[redacted]

AQUATIC ENVIRONMENTS INCORPORATED

RESULTS OF STUDIES OF THE LONG-TERM EFFECTS OF THE TRANS ALASKA PIPELINE SYSTEM ON FISH AND AQUATIC HABITATS

VOLUME II

Prepared for

ALYESKA PIPELINE SERVICE COMPANY

By

AQUATIC ENVIRONMENTS INCORPORATED

J. DenBeste
P. McCart

April 1984 Anchorage, Alaska

ACKNOWLEDGEMENTS

The authors wish to thank the large number of individuals in industry, government, academia, environmental consulting, and construction who provided their insights into the construction process and the ensuing effects on aquatic resources. While the opinions expressed were diverse and often contradictory, they were invaluable in designing various components of this study.

In particular, we wish to acknowledge the invaluable logistic support of Alyeska Pipeline Service Company personnel, especially Ben Hilliker, Dennis Prendeville, and Ken Durley. Their assistance with a wide range of technical and administrative problems is deeply appreciated.

We wish to thank Tim Hansen, Bill Charney, and Mary Maurer for their assistance under difficult field conditions. Benthic invertebrate analysis was performed by Tim Hansen, Mary Maurer, Bob Saunders, and Dave Mayhood in our Anchorage and Calgary laboratories. Computer expertise was provided by Dr. Gordon Walder of Sigma Biometrics, who also provided liaison with representatives of the Instream Flow Group (Fort Collins, Colorado), developers of the polynomial suitability-of-use function. Water analysis was performed by Chemical and Geological Laboratories of Alaska, Inc.

The authors also wish to thank Dave Asquin, who prepared the graphics for the report, and Chantel Pattenden, Kathy Strong-Duffin, and Francine Kwiecien who contributed extensive efforts in data analysis and manuscript preparation.

TABLE OF CONTENTS

LIST OF TABLES

Table 9 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in Brockman Creek on July 20 and September 13, 1981 and June 6, July 23, and September 13, 1982. Standing crop is transformed as log (x+1).

Table 10 Multiple comparisons of benthic invertebrate standing crop at four stations in Brockman Creek using Newman-Keuls procedure with log (x+1) original counts. Numbers in the table body are the studentized range statistic, q. Values significant at the 0.05 level are indicated by a double asterisk. Only those dates where ANOVA shows an overall significant value (Table 9) are included.

Table 11 Statistical comparison of mean benthic invertebrate standing crop (as number of organisms/m^2) in samples collected from Brockman Creek in July 1981 and 1982, and in September 1981 and 1982. Student's t-test value was calculated from the total counts in each individual sample.

Table 12 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in Snowden Creek from July 25 to 26 and on September 11, 1981, and June 2, 1982. Standing crop is transformed as log (x+1).

Table 13 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in Minnie Creek on July 18 and September 15, 1981, and June 3, 1982. Standing crop is transformed as log (x+1).

Table 14 Multiple comparisons of benthic invertebrate standing crop at four stations in Minnie Creek using Newman-Keuls procedure with log (x+1) original counts. Numbers in the table body are the studentized range statistic, q. Stations joined by lines do not differ significantly. Values significant at the 0.01 level are indicated by a double asterisk. Only those dates where ANOVA shows an overall significant value (Table 13) are included.

Table 15 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in Marion Creek on July 22 and September 18, 1981 and June 4, 1982. Standing crop is transformed as log (x+1).

Table 16 Multiple comparisons of benthic invertebrate standing crop at four stations in Marion Creek using Newman-Keuls procedure with log (x+1) original counts. Numbers in the table body are the studentized range statistic, q. Stations joined by lines do not differ significantly. Values significant at the 0.01 level are indicated by a double asterisk. Only those dates where ANOVA shows an overall significant value (Table 15) are included.

Table 17 Selected turbidity and settleable solids data for sampling sites in the Atigun River receiving runoff from disturbance in Atigun Pass. Turbidity sampling sites are shown on Figures 16 and 17. Turbidity values are presented in Formazin turbidity units (FTU) and settleable solids are presented as mg/L. SH = shaken turbidity; ST = settled turbidity; SF = settleable fraction (ST:SH); SS = settleable solids.

Table 18 Mean total standing crop, taxonomic diversity, mean standing crop of Chironomidae, Shannon-Weaver diversity index, and MacArthur equitability of samples collected by Hess sampler at sampling stations in the Atigun River, 1982. Locations which are significantly higher than the control using Student's t-test are indicated with an asterisk ($P < 0.05$, df=6). Bracketed values are mean chironomid standing crop as a percentage of mean total standing crop. Locations of sampling stations are shown on Figure 16 (Roman numerals).

Table 19 Selected turbidity and settleable solids data for sampling sites in the West Branch North Fork Chandalar River receiving runoff from disturbance in Atigun Pass. Sampling sites are shown on Figures 17 and 19 (capital letters). Turbidity values are presented in Formazin turbidity units (FTU) and settleable solids are presented as mg/L. SH = shaken turbidity; ST = settled turbidity, SF = settleable fraction (ST:SH); SS = settleable solids.

Table 20 Mean total standing crop, mean standing crop of Chironomidae, Shannon-Weaver species diversity index, and MacArthur equitability of samples collected by Hess sampler at sampling stations in the North Fork Chandalar River, 1982. Locations which are significantly lower than the control using Student's t-test are indicated with an asterisk ($P < 0.05$, df=6). Bracketed values are mean chironomid standing crop as a percentage of mean total standing crop. Locations of sampling stations are shown on Figure 19 (Roman numerals).

Table 21 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in North Fork Chandalar River on June 9, July 22, and September 7, 1982. Standing crop is transformed as log (x+1).

Table 22 Multiple comparisons of benthic invertebrate standing crop at four stations in the North Fork Chandalar River using Newman-Keuls procedure with log (x+1) original counts. Numbers in the table body are the studentized range statistic, q. Stations joined by lines do not differ significantly. Values significant at the 0.05 level are indicated by an asterisk. Values significant at the 0.01 level are indicated by a double asterisk. Only those dates where ANOVA shows an overall significant value (Table 21) are included.

Table 23 Streams sampled during fish habitat preference studies including length of study reach and total length of representative 100 m study sections, gradient code, benthic diversity code, and standing crop code. Benthic invertebrate codes based on samples collected in mid July using a Hess sampler. Representative study sections included in descriptions of available habitat are indicated with an asterisk. F = Foothills Stream; M = Mountain Stream.

Table 24 Summary of available habitat characteristics for 15 representative streams (unweighted), for all 27 study stream reaches providing fish habitat data (weighted) and for selected Foothills Streams and Mountain Streams (described by McCart et al. 1972). Measurements were made at typical midsummer discharge levels. Coded variables are described in Volume III, Appendix B, and summarized in Table 5.

Table 25 Summary of habitat features used by juvenile grayling, adult grayling, juvenile Arctic char, and adult round whitefish in 27 stream reaches listed in Table 23. n = number of locations observed. Coded variables are described in Volume III, Appendix A, and summarized in Table 5.

Table 26 Bank weight and bank type as a percentage of available habitat and as a percentage of fish use for juvenile grayling, adult grayling, juvenile Arctic char, and adult round whitefish. Relative Suitability Index (RSI) is the ratio of percent fish use vs. percent of available habitat (brackets).

Table 27 Summary of habitat preference features developed by comparing the percentage of fish using a habitat feature with the percent availability in the study area. For increasing values, those parameters listed as + are positively selected for, and those listed as - are negatively selected for. 0 values indicate no effect. Species codes are: CHAR = Arctic char; GRAY = Arctic grayling; RDWT = round whitefish.

Table 28 Comparison of available habitat sites, with and without fish, based on relative suitability for adult and juvenile grayling using Kruskal-Wallis one way analysis of variance (ANOVA) and Mann-Whitney test statistics.

Table 29 Sorted rotated factor loadings (pattern) for physical habitat availability characters. The factor loading matrix (below) has been rearranged so that the columns appear in decreasing order of variance explained by factors. The rows have been rearranged so that for each successive factor, loadings greater than 0.5000 appear first. Loadings less than 0.2500 have been replaced by zero. VP = sum of squares of the elements of the column of the factor pattern matrix for each factor (Variance Explained).

Table 30 Analysis of variance comparison of physical habitat factors at sites with no juvenile grayling compared to sites with at least one juvenile grayling present and sites with no adult grayling compared to sites with at least one adult grayling present. Acceptance Probability (P)=0.05; df=1 and 225. Asterisk indicates significant difference between means.

Table 38 Summary of fish displaced by habitat modification in seven streams mined for granular material during TAPS construction. Estimate of fish numbers based on average late July densities. Displaced fish codes are: A = adults; J = juveniles; V = various. Species codes are: CHAR = Arctic char; GRAY = Arctic grayling; RDWT = round whitefish. ND = not determined.

Table 39 Summary of habitat modifications in seven streams in the Northern District portion of the TAPS corridor. Each habitat parameter is rated according to the effect of any habitat modification on grayling habitat quality. Only the effect of rip-rap is asses in Brockman Creek; not the effect of instream mining. C = channelized; I = improved; NE = no effect; R = reduced.

1.0 INTRODUCTION

This report describes the results of a three-year study of aquatic habitats and fish populations associated with northern portions of the Trans-Alaska Pipeline System (TAPS). Initiated by Aquatic Environments Incorporated (AEI) in late May 1981, the study was designed to document the present status of fish populations, to examine their response to the pipeline and ancillary facilities, and to identify any positive or negative effects now that the pipeline has been in place and operating for six years.

The objective of the study was to address concerns expressed by the public, regulatory agencies, the owning companies, and Alyeska Pipeline Service Company prior to, during, and since construction of the pipeline. Emphasis was placed on assessing possible long-term changes in fish habitat--particularly that of Arctic grayling, round whitefish, and Arctic char--along the northern portions of the pipeline corridor. Since a high percentage of the documented concerns about the effects of the pipeline on fish populations deal with waterbodies inside the Arctic Circle, studies were concentrated on the waterbodies of the Northern District (north of the Yukon River).

The first two components of the study program, A Review of Existing Information and A General Survey of Selected Streams, were essentially completed in 1981. The third component, Detailed Studies of Representative Streams in the Northern District, was planned as a three-year program, designed to accommodate biological variability over time while ensuring statistical reliability. Results of all three of these study components are presented in this final summary report.

From the outset of these studies, it was apparent that the lack of adequate pre-construction baseline data would limit the extent of comparisons with the pre-construction environment. With this limitation in mind, these studies utilized available baseline data, augmented by a series of spatial controls which were established in relatively undisturbed segments of streams.

Most location references in the text are based on the pipeline mileposts (MP) contained in the Northern District Aerials (Alyeska Pipeline Service Company, undated). Where it was necessary to use haul road milepost (H/R), these are also taken from Northern District Aerials. References to pre-construction aerial photographs are to those of Alyeska Pipeline Service Company (Bellevue, Washington).

At the request of Alyeska Pipeline Service Company, the study was confined to those changes which have occurred as a result of pipeline-related development. As a result, other environmental modifications in the corridor (eg. the haul road, unrelated mining operations, access by the public) are not specifically addressed in this report. In a few instances, however, where it is necessary to isolate the effects of Alyeska Pipeline Service Company facilities from those of other activities and facilities in the corridor, the latter are discussed in the text.

This report is presented in four volumes, of which this is Volume II. The volumes within the set are titled as follows:

Volume I	Overview of Studies of Long-Term Effects of the Trans Alaska Pipeline System on Fish and Aquatic Habitats
Volume II	Results of Studies of Long-Term Effects of the Trans Alaska Pipeline System on Fish and Aquatic Habitats
Volume III	Appendix to Studies of Long-Term Effects of the Trans Alaska Pipeline System on Fish and Aquatic Habitats
Volume IV	Catalog of Streams Associated with the Trans Alaska Pipeline System in the Northern District.

2.0 THE STUDY AREA

The northern portion of TAPS traverses the Brooks Range between Prudhoe Bay and the Yukon River, a distance of 568 km, nearly half of it within mountainous terrain. The pipeline, which roughly follows the course of the Sagavanirktok River, Atigun River, North Fork Chandalar River, Dietrich River, and the Middle Fork Koyukuk River, is buried within the floodplains of each of these streams for considerable distances (Figure 1). In addition, the pipeline crosses over 400 streams, channels, and intermittent watercourses, the majority of which support fish at least seasonally (Johnson and Rockwell 1981, Northwest Alaska Pipeline Company 1982).

McCart et al. (1972) and Craig and McCart (1975) classified streams in this area into three categories based on stream origin and the type of terrain traversed: Mountain Streams, Foothills Streams, and Spring Streams. Mountain Streams originate in the Brooks Range and include all the larger streams within the study area (eg. Sagavanirktok, Atigun, Chandalar, Dietrich, Koyukuk rivers) as well as a number of smaller unnamed tributaries draining the Mountain Physiographic Province. These streams generally have relatively high gradients and tend to become highly braided where valleys are broad and flat. Groundwater from small spring sources is common, and generally forms substantial icings when flow persists through the winter. Surface runoff in Mountain Streams occurs only from late May until early winter and with the exception of frequent freshets, tends to peak in early to mid June.

Foothills Streams generally originate in the Foothills Physiographic Province, both north and south of the Brooks Range. These streams are generally low-gradient single-channel systems fed by surface runoff (eg. Kuparuk and Toolik rivers, Oksrukuyik and Bonanza creeks). Springs are rare in these drainages, but where they do occur, braiding and icing formation in winter usually coincide (eg. Oksrukuyik Creek). Since most of these streams cease to flow in winter, they receive only seasonal use by fish. Beaded pools and small interconnected lakes are common in these systems, the latter often providing the only fish overwintering habitat available.

Spring Streams are spring-fed tributaries of Mountain Streams. This stream type is rare along the pipeline route, in part because every effort was made to avoid these important fall spawning and overwintering sites during route selection. We examined two, the Lupine and Ribdon rivers, during the course of our studies. Both streams are east side tributaries of the Sagavanirktok River, but are located outside of the pipeline corridor. Discharge and water temperatures in these streams are relatively stable near the spring orifices, and, except for brief freshets, tend to remain clear year round.

Table 1 summarizes the known fish distribution in major drainages within the study area. Fish previously identified as Dolly Varden in the Dietrich and Koyukuk rivers are listed as Arctic char (Salvelinus alpinus) based on meristic studies described in this report. Records of chum salmon and pink salmon (Oncorhynchus spp.) from the Saganvirktok River drainage are anomalies and do not appear to represent significant reproducing populations. High-gradient drainages (eg. Atigun, Chandalar, and Dietrich systems) tend to support fewer species than the larger, lower gradient systems (eg. Sagavanirktok and Koyukuk rivers) due in part to their harsh conditions and in part to the scarcity of overwintering habitat.

Early studies by McCart and Pepper (1970), McCart et al. (1972), Yoshihara (1972, 1973a), and Netsch (1975) discuss the sensitive nature of fall spawning and overwintering habitat, and identify many of the most important overwintering habitats. With the exception of the lower portions of the Sagavanirktok, Dietrich, and Koyukuk rivers and a few lakes, the pipeline corridor encounters very few of these sensitive habitats. Most of the more than 400 streams and channels crossed by the pipeline alignment are dry during the winter months. For this reason, this study emphasizes changes in stream habitat and access to streams which fish use during the open water season (May to September) only.

Weather plays a major role in determining many aspects of fish migration, particularly precipitation patterns and the timing of breakup and freezeup. The only weather station of continuous record in the study area is Prudhoe Bay. Unfortunately, its coastal location results in quite different weather patterns from those in mountainous areas and on the South Slope.

In general, precipitation levels were above average during the open water season of 1981, particularly during July and August. Precipitation levels during 1982 and 1983 were considerably below normal resulting in unusually low discharge throughout the study area. Except for 1983, breakup occurred during the last week of May and first week of June on the North Slope and during the last two weeks of May on the South Slope. In 1983, an unusual warm spell caused considerable runoff in early to mid May. This was followed by a protracted cold spell which delayed complete breakup on the North Slope until the second week of June.

Freezeup occurred in the third to fourth week of September in 1981 and 1982, but was generally seven to 10 days earlier in 1983. Abrupt cold weather in early September 1981 caused a precipitous decline in water levels which had remained high all summer. An even more severe cold spell (-10°C) in late August 1983 caused considerable ice formation and loss of flow in both North and South Slope streams. This ice persisted until streams ceased to flow or froze in early to mid September.

3.0 APPROACH AND METHODS

This study consisted of three major components:

1. A Review of Existing Information on the effects of TAPS on aquatic organisms.

2. A General Survey of Selected Streams.

3. Detailed Studies of 12 Representative Streams in the Northern District.

The latter two components make up the field studies of this program.

3.1 Review of Existing Information

During the initial review of existing information, published and unpublished documents detailing the state of pre-construction, construction, and post-construction aquatic environments within the entire pipeline corridor were examined. Information on the effects of the construction and operation of TAPS on fish populations, stream hydrology, and water quality was assessed. The objectives of this review were:

1. To collect relevant historical information on the types of disturbance which have occurred in the vicinity of waterbodies along the TAPS alignment and their effects on fish populations and fish habitat; and

2. To use this information in selecting locations which exemplified typical habitat modifications or ongoing environmental concerns once the pipeline was in operation.

Information for this review was obtained from an examination of Joint Federal/State Fish and Wildlife Advisory Team (JFWAT) files, published reports and manuscripts, the records of Alyeska Pipeline Service Company, the formal literature, and discussions with numerous knowledgeable individuals in government, industry, and academia.

Initially, this review included the entire pipeline, but once it was clear that the majority of concerns centered around the area north of the Yukon River, efforts were concentrated on the Northern District exclusively.

3.2 Field Studies

The following is an abbreviated description of the methods used in these studies. They are presented in more detail in Volume III, Appendices A through D. The methods used for the General Survey of Selected Streams and Detailed Studies of Representative Streams in the Northern District are described in Volume III, Appendices A to C.

3.2.1 General Survey

Based on the initial literature review and discussions with Alyeska Pipeline Service Company personnel familiar with the construction process, 72 streams and stream channels representative of stream habitats, natural and modified, were selected and visited at spring breakup and again either in mid to late July or in early September 1981. Tables 2 and 3 present a summary of the parameters examined and the types of equipment used. Benthic invertebrate samples were collected using several techniques including kick nets, a modified Hess sampler (Hess 1941), Surber nets and artificial substrate baskets. Most of these survey samples were only rough sorted, then total standing crop was determined, and the number of species present estimated. These data were used for comparison of fish food availability in streams where fish habitat preference was studied. A few selected samples were more carefully sorted, and major taxa identified as an aid to selecting sites for detailed studies.

Adult and juvenile fish were collected by seining, electrofishing, or by a combination of these two methods. Fry were captured with a long-handled dip net. Except for a few char, taken from the Dietrich, Koyukuk, and Atigun drainages and retained for taxonomic analysis, all captured fish were measured and released alive. The emphasis of the initial survey was on distribution, timing of migration into tributary streams, species composition, and relative abundance of fish, particularly in streams with some apparent disturbance.

During the General Survey, observations were also made of the type and extent of disturbances in each stream and the effects, if any, of the pipeline and haul road facilities on fish use. Bank and stream substrate stability were assessed visually. Any large-scale habitat modifications (eg. materials sites, stream training structures, bank armor) were examined and in many cases measured. Because our informants had frequently expressed concern over the long-term use of low water crossings (LWC) more than 250 of these crossings were visited during the first summer of study.

3.2.2 Detailed Studies

Based on the General Survey, locations were selected for Detailed Studies. Streams selected for these three-year studies included Oksrukuyik Creek, the Kuparuk River, Falcon Creek, Holden Creek, Trevor Creek, Spike Camp/Sten Creek, the Atigun River (uppermost 18 km), the West Branch North Fork Chandalar River (including Airstrip Creek), Brockman Creek, Snowden Creek, Minnie Creek, and Marion Creek (Figure 1). Initially, Happy Valley Creek was considered a possible study site, but studies there were discontinued when a preliminary analysis revealed no evidence of the persistence of the adverse effects of the 1970 to 1972 fuel spills (Newman and Kernodle 1975). The type of disturbance observed in each of the streams selected for Detailed Studies, and the studies conducted in response to each type, are summarized in Table 4.

Detailed benthic invertebrate studies were conducted in Oksrukuyik Creek, the Kuparuk River, Falcon Creek, the Atigun River mainstem, the North Fork Chandalar River, Airstrip Creek, Brockman Creek, Snowden Creek, Minnie Creek, and Marion Creek. Except for the Atigun and North Fork Chandalar rivers, a modified Hess sampler (Hess 1941) was used to collect four samples along each of four transects. In order to distinguish the effects of the haul road from those of the pipeline, one sampling transect was located at a station above the haul road, a second was located at a station between the haul road and pipeline, and two were located at stations below the pipeline.

The Atigun River was sampled primarily to determine the effects of the 1979 crude oil spill (DenBeste and McCart, In Prep), and of heavy sediment introductions from Atigun Pass. A control transect was located at a sampling site above both these areas of disturbance, and study transects were established at nine sampling sites downstream. Similarly, five sampling sites (one control and four downstream) were established in the North Fork Chandalar River to assess the effects of sediment in runoff from Atigun Pass.

Fish studies concentrated on investigating the specific concerns identified in each stream selected for Detailed Studies. In locations where fish entrapment was reported in the vicinity of instream disturbances (eg. Holden Creek, Trevor Creek, the Atigun

---

[1] Unless otherwise indicated, the West Branch North Fork Chandalar River will be referred to simply as the North Fork Chandalar River.

River, Spike Camp Creek, and the North Fork Chandalar River), studies concentrated on seasonal movement patterns, stream discharge configurations and emigration patterns. The numbers and sizes of fish trapped by discontinuous flow or isolated in pools were documented, as were any natural strandings in undisturbed areas. In streams subject to heavy sedimentation resulting from surface disturbances (eg. the Atigun and North Fork Chandalar rivers), data were obtained which described seasonal movement patterns, species composition, distribution, and density of fish, and the distribution of spawning adults, eggs, alevins, and emergent fry.

The effects of habitat modification as a result of instream activity were examined by determining fish densities in disturbed and control areas. Pre-measured sections of streams, generally 100 m in length, were blocked off with seines, and fish were captured using a Smith-Root Type VII backpack electrofisher. The Delury method (Ricker 1975) was used to estimate population size for each species. This technique proved effective in small streams with conductivities greater than 50 µmhos, a category which included most of our study streams. In larger streams or where conductivities were less than 50 µmhos, continuous seining proved most effective in establishing density estimates. Other portions of both control and disturbed habitat were sampled on each sampling date to ensure that the 100 m test sections were representative of adjacent areas.

In conjunction with fish density studies, measurements were made of the physical characteristics of representative sections of both disturbed and control areas. A list of the parameters measured and sampling techniques used is presented in Volume III, Appendix B. The resultant data provide a quantitative definition of the types of changes to fish habitat which occurred as a result of instream mining, stream training, bank armoring at overhead crossings, and natural scouring.

In addition to describing the physical changes at disturbed sites, an assessment was made of the habitat requirements of the most abundant species--Arctic grayling, round whitefish, and Arctic char. Individual fish were observed and the area of stream habitat which they utilized was determined. Many sites were visited on several occasions to ensure that the area used was accurately defined. The fish present were then captured and measured to the nearest mm, fork length. Physical measurements were made of 42 parameters which described the area of utilization. Since this technique relies both on visual observations and on capture, it allows for more precise habitat definition than techniques based on capture alone. Volume III, Appendix A, presents a detailed description of the parameters measured and the classification system used to describe various habitat characteristics.

Since most of the study area is used primarily for summer feeding and rearing, emphasis was placed on describing the habitat used for these activities. Most measurements were made during the period from midsummer to early fall. Migrating fish, spawning fish, and any fish which might be in a location for a reason other than feeding (eg. below a barrier) were excluded from the analysis. Observations were generally not possible in turbidity levels higher than 100 FTU and most were made during periods when waters were relatively clear (ie. <20 FTU). Data describing the habitat requirements of fish were obtained from a total of 27 stream reaches, representing the entire range of stream habitat features available within the study area.

Accurate definition of fish habitat preference requires a comparison between the habitats actually used by fish and the total available habitat. Total available habitat was measured in representative sections of 15 streams using the physical characteristics described in Volume III, Appendix B. Representative 100 m stream sections were divided into either five or 10 equally spaced transects, depending on a visual appraisal of the homogeneity of habitat characteristics. Transects were placed perpendicular to the stream flow and a series of three sampling points marked in each transect representative of the typical depth, velocity, and substrate type in each third of the channel. This provided a total of either 15 or 30 data points depending on the number of transects, for each 100 m section.

There were two or more 100 m study sections in each of the 15 streams, depending on the variability in habitats present. Data describing each 100 m section were weighted during analysis according to the number of metres of stream length with similar habitat in the study streams. The density of fish was determined for 10 or 20 m subsections, centered on the transects, using visual observations, seine net barriers, and the electrofisher as described above for the 100 m sections in disturbed streams.

Frequently, locations were examined which supported no fish, but appeared to have habitat characteristics similar to those of sites where fish did occur. Many of these sites were measured for the same parameters measured at sites supporting fish, as described in Volume III, Appendix A. Statistical comparisons were then made of the physical characteristics of locations supporting fish and locations supporting no fish.

3.3 Statistical Analysis

The statistical methodology is described in Volume III, Appendix D. Further information on the content and structure of the various Biomedical Data Programs (BMDP) referred to in Appendix D, can be obtained from BMDP Biomedical Computer Programs P-series (University of California Press 1977).

Analysis of fish habitat data involved four main steps:

1. Detailed histograms of fish habitat characteristics and available physical habitat characteristics were developed using a packaged computer program (BMDP).

2. The locations preferred by fish and the total available habitat were compared by simple division of the means for each habitat characteristic.

3. A weighted suitability-of-use polynomial function was developed for selected habitat characteristics (Voos 1981).

4. A factor analysis (Harman 1976) was performed on selected habitat characteristics and the resultant factors were then used in a multiple regression, along with a habitat suitability index derived from the polynomial function, to develop a formula for predicting fish density.

This analysis was performed first, for all study locations and second, for only those locations which supported at least one fish. Due to the large number of unused habitats, the latter analysis proved most effective in determining preference. For fish species for which data were available for less than 100 locations (eg. Arctic char and round whitefish) only steps 1 and 2 were completed, because sample sizes of less than 100 observations are generally inadequate for completion of suitability-of-use functions or factor analysis (Bovee and Cochnauer 1977). Thus, steps 3 and 4 were completed only for Arctic grayling.

Weighted suitability-of-use polynomial functions were developed separately for grayling adults ($\geq$ 180 mm fork length) and for grayling juveniles ($\leq$ 220 mm fork length). Data describing depth, velocity, and substrate composition for 100 m disturbed areas and nearby undisturbed control areas were then entered into each of the polynomial functions. The resultant weighted suitability-of-use index was compared with the actual number of fish present in these study sections. In several locations, the number of fish found in disturbed areas was lower than in control areas. The suitability-of-use index, in conjunction with other habitat comparisons (eg. bank height, bank vegetation, etc.) was used to determine whether these reduced fish densities were the result of habitat modification or the result of factors unrelated to habitat (eg. migratory patterns or barriers to migration).

Because a large number of apparently suitable habitats were unoccupied, the factor analysis invariably predicted much higher fish densities, even in disturbed areas, than were actually observed. The density prediction developed from factor analysis thus displayed little predictive value for individual habitats. It was useful in determining which habitat features were most important to juvenile and adult grayling and in establishing the maximum number of fish a stream could support.

Since no fish were killed during these studies, state of maturity could not be determined with certainty. Fork length was used to separate "juvenile-sized" fish from "adult-sized" fish. Considering the difference in size at first spawning of male and female fish and the difference in size between fish in Mountain Streams and Foothills Streams, it was necessary to build in an overlap in fish size. Fish were classified as follows:

Species and Life History Stage	Size
Grayling and Arctic char fry	<75 mm
Grayling and Arctic char juveniles	75 to 220 mm
Grayling and Arctic char adults	>180 mm
Round whitefish juveniles	to 220 mm
Round whitefish adults	>220 mm

Many of the habitat features described in this text are coded variables described in detail in Volume III, Appendix A and B, and summarized in Table 5. Depth at fish collection point and velocity at mean depth were not coded. Substrate, as referred to in this text, is a weighted substrate code derived by multiplying the percent composition of each particle size (Table 5) by its corresponding substrate code. The sum of all 10 substrate classes is divided by 100 to arrive at the weighted substrate code. Cover parameters were coded as absent (0) or present (1). The mean of all cover calculations can thus be read as the percentage of sites with a particular cover feature present (eg. Mean = 0.375 bank vegetation indicates that 37.5% of habitats have bank vegetation).

4.0 OVERVIEW

Our review of the published and unpublished information on the effects of TAPS on aquatic organisms, along with discussions with more than 100 individuals associated with management, construction, operation, regulatory control, and research in the pipeline corridor indicated that the greatest concerns for fish populations were:

1. Habitat Modification
2. Blockage of Migration
3. Crude Oil Spills
4. Entrapment
5. Thermal Irregularities
6. Public Access

Other concerns such as sedimentation, hydraulic instability, altered water quality, and direct mortality were common problems during construction, but generally pose few problems now that construction is complete and the pipeline in operation. In the following sections, we discuss those aspects of TAPS facilities which have caused the concerns listed above. The only major crude oil spill to date, the Atigun River spill, is discussed in detail in a separate report (DenBeste and McCart, In Prep) and is not considered here.

4.1 Materials Sites

Materials sites (MS) are locations where granular borrow material has been mined to provide for construction and maintenance requirements. Many materials sites were located within the wetted floodplains of watercourses, rather than from upland sites, in an apparent attempt to avoid damage to aesthetic values and to terrestrial wildlife habitat. By the time construction of TAPS and the haul road was completed, a total of 49 million m^3 of granular borrow had been removed from more than 280 upland and floodplain sites (Michael Baker Inc. 1977).

In addition to an initial requirement for 31,000 m^3/km used during the construction of the haul road and workpad, the haul road has required 700 m^3/km for maintenance during its first five years of operation. During the same period, Alyeska Pipeline Service Company required an additional 1.5 million m^3 for maintenance of the workpad and facilities sites (Woodward Clyde Consultants 1980a). The use of floodplain sites has received extensive criticism (Northern Engineering Services Ltd. and Aquatic Environments 1975; Burga and Swenson 1977; Woodward Clyde Consultants 1980a, 1980b) and recent granular materials requirements have been derived exclusively from outside of wetted floodplains.

