikalukrok Creek above Mainstem Red Dog Creek to use rearing habitats in Ikalukrok Creek and its tributaries. Grayling Junior Creek, a tributary to Ikalukrok Creek, was sampled for juvenile Dolly Varden in late fall 2000, 2001, 2002, and 2004 as part of baseline studies for future potential shallow gas and mining in the Red Dog Mine area.

Numbers of juvenile Dolly Varden caught from 2000 to 2002 indicate increased use of Grayling Junior Creek (Figure 111). It should be noted that effects on juvenile Dolly Varden distribution in Ikalukrok Creek, upstream of East Fork Ikalukrok Creek, have been documented. Sampling of three sites in upper Ikalukrok Creek twice per year for three years (2000 through 2002) resulted in zero catches of juvenile Dolly Varden. All fieldwork done from 2000 through 2002 in upper Ikalukrok Creek indicate that fish use did not exist in that part of the system for those years. The most likely reason for fish absence is degraded water quality (i.e., heavy metals) preventing movement into upper Ikalukrok Creek and its tributaries.

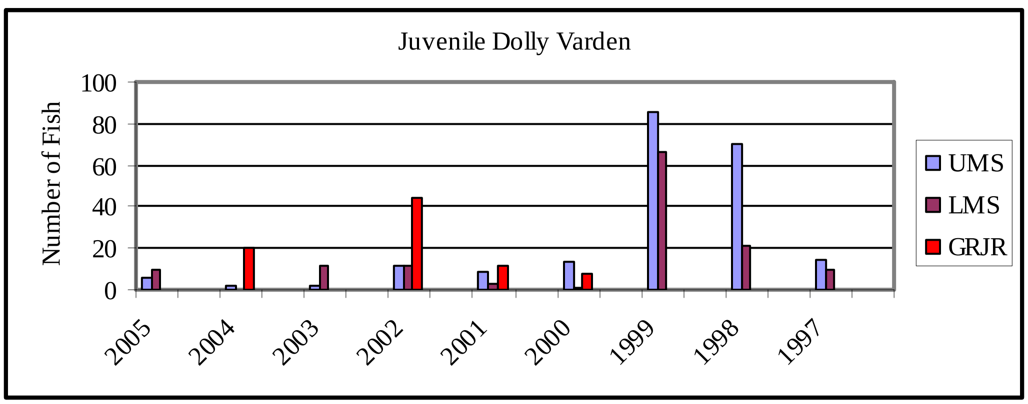

Figure 111. Catches of juvenile Dolly Varden in upper Mainstem Red Dog (UMS), lower Mainstem Red Dog (LMS), and Grayling Junior (GRJR) creeks, 1997 to 2005.

The length-frequency distribution of juvenile Dolly Varden, especially the presence of age-0 fish, indicates successful reproduction and survival. Dolly Varden <65 mm in late July and early August are assumed to be age-0 fish. Length-frequency distributions of juvenile Dolly Varden captured in fall 1997 through fall 2005 are presented in Appendix 6. Smolting can occur as early as age-2, but more commonly at age-3 (DeCicco 1990a); thus these fish are leaving our sample areas to enter marine waters 2 to 3 years after hatching.

Higher catches of age-0 Dolly Varden were seen in 1997, 1998, 1999, 2004, and 2005 (Appendix 6). Catches of small Dolly Varden fry in 1997 and 1998 likely explain the large catch of juvenile fish in fall 1999. Catches of Dolly Varden in both 2004 and 2005 were relatively high, thus we might expect fairly high numbers of juveniles to be present in our fall 2006 catches.

During our spring sample event for adult Arctic grayling returning to North Fork Red Dog Creek to spawn, we caught 37 Dolly Varden. The 37 Dolly Varden ranged in size from 122 to 266 mm (Figure 112). The larger Dolly Varden caught each spring in North Fork Red Dog Creek with fyke nets appear to be resident fish (i.e., larger than smolts, obvious parr marks, and distinct orange/pink dots) (Figure 112).

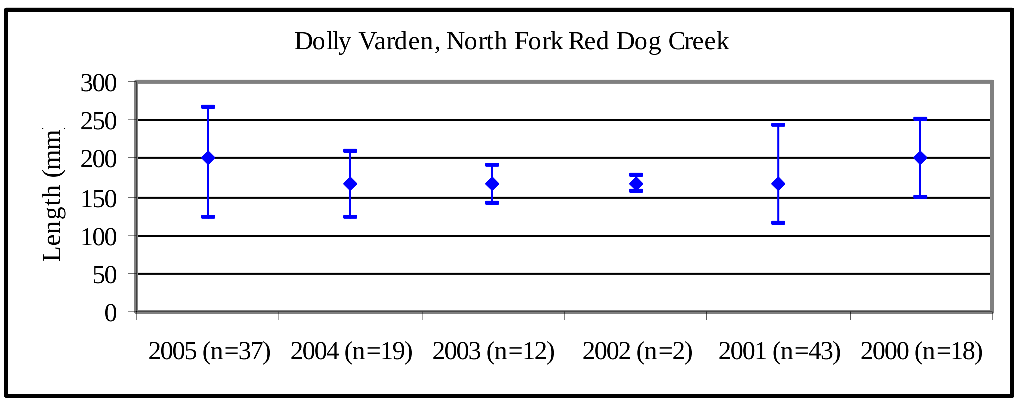

Figure 112. Dolly Varden caught in fyke nets in North Fork Red Dog Creek in June 2005.

In baseline studies, Houghton and Hilgert (1983) only found one Dolly Varden in the headwaters of North Fork Red Dog Creek. Our late May to early June sampling from 2000 through 2005 using fyke nets has caught a number of the larger Dolly Varden each year. It is not known if this change in fish use is related to general water quality improvement in Mainstem Red Dog Creek or simply is due to increased sample effort and the use of fyke nets.

Arctic Grayling

Before mine development, Arctic grayling adults migrated through Mainstem Red Dog Creek in spring when discharges were high and metals concentrations low (EVS and Ott Water Engineer 1983, Ward and Olson 1980, Houghton and Hilgert 1983). Arctic grayling moved through Mainstem Red Dog Creek to spawn in North Fork Red Dog Creek, but no spawning was reported to occur in Mainstem Red Dog Creek. Arctic grayling fry reared in North Fork Red Dog Creek and were displaced downstream by high-water events or outmigrated as water temperatures cooled in the fall.

Arctic Grayling Spawning

Water temperature is the most likely factor determining spawning time, emergence of fry, and first year growth. We have closely monitored Arctic grayling spawning during spring in North Fork Red Dog and Mainstem Red Dog creeks. The purpose of the monitoring is to assess the condition of female Arctic grayling and determine when spawning in Mainstem Red Dog Creek is complete. Until spawning is complete, the wastewater discharge from the treatment plant is controlled to ensure that total dissolved solids (TDS) concentration in Mainstem Red Dog Creek, after mixing with North Fork Red Dog Creek, remains <500 mg/L.

On May 25, 2005, flows were too high in North Fork Red Dog Creek to set a fyke net. Aufeis was minimal to non-existent, a condition not seen in previous years. Flows remained high in North Fork Red Dog Creek until May 30 when a fyke net partially blocking the channel was set. Arctic grayling were captured on May 31 and fish were caught each day until the fyke net was removed on June 7, 2006. Based on water temperatures in Mainstem Red Dog Creek, limited spawning may have begun on May 27, and spawning was complete by June 7 (Figure 113). The first spent females were caught on June 4 in North Fork Red Dog Creek. Based on five years of sampling in both Mainstem Red Dog and North Fork Red Dog creeks, spent females caught in North Fork Red Dog Creek most likely are fish that spawned in Mainstem Red Dog Creek and then moved upstream to feeding areas in North Fork Red Dog Creek. On June 6 and 7, all females caught in North Fork Red Dog Creek were spent. Peak water temperatures in Mainstem Red Dog Creek on June 4, 5, and 6 were 5.4, 6.9, and 6.0°C.

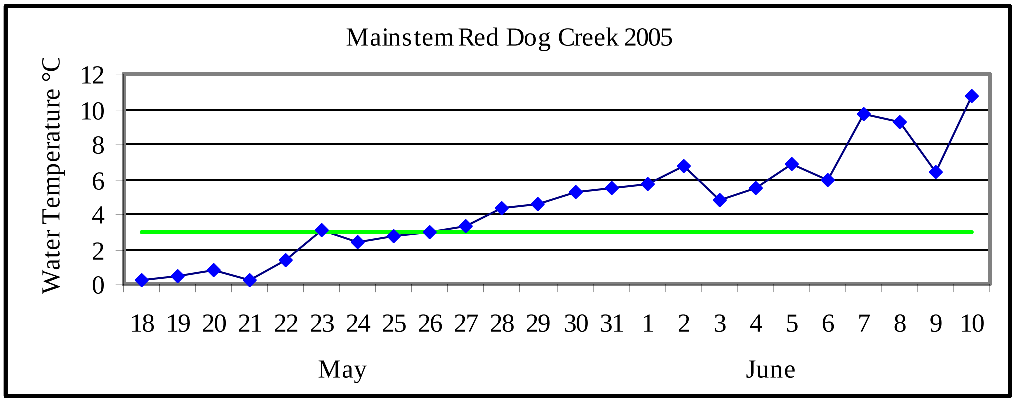

Figure 113. Peak water temperatures in Mainstem Red Dog Creek in spring 2005. Conservatively, there could be limited spawning by Arctic grayling at temperatures exceeding 3°C. Spawning was judged to be complete on June 7.