Woodward Clyde Consultants (1980a, 1980b) documented the effect of instream mining in several large streams in the study area including the Sagavanirktok, Dietrich, and Middle Fork Koyukuk rivers. They documented the following types of changes:

1. Increased braiding;
2. Increased backwater;
3. Increased ponding;
4. Reduced substrate compaction;
5. Reduced instream cover; and
6. Increased fish habitat diversity.

In these large streams, there was no loss of bank cover as a result of instream mining at materials sites. Increases in the areas of backwaters and ponds were generally associated with sediment deposition. While these observations were primarily subjective, they were supported to some extent by physical measurements.

Where pits adjacent to floodplains were excavated to depths greater than 1 m, new habitat was sometimes created and pits in the Dietrich River drainage and Prospect Creek were found to support considerable numbers of fish during summer. Woodward Clyde Consultants

(1980a) add that excavation of these inundated pits to depths greater than 2.5 m may be an effective means of creating overwintering habitat.

Modification of stream configuration as a result of instream mining had several effects on fish (Woodward Clyde Consultants 1980a):

1. Density changes (both increases and decreases);
2. Altered species composition; and
3. Increased stranding.

In addition, overwintering habitat was created at one location (MS-106-2) in the Dietrich River.

Woodward Clyde Consultants report minor changes in benthic invertebrate communities in mined areas. Standing crops of Chironomidae (midges) were reduced in seven of eight, and Cinygmula (a mayfly) in five of eight materials sites examined. Inundated pits supported a benthic fauna typical of lake habitats. Some of these pits have become important summer feeding habitats for grayling.

Elliott (1982) examined mined areas in streams tributary to the Atigun River and reported the following:

1. Reduced fish densities;
2. Altered species composition;
3. Altered population structure; and
4. Increased entrapment as a result of discontinuous flow.

Elliott also reported significant alterations in fish habitat, but did not quantify these alterations with physical measurements. Since the same alterations were examined in detail during our studies, Elliott's observations will be referred to in those sections of this report dealing with specific streams.

4.2 Haul Road

Problems which have occurred along the North Slop Haul Road include the frequent failure of culverts and bridges, impassible culverts, and loss of fish habitat, largely the result of the speed with which the road was designed and built (Morehouse et al. 1978, Wright 1978). While there are continuing problems with culvert installations along the haul road, the State of Alaska Department of Transportation has embarked on a program to replace the most troublesome culverts with bridges. During the summers of 1982 and 1983, new bridges were installed on Marion Creek, Gold Creek, Nutirwik Creek, North Fork Chandalar River, Spike Camp Creek, Trevor Creek, Roche Montonnee Creek, Holden Creek, and Dan Creek. About 18 additional locations are scheduled for bridge installation over the next two or three summers. These installations should alleviate most fish passage problems.

4.3 Low Water Crossings

In contrast to the haul road, most workpad crossings of small streams rely on low water crossings (LWC) rather than culverts to provide for vehicular traffic. LWC's avoided the problems of icing and of velocities exceeding the swimming capabilities of fish, but were criticized for creating barriers to fish migration (Gustafson 1977, Rockwell 1978). From a review of JFWAT field surveillance reports for the construction period, it is apparent that these structures were inadequate to handle heavy construction traffic without causing sedimentation, rutting through the streams, deposition of cobble material below the LWC, blockage of fish passage, and habitat modification. With the reduction in traffic following the completion of construction, most observers agree that problems associated with LWC's have declined substantially. At the completion of construction, there were in total, 170 LWC's in fish-bearing streams within the TAPS corridor, 115 of these in the Northern District (Anctil et al. 1978).

4.4 Stream Sedimentation

While sedimentation was considered a serious problem during the construction period (Morehouse et al. 1978), most observers now agree that except for extreme freshets, the pipeline and haul road are contributing little to the total sediment load of streams within the corridor. An exception to this occurs at Atigun Pass, where runoff from disturbances on the workpad and haul road have resulted in heavy sediment introductions into the headwaters of both the Atigun River and the North Fork Chandalar River. Small settling ponds were constructed in Pipeline Branch on the Chandalar Shelf side of Atigun Pass in an attempt to reduce the amount of settleable solids reaching the North Fork Chandalar River. Dr. Larry O'Nesty (Indiana University, Department of Geography) has been studying sediment transport in the vicinity of Atigun Pass for several years, but has not, as yet, released the results of these studies.

Considerable sediment deposition in materials sites within major rivers was observed by Woodward Clyde Consultants (1980a). Locations in the Sagavanirktok, Dietrich, and Middle Fork Koyukuk rivers reportedly collected sediments in ponded areas, backwaters, and shallow depressions left after site abandonment.

There appears to be no specific documentation of adverse effects on fish resulting from sedimentation during the construction period. Most observations are limited to vague references to "siltation", "turbid water", or "sedimentation" without supporting quantitative information describing concentrations of sediments or effects on benthic invertebrates or fish.

4.5 Fish Habitat Modification

It is apparent that most observers recording non-conformances during the construction period considered all instream activity resulting in modification to the natural environment to be detrimental (eg. Anctil et al. 1978). Some recent research, including our own, suggests that this is not always true. For example, excavation of MS-106-2 created new overwintering habitat when groundwater appeared in the newly excavated pit (Woodward Clyde Consultants 1980a). Several "overmined" areas in floodplain materials sites have become flooded, creating considerable new summer feeding habitat (eg. Prospect Creek, Jim River, Dietrich River).

Anctil et al. (1978) list impacted areas at Sagavanirktok River materials sites at 2,238 ha (5,530.5 acres) or "...66.9% of total lost aquatic habitat along the pipeline route..." and indicate an "...estimated aquatic habitat loss [for the Northern District] of 118,887 ft." These figures, which presumably refer to length of streambed, would be more accurate if they referred to habitat as "modified" rather than "lost". It is apparent that bank armor, stream training structures, culvert plunge pools, and even LWC's have positive as well as negative effects on fish habitat. Alyeska personnel report, for instance, that grayling are often observed spawning on the uniform cobble of LWC's (pers. comm. Ken Durley, Alyeska Pipeline Service Company).

4.6 Fish Entrapment

As stream discharges decline, fish are entrapped by any barrier which prevents their movement out of streams. Entrapment has been reported at culverts where the upstream end has been installed above grade, at LWC's which french drain through loose gravel, and in disturbed areas where there is discontinuous flow. Isolation of fish in shallow depressions, both natural and man-made, can also result in stranding and, eventually, mortality.

Discontinuous flow and stranding in shallow depressions have both been reported in areas where there has been extensive instream activity, particularly instream mining (Woodward Clyde

Consultants 1980a, Elliott 1982). In JFWAT field reports, there are contain frequent references to the stranding of small numbers of fish, primarily grayling fry, in shallow pits left in disturbed areas during construction.

Elliott (1982) documents several fish strandings in the vicinity of materials sites in tributaries to the Atigun River and in the North Fork Chandalar River. These strandings are caused by discontinuous stream flow, and fish migrating downstream to overwintering areas in the fall are unable to escape these streams. In one instance, an estimated 5,000 grayling were observed trapped in two pools above MS-109-3 (expansion 4) in the North Fork Chandalar River (J. Glaspell, Alaska Department of Fish and Game, as reported by Elliott 1982). Of these, an estimated 1,650 grayling were transported (on September 5, 1979) by Alaska Department of Fish and Game (ADF & G) personnel to a new location downstream of the dewatered reach. Other entrapments have been reported in Saganavirktok tributaries, Atigun tributaries, and in the Middle Fork Koyukuk River.

While some observers have suggested that materials site excavations in alluvial fans cause streams to "leak" (pers. comm. J. Rockwell, Office of Special Projects, Bureau of Land Management), this has not been clearly demonstrated to be the case in any of the locations where discontinuous flow has been observed. Discontinuous flow in alluvial fans is a common phenomenon as noted by Elliott (1982), and fish entrapment in isolated pools and in areas of discontinuous flow appears to be a common event in Arctic Mountain Streams whether they have been used as materials sites or not (Table 6).

Elliott (1982) describes another type of entrapment which he suggests results when the thaw bulb of the pipeline captures all remaining surface flow for a short distance. He reports that this occurred in the upper Atigun River upstream of Atigun Camp (MP163.4 to MP162.2) in the fall of 1981. Emigrating fish, primarily grayling, were unable to pass the dewatered stream section. A rescue operation was undertaken to transplant 57 grayling, one Arctic char, and one round whitefish to a location downstream of the discontinuous flow. Elliott adds that "...artificial elevation of the water temperature [by the buried pipe] may have delayed the timely downstream emigration of fish to overwintering areas."

4.7 Thermal Irregularities

Since oil flow began in 1977, various observers have reported heated water emerging over the pipeline trench in areas where the pipeline is buried for long distances. These thermal irregularities apparently occur when intergravel water flows parallel to the uninsulated pipe for some distance, then re-emerges as a plume of warm water. These sites are most obvious during fall and early winter when surface flow declines.

Representatives of ADF & G, Habitat Protection Section, located a relatively large number of these sites in the Atigun, North Fork Chandalar, Dietrich and Koyukuk rivers. The site of a thermal irregularity can often be identified by the presence of considerable quantities of green periphyton (attached green algae) in the heated channel. One location documented by ADF & G personnel was flowing at 33.3°C in the Middle Fork Koyukuk River on March 3, 1982 (Department of Natural Resources 1982).

Temperatures up to 11.0°C were documented at the head of two isolated pools in the Atigun River (MP162.0) on October 7, 1981 (Department of Natural Resources 1982). These two pools contained an estimated 30 to 45 grayling apparently attracted by the warm water while the pools were still accessible. A total of 27 grayling and two round whitefish were found frozen under the ice by the same researchers on March 17, 1982.

While the problem of thermal irregularities has received little detailed study to date, it appears that a combination of pool habitat and heated water does attract some emigrating fish which remain until flows in adjacent stream channels have ceased. The fish are then unable to escape, and may die if the pool freezes to the bottom or becomes anoxic later in winter.

4.8 Stream Crossings

Pipeline stream crossings appear to be causing few problems now that construction is complete. The timing of most instream construction followed pre-designated timing windows developed by JFWAT to avoid sensitive spawning, overwintering, and migrating fish (JFWAT 1975). Since the majority of stream crossings in the Northern District are overhead, they result in little or no instream disturbance. Extensive sections of buried pipe within the floodplain of large streams were installed in winter months when channels were dry or frozen to bottom. In most instances, major overwintering areas were avoided by the final routing. Areas of inherent hydraulic instability were heavily armored with rip-rap to reduce maintenance and prevent serious erosion. Stream training structures comprised of heavy rip-rap were used extensively to protect shallow buried sections of pipe within the floodplain of major streams. These structures have minimized the amount of instream activity required to maintain the shallow buried sections and, in some instances, may create additional aquatic habitat.

5.0 GENERAL SURVEY OF SELECTED STREAMS

During the initial phase of the 1981 field studies, 72 streams and channels were examined between the Yukon River and Prudhoe Bay. Each location was visited twice, once during breakup (May 29 to June 15) and again during a low flow period (either July 10 to August 6, or September 3 to 19). On each occasion, data describing water quality and the physical characteristics of the sites were recorded. These data are presented in Volume IV (Stream Catalog). In addition, more than 250 LWC's were repeatedly visited over the course of the three-year study, and, during periods of low stream discharge, surveys were conducted to locate stranded fish and thermal irregularities over the buried pipeline. Many problem areas identified during our own General Survey and by previous researchers were re-visited during the three-year field study, and an effort was made to visit areas of unstable terrain under a variety of stream discharge conditions. The following is a brief discussion of the observations made during the survey, which formed the basis for the selection of locations for Detailed Studies.

5.1 Stream Crossings

Both elevated and buried stream crossings appear stable and well protected by large rip-rap where necessary. Except in areas of inherent instability, few erosion problems were observed at pipeline crossings. Routine maintenance is apparently adequate to prevent serious erosion in all but the most difficult areas. The only location where erosion appears to repeatedly threaten the pipeline is at Atigun Pass. There, erosion caused by freshets exposed the buried pipeline at least twice during the course of this study. In both cases the exposure was on Pipeline Branch (MP167.0) above the North Fork Chandalar River settling ponds. During midsummer freshets, relatively high turbidity and settleable solids values were recorded from headwater tributaries of both the North Fork Chandalar and Atigun rivers draining Atigun Pass. Concern over the effect of these sediments on the downstream drainages, along with other concerns, led to the selection of the upper reaches of both the North Fork Chandalar and Atigun drainages as Detailed Study Streams. Results of studies in both locations are discussed in Section 6.2.

In addition to the large-scale erosion at Atigun Pass, there were a few instances of minor erosion at stream crossings. At breakup in 1981, as a result of erosion from the workpad, Dan Creek (MP85.0) and Snowden Creek (MP198.5) received minor sedimentation and deposition of fill material downstream of the workpad. Both locations were noted by the Office of Special Projects (Bureau of Land Management 1981) in their annual post-breakup inspection report. An unusually severe breakup in Snowden Creek apparently caused a minor shift in stream alignment in Snowden Creek resulting in the workpad erosion.

The problem in Dan Creek is of a more persistent nature. An icing builds up in front of the workpad bridge during winter and blocks the main stream channel. During May 1981, the rapidly peaking breakup waters broke through the workpad 30 m from the original stream channel and flooded over the tundra for 200 m before returning to the original channel. By June 7, the stream was draining through tundra vegetation and over a 1 m high embankment making fish passage impossible. Downstream of the disturbance, grayling eggs were abundant (>35 eggs/m^2), but no eggs were found upstream of the disturbance.

It is probable that in the spring of 1981, only a few grayling were able to negotiate this washout to spawn in the upper portions of Dan Creek. Some fish may have come downstream from lakes in the headwaters, but the overwintering potential of these lakes has not been assessed. In mid June 1981, the stream returned to its natural course when the ice under the bridge broke up. In 1982, the problem was avoided by installing heat tracing wire under the repaired workpad bridge. When attached to a temporary power source, this wire melts holes through the ice, a technique which accelerates thawing. In 1983, though a heat tracing wire was again in place, it was not used because an unexpected and unusually rapid breakup washed out the workpad a second time in the same location.

Unlike 1981, there was no serious blockage to fish migration at the workpad bridge in 1983 because the bridge icing thawed quickly allowing the stream to return to its natural channel within 48 hours. There was, however, a blockage (the result of improper bridge location), at the haul road bridge further upstream and, by June 10, 1983, an estimated 5,000 grayling had congregated in a single pool under and immediately downstream of the bridge. Although anglers took a heavy toll, it appears the majority of these fish did eventually pass the barrier to spawn successfully. By mid July 1983, grayling fry were abundant and uniformly distributed in Dan Creek.

In early July 1983, a natural slump in the headwaters of an unnamed stream at MP176.7 appeared to be responsible for the complete burial of the stream under an elevated section of pipe and the consequent destruction of nearly 200 m of armored stream channel. During a freshet, mud from this slide was carried along the pipeline to MP177.2, and the culvert at MP176.7 was completely filled with mud and rock. This area is high in groundwater content, as evidenced by an annual winter icing which forms under the pipeline. The mud flow appears to have resulted from this naturally unstable condition, and was not the result of pipeline facilities.

Minor erosion at stream crossings was apparent at several locations during freshets, but in all instances except those previously noted, turbidity levels (Volume IV, Stream Catalog) were not significantly different above and below pipeline crossings (mean above = 32 FTU; mean below = 31 FTU; t = 0.015; df = 60). Considerable scour was noted along buried sections of the pipeline in the Sagavanirktok, Atigun, North Fork Chandalar, and Dietrich rivers, but undisturbed channels generally displayed similar high scour levels. Similarly, turbidity levels in all four rivers were relatively high, particularly during freshets. Visual observations in the field and an inspection of turbidity data indicated that there was no consistent difference in turbidity values for scoured channels over the buried pipeline compared with adjacent undisturbed channels. At no locations within the study area did the pipeline itself pose a significant barrier to fish movements.

5.2 Low Water Crossings

Over 250 LWC's were examined during the course of these investigations. At present, LWC's do not appear to pose a serious problem to migrating fish, though these structures, typically composed of a shallow ford with a cobble base, were highly criticized during the construction period as inadequate to handle heavy construction traffic (Section 4.3). LWC's are now being used only occasionally for inspection and maintenance. While we saw some evidence of minor rutting both within streambeds and along streambanks, and some cobble accumulation on the downstream side of these crossings, Alyeska personnel were able to easily control these problems using hand shovels. Normally, LWC's do not present any problem to migrating fish, and, in nearly all instances where stream flows declined to the point where fish passage through an LWC was in question, numerous natural barriers were already present in undisturbed sections of stream. A few examples of difficult passage were, however, observed.

Some blockage of fish movement was observed at Union Creek (MP224.2) due to rutting across the LWC. In mid July 1982, grayling juveniles (n=8), round whitefish (n=2), and numerous slimy sculpins were unable to move downstream as stream discharge declined. Fish had accumulated in a small pool above the crossing, but were able to escape following a freshet on July 31. The LWC was subsequently repaired by Alyeska personnel and no further problems were observed.

A similar problem in Wood Creek (access MS-129-1) resulted in the entrapment of at least one burbot and numerous grayling fry. Problems at this location and at a similar location in a Sagavanirktok side channel at APL-135-1 (MP18.0) prompted Alyeska to install a combination cement block LWC and low flow culvert. The design is similar to one proposed by Gustafson (1977), which relies on a culvert to handle low flow fish passage, and on a lined LWC to handle overflow during higher discharge periods. The cement blocks prevent degradation of the LWC by vehicular traffic. The newly installed crossings at both Wood Creek and the Sagavanirktok side channel were visited during early September 1983 and were found to be functioning well at low flows. If these crossing designs prove durable at all discharge levels, they may provide an effective replacement for LWC's in other high traffic areas where rutting and LWC failure tend to recur. Overall, however, such problems appear to be rare and it is probable that the new LWC design will be required in only a few locations.

The foregoing was a discussion of fish passage at LWC's; habitat modification associated with these crossings is presented in the following section (Section 5.3).

5.3 Fish Habitat Modification

In general, the most serious and widespread fish habitat modification on the pipeline route has resulted from the instream mining of granular material at materials sites. Instream mining involves the removal of natural streambanks and their associated vegetation, modification of stream configuration and profile, stream channelization, and, in some cases, modification of basic habitat features (eg. depth, velocity, substrate composition, cover). Because of the high gravel requirements of both the haul road and the workpad, a large number of materials sites were required on the floodplains of the Northern District. Since Woodward Clyde Consultants (1980a) have previously examined the effects of materials sites in three larger streams, the Sagavanirktok, Dietrich, and Middle Fork Koyukuk rivers (Section 4.1), as well as locations outside the TAPS corridor, our observations were concentrated on materials sites in the smaller tributary streams.

Initial sampling in tributaries of the Atigun River, the Dietrich River, and the North Fork Chandalar drainage, indicated that fish densities were generally lower in mined areas than in adjacent undisturbed (control) areas. In addition, in two Atigun tributaries, Trevor and Holden creeks, fish tended to be smaller in the channelized materials sites than in adjacent waters. Elliott (1982) reported similar results in studies conducted during 1979 and 1980.

In several streams, our electrofishing results suggested that fish densities in undisturbed areas were two to five times higher than in mined locations. This effect was most apparent in Falcon, Holden, Trevor, Airstrip (a tributary of the North Fork Chandalar River), Snowden, Disaster, and Brockman creeks, as well as in several unnamed tributaries of the Dietrich River. In locations where instream mining involved only surface scraping and not channelization (eg. Atigun, North Fork Chandalar, and Dietrich river mainstem sites), no apparent differences in fish densities were found. In all cases, the most common species present was Arctic grayling. Round whitefish were also present in all mined streams examined except the North Fork Chandalar River drainage. Slimy sculpin were present in all streams but, due to the difficulty in determining even relative numbers of this species, densities were not evaluated. Because of the apparent differences in habitat, fish density, and fish size in several of these materials sites, Detailed Studies were conducted in Falcon, Holden, Trevor, Airstrip, Brockman, and Snowden creeks and the North Fork Chandalar River.

Other types of habitat modification resulted from the construction of river training structures (eg. spur dykes) and linear facilities (eg. haul road, workpad, access roads, and the pipeline). Except for a few locations where the pipeline parallels or overlaps a stream channel (eg. Union Creek, Wood Creek, Tyler Creek, Sagavanirktok River side channels), the majority of stream crossings, including workpad crossings, are at a right angle to streams. The resulting habitat modifications at stream crossings are thus relatively minor, representing only a small percent of total available habitat. Generally, elevated crossings result in less habitat modification than buried crossings. There are two reasons for this: first, elevated crossings usually do not require excavation of the stream channel; second, elevated crossings usually leave the original banks intact, and require less bank armor and rip-rap to ensure stability.

At pipeline crossings, both buried and elevated, LWC's on the workpad, rather than the pipeline itself, appear to have caused the greatest amount of habitat modification. The placement of cobble instream to support right-of-way traffic, combined with a tendency for the stream channel to widen in the vicinity of LWC's, particularly in Foothills Streams, has resulted in localized changes in fish habitat. These disturbances seldom exceed 20 m x 30 m in area.

Such habitat modification is not necessarily detrimental. Of nearly 75 LWC's examined in June of 1981, 18 were found to contain grayling eggs on or immediately adjacent to the LWC (based on kick net sampling). Since Alyeska maintains a ban on vehicular traffic on the workpad during late May and June, with the intent of preventing rutting, it is likely that many of these eggs successfully hatch. Also, during periods of moderate stream discharge, the low-velocity pool habitat at many LWC's supports a disproportionately large number of grayling, particularly juveniles. The apparent attraction of fish to these sites is probably due to the reduced velocity and the tendency of LWC's to form shallow pools.

While culverts through the workpad and under access roads generally reduced habitat quality, there were a few locations where fish used the interior of these structures as cover.

Spur dykes used as stream training structures in the Dietrich and Middle Fork Koyukuk rivers caused substantial habitat modification. In many cases, small stream channels were blocked off or diverted from their original locations. While we could find little evidence that this posed any problem in the turbid, highly braided mainstem, clear side channels and tributaries were an exception. Various JFWAT reports, Johnson and Rockwell (1981) and Elliott (1982), as well as numerous unpublished manuscripts, document the value of such channels as spawning and rearing habitat for grayling, round whitefish and char (eg. Equisetum Creek, Texas Slough, Rosie Creek tributaries). These channels also provide access to several lakes supporting substantial fish populations (eg. Dunder's Dribble).

Undoubtedly, channel diversions in the lower reaches of these streams have adversely affected the amount of habitat available for spawning adult and rearing juvenile fish. In the absence of any pre-construction information for these streams, however, it is difficult to quantify the effects of this habitat modification. During

1981, spawning grayling and newly emergent grayling and round whitefish fry were abundant in these channels, suggesting that reproductive success remains high. Similarly, migration routes through disturbed areas appeared to be generally unrestricted. In the immediate vicinity of several spur dykes, there are groundwater sources which may be of minor importance to overwintering fish. The importance of this groundwater to fish habitat has not been clearly established, however, and it is not known whether it has been adversely affected by the presence of the dykes.

In a few side channels of the Dietrich and Middle Fork Koyukuk rivers, there are fewer fish in the vicinity of stream training structures and channel modifications (Elliott 1982). Elliott (1982) suggests that channel modifications in Jackson Slough, a complex side channel of the Middle Fork Koyukuk River, may have reduced fish densities as a result, first, of the diversion of silt-laden water into what was formerly a clear channel, and second, the channelization of portions of the slough. A similar diversion of silt-laden water into a clear channel was reported at Texas Slough, also a side channel of the Middle Fork Koyukuk, but Elliott observed no comparable reduction in fish densities. Elliott's density comparisons are, however, of doubtful accuracy and inconclusive.

During our studies, these locations, and several similar locations in the Dietrich River, were sampled frequently, but we were unable to establish adequate controls against which to gauge the extent of any reductions in fish density. While it is apparent that channel modification had eliminated a small amount of habitat, the number of fish displaced could not be reliably quantified. In the absence of precise pre-construction baseline data for these small channels, we can only conclude that some minor losses may have occurred.

While it was not part of our Terms of Reference to study haul road facilities, it was necessary to examine haul road stream crossings to assess the effect of any fish blockages on fish distribution and densities within our study reaches. In numerous locations, culvert plunge pools supported disproportionately large numbers of grayling and round whitefish. Occasionally this was due to fish stacking up below an as yet impassible barrier. More commonly, however, fish were attracted by the greater than average depths and low velocities offered by these pools. In many instances, the culvert plunge pool provided the largest and highest quality fish habitat available in the entire accessible reaches of streams. This phenomenon was most common in high-gradient Mountain Streams where the availability of pool habitat is low.

5.4 Entrapment and Stranding

Large numbers of fish strandings have been reported during both the construction and operation of the pipeline (Section 4.6). Because of the apparent importance of this problem, we made a special effort to document evidences of entrapment. The entrapment of fish appears to be widespread, especially during the dry conditions which prevailed in 1982 and 1983, when the combined effects of low water levels, discontinuous flow, pool isolation, and numerous migration barriers resulted in the stranding of fish in numerous streams. Many of these fish died when the pools in which they were trapped were dewatered.

Stranding of fish appears to be a widespread phenomenon in the Arctic and one to which fish populations are well adapted. Most of the fish lost are young-of-the-year or juveniles. Such fish are most likely to be present in susceptible habitats--in small streams, side channels, or shallow, standing water.

In 1981, water levels were high, and fish stranding was generally rare. In midsummer, small numbers of grayling fry were observed in isolated pools in the Lupine, Sagavanirktok, Atigun, Dietrich, and Koyukuk river floodplains. These strandings were natural phenomena resulting from declining water levels which left fish in shallow perched depressions. During early September, grayling young-of-the-year were observed stranded in three of 41 side channel pools examined in undisturbed portions of the Atigun River mainstem, and in three of 19 pools examined in Sagavanirktok River side channels. These fish, along with any still stranded in Foothills Streams, were unable to escape when heavy rains on September 16 triggered a freshet prior to freezeup.

At two locations in the Sagavanirktok River floodplain, instream mining appears to have intensified the stranding problem. In mid July 1981, depressions left in the streambed at MS-123-2 and MS-122-1 both contained large numbers of stranded grayling and round whitefish fry and all size classes of slimy sculpin. While freshets allowed these fish to escape periodically, field visits in September of 1982 and 1983 located stranded fish in both areas. It is likely that all the fish observed during September of the two years died. Studies by Woodward Clyde Consultants (1980a) report similar strandings in shallow pools left by excavation of MS-121-2 in the Sagavanirktok River and MS-101-2 in the Middle Fork Koyukuk River. In both instances grayling were the primary species stranded.

The numerous entrapments which resulted from low water levels in 1982 and 1983 generally occurred in natural, undisturbed areas. Tables 7 and 8 summarize a few of the more serious fish strandings observed during these years. Those associated with materials sites will be discussed in detail in Section 6.4.

In 1982 and 1983, many of the stranded fish (Tables 7 and 8) were able to escape when mid August rains brought stream discharges up. Evidence of sizeable fish kills were found, however, in Poison Pipe Creek, Polygon Creek, Arthur Creek, and in two Sagavanirktok River side channels. These fish all died when the pools in which they were trapped dried up.

Without prior census data on the numbers trapped, it is often impossible to determine exactly how many fish are killed in a single entrapment. Predation by birds and small carnivores and the tendency of fish to burrow into the moist gravel quickly eliminates much of the evidence. The largest natural kill documented in the study area, excluding fry, occurred in Polygon Creek (MP99) in late July, 1982. There, an estimated 300 grayling, primarily juveniles, were stranded in large pools when the stream dried up 100 m upstream of the haul road crossing. By August 2, the isolated pools containing these fish had dried up and only a few fish carcasses remained. Since the evidence of major fish kills is so quickly eliminated, entrapment may be much more common than is apparent from casual observations.

On September 9, 1982, an undisturbed location in a Sagavanirktok River side channel, french draining from a perched pool, contained the following:

3 burbot	150 to 195 mm	3 dead
4 Arctic char	79 to 185 mm	3 dead, 1 alive
7 grayling	54 to 190 mm	5 dead, 2 alive
7 slimy sculpin	70 to 99 mm	1 dead, 6 alive

While the vast majority of fish stranded are grayling, the above example demonstrates that other species are also susceptible under certain circumstances. Woodward Clyde Consultants (1980a) documented the stranding of several species including three species of salmon in depressions left by materials site excavation in South Slope streams.

Outside of materials sites, we located few areas where environmental changes resulting from TAPS construction have increased fish entrapment above natural levels. Entrapments at LWC's are discussed in Section 5.2. Entrapments also resulted from the attraction of fish to heated water originating along sections of pipe buried instream. This problem is described in Section 6.5.

5.5 Access Road and Workpad Culverts

While LWC's are the most commonly used crossing structures in fish bearing streams along the workpad and access roads, culverts are used in numerous locations, primarily to provide cross-drainage. In general, these structures are well maintained and do not pose any problems for fish as a result of blockage or erosion. Alyeska personnel have been prompt at de-icing blocked culverts at breakup thus avoiding serious damming up of water by either the workpad or access roads. In contrast, such problems were extremely common along the haul road in 1982 and 1983.

6.0 DETAILED STUDIES OF REPRESENTATIVE STREAMS

Detailed Studies of Representative Streams in the Northern District were designed to address concerns identified during the Review of Existing Information and the General Survey. As a result, the Detailed Studies were made up of a number of individual studies, each based on a particular concern. These included:

1. A study of benthic invertebrate communities (Atigun and North Fork Chandalar rivers, Falcon, Airstrip, Brockman, Snowden, Minnie, and Marion creeks);

2. A study of sedimentation originating from Atigun Pass (Atigun River and North Fork Chandalar River);

3. An examination of the taxonomy of Arctic Char;

4. A study of fish entrapment in materials sites (Holden, Trevor, Spike Camp creeks and North Fork Chandalar River);

5. A study of the modification of thermal regimes (Atigun, North Fork Chandalar, Dietrich, and Middle Fork Koyukuk rivers);

6. An assessment of fish habitat requirements (based on sampling in 27 stream reaches in 24 individual streams);

7. A study of fish habitat modification (Falcon, Holden, Trevor, Airstrip, Snowden, Brockman creeks and North Fork Chandalar River);

8. An examination of the effects of angling pressure (Oksrukuyik Creek).

The latter study was necessary to assess the effects of angling on fish density, a parameter which was an essential component of our investigations of other concerns.

6.1 Benthic Invertebrate Studies

Benthic invertebrate studies were of three kinds: first were studies of the benthos inhabiting stream substrates in Brockman, Snowden, Minnie and Marion Creeks; second were studies of invertebrate drift in Falcon and Airstrip creeks; and third were studies related to sedimentation in the Atigun and North Fork Chandalar rivers. The first two studies are covered in this section, the third in Section 6.3.

Benthic invertebrate samples collected by Hess sampler from the substrates of Brockman, Snowden, Minnie, and Marion creeks were analysed for total standing crop (n/m^2), taxonomic diversity (s), functional group composition (eg. shredders, scrapers, predators, collector-gatherers), species diversity (d), and equitability (e).

Comparisons were made between undisturbed (control) areas and stations located within, or downstream of, disturbed areas using a one-way analysis of variance (ANOVA) calculated on $\log_{10}(x+1)$ transformed original counts (Elliott 1971). Detailed data are summarized in Appendix E. Fine-mesh (300 μ) Nitex is more efficient in sampling Chironomidae than the coarser material (1,100 μ) used in earlier studies (eg. McCart et al. 1972, Newman and Kernodle 1977, Elliott 1982). Estimates of standing crop presented in this section are, therefore, considerably higher than those of other researchers.

6.1.1 Benthic Invertebrates on Stream Substrates

6.1.1.1 Brockman Creek

Brockman Creek, the site of an extensive instream mining operation (Figure 2), was sampled twice in 1981 (July 20 and September 13) and three times in 1982 (June 6, July 23, and September 13). In 1981, the control station (Station Ia) was inadvertently located within an area which later proved to have received some small disturbance from instream mining. During midsummer of that year, this "control" station supported a significantly higher ($F=4.67$, $p < 0.05$) standing crop than did downstream stations, but by mid September, there were no significant differences among stations (Figure 3 and Tables 9 and 10).

In 1982, a new control station (Station I) was established upstream of the mined area near the bedrock canyon mouth (Figure 2). In June of that year, there was no significant difference in standing crop between this new control and three stations located within the materials site (Table 9). During mid June, however, severe scouring occurred within the relatively unstable materials site (see Section 6.7.9). As a result, by midsummer (July 23), standing crops at the control station were significantly higher, about four times, than those at stations within the materials site (Figure 4). By September, there was again no significant difference between any of the stations (Table 9).

The elevated standing crop at the control station in July of both years was due to an abundance of Diamesa spp., of the collector-gatherer/scraper functional group. Diamesa, which appears to be intolerant of severe scouring and streambed instability, was replaced by Orthocladius sp.4, a collector-gatherer species, at the three stations within the materials site. This shift, while also apparent in 1981, was less pronounced due to the inadvertent placement of the control within the mined area. Apparently, the area above the haul road, though mined, is not as unstable as the area downstream, probably in part due to the existence of the north channel (Figure 2). This channel diverts freshet water out of the main channel, minimizing scour above the haul road.

Despite the severe scour at breakup in 1982, standing crop was significantly higher (Table 11) in July and September 1982 (range 118 to 888 organisms/m^2) than in the comparable periods in 1981 (range 40 to 293 organisms/m^2). Low water levels in 1982 concentrated the benthic invertebrate community in comparatively narrow, shallow channels. Shredders, especially Capnia group, were prominent at Station IV in July 1982, indicating that deposition of detritus may have occurred in this area from scoured areas upstream (Figure 3). (Shredders were not abundant at any station in July 1981.) By September 1982, there was an increasing amount of detritus and algae in Brockman Creek and an increase in the standing crops of shredders at all stations, including the control (Figure 4).

The only significant decline in species diversity was observed at Station II, the most heavily scoured location, in July 1982 (Figures 5 and 6). Deposition of large quantities of fluvial material, including fine sediments, in this area was likely responsible for the reduced diversity. The Shannon-Weaver species diversity index (d) was only 0.773 with an equitability of 0.16. On the same date, d ranged from 1.644 to 2.098 at other locations (Figure 6).

Studies by Woodward Clyde Consultants (1980a) indicate that Cinygmula (a mayfly) was reduced in abundance in five of eight Northern District materials sites studied. Total Chironomidae was similarly reduced in seven of the eight sites studied. In Brockman Creek, we found no significant reduction in the abundance of Cinygmula ($P > 0.05$, $t=0.088$, $df=6$), but total Chironomidae was reduced in the materials site during July of both years (control mean=175 organisms/m^2, MS mean=45 organisms/m^2, t=4.305, df=14 in 1981; control mean=743 organisms/m^2, MS mean=155 organisms/m^2, t=18.451, df=14 in 1982).

It appears likely that, in Brockman Creek, reduced stability caused by instream mining has been responsible for a seasonal reduction in the benthic community within the mined area. The effect is probably less pronounced in years when low water levels limit scour. Even after extremely severe floods, however, typified by breakup in 1982, recovery of the benthic community was complete by September.

6.1.1.2 Snowden Creek

Snowden Creek was sampled twice in 1981 (July 25 and September 11), and once at breakup in 1982 (June 2). Sampling stations were located adjacent to (Station III), and immediately downstream of (Station IV) the armored bank protecting MS-105-1 (Figure 7). Snowden Creek has a steep gradient with a nearly straight configuration and is subject to severe freshets. An unusually severe freshet at breakup 1982, similar to the one reported in Brockman Creek, caused considerable channel migration (see Section 7.7.10). Evidence of the frequency and severity of scour was found in the distribution of benthic invertebrates in midsummer and fall.

As is often the case in high-gradient Mountain Streams, Chironomidae larvae were abundant on rocks along the stream edge, but nearly absent from higher velocity areas near midstream. Non-random benthic invertebrate distribution is common in unstable streams (Cummins 1962). Sediment loading was extremely high in Snowden Creek which frequently had the highest turbidity levels recorded in the study area (4,000 to 8,000 FTU). These sediments undoubtedly contributed to the further impoverishment of the benthic community (standing crop ranged from 35 to 228 organisms/m^2). As a result, Snowden Creek had among the lowest standing crops of any of the study streams. Only Marion Creek was lower (Volume III, Appendix E).

Total standing crop, taxonomic diversity, species diversity, and functional group composition were similar among stations located in the disturbed area and an upstream control station (Figures 8 and 9 and Table 12). Diamesa spp., generally collector-gatherer/scrapers, dominated the July samples and tended to be most abundant near the stream mouth (Station IV). By September, Diamesa spp. were less prominent in all locations and shredders of the Capnia and Podmosta groups were dominant. In September, standing crop was highest at the control station but an overall ANOVA indicates no significant difference between the control and stations within the disturbed area. An isolated comparison of September standing crops at Stations I and II using ANOVA did, however, reveal a significant difference ($P < 0.05$). This sometimes happens because of high variability in the overall test and may be aggravated by the non-random distribution of Chironomidae larvae in fall samples.

Samples from breakup 1982 show a relatively impoverished community dominated by collector-gatherer species, mainly Oligochaeta. Podmosta was the most abundant group among the Chironomidae at three of the four stations, absent only from the location immediately below the haul road (Station II).

Species diversity tended to decline in a downstream direction in July 1981 samples, but the pattern was reversed in fall samples (Figure 9). Station II had a reduced species diversity at breakup 1982. This was probably the result of rechannelization and the dewatering of existing channels associated with severe conditions at breakup.

While there was a higher standing crop in the undisturbed area (Station I) in the fall of 1981, overall, the communities at the control and disturbed stations were similar in structure. There is no evidence of significant differences in the benthic community that might have resulted from stream channelization or other disturbance in Snowden Creek. The effects of rechannelization resulting from construction are probably less severe than those which occur naturally in this very unstable stream.

6.1.1.3 Minnie Creek

Minnie Creek is traversed by a typical overhead pipeline crossing which is extensively armored on one bank, and by a haul road bridge armored on both banks. Other disturbance in this stream has been minimal. Instream activity during the open water season has for the most part been avoided. Benthic invertebrate samples (Figure 10) were collected on two dates in 1981 (July 18 and September 15) and at breakup in 1982 (June 3).

Minnie Creek, in marked contrast to Marion Creek, appears to be a highly productive stream with a lake system in its headwaters. Algae were abundant by midsummer and the benthic invertebrate standing crop averaged almost an order of magnitude greater than that of Marion Creek (range 150 to 1,388 organisms/m^2). The substantial difference in benthic communities may explain the greater abundance of fish in Minnie Creek (Volume III, Appendix Table G-1).

There were only minor differences in the composition of the benthic community at the four stations (Figure 11 and Tables 13 and 14). Oligochaeta tended to dominate samples from all stations, except for Station IV, which supported an abundance of Simuliidae (black flies) and Chironomidae pupae not found elsewhere. The presence of these groups may have been related to a reduced stream gradient and the presence of a nearby slack-water area. Station II had an elevated standing crop on all three sampling dates (significantly higher, $P < 0.05$, in June and July), but this was primarily comprised of larger numbers of the same species complement present at other stations. The only apparent difference in faunal composition at Station III was an increase in the abundance of Ephemerella doddsi, a mayfly species commonly associated with fast-running water. This species is opportunistic in its feeding patterns (Hubbard and Peters 1978) and tends to increase as algal growth increases.

Shannon-Weaver species diversity (Figure 12) was comparable at all stations in July (range 1.496 to 2.56) and September 1981 (range 1.224 to 2.073), but Stations II and III displayed low values at breakup in June 1982 (0.959 and 0.582 respectively). In both cases, the low diversity was the result of a high proportion of Oligochaeta in the total standing crop. A high relative abundance of a single taxonomic group reduces equitability, resulting in lower indices of diversity even if other components of the community remain unchanged. For example, taxonomic diversity at Station III (17 taxa) was higher than that at Station IV (15 taxa), despite the low diversity index.

The elevated standing crop at Station III did not appear to be related to any existing disturbances in the drainage. This type of increase, without accompanying shifts in community structure, is often an indication of mild nutrient enrichment or the removal of forest canopy, both factors which would increase algae production. Neither of these circumstances was apparent in the vicinity of Station III.

Disturbance in Minnie Creek did not appear to have resulted in modification of the benthic community. Armoring of streambanks had not altered scour patterns and, in the absence of instream excavation, the substrate remained highly compacted and stable.

6.1.1.4 Marion Creek

Marion Creek is crossed by a typical buried pipeline crossing, contains extensive instream armoring on one bank, and was disturbed several times a result of changes in culverts and bridges associated with the haul road. The benthic community was sampled twice in 1981 (July 22 and September 18) and once at breakup in 1982 (June 4).

On initial inspection, the high water clarity and lack of algae in Marion Creek suggested a low nutrient system. The relatively sparse benthic invertebrate community provided a further indication of low productivity. Standing crop ranged from 18 to 255 organisms/m^2 with most stations supporting less than 100 organisms/m^2 (Figures 10 and 13). These values are even lower than those found in highly scoured Snowden Creek (Figure 8), and amongst the lowest found anywhere in the study area.

In mid July in 1981 and at breakup in 1982, standing crop at the control location (Station I) was significantly higher ($P < 0.05$) than at the two most disturbed stations (Stations II and III) (Figure 13; Tables 15 and 16).

In September 1981, the invertebrate fauna at the control station upstream of the haul road was consistently dominated by Oligochaeta. Downstream of the haul road, an abundance of Chloroperlinae (functional group unknown) dominated Stations III and IV, resulting in elevated standing crops at both stations. Organisms belonging to this group characteristically inhabit unstable substrates (Merrit and Cumming 1978), and were almost completely absent from the control site on all sampling dates. An inspection of the study reach downstream of the haul road indicated that armor associated with the pipeline and, to a lesser extent, the haul road, had caused a localized increase in scouring adjacent to the armored bank where water velocities were high and increased deposition downstream where velocities were reduced. All of the disturbed stations (II, III and IV) are located within these areas of deposition. Chloroperlinae were also abundant in July 1981 samples from all three stations downstream of the haul road (Figure 13).

The abundance of a single taxonomic group, Chloroperlinae, in September samples was responsible for the low Shannon-Weaver species diversity index at Stations III and IV (Figure 14). Diversity was also relatively low at the control station on all three sampling dates (0.778 to 1.132) in this instance because of the abundance of Oligochaeta. Taxonomic diversity was lowest in September 1981 just prior to freezeup (range four to five species), lower even than breakup levels (range three to 11 species) the following spring in June 1982. Most of the taxa present could not be assigned to functional groups based on our present knowledge of their life history patterns (Figure 13).

There appears to have been a significant change in the benthic community of Marion Creek correlated with the presence of disturbed areas at the haul road and pipeline crossing. As the result of increased scour and downstream deposition associated with the presence of bank armor, Oligochaeta has been replaced by Chloroperlinae. This change has persisted for several years despite the absence of any new instream disturbance.

6.1.2 Benthic Invertebrate Drift Studies

Macroinvertebrate drift includes most species of benthic invertebrates found on stream substrates, but generally excludes the more sedentary forms such as Oligochaeta, Nematoda, and Tricladida which do not have a terrestrial phase in their life cycles. Terrestrial insects, including both the adults of aquatic organisms and organisms which are entirely terrestrial, make up a portion of stream drift and are important food for fish. Opportunistic fish species (eg. grayling) often use stream drift as the primary source of food rather than actively seeking food on stream substrates. The removal of bank vegetation and, in some instances, banks and coarse substrate material could modify the macroinvertebrate drift within materials sites and affect fish food availability.

Preliminary surveys of benthic invertebtrate drift in a wide range of disturbed habitats were conducted in midsummer and fall 1981. In general, it appeared that small-scale disturbances had no effect on overall drift rates or on the composition of the benthic invertebrate community. Two of the largest disturbed areas, the materials sites in Falcon Creek and Airstrip Creek, were selected for more detailed study during a period of stable, low summer flows in mid July 1983. These locations are typical of instream materials sites where there has been complete removal of all bank vegetation and a nearly linear channelization of the stream.

6.1.2.1 Falcon Creek

With all vegetation removed from an area almost 2 km long, Falcon Creek (Figure 1) is one of the most highly modified stream channels in the study area. On July 25 and 26, drift samples from an undisturbed area 500 m downstream of the materials site contained more than five times as many organisms and nearly three times as many taxa as a site located near the lower end of the materials site (Figure 15). In a standardized volume of 2,000 m^3, drift samples at the control site contained an average of 995 organisms/24 hr period (range 840 to 1,260) while drift within the materials site averaged only 189 organisms/24 hr period (range 136 to 234). In total, 26 taxa were found in drift from the control area compared to only nine in the materials site.

Despite the difference in the amount of drift, composition of the drift was nearly identical at the two locations (Figure 15). Members of the Chironomidae (midge) subfamily Diamesinae was the most abundant taxon in both areas, comprising 38% of total drift in the control area and 40% of total drift in the materials site. Ephemeroptera (mayflies), Orthocladinae (chironomids), and terrestrial organisms were the next most abundant taxa in order of occurrence at both locations. Terrestrial forms, comprising 10.2% of the control and 15.9% of materials site drift, were more than three times as abundant in the control area (mean = 102 organisms vs. 30 organisms/24 hr drift period). While only a single terrestrial taxon, Diptera, was found at the station within the materials site, four taxa, including Diptera, Hymenoptera, Homoptera, and Collembola, were represented at the control station. Detailed species composition data for Falcon Creek benthic invertebrate drift are presented in Volume III, Appendix Table E-24.

It is apparent that instream mining has resulted in changes to Falcon Creek which have altered instream drift patterns at least during low flow periods at midsummer. These differences are sufficiently great to reduce the attractiveness of the materials site to feeding fish and, in fact, densities of fish are low during the summer feeding period (Section 6.7.4). At higher discharge levels, typical of the spawning period for grayling, these differences are probably less apparent.

6.1.2.2 Airstrip Creek

At Airstrip Creek, a North Fork Chandalar River tributary (Figure 1), an area over 700 m in length was denuded by removal of granular materials and vegetated banks, then channelized. On July 21 and 22 1983, the mean number of organisms in drift within the materials site was four times higher than that at a control location 1 km downstream (Figure 15). Total numbers in the materials site averaged 1,927 organisms/24 hr period (range 1,405 to 2,210) compared to only 427 organisms/24 hr period (range 390 to 486) in the control area. The numbers of taxa present were nearly identical, 24 in the control and 26 in the materials site, and the composition of the drift was similar despite the difference in total numbers (Volume III, Appendix Table E-25).

Drift in Airstrip Creek appeared to contain a faunal assemblage nearly identical to that found in Falcon Creek with Diamesinae, Orthocladinae, and Ephemeroptera the most abundant major groups (Figure 15). Diamesinae, chironomids, comprise 45% of drift in the materials site, but only 17.5% of drift in the control area. This difference, combined with the greater terrestrial drift in the materials site, accounts for most of the difference in total drift between the two locations. Terrestrial organisms, including four taxonomic groups, represented 6.5% of drift in the control area. Within the materials site, seven terrestrial taxonomic groups were represented comprising 12.7% of total drift. In both locations, adult Diptera comprised over half of terrestrial drift.

Drift in Airstrip Creek appeared to follow a pattern nearly opposite to that observed in Falcon Creek. Despite similar fauna, the materials site in Airstrip Creek appears to enhance stream drift, while an even larger site in Falcon Creek reduced drift. Higher stream drift may be a factor in the accumulation of fish in the excavated pits at the downstream end of the Airstrip Creek materials site discussed in Section 6.7.7.

The difference between the effects of instream mining in Airstrip Creek and Falcon Creek is difficult to attribute to a single factor. One apparent difference is the accumulation of sediment present in the Falcon Creek materials site. In contrast, the substrate of the Airstrip Creek materials site is cleanly washed, most sediments having accumulated in the excavated pits and in the reach downstream of the materials site (a reach which included the control site). These sediments may cause localized reductions in benthic invertebrate standing crop which in turn result in reduced stream drift. The sediments originate from flooding of turbid side channels of the North Fork Chandalar River during freshets, and not from any instability in the materials site.

6.2 Atigun Pass Sedimentation Studies

6.2.1 Atigun River

In 1981 and again in 1982, there was extensive modification of the workpad and adjacent areas on the north side of Atigun Pass. This modification substantially increased sediment transport into the Atigun River. During 1982 and 1983, dry weather throughout most of the open water season minimized erosion from the recently disturbed workpad and allowed some degree of stabilization to occur. In 1981, heavy rains caused numerous prolonged freshets and considerable erosion, however, in 1982 and 1983, few freshets occurred and these were seldom long in duration.

6.2.1.1 Sediment Data

The four sets of selected turbidity and suspended sediment data presented in Table 17 were collected during freshets associated with breakup or summer storms. Turbidity sampling locations (capital letters) are shown in Figures 16 and 17.

During a July 1981 freshet, runoff from the newly disturbed workpad (Site D) yielded a shaken turbidity of 6,600 FTU with a settleable fraction of 0.05 and settleable solids of 1,240 mg/L. Background levels in the West Branch East Fork Atigun River (Site C) measured 400 FTU with a settleable fraction of 0.21 and settleable solids of only 30 mg/L. Runoff from the haul road was also contributing to stream sedimentation (Site E) with a shaken turbidity of 3,700 FTU, settleable fraction of 0.11, and settleable solids of 304 mg/L.

The result of these sediment introductions was apparent in the Atigun River downstream of the pass (Site F) where turbidity measured 4,350 FTU, settleable fraction 0.07, and settleable solids 344 mg/L. Natural sedimentation from unstable soil in undisturbed Atigun River tributaries helped maintain high sediment levels 9 km (6 mi) downstream at Atigun River bridge No. 1 (Volume I, Plate 4), where turbidity measured 4,350 FTU, settleable fraction 0.09, and settleable solids 317 mg/L. At least on this date, runoff from the workpad was contributing significantly to Atigun River sediment loading.

Turbidity data alone from a breakup freshet in June 1982 (Table 17) again showed heavy sediment-laden runoff (3,800 FTU) originating from the workpad. High discharge in receiving waters quickly diluted this to 700 FTU in the Atigun River mainstem (Site F). Only as discharge levels in receiving waters declined the day following the freshet (June 9), did runoff from the workpad elevate turbidity levels in the mainstem. Turbidity from unstable areas in undisturbed tributaries kept readings high 9 km downstream (Site H) on both dates.

By June of 1983, sediment levels in workpad runoff appeared comparable to background levels in receiving waters (Figure 18); however, extensive grading and resurfacing of the haul road greatly increased erosion originating from its surface. While the volume of runoff originating from the haul road was not sufficient to affect turbidity levels downstream, the reddish color of the runoff, characteristic of material from a particular materials site (OMS-111-2), was apparent for several kilometres downstream.

6.2.1.2 Effects on Benthic Invertebrates

The locations of seven Benthic Invertebrate Sampling Stations (Roman numerals) in the Atigun River are shown in Figure 16. Station I, located upstream of the uppermost disturbance in the Atigun Canyon, acted as a control for the six downstream stations. Due to the fine-mesh (300 µ) Nitex used in this sampling, estimates of standing crop are higher than those reported by other authors (McCart et al. 1972, Elliott 1982).

Benthic invertebrate populations in the Atigun River follow a seasonal trend toward increasing numbers, peaking in late fall (Table 18). Sampling locations in the upper Atigun River valley were dry or iced over in early June. Only Station V located downstream of a groundwater source had surface flow. There, a total standing crop of 495 organisms/m^2 was present on June 2. Sampling conducted in 1982 yielded standing crops ranging from 116 to 508 organisms/m^2 in midsummer samples and 1,202 to 3,214 organisms/m^2 by September. The seasonal increase can be attributed primarily to an increase in the abundance of developing Chironomidae larvae.

During mid July, only Station IV (Figure 16) was significantly higher in total standing crop and taxonomic diversity than the control station (Table 18). Groundwater, which forms a small winter icing at this site, may be responsible for the higher invertebrate densities. By September, all Atigun River stations downstream of the Pass were higher in taxonomic diversity than the control (Table 18). Similarly, all stations, except Station IV, had significantly higher standing crops than the control. This increased standing crop downstream is probably a function of decreasing altitude, reduced water velocities, reduced scouring and other factors.

In September 1982, total standing crop was three to 10 times higher than at comparable locations sampled in September 1981 (Volume III, Appendix Table E-1). Other aspects of the community, including taxonomic composition, species diversity, and equitability were, however, comparable at all stations. This pattern was part of a general pattern toward higher standing crops in 1982. The cause appears to be the difference in stream discharge levels. 1982 was an unusually dry year resulting in considerable concentrating of the benthic community in the remaining stream channels.

Overall, the introduction of sediment from pipeline-related activity in Atigun Pass did not appear to have detrimentally affected Atigun River benthic invertebrate populations. Stations immediately downstream of the sediment source (Stations II and III) supported benthic invertebrate communities comparable to stations located up to 11 km downstream (Table 18). In fact, fall standing crop at stations downstream from Atigun Pass (range 1,600 to 3,200 organisms/m^2) appeared to be comparable to those of somewhat more productive tributary streams (eg. Trevor and Tyler creeks; range 2,000 to 4,500 organisms/m^2) where sedimentation and scour were generally less severe. Species composition was comparable to that reported by Miller et al. (In Prep) and Slack et al. (1979).

The reductions in community diversity and shifts in community structure which would be expected in an area subjected to excessive sediment introductions were not apparent in the Atigun River. The benthic community was dominated by Chironomidae larvae, representing from 73 to 97% of the total standing crop, most members of which appear to be largely unaffected by frequent high silt loads which occur naturally.

6.2.1.3 Effects on Fish Populations

Grayling have dominated the catch in all Atigun River studies to date. During 1981, grayling accounted for 90.7% of our total catch of 1,337 fish, followed by round whitefish (8.8%) and Arctic char (0.8%). In 1982, similar results were obtained, with grayling representing 88.7% of the total catch of 1,109 fish followed again by round whitefish (5.9%) and Arctic char (5.4%). In 1983, studies were concentrated in the uppermost 20 km of the Atigun River where the catch of 779 fish was 91.0% grayling, 6.0% round whitefish, and 3.0% Arctic char. Slimy sculpin, a relatively abundant species in the drainage, were not enumerated during these studies. Other species which occur in the deeper low-velocity areas near Galbraith Lake include lake trout, burbot, and possibly Eastern Form Arctic char (see Section 6.3).

While grayling are widely distributed in all accessible waterbodies in the drainage by midsummer, round whitefish are abundant only in the larger pools in the Atigun mainstem and in the larger tributaries (eg. Holden, Roche Montonnee, Trevor creeks and the Atigun River West Fork). Char are most abundant downstream of MP150.0 to the Atigun River mouth. Roche Montonnee Creek and the Atigun River West Fork support numerous juvenile char during the fall, but no mature anadromous fish enter the drainage. Both char and round whitefish are periodically found as far upstream as Atigun Camp (MP163.0), but never in large numbers. Detailed life history information for these species is presented by McCart et al. (1972) and length-frequency distribution data for the Atigun River drainage are presented by Elliott (1982).

Studies reveal a characteristic fish migration pattern within the drainage. Overwintering occurs in lower portions of the Atigun River near Galbraith Lake and several adjacent lakes. Some fish may move as far downstream as the Sagavanirktok River to overwinter, but their numbers are believed to be small due to the difficulty in migrating back upstream through the high-gradient Atigun River gorge.

Elliott (1982) documented the locations of 34 pools deeper than 1.3 m (4 ft) in that portion of the Atigun River immediately above Galbraith Lake. No major overwintering sites are found in the upper 15 to 20 km of the Atigun River, due primarily to the highly braided nature of the floodplain and scarcity of groundwater sources. Substantial icings near the mouth of the Atigun River West Fork (MP157.0) and at Atigun River Bridge No. 1 (MP159.6) indicate the presence of flowing water during winter months but, to date, only small numbers of overwintering fish have been located at either of these sites.

Following breakup, grayling begin to move upstream to spawning and summer feeding habitats, primarily in the tributary streams. This upstream movement generally begins in late May, but in some years, may be delayed until June 1. Clear tributary streams and the outlets of lakes (eg. Vanish Creek, Mainline Spring Creek, Tea Lake Outlet) are the preferred spawning areas for Arctic grayling, although spawning has been documented in Holden Creek, Tyler Creek, Trevor Creek, and, rarely, in a few stable Atigun River side channels. Arctic char and round whitefish follow a similar pattern except that they spawn in the fall.

By the first of June, few fish have moved upstream beyond the confluence with the West Fork Atigun River. During the 1982 and 1983 sampling seasons, grayling were abundant in the Atigun tributary streams up to Trevor Creek (MP156.0) during the first two weeks of June; however, the first grayling were not caught at Atigun Bridge No. 1 (MP 159.6) until June 5 in 1981, June 12 in 1982, and June 7 in 1983.

The low utilization of the upper reaches of the Atigun River (above MP158.0) by spawning grayling or other species is further evidenced by the complete absence of young-of-the-year of any species throughout the summer months. The furthest upstream evidence of young-of-the-year grayling was recorded at MP158.2 in a clear side channel on September 16, 1982. Since these fish had grown to nearly 50 mm in size, they may have moved upstream slightly from known spawning areas near Trevor Creek and in the Atigun River West Fork.

Spawning areas for char and round whitefish in the Atigun River have not been precisely located, but these fall-spawning species require areas with perennial discharge since their eggs must overwinter in the gravel. Deep pools in the vicinity of Galbraith Lake as well as the surrounding lakes are suspected spawning areas. Upper portions of the Atigun River drainage are unsuitable for use by fall-spawning species due to the absence of suitable groundwater sources. Round whitefish fry have been captured in the vicinity of Roche Montonee Creek during September and in Mainline Springs Creek (Elliott 1982), but, to date, no char fry have been caught.

Anadromous (sea-run) char populations are known to utilize the upper Sagavanirktok River as far upstream as the confluence of the Atigun River. While resident char are present in the Atigun River drainage, no mature anadromous char are known to migrate into this system. Small numbers of juvenile anadromous char may use the Atigun River for summer feeding. These fish are apparently able to negotiate the Atigun canyon only at low water levels.

As the summer progresses, the numbers of fish of all species gradually increase in the upper Atigun River, reaching maximum density in the tributary streams by mid August. This tendency is largely a function of declining stream discharge levels, decreasing silt and scour in higher gradient areas, and increasing food availability. As indicated in the benthic invertebrate studies (Section 6.2.1.2), the benthic community is extremely impoverished at breakup, and increases rapidly by midsummer, reaching maximum levels by early September.

At any given time during the open water season, the densities of grayling in the major tributary streams is an order of magnitude higher than in the Atigun mainstem. This distribution reflects the instability of the mainstem which is characterized by rapid fluctuations in discharge, high suspended sediment levels, extreme channel scour, and limited availability of suitable habitat.

During 1981 and 1982, midsummer fish densities in undisturbed portions of three Atigun River tributaries (Holden, Trevor, and Roche Montonnee creeks) averaged 18.25 fish/1,000 m^2 of stream surface area. During the same sampling periods, average biomass for all species combined was 3,152 g/1,000 m^2. In contrast, typical densities in the uppermost 15 km of the Atigun River mainstem average two fish/1,000 m^2 of stream surface area with an average biomass of about 500 g/1000 m^2.

By the first of September, or earlier in low-water years, fish begin migrating out of both the upper Atigun River mainstem and tributary streams. This emigration is triggered by a combination of declining stream discharges and sustained low water temperatures. Most tributaries and the Atigun River mainstem above Atigun Camp (MP163.0) are dry by September 15. Fish begin accumulating in deep pools and lakes in the vicinity of Galbraith Lake and are generally restricted to these overwintering habitats between early October and mid May of the following year.

Since the upper 10 to 15 km of the Atigun River are not used for spawning, and serves primarily as a summer feeding area for large juvenile and adult grayling and round whitefish, sediment introductions are unlikely to seriously affect the fish population. The majority of fish appear to seek the clear tributary streams, particularly during periods of prolonged high turbidity. Since natural turbidity levels regularly exceed levels measured in Atigun Pass runoff, fish inhabiting this and similar drainages must have developed behavior and movement patterns which ensure their survival. We can find no evidence that the relatively small amounts of sediment originating from disturbances on Atigun Pass have detrimentally affected fish in the downstream drainage.