Length-frequency distributions for Arctic grayling captured during the spring sample event in 2005 are shown in Appendix 7 and Figure 114. Length-frequency distributions show good recruitment in 2001 and 2003. Even though catches vary among sample years, large Arctic grayling (>300 mm) dominate the population except in 2003 when they were not present. The most logical reason for a lack of large fish in spring 2003, given the fact that they were present in both 2004 and 2005, is that they moved into North Fork Red Dog Creek prior to our setting of the fyke net. It also is apparent from the distribution lengths in 2004 and 2005 that we have seen recruitment to the population.

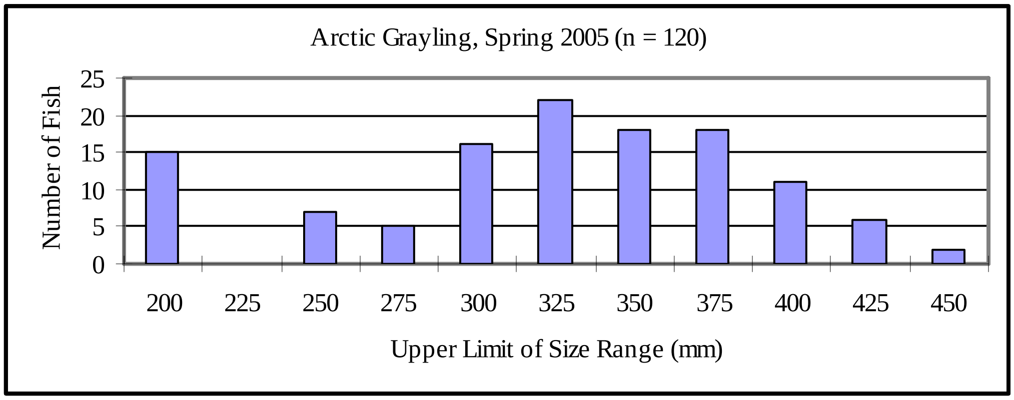

Figure 114. Length-frequency distribution of Arctic grayling caught in spring 2005 using a fyke net fished in North Fork Red Dog Creek.

Arctic Grayling Fry

Since 1992, we have observed adult and fry Arctic grayling in North Fork Red Dog Creek. We have visual observations of active spawning in North Fork Red Dog Creek and have captured fry (12 to 15 mm long) in drift nets at Station 10 in Mainstem Red Dog Creek and at Station 12 in North Fork Red Dog Creek. We also conduct visual surveys along North Fork Red Dog Creek in July to assess the relative abundance of fry (Table 14). We have not observed large numbers of fry in North Fork Red Dog Creek since summer 1999 (Table 14).

Arctic Grayling Mainstem Red Dog Creek

Visual surveys of Mainstem Red Dog Creek have been conducted annually from 1994 to 2005 (Appendix 8) to document fish use and compare these data with information available from baseline studies. Surveys generally are conducted in two reaches: from the mouth of North Fork Red Dog Creek to a rock bluff located about 0.8 km downstream; and from the mouth of Mainstem Red Dog Creek upstream for about 3 km (Station 10).

Table 14. Relative abundance of Arctic grayling fry in North Fork Red Dog Creek (1992 to 2005).

Year	Relative Abundance of Fry	Comments
1992	high	100's of fry, late July
1993	low	Few fry in early August, high water
1994	low	High water after spawning probably displaced fry
1995	low	Fry small (<25 mm) in mid-July
1996	high	Schools of 50 to 200 fry common
1997	high	Average size of fry was 10 mm greater than in 1996
1998	low	Cold water, late breakup, high water after spawning
1999	high	Low flows, warm water after spawning, schools of 50 to 100 fry common
2000	low	Cold water, late breakup, spawning 90% done June 13/14, fry small (<25 mm) and rare in mid-July
2001	low	Cold water, late breakup, spawning 90% done June 19, fry small (<25 mm) and rare in mid-July
2002	low	High flows, spawning 90% done June 8, fry small (<35 mm) in early August and rare, more fry seen in Ikalukrok Creek in early July, probably displaced by high water
2003	low	Cold water, late breakup, spawning 90% done June 14, fry small (<25 mm) and rare in early August
2004	low	Early breakup, spawning 90% done by May 31, fry (<30 mm) on July 10
2005	low	Spawning 90% done by June 7, fry present in early July, several groups of 25 to 30 observed

Fish use of Mainstem Red Dog Creek, prior to mine development, was mostly limited to migration. Arctic grayling adults and fry use Mainstem Red Dog Creek. Adults in small numbers generally are present in lower Mainstem Red Dog Creek in the area of Station 10. Fry are seen some years in the upper portion of Mainstem Red Dog Creek immediately below North Fork Red Dog Creek. Consistently, we see fry in Mainstem Red Dog Creek in backwaters and along stream margins in the Station 10 area.

Arctic Grayling Mark/Recapture and Distribution

Since 1994, we have marked Arctic grayling >200 mm with floy-tags. Most of the marks have been put out in North Fork Red Dog Creek, but we also have caught and tagged fish in Mainstem Red Dog, Grayling Junior, and Ikalukrok creeks. Mark/recapture data are used to determine migration patterns of Arctic grayling during the ice-free season.

In 2005, we marked 87 Arctic grayling during spring in North Fork Red Dog Creek. We saw 17 marked fish that had been tagged in previous years. All of the recaptured fish, except one, had been originally marked in either Maintain Red Dog or North Fork Red Dog creeks.

One of the Arctic grayling caught in spring 2005 in North Fork Red Dog Creek was 287 mm long – this fish had been marked in Bons Pond on June 16, 2003, and was 224 mm long. This is our first evidence, since some of the initial transplanted fish left Bons Pond, of an Arctic grayling leaving Bons Pond and returning to North Fork Red Dog Creek. The Arctic grayling population in Bons Pond is the result of a fish transplant conducted in 1995 and 1996 with fish originally moved from North Fork Red Dog Creek to the reservoir. Fish barriers (i.e., to upstream movement) exist at the freshwater dam spillway below Bons Pond and in Buddy Creek several km below Bons Pond. We assume with the high numbers (population estimate 6,189 for summer 2004, 95% CI of 5,107 to 7,271) of Arctic grayling currently using Bons Pond that we will continue to see these fish enter the Ikalukrok Creek drainage.

In comparison, we have estimated the Arctic grayling population in Mainstem Red Dog and North Fork Red Dog creeks. The only year that we had adequate numbers of marked and recaptured fish to produce an estimate was for the spring spawning migration in 2001. Our estimated Arctic grayling (200 mm) population in spring 2001 was 870 fish (95% CI of 668 to 1,072) (Ott and Weber Scannell 2003). We believe this estimate to be representative of the number of Arctic grayling in the Ikalukrok Creek drainage.

Aerial surveys of Ikalukrok Creek drainage for adult Arctic grayling have been made annually since summer 2000. In summers 2000 and 2002, large numbers (300 to 400) of adult Arctic grayling were seen at the mouth of Grayling Junior Creek and/or in East Fork Ikalukrok Creek. In both 2003 and 2004, concentrations of Arctic grayling were not seen in the Ikalukrok Creek drainage. However, in fall 2005, we did again observe Arctic grayling in East Fork Ikalukrok Creek. During aerial surveys, we estimated about 30 fish in Ikalukrok Creek between Mainstem Red Dog Creek and East Fork Ikalukrok Creek and about 70 in East Fork Ikalukrok Creek. On August 2, 2005, we landed near a deep pool in East Fork Ikalukrok Creek just upstream from its confluence with Ikalukrok Creek. We caught, by angling, 13 Arctic grayling, including large adult fish and a number of smaller juveniles. Three of the fish were recaptures that had been tagged previously in either North Fork Red Dog or Mainstem Red Dog creeks (Table 15).

Table 15. Arctic grayling recaptures in East Fork Ikalukrok Creek in fall 2005.

Tag Number	Color	Length (mm)	Date Captured	Site Captured	Recapture Date	Recapture Site	Length (mm)
10667	Orange	374	6/17/01	Mainstem	8/1/02	Gray Jr.	374
13270	Green	382	6/1/02	Mainstem	8/2/05	EF Ikal.	400
15827	White	335	6/3/05	North Fk.	8/2/05	EF Ikal.	335

We also observed a school of about 30 Arctic grayling moving downstream. Based on the aerial surveys and observations made on the ground, there were a large number of Arctic grayling in East Fork Ikalukrok Creek in fall 2005.

In late June, a TCAK consultant (Houghton) sampled, by angling, Arctic grayling in Mainstem Red Dog and North Fork Red Dog Creek. On June 25 and 26, 2006, Houghton caught and released 60 Arctic grayling in Mainstem Red Dog Creek and 18 in North Fork Red Dog Creek. Eleven of the fish were recaptured and all had been originally marked in either Mainstem Red Dog or North Fork Red Dog creeks. An Arctic grayling tagged in 1995 with multiple recaptures shows a definite trend for returning to North Fork Red Dog Creek in spring (Table 16).

Table 16. Arctic grayling marked in North Fork Red Dog Creek in 1995 (recapture history).

Tag Number	Color	Length (mm)	Date Captured	Site Captured	Recapture Date	Recapture Site	Length (mm)
1509	White	229	6/26/95	North Fk.	7/17/95	North Fk.	237
					7/1/98	North Fk.	335
					6/15/01	North Fk.	364
					6/1/02	Mainstem	377
					5/28/04	North Fk.	385
					6/26/05	Mainstem	400

Slimy Sculpin

Houghton and Hilgert (1983) found slimy sculpin in Ikalukrok and Dudd creeks, but none in the Red Dog drainage. In 1995, we caught slimy sculpin in Mainstem Red Dog and North Fork Red Dog creeks (Weber Scannell and Ott 1998). Slimy sculpin are infrequently captured in the Red Dog drainage and in Anxiety Ridge Creek. Catches of slimy sculpin generally have been highest in Ikalukrok Creek in our sample area upstream and downstream of Dudd Creek. The total catch of slimy sculpin for all sample areas, except Evaingiknuk Creek, is presented in Figure 115.

Trends in total numbers indicate an increasing presence of slimy sculpin from 1996 through 1999, with a decrease from 2000 to 2002, and then an increasing trend through 2005. These data may reflect that slimy sculpin were impacted during 1989 and 1990 prior to construction of the clean water bypass in spring 1991. The second decrease and low numbers for several years may be related to increasing metals from Cub Creek that was first detected visually in 1997. The continued increase in numbers caught from 2003 to 2005 is consistent with general improvements in water quality due to decreased metals from the Cub Creek seep.

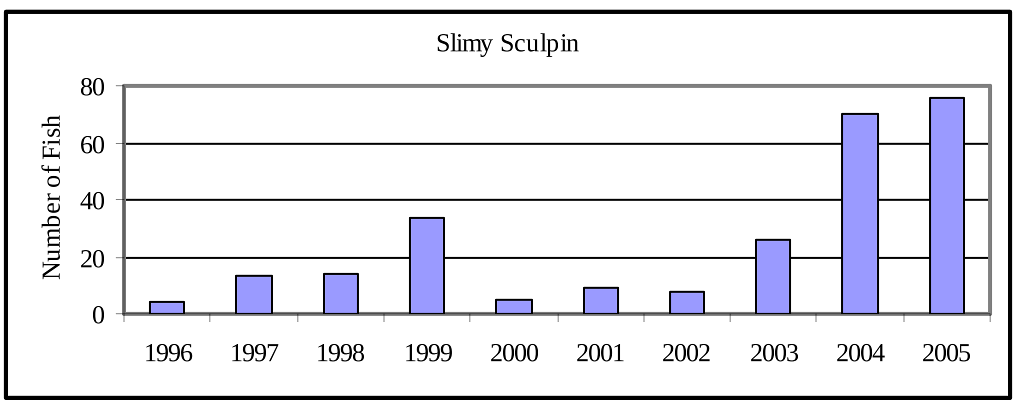

Figure 115. Slimy sculpin caught in Ikalukrok, Red Dog, Buddy, and Anxiety Ridge creeks, 1996 to 2005.

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Appendix 1. Summary of Mine Development and Operations

1982

- Baseline studies initiated, Cominco agreement with NANA finalized

1983

- EIS process initiated, alternatives for mine and road to port site identified

1984

- Stream surveys conducted along proposed road by private consultant

1985

- Permit applications prepared for regulatory agencies
- Implementation of wastewater treatment plant deferred to ADEC by ADF&G
- Wastewater discharge limited to summer
- Potential for acid rock drainage and metals mobilization not recognized

1986

- ADEC solid waste permit and bonding not required
- ADEC permit preceded solid waste regulations
- AIDEA bonds to build road and port site issued

1987

- Construction of road began, budget request to AIDEA prepared by ADF&G
- Reimbursement agreement for logistics with ADF&G to monitor construction made by AIDEA

1988

- Ore body developed
- Road and port site construction began
- Notice of Violation issued to AIDEA by ADF&G for failed road crossing by-passes
- Uniform Summons and Complaint issued for illegal water removal
- AIDEA provided funding to ADF&G for monitoring
- Rehabilitation plans for streams developed and implemented

Appendix 1 (continued).

1989

- Agreement to close-out old solid waste site finalized with Cominco
- Civil work on ore body and surface water drainage control begun
- Complaints about water quality in Ikalukrok Creek received
- Tailing dam becomes full, Cominco's request to siphon untreated water over the dam denied by State
- Elevated metals concentrations identified by red precipitation, were observed in Ikalukrok Creek below the mine
- Winter discharge of treated water authorized by State
- State regulatory agencies and Cominco in disagreement over whether metals exceeded background conditions

1990

- Biomonitoring of fish populations proposed and initiated by ADF&G
- Dead fish from the Wulik River were discovered by the public
- ADF&G sampling indicated very few fish remaining in Ikalukrok Creek
- Installation of sumps and pumps by Cominco prevented metals-laden water from entering Red Dog Creek
- Baseline and current water quality data reviewed by ADF&G
- Clean water bypass system requested by ADF&G
- Zinc levels in Ikalukrok Creek exceeded 40 mg/L
- State regulatory agencies and Cominco in disagreement over cause and extent of water quality problems
- Compliance Order by Consent for water quality violations affecting anadromous fish issued by ADEC
- Notice of Violation for water quality violations affecting anadromous fish issued by ADF&G
- Cominco directed to design and construct a clean water bypass system
- Perceived impairment to the subsistence fishery initiated involvement by the community of Kivalina

1991

- Clean water bypass system designed by Cominco, approved by state agencies
- ADF&G fisheries study funded by Cominco
- Clean water bypass system built
- Clean water bypass system repaired
- Improvements to water quality were documented

Appendix 1 (continued).

1992

- Fish study continued
- Water quality improvements to downstream receiving water continued
- Increasing water volume in tailing impoundment continued
- Water from dirty water collection system entering tailing impoundment increased volume
- Water treatment plant modifications made

1993

- Fish study continued
- Sand filters to remove particulate zinc installed

1994

- Fish study continued
- Use attainability studies of several streams initiated for reclassification
- Water treatment capacity increased by thickening tank conversion
- Wastewater discharge increased from 7.5 cfs to 23 cfs
- Ore processing capability expanded by Cominco

1995

- Fish study expanded to include other aquatic biota
- Work on stream reclassification and site-specific criteria continued by ADF&G
- Metals concentrations in the clean water bypass system increased; contributing sources were identified: Hilltop Creek (Zn), Shelly Creek (Cd), and Rachel Creek (Al)
- Clean water bypass system extended to collect water from Hilltop Creek
- Reserves were doubled after exploration drilling located more ore
- Possible metals contamination in Bons Creek identified by ADF&G

1996

- Public notice for stream reclassification sent out
- Bons Creek water samples from above and below the Kivalina shale dump collected
- Fish and aquatic biota study continued

Appendix 1 (continued).

1997

- Stream reclassification incorporated into regulation (18 AAC 70.50)
- Fish barrier constructed across Middle Fork Red Dog Creek
- Water bypass around the Kivalina shale dump and interceptor trench at the head of the tailing impoundment built
- Gray-white precipitate observed in Middle Fork Red Dog Creek
- Heavy red staining and precipitate seen in Ikalukrok Creek; originated from seep near headwaters of Ikalukrok Creek, located upstream of mining activity
- Laboratory experiments of TDS on egg fertilization and early egg development initiated
- Fish and aquatic biota studies continue
- US EPA brings enforcement action for water quality violations; Cominco initiates Supplemental Environmental Projects
- Two-year aquatic community study in upper Ikalukrok Creek, above and below the Red Dog Mine discharge initiated by ADF&G
- Ground water monitoring wells installed and monitored below tailing dam by Cominco

1998

- Wet fertilization studies to test effects of TDS on fish embryos continued
- Draft 401 certification for a new NPDES permit prepared by ADEC and reviewed by ADF&G
- Discussed extension of the clean water bypass system up Shelly and Connie Creeks to ensure bypass of clean water and collection of seepage water from newly disturbed areas
- Heavy red staining in headwaters of Ikalukrok Creek, originating from seep in headwaters of Ikalukrok Creek, upstream of mining activity, staining extends downstream about 30 km
- Site-specific criteria for Zn in Mainstem Red Dog and Ikalukrok Creeks approved by EPA
- Heavy rains cause an unanticipated release of water into Bons Creek from the Kivalina stockpile
- Plans to increase port site capacity for direct loading of ships released to public
- NPDES permit reissued by US EPA
- Two-year aquatic community study completed
- Biomonitoring, including studies of fish and aquatic biota, required under 1998 NPDES permit

Appendix 1 (continued).

1999

- Two-year drilling program (Shelly and Connie Creeks) proposed
- New station 7 on Ikalukrok Creek established by Cominco, USGS, and ADF&G
- Fish and aquatic biota study expanded to upper North Fork Red Dog, Ikalukrok, and Ferric creeks
- Biomonitoring and USGS gauging work proposals submitted to Cominco
- Study of periphyton communities exposed to different concentrations of TDS in Mainstem Red Dog Creek done by ADF&G and Cominco Alaska Inc.
- Request to increase TDS for periphyton colonization experiment not approved
- Effects to Ikalukrok Creek from Alvinella Creek seepage water continued to below Dudd Creek mouth
- Arctic grayling females in ripe spawning condition collected from North Fork Red Dog Creek for selenium analysis of livers and ovaries

2000

- Effects to Ikalukrok Creek from Cub Creek seep continued; red stain and precipitate observed several km below mouth of Mainstem Red Dog Creek
- North Fork Red Dog Creek silty at breakup, previously not observed
- Minimal precipitate in Middle Fork Red Dog Creek below effluent outfall observed
- Civil work performed in Connie Creek to isolate surface from subsurface flows and bypass flow through disturbed areas
- Effectiveness of pump back system at the Kivalina rock dump verified by presence of juvenile Arctic grayling in creek immediately south of dump
- Site-specific criteria for TDS requested by Cominco
- Biomonitoring study continued
- Baseline fish and aquatic biota studies in streams located in the vicinity of the Anarraaq Prospect begun

Appendix 1 (continued).