Specific data on the amount and size composition of sediments transported in both the Atigun and North Fork Chandalar rivers have been collected by Dr. Larry O'Nesty of the University of Illinois. This information, when available, will provide an accurate estimate of the magnitude of natural sediment transport. The effect of runoff from disturbances on the Pass should be re-evaluated in light of these data once they are available.

6.2.2 North Fork Chandalar River

6.2.2.1 Sediment Data

Settling ponds on the south side of Atigun Pass (Figures 17 and 19) breached by flood waters in 1981, were repaired in 1982 and remained intact throughout the open water season. The upper pond was damaged slightly at breakup 1983, but the other two ponds remained functional throughout the 1983 season. The heavy sediment load originating from Pipeline Branch, which flows immediately adjacent to the buried pipeline along nearly 1.5 km of steep grade (Figure 17), has been a concern to investigators who have observed increased sedimentation in the North Fork Chandalar River. The settling ponds were originally constructed in an attempt to alleviate some of that concern. Elliott (1982) reported that visibility in downstream reaches was obscured in June and July 1980 due to the influx of water from Pipeline Branch.

During a mid July freshet in 1981, discharge to the North Fork Chandalar River from the partially ruptured settling ponds was actually higher in both turbidity and settleable solids than waters entering the upper end of the ponds (Table 19). This unlikely circumstance resulted when accumulated sediments in the ponds were flushed out into the river. Fortunately, natural sediment levels upstream of the haul road (Site I) were nearly as high resulting in little difference downstream of the settling pond confluence (Site L). Sediments from the Pass did, however, increase the total sediment load in the drainage. Following each freshet, undisturbed waters generally cleared within one to two days while runoff from the Pass remained turbid for several more days; occasionally as long as 10 days.

Turbidity data, for a freshet at breakup 1982, again showed only slightly higher turbidity entering the mainstem from Pipeline Branch (Site K) than the control site (Site I) located above the haul road (Table 19). High, but unmeasured, turbidity in an unnamed tributary at MP170.6 was in fact increasing the turbidity of the mainstem more than runoff from the disturbed workpad. Throughout the summer of 1982, runoff from the workpad continued to carry small quantities of sediment into the mainstem on an intermittent basis. Two factors, reduced equipment activity on the Pass and limited summer precipitation, served to minimize the amount of sediment entering the North Fork Chandalar River in 1982.

Data collected during a breakup freshet on June 1, 1983 show relatively high turbidity levels in Pipeline Branch (Site J) compared to the undisturbed mainstem (Site I), but the pattern is reversed for settleable solids (Table 19). The high settleable solids level above the haul road, 490 mg/L, may be the result of sampling error since only 100 m below the confluence with Pipeline Branch (Site L) settleable solids measured only 182 mg/L. Once again there is little difference between either turbidity or settleable solids levels above (Site J) and below (Site K) the settling ponds.

These data illustrate several important points concerning sediments from Atigun Pass entering the North Fork Chandalar River:

1. In the absence of active construction and repair work in Atigun Pass, fewer settleable solids enter the North Fork Chandalar River.

2. During freshets, turbid water entering the North Fork Chandalar from Atigun Pass tends to carry only slightly more settleable solids than background levels in the undisturbed stream.

3. Following freshets, sediment introductions from Atigun Pass persist at higher levels for longer periods of time than natural background levels.

4. Settling ponds at the mouth of Pipeline Branch are relatively ineffective in reducing either turbidity or settleable solids levels.

Heavy equipment operation and extensive maintenance work in 1981 appears to be responsible for the relatively high sediment levels displayed in the July 1981 data. These levels were significantly lower during the 1982 and 1983 freshets, when less disturbance was occurring in the Pass. While the settling ponds appear to be removing some settleable solids during low to moderate flow levels, they are undoubtedly undersized to handle high discharge levels.

The tendency of these structures to flush out accumulated sediments during freshets, or to fail completely and release the entire contents of the ponds into the river within a brief period, makes them of questionable value. A more frequent removal of accumulated sediments from the settling ponds may partially alleviate this problem. Nevertheless, a calculation of the quantities of sediments carried annually by <u>any</u> of the unstable streams in the vicinity of Atigun Pass would undoubtedly demonstrate that it would require dramatically larger settling ponds to significantly reduce sediment transport and bedloads in the North Fork Chandalar River.

6.2.2.2 Effects on Benthic Invertebrates

Detailed benthic invertebrate studies in the North Fork Chandalar River indicated that the community was dominated by relatively sediment-tolerant Chironomidae species (Table 20). Sediments originating from Atigun Pass cause few significant changes to community structure and these effects are localized.

Samples collected on three dates in 1982 (June 10, July 22, and September 7) showed that, while standing crops at all mainstem stations had a tendency to increase as the season progressed (Table 20; Figures 20 and 21), there was no apparent difference in standing crop (Tables 21 and 22), taxonomic diversity, or functional group composition between the control (Station I) and a location downstream of the settling ponds (Station II).

Taxonomic composition varied considerably between stations, however, probably due to the influence of tributary streams. Station IV, located immediately downstream of a frequently silt-laden tributary (opposite MP170.6) showed the highest standing crop on all three sampling dates (range 340 to 5,450 organisms/m^2). A location in the east branch tributary (Station III), generally clearer than the mainstem, supported a comparatively impoverished community (range 115 to 2,620 organisms/m^2).

At breakup, samples were dominated by the collector-gatherer functional group, but the appearance of large numbers of *Diamesa* spp. made collector-gatherer/scrapers the dominant functional group in midsummer and fall samples. Chironomidae larvae, as a group normally relatively tolerant of sedimentation, generally dominated samples in the most silt-laden locations.

A comparison of the benthic community in clear water at Station III with silt-laden water at Station IV (Table 20) revealed that Chironomidae made up 36 to 57% of the total standing crop in the former, but increased to 76 to 96% in the latter. Similarly, the station downstream of the settling ponds (Station II) supported a high percentage of Chironomidae in both July and September samples (89% and 90% respectively). In contrast, the control (Station I) supported a lower percentage on both of these sampling dates (72 and 57% respectively). This pattern was not followed at breakup; in fact, it appeared to be reversed. There may have been water at Station I for only a brief period prior to sampling, as evidenced by the sparse benthic community present (Table 20). Station II receives water from both the mainstem and Pipeline Branch and, consequently, may have had water present earlier than Station I.

Due primarily to the high standing crop of a single species, Diamesa, Shannon-Weaver diversity indices were low, reaching a maximum of 2.36 (Figures 20, 21, and 22). The lowest values were recorded at Station I at breakup (0.40) and at Station II in September (0.64). Low equitability combined with a significant decline in the stonefly Podmosta, a species sensitive to sediment introductions, indicate that the low fall diversity at Station II is probably caused by sediments from Pipeline Branch. Station III, in the clear tributary, produced the highest Shannon-Weaver diversity indices in June and July and was the only station which did not display a decline in diversity in September. Low equitability resulting from high numbers of Diamesa at all stations was responsible for the overall decline in diversity.

With the exception of the decline in September of the genus Podmosta at Station II, sediment introductions entering the North Fork Chandalar had little effect on the benthic community. Stations IV and V (2.5 km and 3.5 km, respectively, downstream of the settling ponds) did not display the changes in community structure which might be expected as a result of sedimentation. In September, Station IV supported a significantly higher standing crop ($P < 0.05$) than Station II (Table 22). Based on these data, it is apparent that any adverse effects from sediment introductions were both minor and localized.

6.2.2.3 Effects on Fish Populations

The upper portions of the North Fork Chandalar River support rearing and summer feeding grayling and slimy sculpin. Round whitefish, common downstream, are rare this high in the drainage. Though Elliott (1982) reported the capture of young-of-the-year grayling downstream of MP172.0, only a few were caught during our entire three-year study, and those were caught only in late August and September. The smallest grayling caught upstream of MP173.0 measured 70 mm in mid July and 86 mm in September. These were yearling fish, since McCart et al. (1972) reported that young-of-the-year in the Atigun River reach only 45 to 55 mm in their first year. Those young-of-the-year caught in the fall downstream of MP173.0 were 37 to 47 mm in length by September.

Overwintering occurs downstream of the lowest pipeline crossing. A large winter icing downstream of the pipeline is an indication of substantial groundwater flow which may support small numbers of fish through winter. The scarcity of fish in the entire area in early to mid June suggests that most fish winter a considerable distance downstream.

Despite repeated intensive electrofishing and seining, no spawning fish were found in the area. Airstrip Creek, a clear tributary arising behind Chandalar airstrip, is not subject to the prolonged high sediment loads typical of the mainstem, but still supports no spawning fish. Elliott (1982) reported that the first fish did not reach the haul road culvert until July 2 in 1980. While our study did not include a late June sampling, we can be certain that no fish were this high in the North Fork Chandalar River until after mid June in 1981 through 1983.

Fish densities increase rapidly in July as large numbers of juveniles immigrate into the area. The uppermost stream sections near the haul road crossing support primarily larger fish (mean length 231 mm). This is due in part to the steep gradient and in part to the haul road culvert, nearly impassible until its recent replacement with a bridge. Opposite Chandalar Camp, juvenile grayling are abundant (mean length = 172 mm).

Despite periodic freshets and high sediment loading, grayling densities in the North Fork Chandalar reach relatively high levels by mid August. Nearly 5,000 grayling were reported stranded above an area of discontinuous flow near Chandalar Camp on September 5, 1979 (J. Glaspell, ADF & G, as reported by Elliott 1982). Our own density studies, detailed in Section 6.7.8, suggest a maximum average overall density of 22 grayling/1,000 m^2 or 1,580 fish between MP169.0 and MP172.0. The bulk of these are found in side channels which support up to 57 grayling/1,000 m^2.

Emigration begins in mid to late August depending on discharge levels and water temperatures. Elliott (1982) reports that fish move out progressively as water levels decline. We found this was indeed the case during our three-year study. However, the timing of these movements tends to depend on prevailing weather conditions. In 1981, a wet year, fish were still abundant in early September, but, in subsequent dry years, densities were relatively low by September 1.

Since the North Fork Chandalar River is not used for spawning in the vicinity of Atigun Pass, and it is unlikely sediments would affect overwintering areas further downstream, the only likely adverse effects on fish would be the result of effects on food organisms used by rearing and summer feeding grayling. There is no evidence in the literature that settleable solids levels of 1,000 mg/L or less will have direct adverse effects on fish larger than 100 mm, particularly grayling, a species which often occurs in turbid waters.

Studies by various authors including McCart et al. (1972) and Yoshihara (1972) have demonstrated that grayling are opportunistic feeders. Chironomidae larvae are the dominant food item in most streams in the region. Since North Fork Chandalar River benthic invertebrate studies have demonstrated that Chironomidae are actually more abundant in turbid waters than corresponding clear tributaries, it is doubtful that Atigun Pass silt introductions have adversely affected food availability. While instability on Atigun Pass is clearly adding to the North Fork Chandalar River sediment load, there appears to be little evidence of serious effects on the aquatic biota.

6.3 Arctic Char Taxonomic Studies

There is some confusion in the literature regarding the taxonomy of char (Salvelinus) in the Atigun, Dietrich, and Koyukuk rivers. Char caught south of the Continental Divide are referred to in the pipeline literature as "Dolly Varden" while those caught in the Atigun River are referred to as "Arctic char". Neither of these areas supports a spawning population of anadromous char. Lakes in the Atigun River canyon support the Eastern Form of Arctic char (McPhail 1961) which only rarely enters streams west of the Mackenzie River. McCart (1980) discusses the taxonomy and meristic characteristics of Arctic char in Alaska and Western Canada and indicates that various forms of char can be separated using simple meristic comparisons.

A sample of 15 char collected from Dietrich and Middle Fork Koyukuk river tributaries in 1982 (76 to 253 mm fork length) displayed an average total gillraker count of 20.8 (upper 8.3; lower 12.5). Pyloric caeca counts ranged from 22 to 34 with a mean of 27.1. These counts are intermediate for, and characteristic of, Western Form Arctic char (Salvelinus alpinus). Since mature females were present in this area at sizes under 250 mm, it appears that this population is a stream-resident (non-migratory) Arctic char population.

Twenty char collected from the Atigun River upstream of Galbraith Lake displayed meristic characteristics similar to those of char caught south of the Continental Divide and in other North Slope streams. Char ranging from 105 to 177 mm had a mean total gillraker count of 21.1 (upper 9.8; lower 11.3). Pyloric caeca counts ranged from 22 to 39 with a mean of 28.6. These counts are also intermediate for, and characteristic of, Western Form Arctic char (Salvelinus alpinus).

The majority of char present in the Atigun River appear in late summer. Few char are present following breakup and through midsummer. Most char are immature juveniles, although a few stream-resident females (250 mm) were caught during this study whose eggs were of a size which suggested that they would spawn in the fall of the year following capture (ie. about 12 months later). It appears that the majority of char in the Atigun River are:

1. Immature juveniles of anadromous populations spawned elsewhere;
2. Immigrants from stream resident populations in other areas; or
3. A combination of both.

In addition to these fish, a few large, non-spawning Arctic char (400 mm+) were caught in the upper Atigun River during our studies. These are believed to be Eastern Form Arctic char which ventured into the Atigun River from nearby lakes where they have been previously reported (McCart and Craig 1971, McCart 1980). No evidence of adult anadromous char in the Atigun River has been found. Elliott (1982) conducted extensive sampling in the Atigun River and reports similar results.

The Atigun River gorge, a high-gradient bedrock chute, appears to be passible to fish only at low water levels. There is sufficient groundwater in the Atigun River to support a spawning population of anadromous char. It appears that most juvenile Arctic char in the Atigun River move downstream to overwintering areas rather than remaining in the upper Atigun River.

6.4 Entrapment of Fish

During this study, in addition to recording the natural strandings of fish described in Section 5.4, we investigated entrapment in the vicinity of major instream materials sites. Included were locations in Holden Creek, Trevor Creek, Spike Camp Creek, each of them a tributary of the Atigun River, as well as the North Fork Chandalar River. In all four cases, the materials site was located in an alluvial fan where stream gradients are low. The sites are characterized by large deposits of granular materials and all display some degree of channel instability.

At all four locations, there appears to be a predisposition to discontinuous stream flow during low discharge periods. Similar undisturbed alluvial fans in the Atigun River Valley, East Branch North Fork Chandalar River, and in the Ivishak River drainage also display discontinuous flow at low flows. Fish entrapment has also been observed in these undisturbed locations (pers. comm. T. Bendock, ADF & G, K. Durley, Alyeska Pipeline Service Company). No specific pre-construction data exist for any of the four study sites which might provide information on the extent of fish entrapment prior to materials site excavation.

Some apparently similar materials sites in the Sagavanirktok, Dietrich, and Koyukuk systems do not appear to produce discontinuous flow even though, in some cases (eg. Brockman Creek), the materials sites are much more extensive and unstable than the fan locations studied. Fish entrapment as a result of discontinuous flow was not observed in these areas at any time during the three-year study.

This is not to say that materials site excavation in the four study locations did not intensify an already existing tendency for discontinuous flow. Any reduction in stability, modification of deposition patterns, or change in stream hydraulics in an area predisposed to discontinuous flow could intensify the problem, resulting in increased fish entrapment. Materials site excavation resulted in the removal of streambank vegetation and stream banks, substrate removal, straightening of winding stream configurations, changes in mean substrate size, and an overall simplification of streambed morphology. Some of these changes are described in detail for the four study locations in Section 6.7 (Habitat Modification Studies).

Only a detailed hydraulic and gravel permeability study could fully assess the role that materials sites have played in intensifying discontinuous flow problems. Our study was limited to a measurement of the extent of discontinuous flow and documentation of the effect on fish populations. As demonstrated in Section 4.6 (Table 6), grayling have been involved in most of the instances of entrapment documented in the region. Previously reported entrapments in materials sites (Woodward Clyde Consultants 1980a, Elliott 1982) have also involved primarily Arctic grayling. The following is a description of studies conducted at our four study sites in 1981 through 1983.

6.4.1 Holden Creek

Holden Creek, the site of several reported fish entrapments (JFWAT Field Surveillance Reports, Elliott 1982), was closely monitored in late August and early September in each of the three years of this study. Elliott reported a kill of at least 31 fish in

1980, about half of them Arctic char. An area of discontinuous stream flow near the lower end of MS-114-1 (Figure 23) was responsible for the isolation of these fish. There were no similar kills in 1981 through 1983, as a result of a variety of circumstances.

In 1981, frequent rains kept stream discharges high until early September when discontinuous flow was first observed. All fish had apparently moved out during freshets in late August. In 1982, a total of 41 grayling, primarily juveniles, and three Arctic char were trapped in Holden by late July. Once again, the majority of these fish appear to have moved out of the stream during an August freshet. Discontinuous flow occurred again in late August 1982, but only five juvenile grayling remained above the dewatered area. In early September, these fish died after jumping onto the rocks in an attempt to escape.

In both 1981 and 1982, Holden Creek appeared to dry up following a consistent pattern. At discharges below 0.1 m^3/s measured at the haul road, stream discharge remained relatively uniform through most of the materials site, dropping off abruptly at a point about 200 m above the lower end of the materials site (or 400 m upstream of the pipeline crossing). Downstream of this, flow declined to an unmeasurably low level, french draining through an accumulation of outwash cobble. All flow ceased about 100 m upstream of the lower end of the materials site and reappeared about 100 m downstream of the materials site (or 100 m upstream of the pipeline crossing). Flow was continuous between the pipeline and stream mouth at all times until freezeup.

As stream discharge declined even further, the dry area expanded downstream as far as the pipeline crossing and upstream to within 100 to 200 m of the upper end of the materials site (or the haul road). Prior to freezeup, the maximum area of discontinuous flow included an area 700 to 800 m long encompassing nearly the entire materials site.

An unusually severe breakup in 1983 scoured out much of the accumulated cobble at the lower end of MS-114-1. Despite low flow during the open water period and cold weather in the third week of August, Holden Creek continued to flow until frozen in September. On September 1, discharge at the haul road (0.07 m^3/s) was nearly identical to that recorded at the lower end of the materials site.

No fish were observed stranded at any time during the 1983 field season. It appears that the problem of discontinuous flow in Holden Creek has at least temporarily corrected itself. With the rather pronounced channelization which occurs over a 700 m long stream section in MS-114-1, any material scoured loose from immediately above or within the materials site will have a tendency to be redeposited below the channelized areas. Since straight stream sections have a greater tendency to scour than winding configurations, there is a possibility that the conditions which produced discontinuous flow in past years will recur.

6.4.2 Trevor Creek

Several small fish kills have been reported in Trevor Creek by JFWAT personnel and, more recently, by Elliott (1982). In early September 1980, Elliott reported that 91 grayling were stranded when the lowest reach in MS-112-2 went dry (Figure 24). All of these fish either died after jumping onto the rocks or were transported and released downstream. Elliott adds that the excavation of materials sites "...apparently increases streambed permeability, causing the premature loss of surface flow during periods of low stream discharge."

While discontinuous flow was observed during September in all three years of our study, fish entrapment occurred only in 1982. In 1981, high discharge levels persisted until nearly freezeup. All fish had moved out prior to the first evidence of discontinuous flow on September 14. In September 1982, a total of 29 grayling, mostly adults, and three juvenile char died when the creek dried up near its mouth. Drying was first observed on September 3 when a 50 m reach at the mouth was dry. By September 12, most of the trapped fish had died after jumping out of the last standing pools onto the rocks. By this date, Trevor Creek had dried up to a point 400 m above the stream mouth (or 250 m downstream of the pipeline crossing).

In 1983, any concerns about stranding in the vicinity of the materials site in Trevor Creek were obviated by a more catastrophic event. In mid June 1983, Trevor Creek was wholly diverted for the purpose of bridge installation, into Tyler Creek, the other distributary of Redwater Creek. This diversion was accomplished by blocking the bifurcation point with boulders and soil using a caterpillar tractor. The result was a sudden dewatering of Trevor Creek and a severe scouring of Tyler Creek, which then received all of the discharge of Redwater Creek. Had this diversion occurred three weeks earlier, the effects would have been greatly lessened.

Based on our studies of movements into Trevor and Tyler creeks, and the progress of spawning activity in Tyler Creek earlier in June of the same year, it appears likely that several hundred adult and juvenile grayling were lost in Trevor Creek and the spawning success of at least 200 adult grayling in Tyler Creek was severely reduced. Flooding in Tyler Creek, normally a low gradient, relatively stable stream, was so severe that all three LWC's were washed out along the workpad. Where newly emergent grayling fry were abundant in the lower 2 km of Tyler Creek during July 1981 and 1982, not a single fry could be located in mid July 1983. Flow was not restored to Trevor Creek until August 31. There was no further use of Trevor Creek by fish in 1983.

In 1981 and 1982, the dewatering pattern in Trevor Creek in was similar to that described by Elliott (1982) except that the timing varied by one to two weeks depending on weather conditions. Trevor Creek dries up near the mouth first, then gradually dries upstream to a point about 100 m below the pipeline crossing.

On September 3, 1982, discharge measured 0.15 m^3/s at the haul road when dewatering first occurred at the mouth. Stream discharge through the materials site was relatively uniform ($\pm$ 25%) to a point 300 m above the stream mouth. Over the next 250 m, discharge declined gradually, ceasing completely only in the lowermost 50 m of the stream. By September 12, discharge above the pipeline crossing was less than 0.1 m^3/s and, beginning at a point 100 m below the pipeline, declined abruptly over the next 100 m to zero. This pattern appeared to vary slightly, depending on scour in the materials site. In September 1983, discharge appeared to drop perceptibly at the pipeline crossing and remained at about 50% of upstream levels to the dewatered point 50 m above the mouth.

Discontinuous flow in the Trevor Creek alluvial fan occurs at approximately the same distance from the incised canyon mouth that it occurs in Holden Creek, about 1,000 m. Both areas were mined because they are deposition areas for large amounts of alluvial material. There is no evidence to suggest that discontinuous flow would not occur in some years even if mining had not occurred. A small unnamed stream on the opposite side of the Atigun valley (adjacent to MP151.0) also displays discontinuous flow periodically. This stream, unaffected by pipeline construction, traverses a broad alluvial fan, but does not appear to be extensively used by fish. A similar, undisturbed stream, Waterhole Creek (MP152.4), also goes "...subterranean across the alluvial fan..." (Elliott 1982).

While it has been speculated that the discontinuous flow in Trevor Creek is the direct result of instream mining (Elliott 1982), without adequate baseline data or more exhaustive hydrological studies, it is not possible to determine whether dewatering of Trevor Creek is a natural phenomenon or a direct result of instream mining.

6.4.3 Spike Camp Creek

Elliott (1982) reported that in 1980 at least 132 fish, mostly grayling, were trapped in Spike Camp Creek below MS-111-1. The materials site in this stream is a large pit located adjacent to Spike Camp Creek (Figure 25). The entrapment occurred in early September, according to Elliott, who adds that "...the loss of water from the Spike Camp Creek water table to Sten Creek apparently caused the premature loss of surface flow in the adjacent reach of Spike Camp Creek, resulting in the entrapment." Sten Creek did not exist before the materials pit was excavated, but was created by the removal of gravel from a pit located in the floodplain adjacent to Spike Camp Creek (Figure 25). The bottom of the pit is at a level below the grade of Spike Camp Creek. Sten Creek appears near the top end of the materials site and is fed by water percolating from the pit walls (primarily from the side adjacent to Spike Camp Creek).

From 1981 through 1983, we observed no major entrapment of fish in Spike Camp Creek. Despite continuous monitoring during late August and September, only one adult grayling (220 mm) was observed stranded, even though Spike Camp Creek displayed discontinuous flow in early September of all three years. Small freshets in mid to late August of 1981 and 1982, and cold weather in late August 1983, may have encouraged most fish to move out.

On September 2, 1982, the creek was dry from a point 100 m above the haul road to its mouth. Discharge was 0.18 m^3/s upstream of the materials site. Discharge in Sten Creek measured 0.11 m^3/s at the haul road. By September 8, Spike Camp Creek was completely dry in at least the lower 2 km of stream; however, discharge in Sten Creek continued at a nearly uniform 0.10 m^3/s along its entire length.

Additional measurements of discharge were made in 1983. On July 27, surface discharge (of all channels combined) measured 0.64 m^3/s 200 m upstream of the materials site, and 0.41 m^3/s at the haul road. A gradual decline in discharge was apparent adjacent to the materials site pit. Sten Creek measured 0.10 m^3/s near its source and 0.27 m^3/s at the haul road. Subtraction of the Spike Camp Creek discharge at the haul road from the discharge above the materials site yielded a loss of 0.23 m^3/s, nearly the total discharge of Sten Creek. Elliott (1982) reported similar results in the fall of 1980. These calculations are based on surface flow alone, and intergravel flow in a highly porous alluvial fan may be substantial.

On September 5, 1983, Spike Camp Creek was again dry at the haul road, but had a discharge of 0.16 m^3/s above the materials site. Discharge in Sten Creek measured 0.26 m^3/s, nearly identical to the midsummer discharge. The difference between 1982 and 1983 fall discharge levels in Sten Creek may be accounted for by an increase in intergravel flow along the length of the materials site. In 1982, nearly all the water flowing in Sten Creek was originating near the top of the materials site. In 1983, 0.17 m^3/s was percolating up near the midpoint in the pit.

These data suggest that a significant part of the discharge in Sten Creek is indeed coming from intergravel flow in the Spike Camp Creek floodplain. Thus the Sten Creek pit may play a role in dewatering Spike Camp Creek. Sten Creek maintains a surprisingly consistent flow even after Spike Camp Creek is dry. Alyeska personnel report that Sten Creek continues to flow well into winter. Observations in all three years of this study indicate that Spike Camp Creek displays discontinuous flow downstream of the haul road prior to dewatering adjacent to the materials site. While there is some possibility of a distinct groundwater source providing part of the discharge in Sten Creek, this appears doubtful since the two streams display similar conductivities and temperatures (125 μmhos at 6.0°C for Spike Camp Creek and 105 µmhos at 6.5°C for Sten Creek, July 28, 1983). It is possible that the early winter flows in Sten Creek represent water stored in the alluvium during the open water season.

The number of fish using Spike Camp Creek appeared to be greater than the number using the Atigun River mainstem upstream of its confluence. Elliott (1982) placed a wire trap in Spike Camp Creek in late August and caught a total of 168 grayling, six round whitefish, and two Arctic char emigrating downstream. The 132 fish reported stranded in 1980 would therefore represent a major portion of all fish using the drainage. Fortunately, entrapment appears to occur only under certain weather conditions. Our own studies reveal extremely low densities of fish in the drainage and no spawning activity. Utilization appears to be restricted to a brief feeding period in July and August. The pond in Sten Creek created by materials site excavation downstream of the haul road is also used by grayling in midsummer, but no fish were caught upstream of the pond.

Undoubtedly the excavation of the Sten Creek pit has intensified an already existing tendency toward discontinuous flow. Combining the two streams into a single channel might alleviate the problem to some extent. Unfortunately, the extent of channel modifications necessary to combine the two streams would be substantial, and might simply result in the combined flow of both streams disappearing in the porous substrate. Installation of a new haul road bridge in 1983, half-way between the two existing channels, leaves open the possibility that there may be some future recombination.

6.4.4 North Fork Chandalar River

Johnson and Rockwell (1981) and Elliott (1982) describe grayling entrapment in the North Fork Chandalar River near MP172.0. These authors report that discontinuous surface flow in the vicinity of MS-109-3 expansion 4 (Figure 26) was responsible for trapping large numbers of grayling near the airstrip access bridge. The largest estimated entrapment was 5,000 fish found in two isolated pools on September 5, 1979 by personnel of ADF & G. An estimated 1,650 grayling and 50 slimy sculpins were rescued on September 8, and moved to areas of continuous flow downstream. Raven and small mammal predation has been credited with the difference in numbers between the original estimate and the actual number rescued (Elliott 1982). Density studies conducted in 1982 and 1983 revealed a maximum of under 2,000 fish (average 1,580 fish for three years) using the affected area at peak summer levels. Either the original estimate of 5,000 fish was too high, or fish densities in the system were considerably lower from 1981 to 1983 than they were in 1979.

Elliott (1982) reported that 11 grayling and one round whitefish were trapped above the dry area in 1980. On September 16, 1981, AEI personnel rescued 525 grayling (120 to 350 mm) of a total of about 1,000 grayling stranded upstream of MP173.0. In addition to the rescued fish, over 300 grayling (70 to 150 mm) were left in isolated pools between MP172.0 and MP173.0. Nearly all fish not rescued had died by September 19 as the last isolated pools dried up or froze. In September 1982, only about 70 grayling (135 to 290 mm) were trapped above the dry area and most of these escaped during a late season freshet on September 15 and 16. In 1983, cold weather in late August forced most fish out early. Only 18 grayling (126 to 248 mm) remained upstream of MP172.0 when the first discontinuous flow occurred on September 5, but 36 more were found in isolated pools downstream. All but six of the fish above MP172.0 escaped during small freshets, but 37 grayling (121 to 135 mm) were still present in isolated pools downstream of MP172.0 on September 9. It cannot be confirmed, but these fish probably died.

Observations of the pattern of streambed drying in the vicinity of MP172.0 vary considerably. Rockwell (pers. comm. Officer of Special Projects, Bureau of Land Management) reports that stranding of fish occurred as a result of an initial dewatering from 25 to 200 m downstream of the airstrip bridge. Rockwell and Johnson (1981) cite an October 5, 1979 memo by Glaspell (J. Glaspell, ADF & G) stating that the next water below the airstrip bridge was 200m downstream. Elliott (1982) reports that on September 18, 1980, discontinuous flow occurred in a 0.6 km long reach downstream of MP172.0.

In 1981, the first discontinuous flow was observed 400 m downstream of MP172.0 on September 8. In 1982, results were similar, with the first discontinuous flow observed 300 m below MP172.0 on September 13. Discharge at the airstrip access bridge measured 0.18 m^3/s and flow through the materials site remained above 0.10 m^3/s. In 1983, the initial dewatering occurred near the top end of the materials site (MP171.9) on September 5. On this date, discharge at the airstrip access bridge measured 0.32 m^3/s, but there was evidence of declining stream discharge within 200 m of the airstrip bridge. By September 9, discharge at the bridge measured 0.21 m^3/s, declining gradually to the dewatered area 100 m inside the materials site. The dewatered reach extended approximately 1 km downstream (MP172.7). During all three years of study, and possibly in 1979 and 1980, an area extending from 25 m downstream of the airstrip access bridge (MP171.6) to the top end of the winter icing (MP173.0) eventually ceased to flow, although discharge was still present between MP170.0 and the airstrip access bridge until it froze during the first severe weather.

Figure 26 shows the limits of MS-109-3 (expansion 4) as originally applied for, together with the limits of the area actually disturbed. The only floodplain disturbance was the clearing of brush and stockpiling of an estimated 5,050 m^3 (6,600 yd^3) of gravel scraped from gravel bars. An application for use of the entire site was rejected by the Bureau of Land Management (BLM) on September 23, 1975. On April 21, 1976, BLM approved the application to the extent that only the stockpiled gravel could be removed and the disturbed area rehabilitated. Reseeding of the disturbed area was undertaken and that seeding is still readily visible on the ground and in aerial photographs (Alyeska Pipeline Service Company, undated). There is no record of a broad disturbance extending from the airstrip access bridge nearly to MP173.0, the area subject to dewatering.

It is apparent that a relatively broad area in the North Fork Chandalar River is subject to discontinuous flow and that the problem is not entirely explained by the presence of the small disturbance at MS-109-3 (expansion 4), as others have suggested. In 1981, a nearly identical area of discontinuous flow was located in the undisturbed East Branch North Fork Chandalar River, at nearly the same altitude and latitude, and with a similar gradient (pers. comm. K. Durley, Alyeska Pipeline Service Company). A large number of char and grayling were reportedly trapped above a dry area under the same circumstances which stranded large numbers of grayling in the West Branch the same year.

It has been suggested by personnel of the Bureau of Land Management, Office of Special Projects (pers. comm. J. Rockwell) that a diversion of the Chandalar River mainstem into Airstrip Creek might alleviate the problem of discontinuous flow. The foregoing assessment of fish densities in Airstrip Creek provides an indication of fish use in comparison to adjacent portions of the mainstem. Diversion of the mainstem would drastically modify habitats in Airstrip Creek, and eliminate those in the existing mainstem channel.

The reasons for delayed grayling emigration from the area downstream of the dewatered reach (ie. downstream of MP172.0) is unexplained. Large groups of juveniles (n = 325 in 1981) have been observed repeatedly by various field personnel (Glaspell, Rockwell, Elliott, and AEI) in the section of stream between MP172.0 and MP173.0. These fish appear to be attracted to the area since nothing is preventing their emigration. Many remain and are stranded in isolated pools at freezeup. It is possible that the presence of small quantities of groundwater are responsible for the delay since the location is near the top end of a major winter icing. It has also been suggested that thermal irregularities caused by the buried pipe are responsible. While there are thermal irregularities at several locations in the North Fork Chandalar River (Section 6.5.2), the pipeline is located at least 200 m east of MP173.0 and there was no evidence of thermal irregularities at this location during 1981 through 1983.

6.5 Thermal Irregularities

Thermal irregularities, described in Section 4.7, were investigated at several locations in the Atigun, North Fork Chandalar, Dietrich, and Middle Fork Koyukuk rivers during the fall of 1982 and 1983. The abundance of algae often makes these areas relatively easy to locate. Since discharge in the Atigun River declined sufficiently by early September to attract fish to heated water, our studies were concentrated there. At other locations, water levels remained too high in September for the small quantities of warm water to attract significant numbers of fish.

6.5.1 Atigun River

Heated water was observed at four locations in the Atigun River floodplain between MP157.0 and MP164.0, including sites located at MP163.7 (1982 only), MP162.2, MP160.8 to MP161.3, and MP157.2. The entire length of buried pipe in the Atigun River floodplain was surveyed by foot on at least two occasions in each of the two years of study and no other locations were found. With the highly fluid streambed typical of this river, thermal irregularities may fluctuate or disappear from one year to the next, depending on the extent of channel migration. The attraction of fish to these locations depends on several factors including the water volume available, water temperature, availability of pool habitat and weather conditions during emigration.

On September 20, 1980, Elliott (1982) found heated water (2.0° to 8.5°C) in the area between MP163.4 and MP164.5. Below this area, the stream channel was dry to MP162.2 where warm water (4.0°C) again re-emerged directly over the pipeline trench. Between MP163.4 and MP164.5, 65 grayling and two round whitefish were stranded by the discontinuous flow. Most of these fish were subsequently rescued and transferred downstream one to three days later. Elliott states that "...a reasonable explanation for the observed variation in flow and temperature is that water was captured by the pipeline trench and/or thaw bulb and was heated by the pipeline." Hemming (1982) reported that over 50 grayling were observed stranded at MP162.2 in late October 1981, and that the remains of 29 dead fish were present on March 17, 1982. These fish were apparently attracted by warm water as stream discharges declined, but were trapped and died as these areas froze or dried up in winter.

On September 3, 1982, an AEI field crew returned to the same area described by Elliott (1982) between MP163.4 and MP164.5. A water temperature of 9.0°C was measured at MP163.7. Streamflow was continuous between MP164.0 and MP163.0, the mouth of Spike Camp Creek, at a discharge of 0.09 m^3/s. No fish were present, probably because low flow levels in the summer of 1982 discouraged use of the upper Atigun River. Cooling of the heated water occurred rapidly and, 200 m downstream, water temperature was the same (4.0°C) as it was upstream of the source of heated water. Ambient air temperature was 5.0°C. This area was dry during early September 1983 but, again, there was no evidence of fish stranding probably because, as in 1982, periodic dry periods in summer limited use of the area by fish.

At MP162.2, fish concentrations were first observed on September 3, 1982. Warm water was discharging into a side channel from directly over the buried oil pipeline. The heated water provided approximately 10% of the total discharge (0.07 m^3/s) in the side channel. Above the warm water source, the side channel water temperature averaged 4.0°C, but water bubbling from over the pipeline trench was 10.5°C. Twenty-seven grayling (138 to 264 mm) were concentrated in a 1 m^2 area immediately adjacent to the warm water source, and a further 31 grayling (135 to 310 mm) and one char (156 mm) were collected in two other small pools within 50 m downstream. By comparison, extensive electrofishing in a 1 km reach upstream to the mouth of Sten Creek produced only 12 grayling (140 to 264 mm) and one round whitefish (196 mm) indicating that most fish had emigrated downstream.

Approximately 50 grayling were still present in this side channel on September 15, when total stream discharge in this reach of the Atigun River was only 0.16 m^3/s. Most of these fish moved out of the warm water plume during a freshet on September 16 when discharge increased to over 4.0 m^3/s. No fish were found at this location after September 16. Low water levels in 1983 limited use of the entire upper Atigun and, by September 4, no fish were present between MP161.0 and MP163.0. Both the Atigun River and Spike Camp Creek were dry upstream of their confluence.

Small concentrations of grayling were also observed in small, warm side channels in the Atigun River floodplain at MP160.8 (n=13; 80 to 190 mm) and at MP161.3 (n=16; 120 to 200 mm). On September 4, 1982, water temperature was 12.0°C at the first site and 8.5°C at the second. Adjacent channels connected to the mainstem averaged 4.0°C on the same date. The September 16 freshet apparently induced most of these fish to move out of the area, but it is not known whether fish returned as water levels declined. Both of these channels are located immediately adjacent to the workpad and the proximity to the east valley wall suggests that considerable cross-pipeline intergravel flow occurs.

In early September 1983, a single warm water source emerged immediately adjacent to the MP161.0 marker. On September 6, mainstem water temperature was 1.0°C; at the warm water source, temperatures reached 10.5°C. The entire side channel from MP160.8 to MP161.3 displayed elevated temperatures ranging from 3.0° to 10.0°C. A 100 m long stream section, ranging in temperature from 6.0° to 10.0°C, was blocked off and all fish present were collected (Figure 27a). For comparative purposes, a similar 100 m section was blocked off in an adjacent unheated channel (1.0°C). Section 1, the heated channel, contained a total of 206 juvenile grayling (82 to 134 mm) with a combined biomass of 1,730 g. Section 2, the control, contained no fish.

The largest number of fish concentrated in a warm water source was observed at MP157.2. Large numbers of juvenile grayling were first observed on September 15, 1982 in a 1 to 2 m wide side channel emerging from the immediate vicinity of the buried pipeline. The channel, which measured 435 m in length and had an average water temperature of 9.5°C, contained an estimated 700 grayling.

A 100 m test section in the warm water channel near its source (Section 1, Figure 27b) harbored 301 juvenile grayling (47 to 123 mm). An adjacent channel, similar in physical characteristics to the warm water channel, and connected to the mainstem at both its upper and lower ends, had an average water temperature of 4°C and contained only three juvenile grayling in a representative 100 m test section (Section 2, Figure 27b). A comparison of the habitat features of these two channels is presented in Section 6.7.10. Other than water temperature, the two channels were found to be identical in habitat characteristics.

Similar results were obtained at this location on September 11, 1983. The warm channel was a uniform 5.0°C while adjacent channels measured 1.0° to 3.0°C. There was no distinct warm water source and discharge levels in the warm water channel were lower than in 1982. Section 1, the 100 m test section in the warm water channel, contained 407 juvenile grayling (84 to 156 mm) with a combined biomass of 3,860 g. Section 2, the 100 m test section in the control channel, measured 2.0°C and contained eight grayling (90 to 104 mm) and two char (133 and 137 mm) with a combined biomass of 132 g. One week earlier, on September 3, water temperature in the warm water channel was 7.5°C compared with 3.0°C in adjacent channels.

The eventual fate of these fish is not known since our studies did not continue past late September. There is considerable evidence of groundwater in the area immediately downstream. A large winter icing forms in the vicinity of the West Fork of the Atigun River which may indicate that there is sufficient groundwater flow to support overwintering. It is likely, however, that any fish which remain in the warm water channel at MP157.2 in the fall will die, since this channel does not appear to have sufficient discharge or depth of water to sustain fish through winter.

6.5.2 North Fork Chandalar River

In the North Fork Chandalar River, there were several observations of warm water adjacent to the buried pipeline in the fall of 1982 and 1983. Only one of these locations attracted fish. On September 7, 1982, a small warm water channel flowing from the pipeline centerline was observed 100 m above the airstrip access bridge (MP171.5). Twelve juvenile grayling (121 to 146 mm) were collected from this channel in a plume of 11.0°C water. Water temperature in the adjacent mainstem averaged 3.0°C on the same date. These fish escaped downstream with most other fish trapped above the area of discontinuous flow during the September 16 freshet mentioned previously (Section 6.5.1). In 1983, the warm source was 7.5°C on September 5, but scour had eliminated all pool habitat and no fish had accumulated in the swift water. Mainstem water temperature on this date was 0.0°C. It appears that, at least in 1982, this warm channel did attract downstream migrant fish, delaying their downstream movements, and intensifying the entrapment problem in this area.

6.5.3 Dietrich River

In the Dietrich River, several areas of warm water discharge were located during the fall of 1982 and 1983. Only two contained fish. On September 13, 1982, a 1 to 2 m wide channel at MP181.1 was flowing parallel to the pipe centerline over a 50 m distance. Average temperature in this channel was 8.0°C over the pipe, but 100 m upstream average temperature in the same channel was only 3.0°C. Discharge in the channel upstream of the warm water was 0.08 m^3/s, but over the pipeline, discharge increased to 0.11 m^3/s. These data suggest that warm water was emerging from the pipeline trench. The entire 50 m warm water section was electrofished producing 23 grayling (112 to 192 mm), one Arctic char (190 mm), and numerous slimy sculpins. No fish were caught upstream of the heated area. No warm water was located in this area in the fall of 1983.

On September 6, 1983, a small side channel at MP179.8 was investigated. Mainstem temperature was 1.5°C but side channel temperature immediately adjacent to the workpad was 10.0°C. A 150 m length of stream was electrofished within the warm water plume yielding 32 grayling (117 to 270 mm), four Arctic char (111 to 114 mm), and numerous slimy sculpins.

6.5.4 Middle Fork Koyukuk River

In the Middle Fork Koyukuk River, despite several previous reports of thermal irregularities, only one area of warm water emerging over the buried pipe was located (MP 208.5). On September 13, 1982, water temperatures in a 2 to 3 m wide channel, flowing for 40 m over the pipeline crossing, measured 7.0°C. In comparison, water temperatures in the same channel upstream of the crossing averaged 3.5°C. Discharge in the channel remained uniform along its entire 90 m length at 0.13 m^3/s. Ninety-seven grayling (56 to 199 mm) were present in the 40 m length of warm water channel over the pipeline crossing, but none was caught in the 50 m length of cooler water upstream of the pipeline crossing.

In 1983, a slight channel migration moved the channel away from the pipeline crossing to a location against the southeast side of the floodplain where the channel crosses the pipeline at a 90° angle. On September 14, warm water bubbling up over the buried pipeline measured a surprising 25.0°C, while water temperatures in adjacent channels were only 4.0°C. The small trickle of water flowed 10 m into the side channel studied the previous year where it was quickly diluted to produce a combined temperature of 5.0°C. No fish were present in the side channel, but discharge was still high (0.21 m^3/s). Considering the depth of the side channel, nearly 1 m against the armored bank, fish could have moved into this channel later in the year. At approximately the same location, Chihuly (1982) reported water temperatures up to 33.3°C on March 16, 1981 and 17.2°C on April 11, 1981. He also observed a "...school of small fish (>30) 2" to 4" [51 to 102 mm] in total length, possibly grayling."

6.6 Fish Habitat Preference Studies

Fish habitat preference studies were designed to fulfill three purposes:

1. To define the habitat preferences of the most common fish species based on their selection from all available habitats;

2. To determine whether modifications in disturbed areas have affected habitat characteristics important to fish habitat selection; and

3. To assess whether reductions in fish density in modified habitats have, in fact, resulted in reductions in overall population levels.

The general approach is not new, having been used in southern locales, (Bovee and Cochnauer 1977, Binns and Eisermann 1979) but it is new to the Arctic. Because there has been little study of fish habitat preference in the Arctic, we examined a much wider range of habitat features than would normally be required, in order to eliminate those for which fish did not select, and to assess the relative importance of the remaining parameters.

Habitat preference determination is based on measuring the range of physical characteristics available in the environment; then establishing a rating system to quantify the frequency of occurrence of each parameter. Habitat preference is then determined by quantifying the characteristics of sites actually used by fish, and comparing them with the characteristics of the total available habitat.

6.6.1 Available Habitat

The following procedure was used to study the habitat preferences of grayling, Arctic char, and round whitefish.

1. In total, 27 streams reaches were visited during the study.

2. Preliminary physical measurements were made to assess the variability of physical characteristics in each stream.

3. Locations which supported fish were observed, all fish present at each observation point were collected and physical measurements were made at each site.

4. Because the effort needed to sample all 34 km of watercourse from which fish were collected would have been prohibitive, representative 100 m sections of stream were selected to characterize the range of available habitat.

5. Selection of representative sections was partially subjective, but an effort was made to include the entire range of physical features present in the 34 km of streams sampled.

6. Detailed physical measurements were made in each of these 100 m long sections along transects spaced at regular intervals (10 or 20 m depending on habitat variability).

7. Data for each 100 m long section was weighted by multiplying the data points times the number of 100 m sections of similar habitat present in the entire 34 km of streams.

In selecting the data base for a description of the available habitat, 27 stream reaches were examined in areas where fish were collected. Based on subjective observations and preliminary physical measurements, 20 of these, encompassing 47 representative 100 m sections, were selected for detailed physical measurement (Table 23). Preliminary computer analysis revealed that, due to the great similarity between 100 m sections in several streams, only 38 representative 100 m sections from 15 stream reaches were required to accurately model all 27 stream reaches in the data set. The ultimate data set included 7,233 data points, which reflected the availability of various habitat features in all study streams. Data for the remaining five streams where detailed physical measurements were made were omitted from the final analysis.

Gradient, benthic invertebrate standing crop, and taxonomic diversity are summarized for all 27 stream reaches studied in Table 23. The 28 physical characteristics measured at each data point in the representative sections are described in Volume III, Appendix B. Table 24 summarizes the physical characteristics of each of the study streams. In the table, the weighted mean column has been adjusted to represent the entire 34.3 km of stream length in which fish habitat preference observations were made. Since cover features (eg. bank vegetation, bank cover, and rock cover) were coded simply as present (1) or absent (0), the weighted mean for these parameters is in fact the percentage of sites where the relevant cover feature was present. Thus, for example, bank vegetation provides cover at 18% of all points within the study area.

Within the data set, stream size is relatively small. Mean stream width is 9.0 m with a mean discharge of 2.64 m^3/s. The Foothills Streams (McCart et al. 1972) within the data set are substantially larger than the mean, averaging 19.5 m in width, compared to 8.2 m in Mountain Streams. Discharge in Foothills Streams averages 5.25 m^3/s compared with 1.99 m^3/s in Mountain Streams. The larger size of Foothills Streams and the greater homogeneity of habitat necessitated fewer measurements. This results in a large cell area for Foothills Streams (Table 24). Cell area was calculated by multiplying the distance between points on transects by the distance between transects. In large streams with few measurements, cell size is invariably large. Since, however, grayling appear to use larger habitats in Foothills Streams than in Mountain Streams (Section 6.6.2) the probability of placing a habitat measurement point within a fish habitat is comparable in both stream types.

Stream depth in the study area averages 0.35 m, with a maximum depth of 2.28 m. While there are a few pools deeper than 2.28 m, particularly in sampled portions of the two Bonanza Creek tributaries, these were excluded from the data set. With the capture techniques used in this study, seines and electrofishers, and with limited visibility, it is impossible to ensure that all fish present in depths over 2.0 m are observed or captured.

Current velocity at mean depth (40% of depth) averages 0.48 m^3/s and maximum velocity is 2.2 m/s. While a few sites in the study area flowed at velocities higher than 2.2 m/s, none of these areas was measured. Since velocities above 2.2 m/s are well above the sustained swimming capability of fish species common to the area (McPhee and Watts 1976), it is unlikely that any of these locations provides habitat for summer feeding fish.

Figure 28 shows the relative abundance of depth, velocity, and substrate classes in the study area. Depths between 0.1 and 0.6 m include most of the available habitat (84.2%) while depths over 0.6 m are increasingly rare. Velocity peaks at about 0.3 m/s and velocities under 0.8 m/s characterize 80.7% of available habitat. Substrates are generally dominated by larger particle sizes with the majority of available substrate (81.8%) in Classes 5 through 8 (2.6 to >40 cm diameter) and 37.6% of all observations were in a single class, Class 7 (25 to 40 cm diameter). Habitats where substrates consisted primarily of fines and the three classes of gravel are relatively uncommon, comprising in total only 18.2 % of available habitat. Organic material and bedrock are too rare in the study area to appear in the analysis.

A classification of habitat types reveals that 50.3% of the area consists of riffle habitat (greater than 0.5 m/s). Pools comprise only 23.2% of the aggregate habitat and runs, areas with intermediate velocity ranging from 0.3 to 0.5 m/s, comprise 20.6% of available habitat. The two remaining habitat types, low-velocity areas along banks and boulder-controlled pools, comprise 4.0% and 1.9% of available habitat respectively.

Of those data points adjacent to banks (omitting the midstream point on transects), gravel bars (57.9% of total bank area) are the most common bank type. Cutbanks are the second most common bank type, comprising 32.0% while sloping loose gravel and rock comprise 7.2% of total bank area. Other bank types are rare (2.9% combined).

6.6.2 Fish Habitat Use

Data describing the habitats used by stream-dwelling grayling, Arctic char, and round whitefish are summarized in Volume III, Appendix Tables F-1 through F-3. These data, based on visual observations followed by fish collections, define the limits of each habitat characteristic selected by summer feeding fish. Fish suspected to be migrating or blocked by either man-made or natural barriers have been excluded from the analysis. The data are based on observations of summer feeding fish at more than 500 individual locations, June through September, 1981 and 1982.

The separation of fish into adults, juveniles, and young-of-the-year was based on fork length and not on a determination of state of maturity or age analysis. Since few fish were killed during these studies, fish could not be dissected to look for evidence of previous spawning. A slight overlap was designed into the separation of juveniles and adults to ensure that most immature fish were included in the immature category. For example, grayling up to 220 mm are considered juveniles and grayling down to 180 mm were considered adults. This 40 mm overlap resulted in the inclusion of a few of the same fish in both data sets. The method of separating adults and juveniles is described in greater detail in Volume III, Appendix D (Statistical Methodology).

Grayling are the most numerous species in the study area, accounting for 83.5% of the 1,934 fish observed in habitat preference studies. Arctic char made up 8.4% of the sample and round whitefish the remaining 8.1%. The only other species present in significant numbers is the slimy sculpin which, due to difficulties in obtaining accurate census data, were not included in these studies. The slimy sculpin, an essentially bottom dwelling species without a swim bladder, is nearly impossible to census using the techniques employed in this study.

Round whitefish and Arctic char are found in greater numbers in larger streams and areas with perennial groundwater flow. Both species are fall spawners and must use areas with a continuous supply of well-oxygenated water through winter for successful spawning. Since these areas are relatively rare in our study area, the habitats sampled must be considered marginal habitat areas for both species. In contrast, grayling spawn at breakup and are able to use streams in our study area for spawning, rearing, as nursery area and, in a few locations, for overwintering. As a result, the habitats within our study area are more optimal for grayling than for the other species.

Young-of-the-year grayling were abundant in the study area, and small numbers of young-of-the-year Arctic char occurred as well. Since, however, none of the modified habitats studied in detail is an important spawning or nursery area for these fish, data describing their habitat use are incidental to the study, though they are included in Volume III, Appendix F.

6.6.2.1 Juvenile Grayling

The habitats used by juvenile grayling and other fish are summarized in Table 25. Coded variables are defined in Volume III, Appendix A, and summarized in Table 5.

Grayling juveniles were found in water with an average depth of 0.5 m. Average velocities at the collection point were 0.10 m/s at the depths at which fish were observed and 0.23 m/s at mean depth. Most juveniles, 56.8%, were observed within 10 cm of the bottom except while feeding. Despite the low velocity of occupied habitats, 59.8% of juveniles observed were located in habitats immediately adjacent to swift water (>0.5 m/s).

Pools contained 51.4% of juvenile grayling; runs 26.4%; low-velocity areas against banks 11.2%; and boulder-controlled pools 9.9% (Table 25). Riffles were the least used of the five habitat types, supporting only 1.1% of juvenile grayling. The mean area of habitat used by juvenile grayling was surprisingly large at 126 m^2.

Mean width measured 5.1 m and mean length 16.3 m. Because habitats are not regularly shaped, habitat area was estimated separately from the width and length (both maximum values) and cannot be calculated by multiplying length by width. These relatively large habitat areas are indicative of a tendency, most notable in low-gradient streams, for juvenile grayling to use large pools, particularly in Foothills Streams. The minimum habitat area most often encountered in small, boulder-controlled pools in steep gradient Mountain Streams, was 1.0 m^2 with a minimum width of 0.5 m and a minimum length of 0.5 m.

The percentages given in Table 25 for cover types indicate the percentage of all juvenile grayling observed that were found in proximity to each of the nine cover types. Thus 55.2% of juvenile grayling used the deepest water available as cover, 22.4% used locations with overhanging bank vegetation, 29.3% used locations where banks provided cover, and 49.8% were found in locations where coarse rocks or boulders provided cover. Despite the marked use of pool habitats, 26.2% of juvenile grayling were found in locations where water turbulence provides some cover. Of the nine cover features examined, an average of 2.2 cover features were present at each location supporting juvenile grayling.

The average channel width at locations supporting juvenile grayling was 7.8 m, but fish were found in all channel widths up to 26 m. If fish displayed an avoidance of banks, the average distance from the bank would be slightly less than half the channel width or, in this case, 3.5 m. The average distance from the bank was in fact 1.5 m, suggesting an affinity for banks as cover and/or for low-velocity areas which are common along banks. Another factor which may be involved in the selection of habitats near banks is the availability of rock cover. In most streams with a U-shaped configuration, exposed rocks are most common near the banks where depths are slightly shallower than in midchannel.

Juvenile grayling used streams with an average benthic invertebrate standing crop code of 1.1 and a diversity code of 1.7. While the entire range of benthic standing crop and diversity was used, these codes correspond to a standing crop of food organisms of 550 organisms/m^2 and a taxonomic diversity of eight taxa.

6.6.2.2 Adult Grayling

Adult grayling were found in an average water depth of 0.6 m, slightly deeper than the average for juveniles (Table 25). Average velocities at the collection point were 0.10 m/s, at the depths at which fish were observed, and 0.21 m/s at mean depth. Both averages were virtually identical to those recorded for juveniles. Like juveniles, adults also remained near the stream bottom except while feeding. Of fish observed, 53.8% were found within 10 cm of the bottom. Despite their use of deep low-velocity areas, 69.7% of adults were observed in habitats adjacent to swift water (>0.5 m/s). This figure is even higher than the figure for juveniles (59.8%), probably reflecting the importance of current to adults in providing a steady source of food.

Pool habitats supported 65.4% of the adult grayling; run habitat 21.0%; low-velocity areas 6.4%; boulder-controlled pools 7.1%; and riffles only 0.2%. Mean area of habitat for adults (169 m^2) was substantially larger than that recorded for juveniles (125 m^2). Mean width of habitat (7.3 m) was wider than that used by juveniles (5.1 m), but mean length of habitat (18.5 m) was comparable to that used by juveniles (18.3 m). Again, the large size of habitats is indicative of the tendency of grayling to use large pools. Minimum habitat size for adult-sized fish was 1.5 m^2 in the boulder-controlled pools typically found in Mountain Streams. The extremely large maximum habitat size, 1,250 m^2, is typical of the large beaded pools found in Foothills Streams (eg. Oksrukuyik Creek) where fish forage around the entire area of the pool.

On the average, adult grayling utilized 2.3 of the nine cover features examined. Depth as cover (59.7%) was the most commonly used cover feature, followed in decreasing order by bank cover (38.3%), rock cover (29.6%), overhanging bank vegetation (28.7%), and shading (26.7%). Bank cover, overhanging vegetation, and shading were more important to adult graying than to juveniles, but rock cover was considerably less important. Shading is often a function of bank cover and vegetation, since cutbanks and large streamside vegetation often create shaded areas. Turbulence provided cover for only 16.9% of adult fish, again reflecting a tendency for them to use large placid pools.

Average channel width for adult grayling was 10.0 m, a slight increase over the 7.8 m average for juveniles. Adults were still found in the proximity of banks which were an average 1.8 m distant. If fish displayed no selection for banks, an average distance closer to 5 m, half the mean channel width, would be expected.

As indicated by the higher mean code values (Table 25), adult grayling had a tendency to use streams with higher benthic invertebrate species diversity and larger standing crops than did juveniles. This difference reflects the attraction of larger fish to low-gradient Foothills Streams which support more abundant and diverse benthic invertebrate communities than Mountain Streams. Juvenile grayling are often found in small streams subject to periodic dewatering, which limits the development of benthic communities.

A higher percentage of adults (23.2%), compared to juveniles (16.1%), were found in proximity to slumping unstable banks. Instream slumps are important velocity barriers in a few Mountain Streams (eg. Holden Creek, Falcon Creek, Roche Montonnee Creek). Adult fish were generally more abundant in these areas than juveniles. Instability apparently does not always have a negative effect on fish use.

6.6.2.3 Arctic Char

While the sample size for Arctic char is relatively small (n=83 locations), the locations studied were representative of those areas used by Arctic char in the study area. Juvenile char were found at an average depth of 0.3 m, considerably shallower than either juvenile or adult grayling. Average velocities at the collection point were 0.03 m/s at the depths at which fish were observed and 0.05 m/s at mean depth. Both averages were considerably slower than velocities used by grayling. Adult char were rare in the study area (n=11 locations), but, where they were present, used an average depth of 0.4 m, and average velocities at the collection point of 0.06 m/s at the depths at which fish occurred, and 0.14 m/s at mean depth. Nearly all char observed (85.2%), both adults and juveniles, occupied habitats adjacent to swift water (>0.5 m/s). A steady food supply provided by rapidly flowing water appears to be important to the use of habitats by Arctic char.

The attraction of both juveniles and adult char to low-velocity areas is accounted for by the high percentage of fish found in pools. Habitat type was identified as pool for 87.5% of the juveniles and 63.6% of the adults included in the sample. Juvenile char were most abundant in narrow stream channels having an average width of only 4.5 m. Adult char were found in slightly wider channels averaging 6.4 m.

The average number of cover features used by juvenile char was 1.8 and by adult char 2.6. Bank vegetation (45.8%), instream vegetation (36.1%), shading (29.2%), and rock cover (27.8%) were the most important cover features for juvenile char (Table 25). Of the 11 locations where adult char were observed, seven were near rock cover and six were in the immediate vicinity of the streambank.

The habitat area used by char was relatively small compared to that utilized by grayling, averaging 23 m^2 for juvenile char and 40 m^2 for the small sample of adult char. The smallest habitats used by both adult and juvenile char measured 1.0 m^2.

6.6.2.4 Round Whitefish

Like Arctic char, round whitefish were relatively rare in the study area (n=107 locations, of which 30 were utilized by juveniles and 67 by adults). Round whitefish occupied habitats which were similar to those used by grayling. The two species were often found together in mixed schools, particularly in Foothills Streams. Round whitefish juveniles used habitats with the same average depth as those utilized by grayling, 0.5m, but velocities were slightly slower, averaging at the collection point, 0.08 m/s at the depths where fish occurred, and 0.21 m/s at mean depth. Adults were found in considerably deeper water, averaging 0.8 m, with velocities at the collection point nearly identical to those recorded for juveniles (0.08 m/s at the depths where fish occurred and 0.17 m/s at mean depth). A high percentage of both juvenile and adult round whitefish were found in habitats immediately adjacent to swift water (>0.5 m/s). Of the 30 locations supporting juvenile round whitefish, 73.3% were located adjacent to swift water. Adults, observed in a total of 67 locations, were adjacent to swift water in 76.1% of habitats observed.