2001

- Effects to Ikalukrok Creek from Cub Creek seep continued, red stain and precipitate observed in Ikalukrok Creek to Station 8 below Mainstem Red Dog Creek, affects minor near mouth of Dudd Creek
- North Fork Red Dog Creek, siltation (natural) less than in summer 2000
- Minimal precipitate in Middle Fork Red Dog Creek below effluent outfall
- Water quality was monitored in Shelley, Rachel, Connie, and Middle Fork Red Dog creeks upstream and downstream of surface disturbance, catch-box and pipeline (about 430 m) placed in Shelley Creek to move water pass disturbance
- Juvenile Arctic grayling observed in Bons Creek just south of the Kivalina rock dump, pump-back system working based on fish use
- Fish weir repairs made during 2000, no problems observed in 2001
- Stream survey of cross drainage structures made along the Delong Mountains Transportation System, some minor work at some crossings identified
- Site-specific criteria for TDS still being worked, data on Arctic grayling spawning/water temperature collected in North Fork Red Dog and Mainstem Red Dog creeks, supplemental data gathered at the Ft. Knox mine
- Studies expanded to include the Delong Mountains Transportation System based on a National Park Service report that metals concentrations adjacent to road were elevated, water sites established upstream and downstream of road and sampled by Teck Cominco, juvenile Dolly Varden samples collected in Omikviorok River and Aufeis Creek, vegetation sampling started by Teck Cominco
- New haul trucks brought on site, hard-covered trucks to minimize loss of zinc and lead concentrates during transport
- Exploratory drilling (ore and shallow gas) continued, focus on North Fork Red Dog Creek and Wulik River basins near Anarraaq and Lik, including west of the Wulik River, another ore prospect found northwest of Anarraaq, shallow gas results promising
- State and Teck Cominco agree to start the state’s large mine team to work on issues, key issue identified was development of a solid waste permit with bonding for the tailing dam, other issues include site-specific criterion for total dissolved solids, clean-water bypass system, waste rock dumps (acid-rock drainage, and truck wash to minimize metal transport)
- Biomonitoring study continued, baseline fish and aquatic biota studies in streams located in the vicinity of the Anarraaq Prospect continued for the second field season, four new sites added to study tributaries on west side of Wulik in the area of the Lik Deposit and potential shallow gas development

Appendix 1 (Continued).

2002

- Effects to Ikalukrok Creek from Cub Creek seep continued, red stain and precipitate observed in Ikalukrok Creek to Station 8 below Mainstem Red Dog Creek, affects minor near mouth of Dudd Creek
- North Fork Red Dog Creek, siltation minor during summer 2002
- Minor precipitate in Middle Fork Red Dog Creek below effluent outfall
- Fish weir operating as designed
- Data on Arctic grayling spawning/water temperature collected in North Fork Red Dog Creek, supplemental data gathered at Ft. Knox
- Pit expansion continues to the north of the clean-water bypass system, road crossing added for access
- A bypass was installed for Connie Creek during winter 2001/2002. The bypass captures the upstream creek and carries the water in a pipe to the clean-water bypass system
- The bypass system for Shelly Creek was modified during summer 2002 to correct an overflow problem that occurred during breakup (the overflow water was captured in the pit and did not affect downstream waters). The modification involved adding a lined ditch to contain overflowing clean water and direct the water to the clean-water bypass system
- Juvenile Dolly Varden collected at eight sites located upstream and downstream of the Delong Mountains Regional Transportation System, whole body metals analyses for Cd, Pb, Se, and Zn
- Site-specific criteria for total dissolved solids is still being worked
- State and Teck Cominco continue to work on key issues, e.g., solid waste permit with bonding for the tailing dam, site-specific criterion for total dissolved solids, clean-water bypass system, waste rock dumps (acid-rock drainage, and truck wash to minimize metal transport)
- Biomonitoring study continued, baseline fish and aquatic biota studies in streams located in the vicinity of the Anarraaq Prospect and shallow gas exploration
- Arctic grayling adults remained in North Fork Red Dog Creek through early August, only the second time since 1992 that most of the adults stayed in the creek during summer, most years adults outmigrate shortly after spawning in spring
- Arctic grayling adults present in Buddy Creek just below the falls, about 50 adult fish in sample reach (0.3 km) in early July, all gone by early August
- About 50 to 60 adult Dolly Varden in Ikalukrok Creek at mouth of Dudd Creek from early July through late August
- Effluent discharge ceased on October 5, 2002, to allow time to winterize the water treatment plant

Appendix 1 (continued).

2003

- Effects to Ikalukrok Creek from Cub Creek seep continued but were much less than seen in the last two to three years
- North Fork Red Dog Creek, natural siltation throughout most of the summer was minor in summer 2003
- Minor precipitate in Middle Fork Red Dog Creek below effluent outfall
- Fish weir operating as designed
- Data on Arctic grayling spawning/water temperature collected in North Fork Red Dog Creek, supplemental data gathered at Ft. Knox
- Site-specific criteria for total dissolved solids was finalized
- USEPA modified the NPDES effective August 22, 2003, to incorporate the ADEC Site Specific Criteria and mixing zones for total dissolved solids in Mainstem Red Dog and Ikalukrok creeks with conditions that ensure total dissolved solids are at or below 500 mg/L during Arctic grayling spawning in Mainstem Red Dog Creek and during chum salmon and Dolly Varden spawning in Ikalukrok Creek, the modified permit was appealed by the Kivalina Relocation Planning Committee
- State and Teck Cominco continue to work on key issues, e.g., solid waste permit with financial assurance for the tailing dam, site-specific criterion for total dissolved solids, clean-water bypass system, waste rock dumps (acid-rock drainage, and truck wash to minimize metal transport)
- Arctic grayling adult returns to North Fork Red Dog Creek were low, number of adult Arctic grayling seen in the Ikalukrok Creek drainage was the lowest seen since aerial surveys were begun in the late 1990s
- Arctic grayling population estimate was completed for Bons Pond the site of a fish transplant made in 1994 and 1995, estimated population in the reservoir was 6,773
- Modification to Shelly Creek bypass ditch completed, a better designed and constructed lined ditch was built and commissioned in August, 2003
- In 2003, a permanent lined ditch was constructed parallel to the Connie Creek diversion pipeline to avoid spring freeze-up issues
- In 2003, a permanent monitoring station was established at the end of the mixing zone in Mainstem Red Dog Creek, the location designation is Station 151, and is fitted with real time total dissolved solids and flow determination equipment and telemetry to link the station directly into the mill process control system
- Station 150, at the end of the mixing zone in Ikalukrok Creek, was fitted with real time total dissolved solids and flow determination equipment and telemetry to link the station directly into the mill process control system

Appendix 1 (continued).

2004

- Wastewater discharge began on May 20, ended on September 26, total discharge about one billion gallons
- Effects to Ikalukrok Creek from Cub Creek seep continued but were minor
- North Fork Red Dog Creek, natural siltation minor during ice-free season
- Minor precipitate in Middle Fork Red Dog Creek below effluent outfall
- Fish weir operating as designed
- Arctic grayling spawning/water temperature data collected, Arctic grayling from North Fork Red Dog Creek used for TDS fertilization experiment
- State and Teck Cominco continued to work on key issues associated with the solid waste permit and closure plan for the mine
- Arctic grayling adult returns to North Fork Red Dog Creek were low, number of adults seen in Ikalukrok Creek drainage remained low as in summer 2003
- Bons Pond (the site of a fish transplant made in 1994 and 1995), estimated Arctic grayling population for summer 2003 was 6,773 and for summer 2004 was 5,739
- Chinook salmon juveniles were documented for the first time in Ikalukrok Creek, near Dudd Creek, and in Anxiety Ridge Creek
- Age-1 Arctic grayling were caught in minnow traps fished in Ikalukrok, Mainstem, and Buddy creeks, since age-1 fish are seldom captured in minnow traps this may indicate good survival of fry spawned in spring 2003
- Red Dog Creek diversion (clean water ditch) was realigned to the west side of the pit. Realigned configuration is a combination of large diameter culvert and open lined ditch.

2005

- Wastewater discharge began on May 10, 2005, ended on October 6, 2005, total discharge about 1.501 billion gallons
- Major precipitate observed on streambed in Middle Fork Red Dog Creek below effluent outfall in July and August, precipitates (gray colored) evident for at least 1 km downstream of effluent outfall
- Fish weir operating as designed
- Effects to Ikalukrok Creek from Cub Creek seep substantially greater than seen for past several years, water opaque and streambed coated with red precipitate at confluence with Mainstem Red Dog Creek, TCAK water sample from Cub Creek seep with a pH of 3.3
- Arctic grayling spawning/water temperature data collected, Arctic grayling from North Fork Red Dog Creek used for TDS fertilization experiment
- Attended and participated in a NPDES permit renewal meeting in Seattle with EPA, TCAK, and Nana, identified and discussed key issues

Appendix 1 (concluded).