Both adult and juvenile round whitefish display a strong attraction to pool habitats--73.3% of juveniles and 83.6% of adults were caught in pools. Average channel width for adults was 11.3 m, the largest channel size for the three species studied. The affinity of this species for large rivers would have resulted in a much wider mean channel width had larger streams (eg. lower Atigun, Sagavanirktok, lower Dietrich rivers) been included in the data set. Juvenile round whitefish used only slightly smaller channels, averaging 9.7 m in width.

Round whitefish adults and juveniles were similar in the average number of cover features they used (2.3). Juveniles used banks (60.0%), depth (53.3%), rocks (36.7%), bank vegetation (30.0%), and shading as cover (Table 25). Adults used depth (77.6%), banks (59.7%), and bank vegetation (26.9%) as the predominant forms of cover.

Round whitefish occupied habitats with an even larger average size than those recorded for grayling. Juvenile habitats averaged 180 m^2, and adult habitats averaged 334 m^2. The extremely large figure for adults reflects their relative abundance in the largest beaded pools in Foothills Streams.

6.6.3 Habitat Preference

A comparison of data describing available habitat (Section 6.6.1) with data describing the habitats selected by fish (Section 6.6.2) using histograms, revealed that most of the parameters measured were:

1. Interrelated with other habitat features and did not, therefore, vary independently;

2. Similar in both availability and selection frequency; or

3. Poorly defined as available habitat since fish were not present to define the boundaries of the area measured (eg. depth of fish, collection point velocity, habitat area).

As an example of the latter, comparisons of a parameter such as habitat size with the arbitrary cell size used in defining available habitat have little value in predicting fish density. In determining habitat preference, any parameters which have any of the characteristics listed above have been eliminated from further consideration, since only those characteristics which define the characteristics of habitats which fish use in frequencies greater than those found in the natural environment are of predictive value in determining fish densities.

Of the three species examined, only grayling were present in sufficient numbers to allow development of polynomial suitability-of-use functions. These functions have been developed for depth at the collection point, mean velocity, and substrate composition for both juvenile and adult grayling (Section 6.6.3.2). The following section explores other habitat characteristics which do not lend themselves to inclusion in the suitability-of-use function. Since the number of habitat features measured is large, this discussion is limited to only those features which are selected for by fish, and which are likely to be modified by instream activity.

6.6.3.1 Histogram Analysis

In presenting the data for histogram analysis, a relative habitat suitability index (RSI) was used for most parameters to assess the degree of selection, either positive or negative. We have defined this index as the percentage of fish using a habitat feature divided by the percentage availability of that feature. Increasing values of the RSI indicate increasing selection preference in favor of the habitat feature. Values less than 1.0 indicate negative selection preference, values of 1.0 indicate no selection preference, and values greater than 1.0 indicate positive selection preference.

Juvenile Grayling

Grayling juveniles showed a preference for habitats with bank heights of 0.4 m or greater (Table 26). These habitats tended to be areas with cutbanks, slumping, or stable vegetated soil, rip-rap, or boulder banks. Gravel or rock bars with heights of 0.2 m or less made up 62% of available stream banks in the study area, but supported only 27% of juvenile grayling (RSI 0.4). While 74.3% of measured habitats had stream banks 0.4 m or less in height, these habitats supported only 36% of juvenile grayling (RSI 0.5). Slumping earth banks had a high RSI (20.8), but were rare in the study area (0.4% of available habitat). Cutbanks and sloping loose gravel or rock were the most abundant of the preferred bank types in the study area. Together these two bank types were present in 33.7% of habitats and supported 55.9% of juvenile grayling (combined RSI 1.7).

Juvenile grayling were most abundant in narrow stream channels suggesting a preference for bank and cover features associated with narrow channels. Preference was greatest for channels ranging from 1 to 8 m in width. Channel widths greater than 14 m were selected against. This preference for narrow channels may also be a function of preference for low current velocities or pool habitat associated with bank features.

Pools made up only 17.2% of available habitat, but 58.2% of juvenile grayling were observed occupying these habitats (RSI 3.4). High-velocity riffle habitat comprised 54.2% of available habitat, but supported only 0.9% of juvenile grayling (RSI <0.1). Runs, boulder-controlled pools and low-velocity areas near banks all displayed greater use by juvenile grayling than availability of these features would suggest. When the five categories of habitat type were ranked, with the deepest low-velocity habitats on the left and shallowest higher velocities on the right, the relationship shown in Figure 29 emerged. The relative suitability of habitat types declined with decreasing depth and increasing velocity.

Juvenile grayling selected for all of the nine cover types examined except turbulence, turbidity, and slumps (Figure 30). Rock cover, used by the second largest percentage of fish, was the most preferred cover type with an RSI of 3.2. Depth, used by the highest percentage of juveniles, was the least selected for of the six cover features preferred by juvenile grayling. The high availability of depth as cover in the study area, 34.2% of available habitat, resulted in an RSI of only 1.6. Bank cover, instream vegetation, and shade all have RSI's above 2.0. Of these, bank cover was the most important. 29.3% of juvenile grayling captured were located near some form of bank cover. Shade, present at 17.7% of locations supporting graying juveniles, is probably closely related to bank cover and bank vegetation, both of which provide shade.

Juvenile grayling did not select for food availability and food diversity. Often Foothills Streams with the highest food availability and diversity supported mostly adult-sized grayling while juveniles were more abundant in smaller streams and channels. Competition by adult fish may have discouraged juvenile fish from using these areas until declining water levels forced larger fish to emigrate. Despite the apparent lack of preference for the greater food availability in Foothills Streams, juvenile grayling selected for reaches of streams with an average gradient of 0.65%--the average gradient in the study area was 1.20%. Of the juvenile grayling observed, 71.0% used stream reaches with gradients between 0.5 and 1.0%.

Adult Grayling

Adult grayling preferred pool habitats with banks greater than 0.6 m in height. Habitats with no banks (midstream) or those with banks less than 0.6 m in height, comprised 74.3% of available habitat, but supported only 19.6% of adult grayling (Table 26). Of habitats with banks, 61.9% were gravel or rock bars, but supported only 11.8% of adult grayling (RSI 0.2). Cutbanks, 22.4% of available habitat, supported 54.7% of adults (RSI 2.4). Of the remaining six coded bank types, only bedrock and sloping loose gravel and rock were not selected for positively (ie. RSI less than 1.0).

A graph of the RSI's for each of the five coded habitat types (Figure 29) reveals a pattern similar to that for juvenile grayling. Pool habitats comprised only 17.2% of available habitat, but supported 65.4% of adult grayling. This figure represents nearly four times the number expected if no selection of this habitat feature occurred (RSI 3.8). Other habitats were preferred less by adult fish than by juveniles. Run and riffle habitats were both negatively selected for (ie. RSI less than 1.0).

Adult grayling used a range of channel widths comparable to available habitat, but displayed a negative preference for channel widths less than 6.0 m. While stream channels of 5.0 m or less comprised 39.4% of available habitat, these channels supported only 16.9% of adult grayling (RSI 0.4). This difference is probably a function of a preference by adult grayling for deep pools and habitat areas larger than those used by juveniles (Section 6.6.2).

With regard to cover types (Figure 30), adult grayling displayed a stronger preference for depth, bank cover, bank vegetation, and instream vegetation than juvenile fish, but considerably less preference for rock cover. Shaded habitats, probably a function of high banks and bank vegetation, also appeared strongly selected for. While only 34.2% of available habitat was over 0.3 m in depth, 59.7% of adult grayling selected sites deeper than 0.3 m as cover (RSI 1.7). Bank cover was available at 13.0% of sites, but these sites supported 38.3% of adults (RSI 2.9). Bank vegetation, comprising 12.5% of available habitat, was used by 28.7% of adults (RSI 2.3). Rock cover, present at 15.4% of sites, was used by 49.8% of juvenile grayling (RSI 2.3) but only by 29.6% of adults (RSI 1.9). Shading, available at 8.0% of all locations, was used by 26.7% of adult grayling fish (RSI 3.3) compared with 17.7% of juveniles (RSI 2.2). While its availability in the study area was low (5.0%), instream vegetation was the most sought after cover feature (RSI 3.4).

The preference of adult fish for bank-related cover features is further exemplified by a comparison of midstream habitat sites with no banks. These locations which included 30.7% of available habitat, supported 24.0% of juvenile grayling, but only 8.0% of adult grayling.

Adult grayling appeared to use habitats with a slightly higher food diversity and food availability than the average for the study area. This habitat use reflects a slight preference for Foothills Streams, which support a higher standing crop and greater taxonomic diversity of benthic invertebrates than Mountain Streams (McCart et al. 1972). Adult graying selected stream reaches with even lower gradients (average of 0.5%) than those selected by juveniles (average 0.65%).

Arctic Char

Only juvenile Arctic char were caught in sufficient numbers for an analysis of habitat preference. Arctic char juveniles preferred shallow, pool habitats with rocks, boulders, or cutbanks. Most juvenile char (98.6% of those observed) were found within 2 m of a bank. Unlike grayling, juvenile char displayed little aversion to locations with bank heights of less than 0.2 m (RSI 1.3). While cutbanks were still the most heavily used bank type compared to their availability (RSI 1.7), gravel and rock bars displayed only a slight negative selection pressure (RSI 0.7). Juvenile and adult grayling showed a stronger avoidance of habitats with gravel or rock bar banks (RSI 0.4 and 0.2, respectively). Unlike grayling, juvenile char appeared to prefer the narrow channels (6.0 m or less) typical of braided floodplains; hence the higher percentage of fish found in habitats with gravel or rock banks (Table 26).

Other bank types selected for by juvenile char included slumping earth (RSI 3.5) and boulders (RSI 10.5). Both of these bank types were rare in the study area, comprising only 0.8% of available habitat in total (Table 26).

Of the 72 locations where juvenile Arctic char were observed, 87.5% were pool habitats (RSI 5.1). Of the remaining four habitat types, boulder-controlled pools were the only other habitat type selected for positively (RSI 1.4). This selection is consistent with the use of habitats with boulder banks.

Vegetation, both on streambanks and within streams, appeared to be the most important cover feature for juvenile char (Figure 31). Depth as cover and bank cover, both important to grayling, are of little value to juvenile char. Bank vegetation, present in 18.0% of available habitats, provided cover for 45.8% of juvenile char (RSI 2.5). Instream vegetation was present at only 5% of measured habitats, but these sites supported 36% of juvenile grayling (RSI 7.2). Because large slumps of tundra usually carry dwarf willows into the stream, the preference for habitats with slumps was closely related to the use of instream vegetation as cover.

Rock cover, slumps, and shade (RSI's 1.8, 4.7, and 3.7, respectively) were also positively selected for (Figure 31). The use of rocks as cover corresponds with the preference for boulder banks. Shade, in this case, was probably closely related to bank and stream vegetation. Banks, which were negatively selected for as cover (RSI 0.2), were not responsible for shading in the habitats selected by juvenile char. Apparently, those cutbanks which were selected for by juvenile char provided little cover. Juvenile char may have been selecting streams which had a higher than average percentage of cutbank, rather than selecting specific habitats where cutbanks provided cover. The tendency for juvenile char to seek cover in shallow water with overhanging or instream vegetation may be a response to predation by larger fish, primarily other char.

Round Whitefish

Only round whitefish adults were caught in sufficient numbers to allow any analysis of habitat preference. Adult round whitefish appeared to prefer larger streams characterized by large pools and cutbanks. Channel widths greater than 10 m appeared to be used by a higher percentage of fish (56.7%) than habitat availability would suggest. (Channels over 10 m wide represent 33.2% of available habitat.) Bank heights of 1.0 m or greater were found at only 19.9% of locations in the study area, but these habitats supported 82.0% of adult round whitefish (Table 26). Pool habitats, comprising 17.2% of available habitat, supported 83.6% of these fish (RSI 4.8).

Overall, round whitefish adults appeared to prefer cover types similar to those preferred by adult grayling (Figures 30 and 31). Depth was selected as cover by 77.6% of adult round whitefish (RSI 2.3), compared to 59.7% of grayling (RSI 1.7). Since only 34.2% of available habitat was over 0.3 m in depth, round whitefish adults appeared to be highly selective in seeking the deepest habitats available. Bank cover, present at 17% of available habitat, was used by 59.7% of adult round whitefish (RSI 3.5). Instream vegetation and shade were also high in relative suitability for round whitefish (RSI's 3.6 and 2.9, respectively). Shade, in this case, was probably closely related to bank cover and vegetation. Rock cover, present at 15.4% of available habitat, was selected for only slightly (RSI 1.1). Adult grayling, in contrast, selected more strongly for rock cover (RSI 1.9). As was the case with grayling, adult round whitefish displayed negative selection toward slumps, turbulence, and turbidity.

Table 27 presents an overall summary of those habitat features preferred by the four most abundant classes of fish: juvenile grayling, adult grayling, juvenile char, and adult round whitefish. Those habitat features identified as positively selected for will be considered in assessing the effects of habitat modification (Section 6.7).

6.6.3.2 Polynomial Suitability-of-Use Functions

After consideration of the parameters available for a polynomial function defining habitat preference, only depth, velocity at mean depth, and substrate composition appeared appropriate for inclusion. Coded variables did not allow development of curves necessary for equation development. In several instances, bank-related parameters were given measured values, but midstream locations had no banks to permit comparison of fish densities, and it is a prerequisite of the polynomial function that all data be available for each parameter at every data point.

Based on the results of factor analysis, stream width was also considered for inclusion. Experience with stream width as a character in the habitat equations in southern locales reveals that it often displays a strong relationship to fish density (Binns and Eiserman 1979). This parameter, however, is a dependent variable, which changes with bank type, shading, bank vegetation, bank cover, and several other parameters which may in fact be the true features attracting fish. Depth, velocity, and substrate appear to vary independently of most other habitat features, and are consequently, with the appropriate interaction terms, ideal for inclusion in the polynomial function.

Initial scatterplots of depth, velocity, and substrate in locations supporting fish, compared with plots of habitat availability, suggested that there was an apparent selection by adult and juvenile grayling for each of these three parameters. Scatterplots of habitat variable interactions (parameter vs. parameter) showed that an interaction term was necessary for depth vs. velocity and for velocity vs. substrate. No interaction term was necessary for substrate vs. depth.

Juvenile Grayling

The juvenile grayling probability density functions for depth, velocity at mean depth, and substrate (weighted average code) are presented in Figure 32. These functions describe the density of juvenile grayling over the range of depths, velocities, and substrates available in the study area. The Relative Suitability Functions for juvenile grayling were produced by combining these data with data describing the range of available habitat (Figure 28). For juvenile grayling in this study area, the Relative Suitability Function is:

$$f(d,v,s) = 1/N \times \exp[-(a_1,d+a_2v+a_3s+a_4d^2+a_5v^2+a_6s^2+a_7s^3+a_8dv+a_9vs)]$$

where:

- d = depth (m)
- v = velocity at mean depth (m/s)
- s = substrate (weighted average code)
- N = Normalization factor

values for juvenile grayling:

N	a^1	a^2	a^3	a^4	a^5	a^6	a^7	a^8	a^9
1.9034	-7.68	3.38	3.28	5.89	4.18	-0.730	0.0551	0.934	-0.187

limits for the suitability function:

Depth:	0.01 to 2.30 m
Velocity:	0.00 to 2.20 m/s
Substrate:	1.00 to 8.00 (weighted average code)

Based on this function, the relative suitability curves shown in Figure 33 were developed. The maximum value of the suitability function is reached at a depth of 0.65 m, a mean velocity of 0.0 m/s (ie. no flow), and a substrate (weighted average code) of 1 (fines). With regard to depth, relative suitability increases from near zero in the shallowest areas to a maximum value of 0.5 m, then declines to low levels at depths greater than 1.25 m. Velocity is nearly asymptotic, with relative suitability increasing toward zero velocity. Relative suitability drops to near zero at velocities of 0.6 m/s or greater. Substrate shows decreasing relative suitability with increasing substrate size. Juvenile grayling prefer intermediate depths where cover is readily available, the lowest possible velocity, and fine-grained substrates. At increasing depths, juvenile grayling may be subject to predation by larger fish, have less available cover, or be in direct competition for food and space with adult grayling.

Adult Grayling

The adult grayling probability density functions for depth, velocity at mean depth, and substrate (weighted average code) are presented in Figure 32. These functions describe the density of adult grayling over the range of depths, velocities and substrates available in the study area. When these functions are combined with the functions describing the distribution of available habitats (Figure 28), Relative Suitability Functions for adult fish are generated. Values for adult fish can be inserted into the same equation used for juveniles.

Values for adult grayling:

N	a^1	a^2	a^3	a^4	a^5	a^6	a^7	a^8	a^9
0.5718	-11.8	7.93	6.81	7.40	11.9	-1.68	0.133	1.56	-2.20

The same limits for the suitability function presented for juvenile grayling also apply to adult grayling.

Relative suitability curves for adult grayling are shown in Figure 33. Maximum values for relative suitability occur at a depth of

0.80 m, a velocity at mean depth of 0.0 m/s (ie. no flow) and on a substrate (weighted average code) of 1 (fines). Adult grayling apparently prefer deeper habitats, but display even less tolerance of high current velocities than juvenile fish. While undoubtedly able to migrate through areas of high velocity more effectively than smaller fish (McPhee and Watts 1976), adult fish appear to be extremely selective in seeking feeding areas with as little current as possible.

Adult grayling display a distinct bimodality, however, in selecting substrates. While fines are the preferred substrate, weighted substrate codes between four and eight also display an elevated suitability. These codes correspond to coarse gravel (2.6 to 6.0 cm) through coarse rock (26 to 40 cm) sized substrate particles. Boulders were often categorized as pool control features and not included in the substrate composition unless they were submerged. As a consequence, the value of the largest substrate class to adult fish may have been slightly underestimated.

A statistical comparison of relative suitability at sites with no fish vs. sites supporting as least one fish (Table 28) revealed significantly higher relative suitability ($P < 0.01$) at sites supporting both juvenile and adult fish. Because of the extreme non-normality of the data, a non-parametric test (Kruskal-Wallis one-way ANOVA) was used to compare juvenile and adult data. Suitability was extremely low or zero at the majority of sites, resulting in great similarity between the juvenile and adult comparisons. Based on the comparison of sites which supported fish with sites which did not, it is apparent that relative suitability as predicted by the polynomial function is of value in assessing habitat potential.

Scattergrams of average fish diversity plotted against mean relative suitability (determined by the polynomial function) indicated that factors other than depth, velocity, and substrate were affecting fish distribution throughout the study area. Within individual streams, however, relative suitability (determined by the polynomial function) explained a high percentage of the variability in fish density. Juvenile and adult suitability will be included in the factor analysis presented in Section 6.6.3.3. This analysis provides an estimate of the overall predictive capability of the Polynomial Suitability Index (PSI) as determined by the polynomial functions.

6.6.3.3 Factor Analysis

In the histogram analysis, we examined each habitat parameter as if it were acting independently in influencing fish habitat selection. Certain combinations of independent parameters may in fact act together to attract fish (eg. bank vegetation and bank height) so that, while other sites may have higher relative suitability indices for a single parameter, only the combination of two or more parameters at optimal levels will attract high numbers of fish. In order to assess this possibility, we made use of factor analysis which combined several selected parameters.

After plotting values for parameters likely to be important in habitat selection against fish density, and eliminating first, obviously dependent variables and, second, those variables which could not be correlated with available habitat, the following list of habitat characteristics was selected:

Stream width	Percent Overhanging Vegetation
Gradient	Percent Unstable Banks
Discharge	Mean Depth
Water Temperature	Mean Velocity
Conductivity	Mean Substrate
Turbidity	Bank Height
Food Availability	Bank Vegetation
Food Diversity	Bank Cover
Percent Pool	Rock Cover
Percent Cover	

By combining as many of these parameters as possible into a series of factors, those parameters which were closely related to other parameters were lumped together. The relationship of each of the resultant factors to fish habitat preference was then examined.

After eliminating depth, velocity, and substrate, already included in the polynomial habitat suitability functions, factor analysis was performed on the remaining variables. After several runs, the list of variables was reduced and transformations applied as follows:

Variable	Transformation
Stream width	log (x + 1)
Gradient	log (x + 1)
Conductivity	log (x)
Turbidity	log (x + 1)
Food availability	none
Food diversity	none
Percent cover	log (x + 1)
Percent overhanging vegetation	log (x + 1)
Percent unstable banks	log (x + 1)
Bank height	log (x + 1)
Bank vegetation cover presence	none
Bank cover presence	none
Rock cover presence	none

Table 29 presents the results of the sorted, rotated factor analysis. These five factors accounted for 74.9% of total variance in physical characteristics listed above. Based on the composition of each factor, we named the factors:

1. Bank
2. Food
3. Scour/Stability
4. Cover
5. Width

The latter factor, stream width, sorted out independently of all other parameters and accounted for 7% of variance explained.

Factor 1, the bank factor, accounted for 33.1% of total variance explained. Variance explained for the other factors is included in Table 29.

Using data collected from equally-spaced transects in the representative 100 m study sections, it was possible to compare the five factors individually at those locations supporting fish and those locations supporting no fish. A comparison of 50 locations which supported at least one grayling with 177 locations containing no grayling (Table 30) revealed that the only significant differences occurred at sites where values of Factor 1, the bank factor, were highest. Sites which supported at least one adult grayling had significantly higher Factor 1 values than sites which supported no fish ($P < 0.05$). While Factor 1 also had the highest F value (3.77) for juvenile grayling, the difference between the means was not significant ($P > 0.05$). This is in accord with the results of the histogram analysis (Section 6.6.3.1), which indicated bank-related cover factors were more important to adult grayling than to juveniles.

This comparison also illustrates that, in general, the five factors cannot be used independently of each other and of the depth, velocity, and substrate parameters included in the polynomial suitability factor. For instance, Factor 5 (channel width), which later proved to be the most important of the five factors in determining juvenile density and in controlling adult density in those locations which supported fish, was not significantly different in value at sites supporting fish compared with sites supporting no fish (Table 30). This similarity results from the preponderance of sites which had optimal stream widths for either juveniles or adults, but which were unsuitable with respect to their other characteristics (eg. velocity too high, depth too shallow, no cover). In fact, Factors 2 through 5 acting independently did not increase the probability of fish being present. Only in combination with other factors was any predictive capability for these factors realized.

The five factors, along with the polynomial suitability function (Section 6.6.3.2), were then calculated for each transect in representative stream sections and compared with fish densities at each transect in a step-wise multiple regression. A scattergram of each factor vs. fish density revealed Factor 4, the cover factor, was parabolic in shape. A quadratic term (F_4^2) was included for Factor 4 and forced to enter the equation. The calculated PSI, an average value for the three points on each transect, was transformed to arcsin ($\sqrt{x + 0.00001}$). Fish density (n/100 m^2) was transformed to $\log_{10}$ (x + 1). The analysis was run once excluding sites with no fish, and again with all sites included.

A comparison of the analysis including all sites with one including only those sites with fish, suggested a distinct non-normality in the distribution of fish densities in the former case. Apparently there were a very large number of sites with habitat features favorable to fish which supported no fish. The result was a large number of negative residuals when all sites were plotted against increasing predicted fish density. While in virtually any environment, even in more temperate areas, there are some unoccupied usable habitats, grayling in this study area appear to have a large supply of unused summer feeding habitat available.

It appears from the large number of vacant habitats, that a great deal of available habitat was not utilized on a continuous basis. To determine whether these unused habitats were in fact similar in character to those supporting fish, a group of 50 locations was selected based on apparent similarity to occupied habitats (Table 31). It is apparent from the table that these 50 sites were almost identical to adjacent occupied sites in virtually any habitat characteristic which could be identified. A similar pattern of unoccupied sites was observed in virtually every stream habitat examined during this study.

Tables 32 to 35 summarize the final step in a step-wise multiple regression for grayling adults and for grayling juveniles with zero fish densities included, and with zero fish densities omitted. For both sizes of grayling, the latter appeared to provide the best predictive capability. The large number of sites with high predicted habitat value, but no fish present, appeared to greatly reduce the overall predictive capabilities of the function. The function with the greatest predictive capabilities was derived by including in the multiple regression only those transects with at least one fish present. Equations derived in this manner assume that all usable habitats or niches are occupied by fish and thus represent a maximum possible value for a given length of stream. Unfortunately, with a large number of unoccupied habitats, the resulting equation did not estimate fish densities comparable to those in our study streams. It was valuable, however, in assessing which of the factors was most important in determining the probable density of fish.

Adult Grayling

Using the coefficients in Table 32, the regression equation describing the density of adult grayling at all locations (ie. including locations at which fish were and were not present) is:

$$\log(\text{density} + 1.0) = -0.03263 + 0.04107\,[\arcsin(\sqrt{s + 0.00001})] + 0.05068(F_1) + 0.03156(F_3) - 0.02421(F_4) - 0.03016(F_5) + 0.06730(F_4^2)$$

where:

S	=	polynomial suitability index (adults)
F_1	=	Factor 1
F_3	=	Factor 3
F_4	=	Factor 4
F_5	=	Factor 5

This equation yielded a total R^2 value of 0.25. Of the five factors which entered the equation, adult suitability was the most significant factor, yielding an R^2 of 0.16. Among the remaining factors, Factor 1 (the bank factor) and Factor 4 (the cover factor, including the quadratic term), each accounted for an R^2 of 0.03. In our earlier analysis of individual factors (Table 30), Factor 1 was the only factor which displayed some predictive value acting independently of all other factors (excluding adult suitability). Factor 5 (stream width) displayed the lowest predictive value of the factors included in the equation with an R^2 of only 0.01. Factor 2 (the food factor) failed to enter the equation despite the fact that histogram analysis suggested that adult grayling select for streams with higher food availability.

When the preponderance of sites without fish were ignored, and the regression biased toward only those sites which contained some fish (Table 33), the regression equation becomes:

$$\log(\text{density}+1.0) = 0.50604-0.02939(F_4)-0.18020(F_5)+0.06877(F_4^2)$$

For this function R^2=0.48, nearly twice that of the unbiased equation. Of the individual factors, Factor 5 (stream width) showed the highest correlation with adult density, yielding an increase in R^2 of 0.29. Factor 4 (the cover factor, including bank height and rock cover), produced the remaining R^2 of 0.19, with the quadratic included.

While it was demonstrated that sites which supported adult grayling had significantly higher adult suitabilities than sites which supported no fish (Section 6.6.3.2), adult suitability failed to enter the biased regression equation. Apparently, depth, velocity, and substrate were important in determining whether or not adult grayling were present, but there was little or no correlation with the density of adult grayling for those sites which already had fish present.

Adult fish apparently have a tendency to school up at a few optimal sites, leaving other sites with high adult suitabilities unoccupied. Field observations over the three-year term of this study strongly suggested that this was indeed the case. Often a single pool near the upper limit of access in tributary streams supported as many adult grayling as several kilometres of the downstream drainage. This despite depth, velocity, and substrate characteristics nearly identical to adjacent pools.

Juvenile Grayling

The equation for juvenile grayling habitat preference for all locations (Table 34) was:

$$\log(\text{density} + 1.0) = -0.07284+0.03796[\arcsin(\sqrt{s+0.00001})] \\ -0.03974(F_2)-0.04376(F_4)+04582(F_4^2) \\ -0.04660(F_5)$$

For this unbiased equation, R^2=0.38. Juvenile suitability provided most of the predictive capability, accounting for an R^2 of 0.31. The predictive value of other factors was relatively low. Of the remaining factors, Factor 5 (stream width) again provided the largest increase (0.03) in R^2. Factor 1 (the bank factor) and Factor 3 (the scour/stability factor) did not enter the equation.

When the large number of usable habitat sites which supported no juvenile grayling were omitted, the predictive capability of the function improved considerably (R^2=0.53). The new equation, (Table 35), biased toward sites which supported at least one juvenile grayling, is:

$$\log(\text{density} + 1.0) = 0.39498+0.01411[\arcsin(\sqrt{s+0.00001})] \\ -0.08043(F_2)-0.07010(F_4)+0.04411(F_4^2) \\ -0.01477(F_5)$$

As with the unbiased equation, only Factors 1 and 3 failed to enter the equation. Juvenile suitability had a lower predictive value, accounting for an R^2 of 0.21. Of the remaining factors, Factor 5 (stream width) remained most important, but now accounted for an R^2 of 0.18. Factor 4, including the quadratic term, accounted for 0.11 of total R^2, compared to 0.19 in the biased equation for adult grayling. Overall, this cover factor is more important to grayling adults than to juveniles. This result agrees with the results of the histogram analysis in Section 6.6.3.1 (Figure 30).

6.6.3.4 Application of Habitat Preference in Habitat Modification Studies

Even a predictive capability of 53% is relatively poor, considering the number of habitat features included in the factors (n=13) and in the suitability index (n=3). The relatively low predictive capability of all of these functions, despite the large number of habitat features included, reflects several features of grayling distribution:

1. A large number of apparently good habitats are not used at any given time;

2. Adult fish have a tendency to "school up" in a few habitats;

3. Factors other than physical habitat features are influencing the density of fish in any specific stream or location (eg. migration patterns; availability of, and distance to, overwintering habitat).

The variability in the density of grayling in study area streams with similar habitat features is high. Streams located considerable distances from overwintering areas are the last to be occupied each summer, the first to be vacated, and often support low densities of fish even in midsummer. Unless these non-habitat parameters are considered, no equation will have a high capability to predict fish density. Obviously, the location of many overwintering areas is not known and difficulty encountered by fish in migrating into any particular stream is nearly impossible to quantify.

Considering these problems, the equations derived from the multiple regression are of little value in predicting the density of fish in any specific stream. Even the biased equations for both juvenile and adult grayling, which yielded the highest R^2 values, predicted only the maximum densities, assuming that all usable habitats are occupied.

For the purpose of comparing disturbed and undisturbed habitats within individual streams, we elected not to use the predictive capabilities of the equations. Instead, the analysis of habitat modification (presented in Section 6.7) emphasizes changes in those factors which were of greatest predictive value within the unbiased equations. Rather than attempting to predict fish densities from an equation, actual measurements of fish densities were used to compare disturbed and undisturbed habitats within individual streams.

For adult grayling, the most important factors, in order of importance, are:

1. Adult suitability (depth, velocity, and substrate)
2. Factor 1 (bank vegetation, bank cover, bank height, total cover)
3. Factor 4 (rock cover, bank height, gradient)

4. Factor 3 (percent unstable, gradient, turbidity, conductivity, percent vegetation on banks)
5. Factor 5 (stream width)

For juvenile grayling, the most important factors, in order of importance, are:

1. Juvenile suitability
2. Factor 5 (stream width)
3. Factor 4 (rock cover, bank height, gradient)
4. Factor 2 (food, negatively affected by conductivity and turbidity)

Since adult and juvenile suitability are of the greatest predictive value in both unbiased equations, comparisons of modified and undisturbed habitats will emphasize changes in parameters included in the polynomial (ie. depth, velocity, and substrate). While the other factors are less important to fish habitat selection, any significant changes are also discussed.

The polynomial suitability function was used to calculate adult suitability and juvenile suitability in 100 m long representative sections of disturbed and undisturbed streams in the vicinity of materials sites (Section 6.7). Suitabilities were calculated for all 30 individual data points in each 100 m test section. Since it has been demonstrated that grayling select from among the sites with higher suitability values and that not all sites are occupied, it would be inappropriate to average the values for all 30 data points. By averaging the sites together, a few locations with high suitabilities are combined with a large number of low suitability points, while, in fact, in areas with an abundance of unused habitat, fish select only from among those habitats with relatively high suitabilities. In order to better reflect the quality of the habitat actually used by fish, we selected only the best 10 habitats from each

100 m representative section. Using the mean of the 10 best locations among a total of 30 in each representative section is equivalent to determining the mean suitability of the best one-third of the habitat in the total stream area available. Using a combination of the adult and juvenile suitability, the most important factors from histogram comparisons (Section 6.6.3.1) and the factors derived in the unbiased multiple regression, it was possible to assess whether modifications made to stream environments have been detrimental to fish habitat quality.

6.7 Habitat Modification Studies

6.7.1 Study Design

While many aspects of TAPS construction resulted in minor localized habitat modifications, only materials sites and stream training structures caused habitat modification affecting large areas of individual watercourses. Since stream training structures were used only in the large braided streams where channel migration is a concern, they affect only the turbid braided channels of large streams (generally considered relatively poor fish habitat) and the small clear tributary streams which often parallel the mainstem. The latter are important as spawning areas for Arctic grayling, as rearing habitat for grayling, round whitefish, char and slimy sculpin, and, in some instances, as access routes to nearby lakes. Elliott (1982) addressed the problems resulting from modifications of some of these small tributary streams in the Middle Fork Koyukuk River drainages. He found that stream training structures had resulted in sedimentation, channelization, and various channel modifications which apparently reduced fish use.

Our studies concentrated on the effects of the even larger scale habitat modification in materials sites. Since reports prepared by Woodward Clyde Consultants (1980a, 1980b) have dealt with the effects of materials sites in the largest streams (Section 4.1), the present studies emphasize the effects of materials sites in tributary streams. In general, these tributary streams do not provide overwintering habitat, but represent important spawning, nursery, rearing, and summerfeeding areas. In some instances, these streams are migratory corridors to upstream lakes and streams.

Habitat modification studies included two different types of sampling:

1. Detailed physical measurements in both control and disturbed areas;

2. A determination of the numbers, size, species composition, and biomass of fish present in both control and disturbed areas.

An attempt was made to select control locations in areas located as close to the disturbed area as possible. Control locations were chosen based on their similarity to the disturbed area prior to materials site excavation. If possible, locations with similar gradient, channel configuration, substrate composition and bank configuration were selected. Aerial photographs from the pre-construction period (Alyeska Pipeline Service Company 1969) were invaluable in locating sites with characteristics similar to the pre-construction environment.

Two concerns about sampling conditions were apparent from the outset of these studies. First, the methods for determining fish densities in different habitat areas had to be accurate under a range of conditions. In the present study, this concern was addressed by testing a number of sampling techniques in a range of habitat areas, and assessing the effectiveness of each method under a variety of conditions. Second, the proximity of many materials sites to facilities such as the haul road, pump stations, and highway maintenance camps means that the number of anglers with access to the study streams is high enough to influence fish numbers at study locations. If anglers were to remove a disproportionate number of fish from either control or disturbed locations, any comparison of the two areas would be affected. This concern was addressed by comparing fish densities in two sections of Oksrukuyik Creek, one receiving moderate angling pressure by the personnel at Pump Station No. 3, the other receiving angling pressure which was either light or absent.

6.7.2 Assessment of Density Study Techniques

During June and July 1981, the effectiveness of various sampling techniques was assessed in several types of streams ranging from clear Foothills Streams with low conductivities, to turbid Mountain Streams with high conductivities. Several test sections were blocked off within these streams, and repeat passes made through each test section using pole seines, beach seines, electrofishers, electrofishers in combination with a pole seine, and visual assessments of fish numbers. In some instances, test sections were left blocked off for up to 48 hours and re-sampled several times to ensure that no fish remained uncaptured. The following conclusions are based on the results of these tests:

1. The Smith-Root type VII electrofisher is ineffective at conductivities lower than 50 µumhos. Conductivities at this level occur in most Foothills Streams at breakup, and in many Foothills Streams for the entire open water period.

2. At conductivities ranging from 50 µmhos up to 600 µmhos, the electrofisher used in conjunction with block nets can be 90 to 100% effective in capturing all fish over 75 mm in length, excluding slimy sculpin. The latter tend to seek

cover under rocks and are easily missed even during repeated electrofishing.

3. Densities of fish under 75 mm could be assessed using seines on fine-grained substrates, but on fine rock (6.0 cm diameter) or larger substrates the densities of these fish could not be quantified by any non-lethal technique.

4. In streams wider than 10 m, electrofishing combined with pole seining was effective in preventing fish from moving around the field of the electrofisher.

5. In large low conductivity streams the 20 m beach seine was effective in capturing all fish over 75 mm, excluding slimy sculpin. No attempt was made to seine streams larger than 20 m in channel width.

6. Electrofishing was generally ineffective at conductivities over 600 µmhos. Conductivities at this level, encountered in only a few Dietrich River tributaries, resulted in very high current flow with little effect on fish.

Based on these observations, the sampling technique appropriate to each Detailed Study Stream was selected. Capture of all fish in blocked off study sections, generally 100 m in length, was most easily accomplished in areas with low turbidity and low water levels. During July and September, when most sampling was conducted, turbidity and discharge levels were generally low, facilitating capture. In a few instances, it was possible to locate every fish in a length of stream prior to sampling, and thereby assess the accuracy of the visual techniques used for studies of fish habitat preference (Section 6.6).

As a final check of sampling efficiency, several stream sections were blocked off, sampled until no further fish were captured, then stocked from adjacent areas with a known number of fish. After a period of 24 hours, these stocked fish were re-sampled, by electrofishing in Brockman, Airstrip, and Trevor creeks, and by beach seining in Oksrukuyik Creek. In all four locations, the techniques were effective in removing 100% of the stocked fish in two passes with the sampling equipment.

In calculating fish densities, it became apparent that habitat modification often resulted in changes in both the area and the volume of available habitat in a length of stream. In reporting the results of these studies, therefore, densities have been expressed as fish/100 m (length of stream), fish/1,000 m^2 (surface area) and fish/100 m^3 (volume). Assuming that similar sections of stream originally had similar width and depth, it is likely that two identical lengths of stream would have similar areas and volumes, and, in theory, similar fish densities. In comparisons of modified and disturbed areas, these parameters often varied independently, depending on the nature of the modification.

6.7.3 Angling Studies

Initially, it was intended that studies to determine the effect of angling on fish densities be conducted in Prospect Creek where the results could be compared with tagging studies by Netsch (1975). This intention was abandoned when initial studies revealed that a tagging program would be necessary to effectively determine fish density. Further, preliminary studies revealed that despite moderate angling pressure, fish densities in Prospect Creek were atypically higher than most other streams in the study area. As a result, it was decided to base the angling study in Oksrukuyik Creek, a typical North Slope Foothills Stream (McCart et al. 1972).

Oksrukuyik Creek has its headwaters in a series of lakes, and drains into the Sagavanirktok River 2 km north of Pump Station No. 3. It is crossed twice by the haul road, once near its mouth and again 20 km upstream. Access for anglers is provided by the haul road and by by walking down the workpad from Pump Station No. 3 (Figure 34). During the course of these studies, dozens of individuals were interviewed, including those who regularly angled the lower 3 km of Oksrukuyik Creek and those registered in an annual fishing derby at the Pump Station No. 3 temporary quarters. From these discussions, it was learned that most angling in the areas was "catch and release", since most anglers did not have an effective way to store and transport fish. Exceptions were a few truckers headed south, and a few construction personnel, residents of the temporary quarters, who retained their fish for an annual barbecue. Altogether, it appears that fewer than 500 grayling are actually killed by angling in Oksrukuyik Creek annually. In our experience, it appears that this stream is among the most heavily angled streams in the pipeline corridor north of the Dietrich Check Point.

Two representative 1 km test sections were blocked off in Oksrukuyik Creek (Figure 34). Section 1 (the control) was located 1 to 2 km upstream of the TAPS crossing, above the area used by most anglers. Section 2 was located between the haul road and workpad, the area most accessible to anglers.

In mid summer 1982 and 1983, the number of grayling in Section 2 was 22 to 24% lower than it was in Section 1 (Table 36), indicating that angling may have affected fish numbers. The number of round whitefish, however, a species that is seldom successfully angled, was similarly distributed, with 61% fewer fish in in Section 2 in July 1981, and 36% fewer fish in July 1983. These results suggest that the lower fish density in Section 2 may have occurred because the habitat of the control area is slightly more attractive to fish.

Migration patterns may also play a role in fish density. In early September 1981, for example, the densities of both grayling and round whitefish were higher in the angled area than in the undisturbed control. The movement of fish out of Oksrukuyik Creek toward overwintering areas or spawning sites (in the case of round whitefish) is believed responsible for the higher fish densities found near the stream mouth.

These data suggest that even moderate angling pressure, particularly of the "catch and release" type, does not cause large reductions in the number of fish present in a particular length of stream. It appears that there is sufficient movement between areas to replace most fish removed by angling. These data are applicable to any location where access is restricted to a single area. At such locations, the reservoir of fish in undisturbed areas is many times larger than the number of fish removed from the single accessible area, ensuring that population levels will be maintained.

Based on these results, it is assumed that other streams in the study area, where angling pressure is even lower, would not have catastrophic reductions in fish numbers as a result of angling pressure. It is also assumed that, where differences of several hundred percent or even a full order of magnitude occur in fish density, that these differences must be the result of barriers, habitat differences, or factors other than angling.

6.7.4 Falcon Creek

Falcon Creek is a tributary of Notravak Creek which flows into Galbraith Lake near the Galbraith airstrip. Although it is not crossed by either the pipeline or the haul road, Falcon Creek contains one of the largest materials sites (MS-114A-5) examined during this study (Figure 35). A nearly 2 km length of Falcon Creek has been mined for gravel, leaving a highly channelized stream with little cover and no bank vegetation.

During an initial survey of Falcon Creek in July 1981, grayling and round whitefish were common up to the lower end of the materials site. Newly emergent grayling fry were abundant, suggesting that the stream is an important spawning area for fish inhabiting Galbraith Lake. Within and upstream of the materials site, neither larger fish nor fry were found. During an August 7, 1980 survey of this materials site, Elliott (1982) reported the capture of only four grayling and three round whitefish.

Since there are no barriers to migration in this reach of Falcon Creek, the difference in fish distribution appears to be primarily the result of habitat modification. In July 1983, two 100 m study sections were established in the stream--Section 1 (located in the lower half of the materials site) and Section 2 (located approximately 500 m downstream of the materials site) (Figure 35). On July 7, Section 1 supported no fish (Volume III, Appendix Table G-3), but Section 2 supported 4.2 grayling/1,000 m^2 and 2.8 round whitefish/1,000 m^2. The combined biomass of these species was 1,957 g/1,000 m^2. Young-of-the-year were also present in Section 2, but were not quantified. Areas adjacent to Section 2 supported similar densities of adult grayling and round whitefish.

A comparison of physical data (Figure 36) for the control area (Section 2) with the disturbed area within the materials site (Section 1) suggests that materials site excavation within Falcon Creek has caused a reduction in the size of stream substrate material, a 46% reduction in mean depth, and a 56% reduction in the stream area with depths over 20 cm and velocities less than 30 cm/s (depths and velocities shown to be preferred by grayling--Section 6.6.3). There has been a corresponding reduction in stream volume per 100 m of stream length from 170 m^3 to 101 m^3, though there has been little change in total surface area or velocity. This difference is accounted for by the presence of nearly 43% more pool habitat in the undisturbed area (Figure 37). While total cover and overhanging vegetation have been drastically reduced in the materials site, the percentage of unstable bank is zero as a result of channelization.

Juvenile grayling suitability (PSI--see Section 6.6.3.4) in the best habitats in undisturbed Falcon Creek averaged three times higher than that in the best habitats within the materials site (0.0871 vs. 0.0240--Table 37). The difference in adult grayling suitability is even greater, averaging 0.0004 in the materials site and 0.0588 in the control area (Table 37). Thus, based on the characteristics of depth, velocity, and substrate alone, modifications in the materials site have reduced adult suitability by more than a factor of 100.

Since Falcon Creek is inhabited almost exclusively by adult-sized fish (except for young-of-the-year which are not included in our analyses), factors affecting the habitat preference of adult fish will also affect fish distribution. Factors 4 and 5 from the factor analysis, including rock cover, bank height, and stream width are correlated with the presence of juvenile and adult grayling (Section 6.6.3.4). Modifications in the Falcon Creek materials site have resulted in the elimination of stream banks and any associated cover, no change in rock cover, and little or no change in mean stream width (control 7.2 m wide and materials site 7.8 m wide).

It is clear that the absence of fish from the Falcon Creek materials site is directly related to reductions in habitat quality caused by instream mining. While the habitat suitabilities found in undisturbed portions of Falcon Creek are among the highest in any of the mined streams studied (Table 37), fish densities in this stream are among the lowest, averaging only five grayling and two round whitefish per 100 m of stream length. It is unlikely that low densities of fish in Falcon Creek are related to the availability of overwintering habitat--the drainage flows directly into Galbraith Lake where both grayling and round whitefish overwinter. It is likely, however, that the periodic low water levels common to Falcon Creek have caused selection pressure against fish using of this stream for summer feeding.

Applying the fish densities typical of undisturbed areas in Falcon Creek to the materials site prior to disturbance, it is probable that the 2 km of mined stream formerly supported an average of 60 adult grayling (biomass 20 kg) and 20 round whitefish (biomass 4 kg), almost exclusively adults, prior to disturbance. Since it supports few or no fish now, this habitat can be considered eliminated for both species.

6.7.5 Holden Creek

Holden Creek, an Atigun River tributary located at MP145.7, is highly channelized for 700 m through MS-114-1 (Figure 23). Formerly a single winding channel, the channelized portions of Holden Creek are now nearly straight, with steep banks comprised of coarse material.

Preliminary studies in Holden Creek indicated a possible difference in habitat quality between the materials site and undisturbed areas. Elliott (1982) indicated that, because smaller fish had a greater tendency to use the materials site, the ratio of juvenile to adult fish was higher in that area than in undisturbed areas downstream.

High water levels in 1981 discouraged use of the materials site by smaller fish, and no difference in the size of fish in the materials site and those in downstream undisturbed areas was apparent. In 1982 and 1983, low water levels facilitated use of the area by small numbers of juvenile grayling, but larger fish were uncommon within the the materials site. On July 16 and 17, 1982, for example, adult-sized grayling (>220 mm) accounted for 75.8% of the total catch from all undisturbed areas, but for only 55.6% of the total catch in the materials site. While there were fewer mature fish in the materials site, there was no significant difference significant difference between the mean fork lengths of fish from the entire length of the materials site and a sample from undisturbed habitats downstream in either 1982 ($t=0.057$, $p>0.05$, $df=57$) or 1983 ($t=0.094$, $p>0.05$, $df=80$).

To investigate these differences in the distribution of fish further, three 100 m detailed study sections (Sections 1, 2, and 3) were established in Holden Creek (Figure 23). Section 1 was located near the lower end of the materials site, Section 2 was located immediately downstream of the materials site, and Section 3 was located downstream of the pipeline crossing. The latter two sections, which were undisturbed, served as controls.

The area upstream of the materials site could not be included in the comparisons of disturbed and undisturbed areas, since the bridge that replaced the haul road culvert in 1983 had not yet been installed, and few fish were able to pass through the culvert. In 1981, the density of fish upstream of the haul road culvert was low, and only 22.0% were juveniles. In 1982, fish densities upstream remained low, but 100% of fish caught in that year were adult-sized grayling, despite the fact that, in that year, juvenile grayling were more abundant (44.4% of total catch) in the materials site immediately downstream. Apparently, the movement of small fish through the haul road culvert was restricted at low water levels.

During all three years of the present study, the materials site (Section 1) supported fewer fish and a lower fish biomass than the either of the control areas (Sections 2 and 3) in undisturbed habitats downstream (Figures 38, 39, and 40). This difference was most pronounced in 1981, when no fish were present in Section 1, and high water velocities through the materials site had virtually eliminated all usable habitat in this study section.

Over the three-year study period, midsummer fish densities averaged 7.1 fish/1,000 m^2 in Section 1 (Figure 41), all of which were grayling. Sections 2 and 3 averaged 40.8 fish/1,000 m^2 and 39.8 fish/1,000 m^2, respectively. Of these, 38.0 fish/1,000 m^2 in Section 2 and 28.9 fish/1,000 m^2 in Section 3 were grayling. The mean lengths of fish were 88 mm (range 75 to 182) in Section 1; 144 mm (range 75 to 327) in Section 2; and 172 mm (range 76 to 362 mm) in Section 3. As a result of the greater number and larger size of fish in undisturbed areas, mean biomass for the three-year period was 78 g/1,000 m^2 in Section 1; 2,398 g/1,000 m^2 in Section 2; and 3,730 g/1,000 m^2 in Section 3.

Within the materials site, substrates were generally coarser than in control sections (Figure 42) and, a consequence of stream channelization, average depths (13 cm) were shallower than they were in either Section 2 (0.15 cm) or Section 3 (0.20 cm). Average velocity in the materials site was intermediate between the two control sites, and, when the percentages of locations with depths over 20 cm and velocity under 30 cm/s were compared, Section 1 and Section 3 were identical. The higher number of fish and greater biomass in Section 3 compared to Section 1 cannot be explained by the depth/velocity relationship alone. A comparison of the availability of pool habitat in the three study sections (Figure 43) revealed a relationship similar to that for fish density and biomass. Pool habitat as a percentage of total available habitat was an order of magnitude lower in Section 1 than it was in either of the control sections.

Although the total percent cover was similar in all three areas, there was no overhanging vegetation in the materials site. Cover in the materials site was provided largely by the coarse substrate which created numerous shallow pools, generally unusable by larger fish. The greater bank stability in the materials site was a function of stream channelization which had eliminated meanders and reduced the value of banks in providing cover. Downstream of the materials site, numerous tundra slumps played an important role in creating both pools and stream meanders.

Both adult and juvenile grayling habitat suitability (PSI) were 2.5 times higher in Section 2 than they were in the materials site (Table 37). Within both the materials site and Section 2, adult suitability at the 10 best sites was only 18% of juvenile suitability. Within Section 3, both adult and juvenile suitability were nearly identical to those in the materials site. Despite the greater depth of water in Section 3, high current velocity reduced overall suitability values. This was the only location, among the seven where materials sites were studied in detail, where PSI did not correlate well with fish density. Factors other than depth, velocity, and substrate (eg. pool habitat, bank cover) were probably responsible for the higher numbers of fish in Section 3 compared to Section 1.

Channelization in Holden Creek has caused an increase in stream width by eliminating stream meanders. In the materials site, average stream width in the materials site was 8.0 m; in undisturbed areas, it was 6.1 m. Since increased stream width is negatively correlated with both adult and juvenile grayling presence in factor analysis, the width increase is probably responsible for some apparent reductions in use. Section 1 displayed greater average bank height and more rock cover than either Sections 2 or 3, both factors which are positively correlated with increased numbers of grayling; however, grayling display a marked preference for cutbanks (Section 6.6.3), which were common within the control sections. Banks in the materials site averaged 1.5 m in height, and were comprised of boulders and coarse rock, materials which provide little cover for fish.

Overall, the control sections (Sections 2 and 3) both provided better fish habitat than the materials site. Applying the average midsummer fish density (Volume III, Appendix Table G-4) in undisturbed portions of Holden Creek (20 grayling, 3.9 round whitefish, and 0.5 Arctic char/100 m), and subtracting the average density of fish present in the materials site (5.6 grayling/100 m), yields the average loss of fish as a result of habitat modification. Assuming habitat in the materials site was originally comparable to that of the two control sections, it is estimated that instream mining has eliminated habitat for 100 grayling in all size classes with a total biomass of 7.8 kg. Habitat can also be considered eliminated for an estimated 27 round whitefish (mostly juveniles) with a total biomass of 1.9 kg. There is no evidence that habitat quality for char has been reduced in the materials site.

6.7.6 Trevor Creek

Trevor Creek, a distributary of Redwater Creek, is crossed by the pipeline approximately 650 m from the stream mouth (Figure 24). During the present study, the lowermost 700 m of this stream, included within MS-112-2, was completely denuded of bank vegetation and, though not completely channelized, appeared highly scoured and unstable. The stream channel was braided in the lower portions of the materials site, but generally flowed within a single channel in upstream areas.

As at Holden Creek, fish passage problems created by a haul road culvert prevented any comparisons with fish densities in undisturbed areas upstream of the road. From 1980 through 1982, over 90% of the grayling caught above the haul road were adult-sized fish. Replacement of the culvert by a bridge, planned for 1983, will no doubt improve the passage of juvenile fish upstream.

Studies conducted in 1981 indicated that, while the number of fish using the Trevor Creek materials site was greater than the number using undisturbed areas (Figure 38), the fish in the materials site were smaller than those in undisturbed areas. In contrast, Elliott (1982) reported that the density of adult fish in 1980 was six times higher in undisturbed habitats than in the materials site, that the adults/juvenile ratio was lower in the materials site (0.15) than it was in undisturbed areas (1.09), and that the density of juveniles was nearly equal. During 1980, however, conditions may have been dramatically different from those that prevailed during 1981. Elliott (1982) further reported that the peak number of fish present in Trevor Creek in 1980 (August 13) was 84. The peak number recorded in 1982 was approximately 900, a full order of magnitude higher.

In 1982, grayling successfully spawned in the Trevor Creek materials site, and, in mid-July, numerous fry were collected near the stream mouth. In 1981, frequent freshets apparently prevented successful spawning in that year, and in 1983, the complete dewatering of the stream in mid June (Section 6.4.2) probably wiped out both adults and eggs.

Three 100 m detailed study sections were established to examine the effects of instream mining on fish densities in Trevor Creek (Figure 24). Section 1, located between the haul road and the pipeline in an undisturbed area (Volume 1, Plate 7), served as the control. Section 2 was located within a moderately channelized area immediately downstream of the pipeline, and Section 3 was located in a highly braided area near the stream mouth. Both Sections 2 and 3 were within the area originally mined for granular material.

In 1982, the density and biomass of fish (Figure 39) was higher in the undisturbed habitat (Section 1) than in either of the two materials site study sections (Sections 2 and 3). In comparing the control and the disturbed sections, however, there was no significant difference between the size of fish in Section 1 and those in Section 2 ($t=0.068$, $P > 0.05$, $df=34$) or Section 3 ($t=0.043$, $P > 0.05$, $df=32$). Above the materials site, 86.5% of grayling sampled were adult-sized fish (>220 mm) for an adult/juvenile ratio of 6.4. Within the materials site, 76.0% of grayling sampled were adult-sized fish for an adult/juvenile ratio of 3.2.

The differences between the 1982 results, those of our 1981 studies, and those reported for 1980 (Elliott 1982) are probably related to two factors. First, differences in the migration patterns of juvenile fishes may have had an effect. The 1982 season was unusually dry, resulting in low midsummer discharges. In that year, fewer juvenile fish were present in Trevor Creek, and in several other upper Atigun River tributaries, than in the previous year. Second, an unusually severe breakup in 1982 heavily scoured the upper portions of the materials site, altering fish habitat. Where the stream had been braided in 1980 and 1981, it became confined to a single channel. The resulting higher velocities undoubtedly proved less attractive to smaller fish with limited swimming capabilities, than the lower velocities of the original stream.

When data for 1981 and 1982 are averaged, it is apparent that, except for the braided area near the stream mouth, the average density of fish using the materials site was similar to that of the control (Figure 41). In contrast, both average biomass and the size of fish in the undisturbed area were greater than those recorded for in the materials site. Due to the lack of pools in the materials site, the volume of water in a 100 m section was low, making comparisons based on volume less dramatic than comparisons based on a length or area of stream channel.

The lower density of fish in 1982, and the smaller size of fish inhabiting the materials site in 1980 and 1981, were the direct result of reduced habitat quality (Figures 43 and 44). Substrates in the materials site (Sections 2 and 3) had less boulder-sized material (>40 cm diameter) and were higher in rock size classes (6 to 40 cm diameter) than substrates in the control (Section 1). While there appeared to be little difference in average velocity between sections, and only slightly deeper average depths in the control area, the percentage of area with depths over 30 cm and velocity under 30 cm/s was more than double in the control area than it was in comparable habitats in the materials site.

Total area of pool habitat (Figure 43) was correspondingly greater in the control area, in part due to the presence of large boulders. The total percentage of bank with overhanging vegetation was 17% in the control area and 0% in the materials site. The relatively high total cover value for Section 2, near the upper end of the materials site, resulted from the presence of coarse rocks, which provided small protected habitats in shallow swift water. These habitats are generally not usable by larger fish (>150 mm). The banks in the materials site were uniformly unstable compared to those of adjacent undisturbed areas, the reverse of the conditions found in Holden Creek. There was no evidence that tundra slumps provided habitat in Trevor Creek, at least to the extent observed in Holden Creek or Falcon Creek, probably because scour quickly eliminates any tundra slumps that may occur in this stream.

As was the case in Holden Creek, the lack of usable cover and the lack of pool habitat in the Trevor Creek materials site appeared to be responsible for changes in fish use. The position of the materials site was transposed in the two streams--the majority of usable undisturbed habitat in Trevor Creek was upstream of the materials site; nearly all usable habitat in Holden Creek was downstream of the materials site. This suggests that the greater fish use of undisturbed habitats in both streams was not the result of migratory patterns, but was instead a result of habitat preference. Investigations in Roche Montonnee Creek, a relatively undisturbed Atigun River tributary located between Holden and Trevor creeks, produced comparatively uniform densities in most areas where similar habitats occurred.

While juvenile habitat suitability (PSI) based on the 10 best sites declined only slightly in the materials site (Table 37), adult suitability declined from 0.0027 in the control section, to 0.0010 in Section 2, and an even lower 0.0003 in Section 3. This drop was apparent only if the best sites were considered in all three areas, since the mean suitabilities for both adults and juveniles were nearly identical for all three areas. As discussed in Section 6.5.4.3, the mean values included many locations which were never used by fish, masking substantial habitat differences. The pattern of declining adult suitability corresponded to the reduced numbers of adult-sized fish found in the materials site.

Stream width, negatively correlated with juvenile grayling presence in the factor analysis, was unchanged in Section 2, but appeared to have increased in Section 3, as a result of the higher degree of braiding in that portion of the materials site. Both rock cover and bank height, two components of Factor 4, were less in the mined area. Since these features were positively correlated with the presence of both juvenile and adult grayling, the net effect was a reduction in habitat quality.

It appears that the reduction in fish density and the smaller size of fish in the Trevor Creek materials site were the result of habitat changes caused by instream mining. By applying the average density of fish in undisturbed portions of Trevor Creek during late July 1981 and 1982 (20.5 grayling; 1.0 round whitefish; and 0.5 char/100 m) to the materials site, and subtracting the densities of fish recorded for the materials site, it is possible to estimate the numbers and biomass of fish which might have occupied the reach within the materials site prior to disturbance.

These calculations suggest that, after disturbance, the 700 m long materials site supported 70 fewer grayling in all size classes with a total average biomass of 14.7 kg than it had prior to disturbance. Considering the substantial variation in the average size of grayling present in Trevor Creek between 1981 and 1982, it is probable that, from year to year, the size range and biomass of grayling vary considerably from the average values presented above. Average densities of round whitefish and Arctic char appear to have been unchanged as a result of instream mining.

6.7.7 Airstrip Creek

Airstrip Creek, a small, winding, single-channel tributary of the North Fork Chandalar River, located just east of the Chandalar Airstrip (Figure 19), contains materials site MS-109-3 (expansion 2 and 3). The Creek is not fed directly by the North Fork Chandalar River, but arises in the floodplain 500 m above the materials site, and flows about 3 km before joining the mainstem. The materials site, which is the largest in the North Fork Chandalar River drainage, required channelization of a 700 m long section of Airstrip Creek. Within the channel, excavation at the downstream end of the materials site has created two shallow pools.

No detailed studies of fish densities or habitat characteristics in the North Fork Chandalar River drainage have been done previously. During studies in 1980, Elliott (1982) observed few fish in that portion of Airstrip Creek within the materials site, but did observe a few grayling upstream of the materials site, and reported heavy use of the ponds at the downstream end of the materials site, He found that the largest number of fish (291 grayling) were present in undisturbed portions of Airstrip Creek in late August.

While Airstrip Creek was sampled during all three years of this study, detailed measurements of fish densities and physical characteristics were made only in midsummer of 1982 and 1983. A few fish are present in the study area in June. In most years, fish begin emigrating out of the stream by late August, limiting the maximum period of use to about 2 1/2 months--even less for most fish.

To assess the effects of instream mining, three 100 m long study sections were established in Airstrip Creek (Figure 19). Section 1, the control, was located downstream of the materials site in an undisturbed reach. Section 2 was located within the channelized portion of the materials site, and Section 3 was located in the ponded area at the downstream end of the materials site.

On July 24, 1982, Section 1 (control) of Airstrip Creek supported more than 15 times the density and 25 times the biomass of grayling found in Section 2 within the channelized materials site (Figure 45). On July 21, 1983, the density of fish in Section 1 was lower than in the previous year, but no fish at all were present in Section 2 (Figure 40). For the two-year period, the average midsummer density was 30.4 grayling/1,000 m^2 in Section 1, and 1.6 grayling/1,000 m^2 in Section 2 (Figure 46). Average biomass was 1,926 g/1,000 m^2 in Section 1, and 52 g/1,000 m^2 in Section 2.