2005

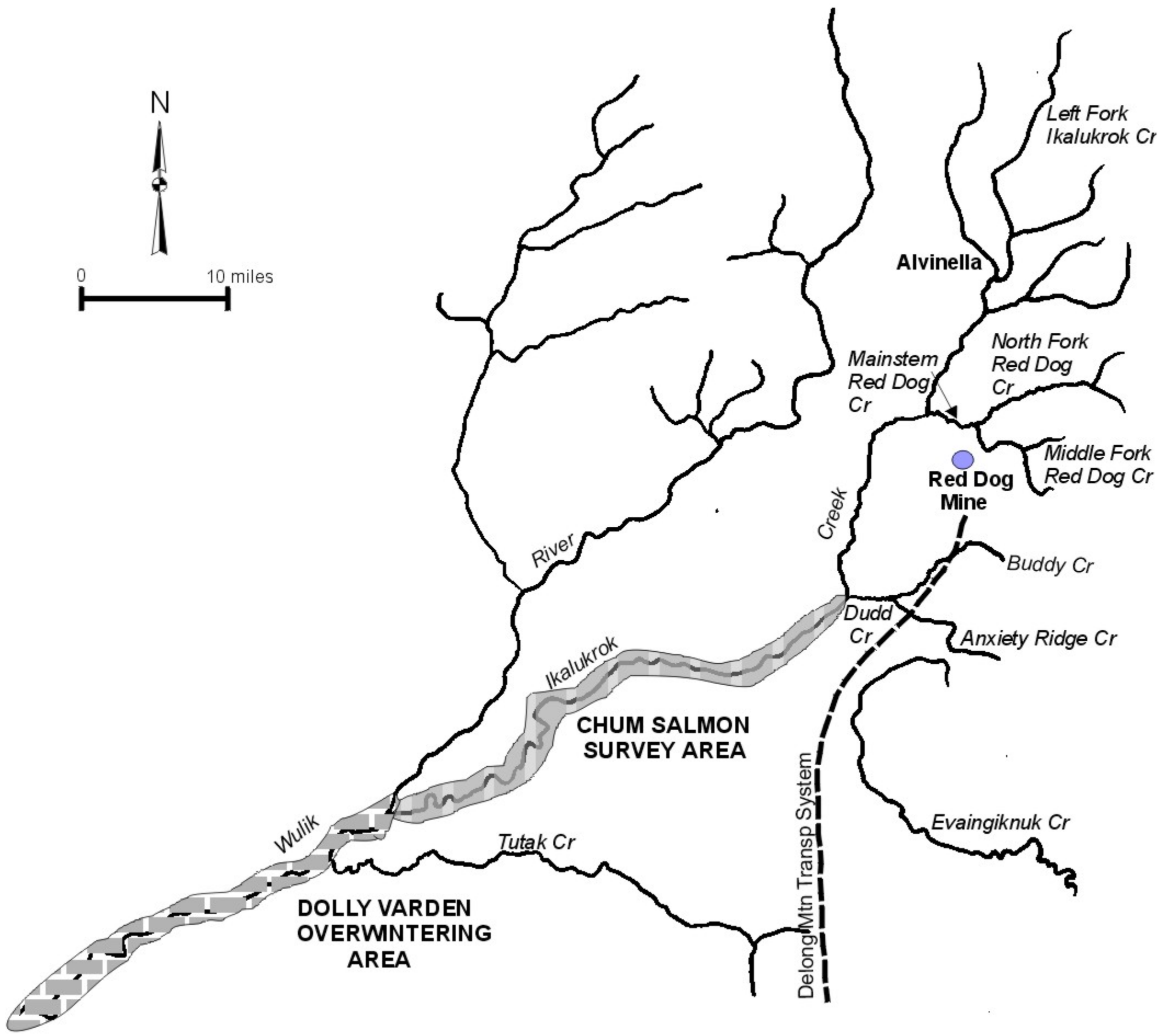
- Red Dog Creek diversion (clean water ditch) mine engineering drawings (r4) were provided by TCAK showing the culverts and lined ditch that carry water from tributaries and Middle Fork Red Dog Creek through the pit area
- Recommendations for changes to the Red Dog biomonitoring program based on field data collection and analyses since 1999 were made for possible incorporation into the renewed NPDES permit or ADEC's solid waste permit for the tailing impoundment
- TCAK distributed the 2005 draft report on Arctic grayling fertilization studies that concluded TDS concentrations at or below 1,500 mg/L at Station 10 in Mainstem Red Dog Creek would provide for proper protection of Arctic grayling in the Red Dog Creek drainage, OHMP supported these findings in a letter to Pete McGee (ADEC) dated August 17, 2005
- Dr. Weber Scannell prepared comments on fish tissue data (Dolly Varden from Wulik and Kivalina rivers) collected by Maniilaq Association and compared these data with existing information from other sources in both Alaska and nationwide
- OHMP prepared a summary report (letter to Jim Kulas dated August 23, 2005) on temperature/spawning data collected for Arctic grayling in Mainstem Red Dog and North Fork Red Dog creeks from 2001 through 2005, a recommendation for determining start and completion of spawning based on temperature was developed for Mainstem Red Dog Creek
- State and TCAK continued to work on key issues associated with the solid waste permit and closure plan for the mine ADEC
- Wastewater Treatment Plant (WTP) #3 began operations in late summer 2005 to treat mine sump water and drainage from waste rock dumps prior to placement of these waters into the tailing impoundment, purpose is to improve water quality in tailing impoundment over time
- Exploratory drilling and flow testing for gas in North Fork Red Dog Creek basin was conducted, access road and pads inspected, corrugated pipes installed to provide cross drainage, no evidence of erosion noted along road to and connecting the drill pads
- ADEC amended the site-specific criteria (SSC) for TDS in Mainstem Red Dog Creek, the 500 mg/L limit during Arctic grayling spawning was removed and replaced with a 1,500 mg/L limit, EPA approved the new SSC in April 2006
- A road was constructed to Station 151 (end of mixing zone in Mainstem Red Dog Creek
- Work to expand and relocate the water treatment plant sand filters was initiated

Appendix 2. Dolly Varden Aerial Surveys

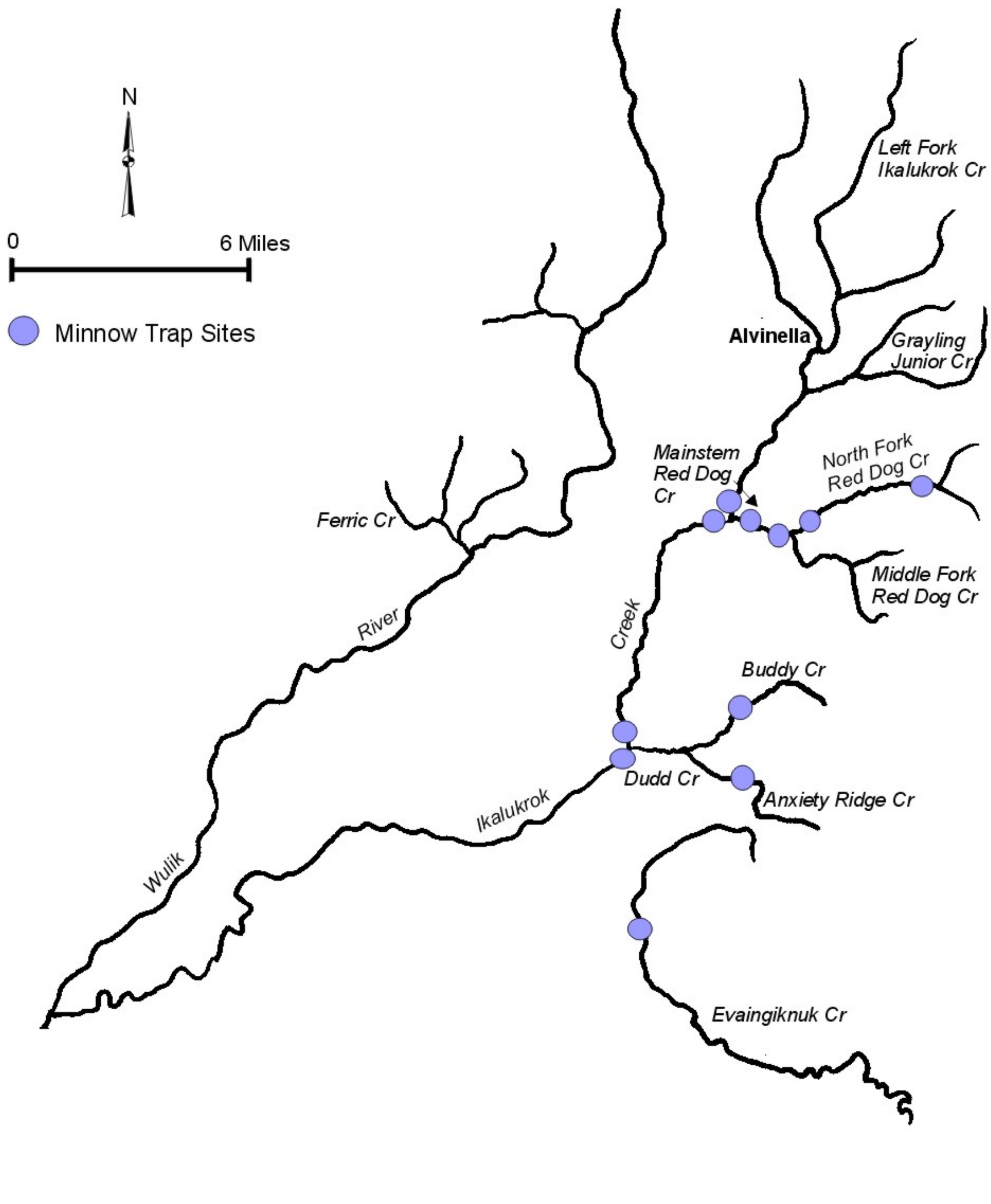
Estimated number of overwintering Dolly Varden in the Wulik River before freezeup. Surveys conducted by ADF&G (DeCicco 1989, 1991-1999, 2001-2002, and 2004-2005.

Year	Wulik River upstream of Ikalukrok Creek	Wulik River downstream of Ikalukrok Creek	Total Fish	Percent of Fish downstream of Ikalukrok Creek
Before Mining				
1979	3,305	51,725	55,030	94
1980	12,486	101,067	113,553	89
1981	4,125	97,136	101,261	96
1982	2,300	63,197	65,497	97
1984	370	30,483	30,853	99
1987	893	60,397	61,290	99
1988	1,500	78,644	80,144	98
During Mining				
1989	2,110	54,274	56,384	96
1991	7,930	119,055	126,985	94
1992	750	134,385	135,135	99
1993	7,650	136,488	144,138	95
1994	415	66,337	66,752	99
1995	240	128,465	128,705	99
1996	1,010	59,995	61,005	98
1997	2,295	93,117	95,412	98
1998	6,350	97,693	104,043	94
1999	2,750	67,954	70,704	96
2001	2,020	90,594	92,614	98
2002	1,675	42,582	44,257	96
2004	16,486	84,320	100,806	84
2005	10,645	110203	120,848	91
The population estimate (mark/recapture) for winter 1988/1989 for fish >400 mm				
was 76,892 (DeCicco 1990b)				
The population estimate (mark/recapture) for winter 1994/1995 for fish >400 mm				
was 361,599 (DeCicco 1996c)				
Fall 2000 aerial survey was not made due to weather.				
Fall 2003 aerial survey was not made due to weather.				

Appendix 3. Dolly Varden and Chum Salmon Survey Areas



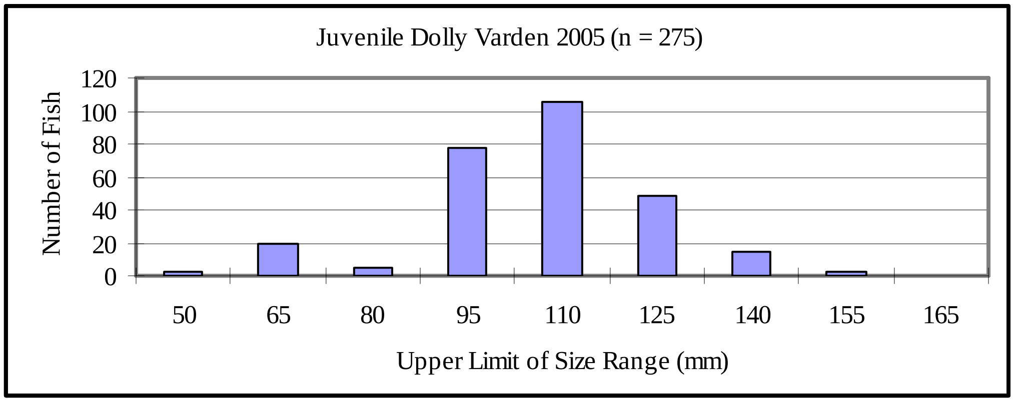
Appendix 4. Juvenile Dolly Varden Sampling Sites

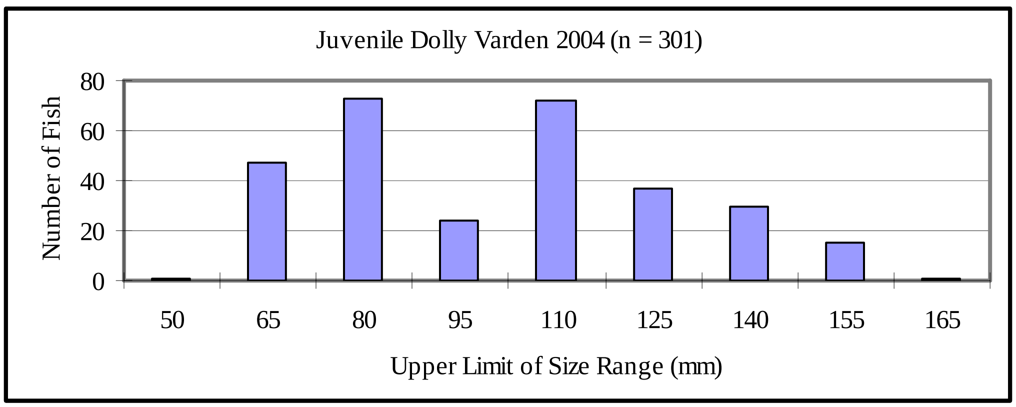


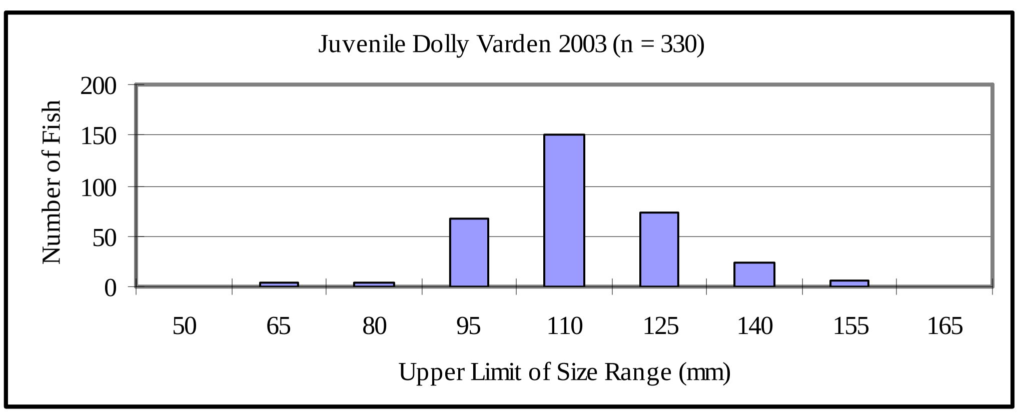
Appendix 5. Juvenile Dolly Varden Catches

Number of Dolly Varden Caught in Late-July/Early August with ten minnow traps per sample site										
Sample Site Description	2005	2004	2003	2002	2001	2000	1999	1998	1997	
Evaingiknuk (Noatak Tributary)	29	71	64	20	7	2	38	27	54	
Anxiety Ridge	121	116	98	33	6	27	271	94	68	
Buddy	59	59	104	57	34	11	306	154	48	
North Fork Red Dog Creek (Sta 12)	8	1	0	1	1	1	17	12	0	
Mainstem (below North Fork)	6	2	2	12	9	13	86	70	14	
Mainstem (Station 10)	10	0	12	12	3	1	66	21	10	
Ikalukrok Creek (below Dudd)	36	27	17	17	6	31	55	51	13	
Ikalukrok Creek (above Dudd)	6	11	27	22	0	14	37	53	3	
Ikalukrok Creek (below Mainstem)	0	2	3	15	11	6	28	19	4	
Ikalukrok Creek (above Mainstem)	0	12	3	18	2	5	41	44	3	
Total Catch Dolly Varden	275	301	330	207	79	111	945	545	217	

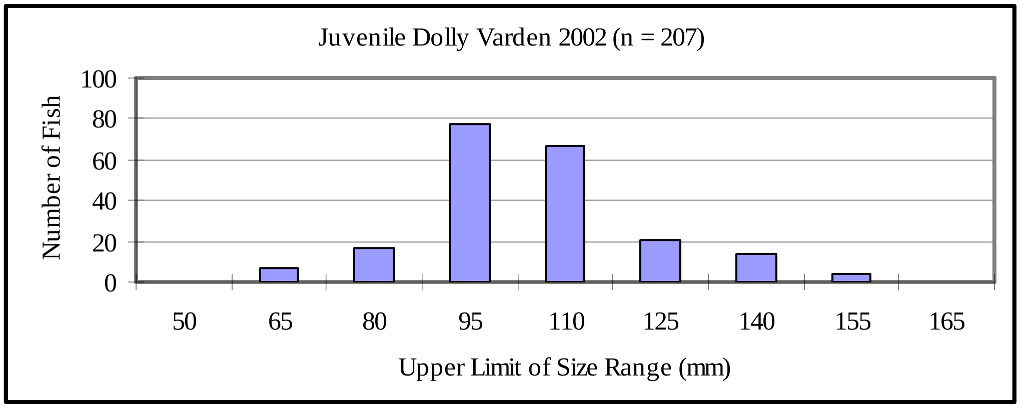
Appendix 6. Length-Frequency Distribution of Juvenile Dolly Varden

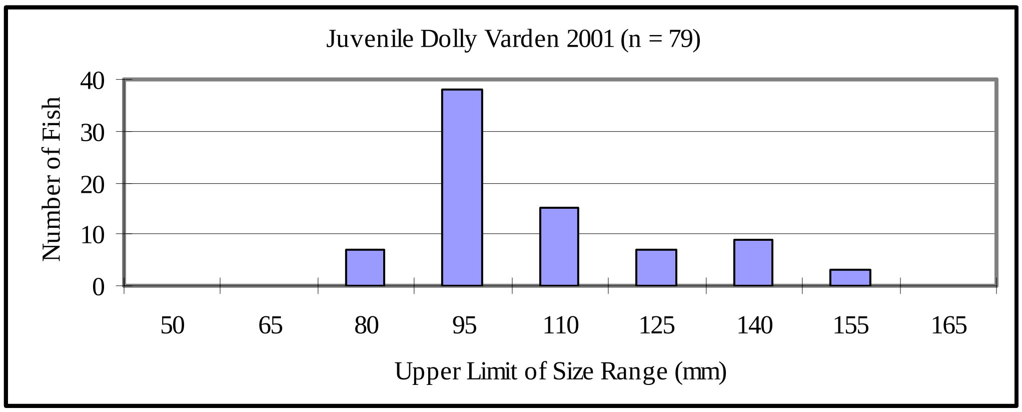


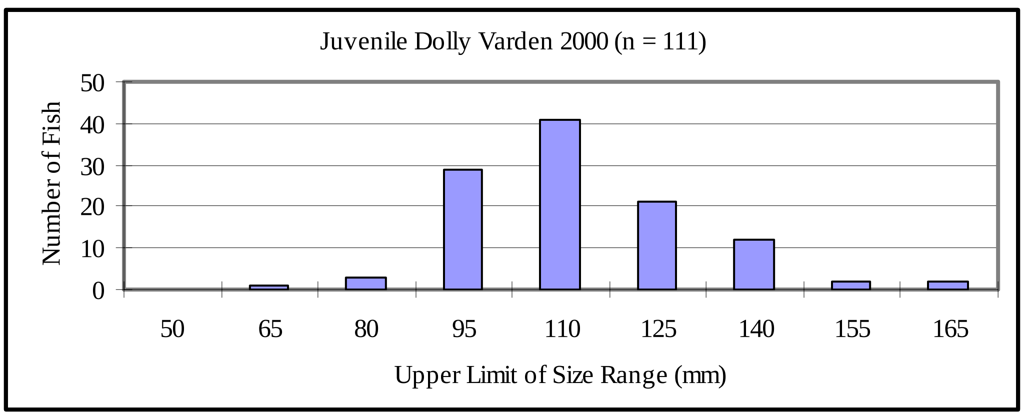




Appendix 6 (continued).







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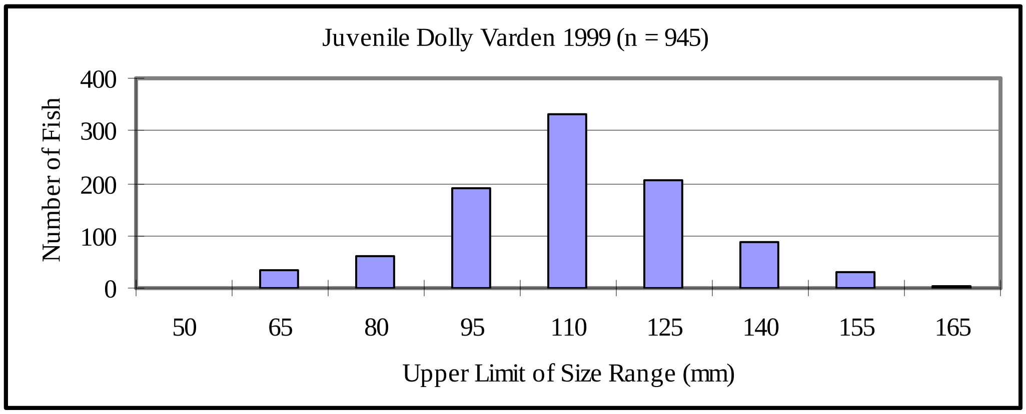
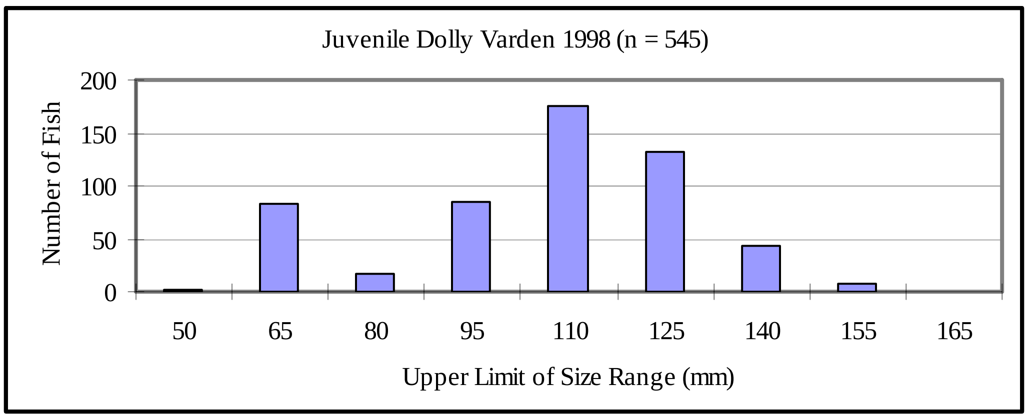
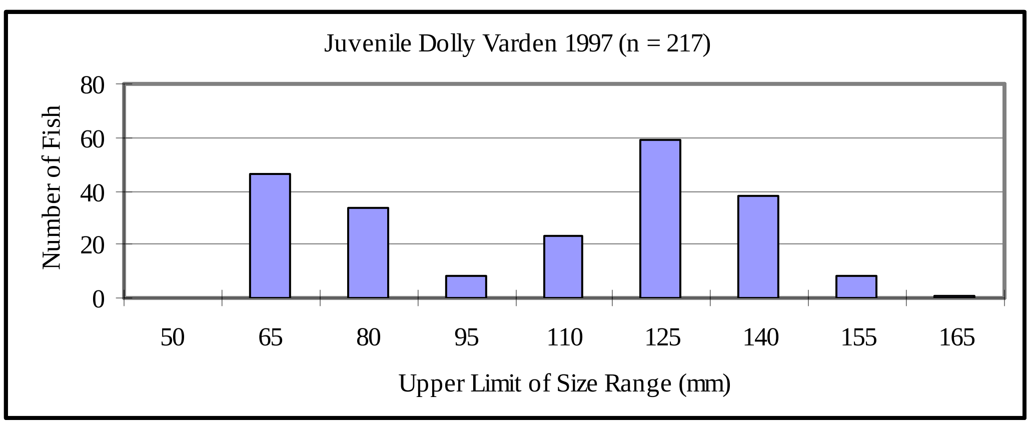
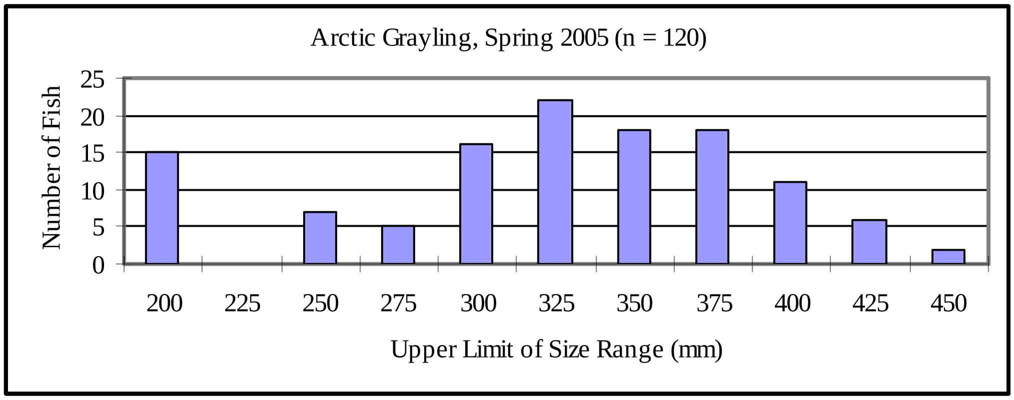
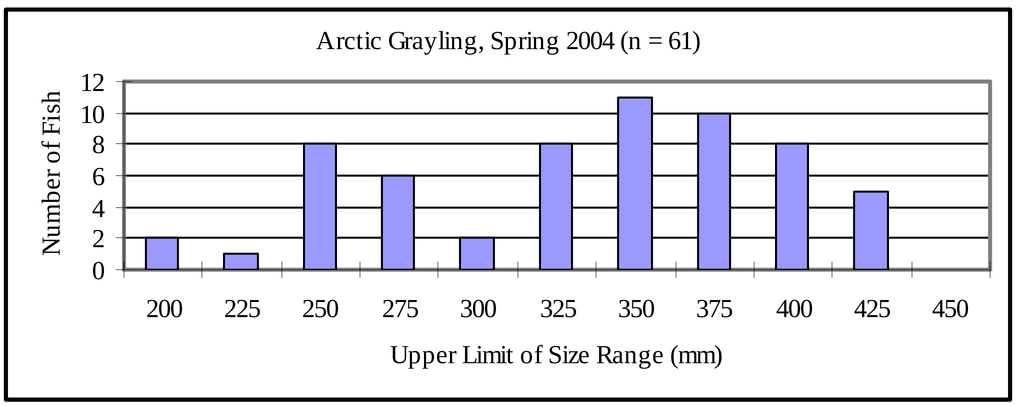


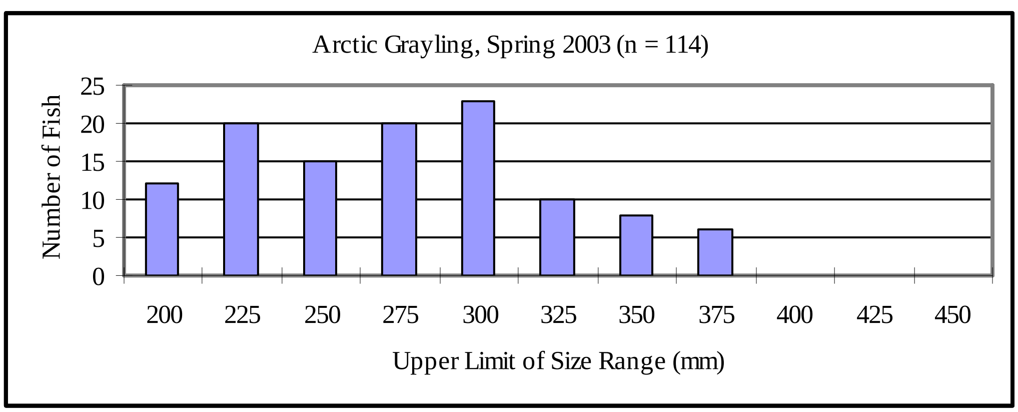




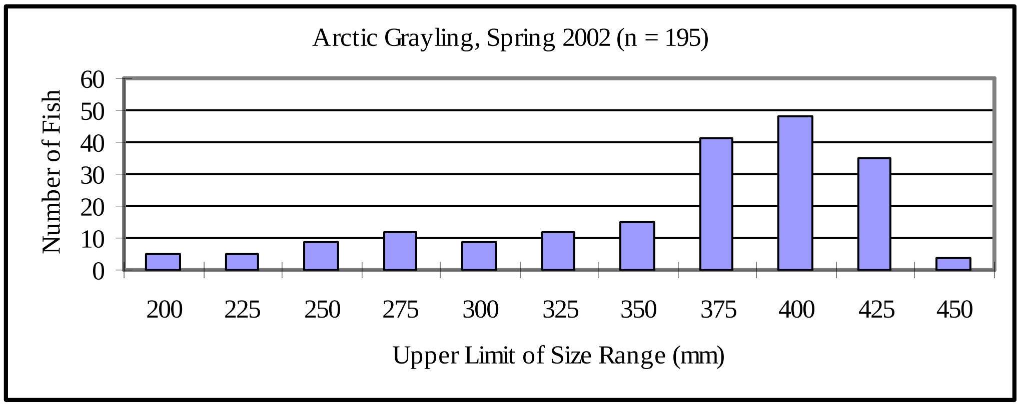
Appendix 7. Length-Frequency Distribution of Arctic Grayling in North Fork Red Dog Creek

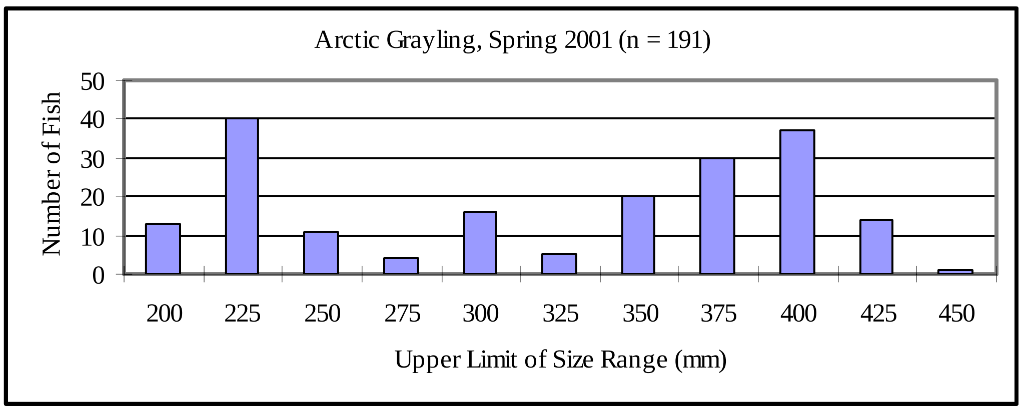


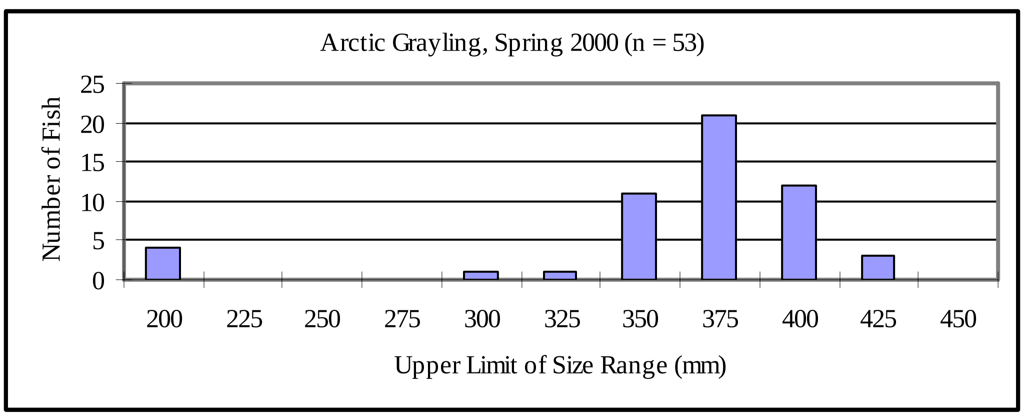




Appendix 7 (concluded).







Appendix 8. Arctic Grayling in Mainstem Red Dog Creek

Observations and catches of Arctic grayling in Mainstem Red Dog Creek below confluence of North Fork and Middle Fork Red Dog creeks since 1994.

6/5/05 – aerial, observed 30 adult Arctic grayling, only two sets paired
7/4/05 – visual, 8 adults and fry (about 70) observed near Station 10
6/25 and 26/05 – Houghton reported catching about 60 fish in Mainstem between mouth and North Fork Red Dog Creek
7/28/05 – visual, small numbers of fry in backwaters near Station 10

7/8/04 – angling, three adults (373, 297, 356 mm) near Station 10
7/8/04 – visual, fry in all backwaters near Station 10
7/7/04 – angling, two adults (333, 325 mm) near Station 151
7/7/04 – visual, fry common near Station 151
5/26/04 – fyke net, four adults near Station 10
5/25/04 – visual, two adult males near Station 10

9/7/03 – visual, two adults and five fry near Station 151
7/8/03 – visual, ten adults near Station 10
7/7/03 – visual, fry in backwaters near Station 10, one group of 30
6/14/03 – angling, eight adults, one spent male near Station 10
6/12/03 – visual, ten adults, three active spawning pairs observed near Station 10
6/11/03 – aerial, 48 adults, two spawning pairs seen

7/28/02 – visual, adults present near Station 10, three to four per pool
7/27/02 – visual, few fry (<10) seen
6/7/02 – angling, 10 adults and three juveniles marked and released near Station 10, most of the females were spent
6/4/02 – fyke net, three adults and three juveniles marked and released near Station 10
6/3/02 – fyke net, three adults marked and released near Station 10
6/2/02 – fyke net, eight adults marked and released near Station 10
6/1/02 – fyke net, 31 adults marked and released near Station 10
5/31/02 – fyke net, seven adults marked and released near Station 10

Appendix 8 (continued).

7/29-31/01 – visual, very few fry seen (about 20 mm), late breakup, cold temperatures resulted in late spawning
6/17/01 – angling, 11 adults marked and released near Station 10, all females spent
6/15-18/01 – visual, walked creek to check for spawners in proposed mixing zone, none observed, one adult seen feeding at rock bluff (about 0.8 km below North Fork)

7/28/00 – visual, several fry in backwaters and along stream margins, not numerous
7/6/00 – visual, walked most of creek, tagged three adults near Station 10, most pools held one to three adults
7/5/00 – visual, two adults feeding at rock bluff (0.8 km below North Fork), juvenile observed
6/11-12/00 – fyke net, adults captured, marked, and released

8/9-10/99 – visual, numerous fry in backwaters and along stream margins
7/8-9/99 – angling, two adults captured, marked, and released near Station 10
7/8-9/99 – visual, 12 adults and some fry near Station 10
7/8-9/99 – visual, two adults at rock bluff (0.8 km below North Fork)
5/30/99 – fyke net, 32 adults caught about 100 m below North Fork mouth
5/29/99 – angling, three adults caught just below North Fork mouth

6/28/98 – visual, one adult feeding at rock bluff (0.8 km below North Fork)
6/10/98 – visual, no fish seen between North Fork mouth and rock bluff 0.8 km downstream

9/29/97 – minnow traps, seven fry caught near Station 10
8/10/97 – visual, fry in backwaters
6/27/97 – visual, fry numerous at Station 10
6/26/97 – angling, 15 adults marked and released near Station 10
6/25/97 – drift net, fry caught at Station 10, 13-15 mm long
6/25/97 – visual, two adults at rock bluff 0.8 km below North Fork

8/12/96 – visual, fry near rock bluff 0.8 km below North Fork
8/11/96 – visual, fry in shallow eddies at mouth of Mainstem
7/15/96 – angling, seven adults marked and released near Station 10
6/19/96 – visual, one adult near Station 10

Appendix 8 (concluded).

8/14/95 – angling, 11 adults marked and released, rock bluff 0.8 km below North Fork
8/11/95 – visual, fry (about 30) below North Fork
7/20/95 – visual, one adult near rock bluff 0.8 km below North Fork
7/17/95 – angling, two adults near rock bluff 0.8 km below North Fork
6/29/95 – angling, one adult just below North Fork

7/27/94 – visual, two adults just below North Fork