During both years of the present study, Section 3, which included the excavated ponds at the lower end of the materials site, supported a higher midsummer density and biomass per unit stream length than Section 1 (Figures 40 and 45). In 1982, Section 3 supported a density of 52 grayling/100 m with a biomass of 6,410 g, and Section 1 supported a density of 31 grayling/100 m with a biomass of 1,726 g. In 1983, Section 3 supported 43 grayling/100 m with a biomass of 5,297 g, and Section 1 supported 10 grayling/100 m with a biomass of 501 g. This difference was less apparent when volumetric comparisons were used, since the greater water depth (0.6 m) in the ponds resulted in a higher volume in Section 3 (300 m^3) than in Section 1 (59 m^3).

In both 1982 and 1983, the mean size of fish caught in Section 3 was larger than it was in either Section 1 or Section 2 (Figures 40 and 45). In Section 3, average size of fish for both years combined was 232 mm (161 to 298 mm); in Section 1, average size was 167 mm (range 86 to 230); and in Section 2, within channelized portions of the materials site, average size was 152 mm (144 to 160 mm). Based on the high utilization of Section 3 by large grayling, the deep water and low velocity found in Section 3 appeared to represent an enhancement of habitat. It is possible, however, that the number of fish present may have been inflated by the refusal of some fish to migrate through the channelized materials sites.

For reasons which remain unclear, the mean fork length (176 mm) of a combined sample of fish captured in midsummer 1982 was significantly smaller ($t=2.160$, $P<0.05$, $df=200$) than the mean fork length (202 mm) of a similar sample collected in 1981. There was no significant difference in size between 1982 and 1983 samples ($t=0.056$, $P>0.05$, $df=422$). The smaller size of fish in 1982 and 1983 may be related to lower discharge levels in those years.

The estimate of 291 fish reported for the entire length of Airstrip Creek for late August 1980 (Elliott 1982) was considerably lower than the numbers collected in July 1982 and 1983. In late July 1982, based on 300 fish collected in a 1 km long section, it was estimated that the entire stream supported 650 grayling. In late July 1983, a 1 km long section supported 196 fish, and the population of the entire stream was estimated at 425 grayling. While we did not examine Airstrip creek during August, Elliott (1982) reported that maximum densities in 1980 occurred in late August. The timing of this peak suggests that the maximum number of fish present in 1982 and 1983 may have reached even higher levels later in the summer.

Substrate composition within Section 2 (the channelized area of the materials site) was characterized by a predominance of coarse gravel and fine rock (Figure 47). Substrates in Section 1 (control) were more evenly distributed between size classes, with a higher percentage of gravel and fines. In comparison with the mined area, Section 1 had a greater average depth, lower average velocity, and a greater preponderance of habitat with depths greater than 20 cm, and velocities less than 30 cm/s. As a result of these differences, there was a higher percentage of pool habitat in Section 1 (Figure 37). In addition, instream mining had obliterated virtually all cover and overhanging vegetation, greatly reducing fish habitat quality in Section 2 (Figure 37).

Section 3 (the ponded area at the downstream end of the materials site) was devoid of cover or overhanging vegetation (Figure 37), with nearly uniform water depth (0.6 m), near 0 velocity, and a substrate of fines. Almost 95% of the area was usable pool habitat. In Section 1, only 34% of available habitat was pool habitat. Since grayling select for deeper, low-velocity habitats (Section 6.6.3.2), the modifications in Section 3 resulting from instream mining appeared to be at least a temporary habitat enhancement. There were indications, however, that sediment deposition was filling in these ponds and would eventually eliminate them.

Both juvenile and adult habitat suitability (PSI) as indicated by the 10 best habitats, have been greatly reduced by instream mining (Table 37). Juvenile suitability of the best habitats averaged 0.0652 in Section 1, and only 0.0037 in Section 2. The difference suggests that, based on depth, velocity, and substrate alone, habitats in the Section 1 were 17.5 times more suitable for juvenile grayling than those in Section 2. In fact, the average late July fish density in the control was 20 times higher than it was in the channelized sections of the materials site.

Of those characteristics that were significant in the factor analysis, instream mining decreased bank height from an average 0.3 to 0 m, and increased rock cover from 0 to 13.3%. Stream width changed little, averaging 5.8 m in the control area and 6.3 m in the materials site. Since the bank eliminated was 16.7% cutbank, a type that grayling select for (Section 6.6.3), the elimination of banks is even more important than indicated by factor analysis.

By applying the average density of grayling in undisturbed areas (20.5 fish/100 m) to conditions in the materials site prior to disturbance, and subtracting the average density of grayling found in the materials site, habitat for an estimated 156 grayling has been eliminated in Airstrip Creek. This estimate must be reduced by the number of fish present in the excavated ponds, which averaged 47.5 grayling. Instream mining thus eliminated habitat for an estimated 108 grayling, primarily juveniles, with an average total biomass of 5.9 kg. These estimates are based on late July densities. Densities may have continued to increase in early August as reported for 1980 by Elliott (1982). If this increase recurred in 1982 and 1983, the estimate of the number of grayling displaced may be a conservative one.

6.7.8 North Fork Chandalar River Mainstem Channels

In the North Fork Chandalar River, materials site MS-109-3 (expansion 4) is located on the river mainstem (Figure 19). Within this materials site, a small quantity of gravel (6,600 yds) was scraped from an area approximately 200 m long (Figure 26), eliminating most of the bank vegetation associated with the site. Though channel configuration was not altered, bank stability and possibly substrate stability appeared to be reduced by instream mining. This mainstem materials site is described in more detail in Section 6.4.4.

The North Fork Chandalar River mainstem was sampled during all three years of this study, but detailed measurements of fish densities and physical characteristics of detailed study sections were made only in midsummer of 1982 and 1983. During these studies, it became apparent that the highly scoured mainstem channels paralleling the buried pipeline provided poor habitat quality compared to that found in the stable, vegetated side channels. Although this reduction in habitat quality was a function of natural scouring in the mainstem channels, rather than an effect of pipeline installation, representative test sections were selected to enable comparisons to be made between these different channel types.

In 1982, two 100 m long detailed study sections were established in the vicinity of the North Fork Chandalar River, and designated Section 1 and Section 2. Section 1 was located within a naturally scoured undisturbed channel of the mainstem; Section 2 was located within a stable, well-vegetated side channel. In 1983, a third study section (designated Section 3) was established within the materials site itself (Figure 19).

On July 24, 1982, the stable side channel (Section 2) supported a density of fish four times, and a biomass three times, greater than that of the naturally scoured mainstem channel (Section 1) (Figure 45). While the number of fish in the two channels (n=25) was too small for reliable statistical comparison, the mean length of the fish in the scoured mainstem channel (200 mm) was slightly greater that of the fish in the stable side channel (170 mm). On July 22, 1983, Section 2 supported almost 15 times the density of fish and nearly 10 times the biomass found in Section 1 (Figure 40). Fish again appeared slightly smaller in Section 2 (control) than they were in Section 1 (mean length=169 mm and 201 mm, respectively).

Fish were not sampled within the materials site (Section 3) until 1983. In that year, comparisons between Section 3 and Section 1 revealed that fish densities and biomass in the two sections were similar (Figure 40). On July 22, 1983, the mean length of fish in Section 3 was 184 mm (142 to 308 mm), similar to that of fish in both Section 2 (188 mm, 126 to 308 mm) and Section 1 (201 mm, 138 to 257 mm).

Differences in fish use among study sections (Figure 46) can be attributed primarily to the greater availability of pool habitat and the presence of stable banks (Figure 37) in the side channel (Section 2). High bank stability allowed the establishment of overhanging vegetation which provided substantial cover. In the naturally scoured mainstem channel (Section 1), overhanging vegetation was sparse, but cover was provided by a high percentage of actively eroding cutbanks. Within the materials site (Section 3), overhanging vegetation was also sparse, and, owing to the absence of coarse substrate, slumping cutbanks, or other cover features, total cover was only 3% in this section. In general, however, it did not appear that instream mining had reduced habitat quality in the materials site below the level found in the naturally scoured mainstem channel.

A comparison of the relative suitability (PSI) of the 10 best grayling habitats in the three study sections (Table 37) confirmed that mining had had little effect on habitat quality. The best locations in the materials site (Section 3) had suitabilities for both grayling adults and juveniles that were almost identical to those of the naturally scoured channel (Section 1). Suitabilities in the stable side channel (Section 2) were six times higher for both adults and juveniles than suitabilities in either the materials site or the scoured mainstem channel. Since neither the number of fish present nor the relative suitability of habitats in the materials site are lower than values for the undisturbed scoured channel, it is likely that instream mining has caused no reduction in fish use.

Where stream stability is low (eg. braided floodplains), scour appears to have a devastating effect on habitat quality. Any activity which tends to reduce stream stability, such as instream mining, tends to increase scour in high gradient streams resulting in a reduction in fish habitat quality. Where natural scour is already severe, further disturbance is unlikely to have a measureable effect on habitat quality.

6.7.9 Snowden Creek

Snowden Creek was channelized along the south bank by a 300 m long rip-rap dyke designed to prevent flooding and channel migration into materials site MS-105-1, located adjacent to the stream (Figure 7). In this materials site, mining of granular material was restricted to that area of historic floodplain located south of the rip-rap dyke.

Other than confining the formerly braided stream to a single channel, no disturbance of the streambed occurred except at the workpad and and haul road crossings. In 1981, two study sections were established in Snowden Creek, and designated Sections 1 and 2. Section 1 was located in the channelized area of the materials site, and Section 2, which served as the control, was located in the undisturbed braided area near the stream mouth.

Initial studies in July 1981 indicated higher numbers of fish were using the braided area (Section 2) than were using the channelized area in the materials site (Section 1). By September 11, however, both fish density and the size of fish using the two areas were nearly identical. During breakup in 1982, the north bank of Snowden Creek opposite the materials site, and the south bank downstream of the materials site, were severely eroded; and, between the haul road crossing and the stream mouth, Snowden Creek became a single high-velocity channel. Probably as a result of high velocities, no fish were present in any of the study sections in 1982. In 1983, a few fish were present, but densities remained low. In that year, there were more fish in the channelized area of the materials site (Section 1) than there were in the control (Section 2). In August 1983, a major storm again modified the channel structure near the stream mouth, restoring it to a braided configuration.

The low fish densities found in Snowden Creek (average 2.5 fish/1,000 m^2) were probably comparable to those found prior to construction (Netsch 1975, Hallberg 1975). Hallberg (1975) reported that water velocities in this stream were high, that habitat was generally poor, and few pools occurred. Considering the severe scouring that is characteristic of this stream, it did not appear that modifications associated with the workpad or materials site had affected fish habitat. Natural events appeared to have outweighed man-made habitat changes in Snowden Creek.

6.7.10 Brockman Creek

Brockman Creek was extensively mined for granular material over a 3 km long reach between the canyon mouth and the stream mouth (Figure 2). Since the stream channel was already a broad braided floodplain prior to mining, instream activity resulted in little change to the fundamental character of the stream. Because severe scouring is characteristic of this stream, the rip-rap used to armor and stabilize the stream channel and create an S-shaped configuration in the lower portions of the mined area has had little effect. Where the outer banks of the active floodplain were groomed with heavy equipment, cutbanks have been tapered and overhanging vegetation eliminated, so that no bank cover is now available in these areas.

As with other tributary streams in the Dietrich River drainage, the density of fish in Brockman Creek is dependent on discharge. In 1981, overall fish density in Brockman Creek averaged 15.6 fish/1,000 m^2 downstream of the haul road. Lower discharge in 1982, combined with severe scour at breakup, limited fish movements into this stream. Overall fish densities were estimated at less than 20% of their 1981 levels in the lower 2 km of materials site. In 1983, discharge levels dropped to near 0 in July and early August and no fish were present. Higher discharge levels in late August allowed a few fish to enter the stream, but on September 11, only 37 grayling (mean length=130 mm; range 57 to 260 mm) were present between the haul road crossing and the stream mouth. Nearly 10 times that number were present in the same area (n=294) on September 13, 1981 including some char and round whitefish.

Fish distribution in Brockman Creek was studied as a means of assessing the value of rip-rap as fish habitat in disturbed fluvial areas. Two detailed study sections with similar surface areas were established, and designated Section 1 and Section 2. Section 1 was made up of two lengths of stream each having a single armored bank;

Section 2 was located in an area with no bank armor, and served as a control (Figure 2). A third study section, originally located above the haul road was abandoned early in the study, when it was determined that the haul road culvert was restricting fish access. Since there was no suitable area for an unmined control, no attempt was made to compare mined and undisturbed habitats in Brockman Creek.

On July 20, 1981, the lengths of armored stream (Section 1) supported an average of 11 grayling/1,000 m^2 . On September 13, the same area supported 19.1 grayling/1,000 m^2 and 0.7 char/1,000 m^2 (Figure 48). The unarmored control (Section 2) supported 7.4 grayling/1,000 m^2 and 1.2 char/1,000 m^2 in July; and 19.6 grayling/1,000 m^2, 1.5 char/1,000 m^2, and 0.5 round whitefish in September. In July, the mean size of grayling was larger in the armored section than in the control (154 vs. 121 mm); in September, mean size was larger in the control than in the armored section (135 vs. 95 mm). Owing to the wide variability in the size of grayling in both study sections, these differences were not significant for either July ($t= 0.871$, $P >0.05$, $df=32$) or September ($t=1.120$, $P >0.05$, $df=64$).

Results for July 7, 1982 were similar to those for 1981, with nearly identical numbers of fish present in both armored and unarmored habitats (Figure 49). Fish in the armored section (Section 1) were significantly ($t=2.411$, $P <0.05$, $df=19$) larger (mean length=209) than fish in the control (124 mm). In 1982, the average number of fish in the armored section was only 7.1 grayling/1,000 m^2, compared to 11.0 grayling/1,000 m^2 in 1981, a decline which reflected the lower fish densities in all Brockman Creek habitats in 1982. Due to extremely low water levels in September 1982, nearly all fish present were less than 75 mm, too small to quantify on coarse substrates.

At low water levels, armored banks provide small deep pools which support larger fish than stream lengths with unarmored banks. In this respect, bank armor appears to improve habitat quality for larger grayling. At normal discharge levels, however, there are more large pools in unarmored areas, and larger fish tend to select for these large pools rather than for the steep-sided pools created by bank armor. Since, at all higher discharge levels, pools created by bank armor do not appear to attract more or larger fish, bank armor does not represent a habitat enhancement.

These data represent only a single attempt to restore stream configuration in a highly scoured unstable floodplain. The fluidity of this mixed floodplain has resulted in considerable washing out of bank armor and filling in of the pools created by armor. With the exception of bank stability, habitat features in both armored and unarmored areas are similar (Figure 43), indicating that rip-rap has done little to improve habitat quality. These data were collected under moderate discharge conditions (0.45 m^3/s). Had physical data been collected for low flow conditions, armored areas would undoubtedly display more availability of pool habitat and cover than the control area.

During breakup in 1982, Brockman Creek left its original channel, and flowed through an alternative channel. It returned to its original channel two weeks later, however, threatening the haul road in the north channel, and severely eroding stabilized portions of the materials site downstream of the haul road. The resultant cutting and filling caused a loss of pool habitat and was a factor in reduced fish use of this stream during 1982 and 1983. While the severe freshet was certainly not related to instream mining, the reduced substrate stability may have contributed to channel diversion, severe bank erosion below the haul road, and migration of large quantities of gravel and fine rock downstream into the lower 1 km of watercourse.

The habitat suitability (PSI) values for grayling in Brockman Creek (Table 37) are representative of moderate discharge levels (1 m^3/s) following the severe 1982 freshet. Deposition of considerable quantities of fluvial material in pools along armored banks severely reduced habitat quality. The 10 best locations in the unarmored control (Section 2) had an average suitability 3 1/2 times higher for juveniles and five times higher for adults than the 10 best locations in the armored area (Section 1). Based on these suitabilities alone, it is apparent why bank armoring failed to enhance habitat quality and increase the number of grayling or other species present.

In view of the lack of both adequate baseline data and a suitable control, it was not possible to estimate the change in fish use in Brockman Creek resulting from the mining of granular material. Pre-construction aerial photographs (Alyeska Pipeline Service Company, Bellevue, Washington 1969) indicate that Brockman Creek was a broad braided floodplain prior to mining. While instream mining undoubtedly reduced channel stability and increased the migration of fluvial material, it is not known whether these changes have affected overall fish use of the stream.

6.7.11 Atigun River Warm Water Channel (MP157.2)

A detailed comparison was made between habitat quality in the warm water channel at MP157.2 (Figure 27b) and a nearly identical mainstem channel adjacent to it (Figure 49). In September 1982 and 1983, larger numbers of juvenile grayling were found in the plume of warm water originating from near the buried pipeline than in an adjacent unaffected channel (Section 6.5.1). Both channels had similar average depths (0.10 m vs. 0.08 m), widths (2.8 m vs. 3.0 m), velocities (0.26 m/s vs. 0.27 m/s), and substrate composition (coarse gravel to medium rock). The availability of pool habitat, cover and unstable banks was nearly identical (Figure 37). Neither area has overhanging vegetation. The only apparent difference in habitat quality was the temperature difference (9.5°C compared with 1.0°C on September 15, 1982--Section 6.5.1).

6.7.12 Effects of Habitat Modification

Instream mining of granular material in Falcon Creek, Holden Creek, Trevor Creek, and Airstrip Creek has resulted in the loss of habitat for an estimated 338 grayling and 47 round whitefish (Table 38). This estimate is based on late July fish densities during the three-year study period. Since it has been demonstrated that fish densities in many Mountain Streams do not reach maximum levels until mid August, this estimate may be conservative.

The types of habitat modification which have occurred within materials sites (Table 39) are long-term in nature, and the loss of habitat is for all practical purposes permanent. Of the seven materials sites studied, both adult and juvenile suitability (PSI) values were reduced in five. Stream stability was reduced in five of the seven streams, despite the channelization of three streams. Changes in channel widths in three streams reduced habitat values. Shallower depths resulted in reduced habitat quality and a loss of pool habitat in four materials sites, but increased depths produced by bank armor resulted in improved habitat quality in two streams.

Bank height was reduced in four of seven materials sites, but was increased by bank armor in two materials sites. In six of the seven materials sites examined, banks were reduced in quality as fish habitat. At the majority of sites studied, of the six cover types selected by grayling, only the availability of rock cover was improved by instream mining. The availability of depth, bank vegetation, instream vegetation, bank cover, and shade cover were all reduced at most locations studied. The availability of turbulence as cover was improved at three of the seven locations studied, but turbulence was generally not used as cover by grayling. The total number of cover types available was reduced in three streams, but was increased in two streams.

Since the earliest studies of fish populations in the TAPS corridor, various authors have discussed the importance of overwintering areas to all species of stream dwelling fish. Most of the small tributary streams in the vicinity of the study area are dry for up to eight months annually, forcing fish to winter in lakes, near groundwater sources, or where stream channels have sufficient depth and winter flow to prevent freezing to bottom and low dissolved oxygen. This habitat remains poorly defined, but undoubtedly represents a limited area (ie. <1.0% of total available summer habitat). Since the entire fish population must utilize this restricted habitat for up to eight months a year, the availability of winter habitat is a critical factor in determining population size.

The wider distribution of fish populations over the much larger areas of summer feeding habitat represents an adaptation to allow more rapid growth and reduce competition. This widespread distribution leads to the conclusion that summer feeding habitat is available in excess and is not the most important factor controlling overall population size. The loss of small quantities of summer feeding habitat would simply encourage fish which might have a tendency to return to the same area every summer to seek alternate habitats.

The apparent excess of summer feeding habitats for grayling (Section 6.6.3), both in disturbed and undisturbed streams in the study area, supports the argument that availability of summer feeding habitat is not a factor controlling overall population size. A loss of a few hundred metres of stream channel as a result of an instream barrier or dramatic habitat modification would cause displacement of fish rather than their complete elimination from the population. Assuming overwintering sites are adequately protected, there would be a general reduction in population levels only if damage to summer feeding habitat was so widespread that it forced fish to concentrate within remaining habitats or resort to using sub-optimal habitats.

While streams containing major disturbances (eg. Falcon, Holden, Trevor, and Airstrip creeks) may support fewer fish now than they did 10 years ago, this does not mean that there has been a reduction in the number of fish in the entire region. Even in the undisturbed areas in each of these modified streams, there is still a surplus of apparently suitable habitat. It is probable that habitat modifications in a few of the larger materials sites caused temporary increases in numbers in adjacent undisturbed areas. One example of increased fish densities adjacent to a disturbance was observed in 1983, when bridge installation in Trevor Creek caused a complete loss of habitat in both Trevor and Tyler creeks. Densities of grayling in adjacent portions of the Atigun River (MP152.0 to MP158.0) were nearly double those observed during similar low flow periods in 1982 when both tributaries were accessible to fish (See Section 6.4).

Overall, the loss of habitat in these streams and other small streams in the TAPS corridor has had little or no effect on the total population levels of fish. Since critical overwintering habitat was not affected in any of the tributary streams examined, and since it has been demonstrated that availability of summer habitat is not a limiting factor, it is likely that fish select alternate summer feeding habitats when disturbed sites are encountered. The large excess of unused habitats in the study area has provided habitat for displaced fish, ensuring that population levels are maintained. Assuming that habitat modification in any one area does not become too extensive and that overwintering habitat and important spawning habitat continue to be protected, the effect of habitat loss in disturbed areas will continue to be localized.

7.0 SUMMARY AND CONCLUSIONS

7.1 Benthic Invertebrates

Disturbance in the northern portions of the TAPS corridor has had few effects on benthic invertebrate communities. What effects there are, tend to be localized. During this study, it was observed that:

1. In streams where stability was reduced or scour increased (eg. Brockman Creek), there were minor shifts in taxonomic structure and declines in standing crop.

2. In streams where channelization related to instream mining of granular materials increased stability (eg. Airstrip Creek), there were no apparent effects.

3. In streams which are naturally unstable and subjected to severe scour (eg. the Atigun River), effects of pipeline-related disturbance cannot be distinguished from natural ones.

As a result, instream mining and other instream activities have had a greater effect on benthic invertebrate communities in stable tributary streams than they have in large braided streams, such as those examined by Woodward Clyde Consultants (1980a).

With regard to the specific modifications that have occurred, buried crossings are more likely to require rip-rap and channelization of stream crossings and are therefore more likely to result in localized stream scour than elevated crossings. Benthic invertebrate communities downstream of highly armored buried crossings (eg. Marion Creek) occasionally display localized alterations which do not occur at the less disturbed overhead crossings (eg. Minnie Creek).

Sedimentation from unstable areas occasionally results in localized modification of benthic invertebrate communities, but only in locations where persistent sediment introductions occur (eg. North Fork Chandalar River). With the high sediment loads which characterize most streams during breakup and frequent freshets, it appears that benthic invertebrate communities inhabiting these streams are well adapted to frequent exposure to sediments.

Removal of overhanging vegetation in materials sites appeared to reduce the terrestrial component of benthic invertebrate drift only in an area (Falcon Creek) where the disturbance was extensive. Studies of the effects on drift in a smaller materials site (Airstrip Creek) were inconclusive.

7.2 Status of Fish Populations

Overall, the development of TAPS and its ancillary facilities has had little effect on fish populations within the pipeline corridor north of the Yukon River. Overwintering areas have been adequately protected by routing and timing decisions made during construction. Spawning success appears high in all areas where it was documented prior to or during construction.

There is evidence of reduced fish densities in a few localized areas where fish passage has been restricted or habitat modifications have been extensive. Since there is an apparent excess of summer feeding habitat available in the study area, minor losses of habitat have resulted in the displacement of small numbers of grayling, Arctic char, round whitefish, and slimy sculpin rather than reductions in the overall populations of these species.

7.3 Effects of Stream Crossings

At no time during this study did the pipeline or its related components (eg. check valves, pump stations, bank armor) directly interfere with fish migration. At locations where overhead crossings were used, any disturbance of the streambed has been avoided; and, with the exception of those few areas where bank armor has been installed, habitat modification in the vicinity of these crossings is minimal. Buried crossings generally result in greater modification of habitat, but where these crossings were constructed perpendicular to the stream channel, they are stable and pose few problems for fish.

Sections of pipeline buried in the floodplains of major streams are also stable in most areas, but have necessitated the installation of stream training structures. These structures have caused habitat modifications in a few small side channels in the Sagavanirktok and Middle Fork Koyukuk rivers. In areas where the pipeline has been buried parallel to major stream channels, numerous thermal irregularities occur. In the vicinity of the upper Atigun River, the pipeline trench may capture declining surface flow, causing discontinuous flow within the stream. In September 1980, the latter reportedly caused fish entrapment (Elliott 1982), but was not a problem during the period of our studies, 1981 through 1983.

7.4 Low Water Crossings

During the construction period, low water crossings were a major concern, but during the operation of the pipeline they have posed few problems. Over the course of this study, there were minor blockages of fish in several streams, primarily Foothills Streams, caused by rutting within the streambed and by streamflow french-draining through accumulated loose cobble. In all instances, however, minor maintenance with a hand shovel was adequate to prevent or alleviate these problems.

It appears that under light traffic loads, low water crossings are adequate to provide for fish movements. In general, we found that when stream discharges declined to the point that low water crossings became impassible to fish, other areas in the stream were impassible as well. Assuming that a reasonable level of maintenance continues, low water crossings will be less of a problem for fish passage than culverts.

7.5 Access Road and Workpad Culverts

Culverts in the workpad and under access roads had little impact on fish-bearing streams. At breakup, however, ice formation within these structures causes considerable flooding, and maintenance requirements appear to be high. During the course of our study, several culverts were washed out, resulting in minor sedimentation of streams. Culverts in the workpad and under access roads were not responsible for any significant fish blockages, largely because culverts were not installed where fish passage was a concern. While it was not within our Terms of Reference to examine culverts associated with the haul road, it was observed that the recent replacement of these structures with bridges is alleviating many of the problems with fish passage.

7.6 Thermal Irregularities

In numerous locations, water which flows along the pipeline trench is heated and resurfaces in the Atigun, North Fork Chandalar, Dietrich, and Middle Fork Koyukuk rivers. Small numbers of emigrating fish, primarily juvenile grayling, are attracted to these locations by the elevated water temperatures, and will remain in the area as stream discharge declines in the fall. Our studies documented hundreds of fish attracted to these sites, most of them in the Atigun River, but we were unable to ascertain whether these fish subsequently emigrated out of the area. Based on our observations in September, and other observations by ADF & G personnel in late fall and winter, it appears that at least several hundred fish annually die when they are unable to escape these thermal traps. Overall, however, the loss of this number of fish is likely to have little effect on regional population levels.

7.7 Habitat Preference

Grayling, both adults and juveniles, prefer deep pool habitats with low velocities and fine-grained substrates. Juveniles prefer substrates dominated by fines; adults display a preference for both fines and rock substrates. Medium-sized substrates (gravels) are not used extensively by either adult or juvenile grayling. Polynomial suitability-of-use functions for both adults and juveniles, based on depth, velocity, and substrate preference, are presented in Section 6.6.3.2.

Cover is important to both juvenile and adult grayling. Banks, and those cover features associated with them, are most important to adults, while rock cover is most important to juveniles. Other cover features important to grayling include bank vegetation, depth, instream vegetation, and shade. A summary of the most important factors used by adult and juvenile grayling, based on a multiple regression with measured fish density, is presented in Section 6.6.3.4.

Arctic char, rare in this study area, prefer bank vegetation, instream vegetation, and rocks as cover. Juvenile char select shallow low-velocity habitats with medium to coarse rock substrates. They prefer channels of 6 m or less in width, and are most often found in proximity to cutbanks or boulder banks. In general, juvenile char display less attraction to areas where banks provide cover than do juvenile or adult grayling. Adult char were too rare in the study area to permit analysis of habitat preference. Adult anadromous char do not occur.

Adult round whitefish prefer deep pools in large streams with relatively low velocities and coarse substrates. The cover requirements of round whitefish are similar to those of grayling, with bank-related cover features highly selected for. Round whitefish use the largest habitat of any of the three species studied. (Char generally use the smallest.) In Foothills Streams, round whitefish are most often found in the vicinity of cutbanks, which are typical of preferred habitats in these streams. In the small streams in which our studies were conducted, round whitefish and grayling had generally similar habitat requirements, and were often found in mixed schools. These small streams are, however, probably marginal habitat for adult round whitefish, since these fish typically prefer deep pools in large streams, a habitat type which was not included in our studies.

7.8 Atigun Pass Sediment Studies

Sediments originating from disturbance associated with the pipeline and the haul road are contributing significant quantities of sediment to both the Atigun and North Fork Chandalar rivers. Repair work conducted during and following freshets causes increased erosion along the workpad, and is responsible for a significant proportion of both turbidity and settleable solids originating in Atigun Pass. The problem appears to be less severe during periods of low precipitation or when there is no construction equipment active in the area. Settling ponds on the south side of Atigun Pass are not large enough to handle high sediment loads, and cannot be maintained during severe freshets.

In the North Fork Chandalar River, benthic invertebrate studies indicate that any effects from sediment introductions are localized and are apparent only in the fall, when naturally occurring sediment introductions are less common. In the Atigun River, sediment introductions have little effect on the benthic invertebrate community. Evidently the benthic community of both streams is comprised of a fauna well-adapted to the high sediment loads, as well as the highly variable discharge and severe scouring which characterize both drainages.

Grayling dominate the upper portions of both the Atigun and North Fork Chandalar drainages, but no spawning occurs in the upper portions of either system. Only in the fall have fry have been observed upstream as far as MP158.5 (in the Atigun River) and MP173.0 (in the North Fork Chandalar River). These locations are, respectively, about 11 km and 10 km downstream of the sources of sediments. Since both adults and juveniles are well-adapted to frequent freshets and the accompanying high suspended sediment levels, it is unlikely that sediment introductions have adversely affected fish populations in either stream.

7.9 Entrapment of Fish

Stranding of large numbers of fish, primarily grayling, is a common natural phenomenon in the Brooks Range and in streams in the coastal plain. During low discharge periods, these fish can become stranded in isolated pools and, if a timely freshet does not occur, they die. While a few fish were stranded at low water crossings and in the vicinity of thermal irregularities, the greatest concern is entrapment of fish above areas of discontinuous flow in materials sites.

Discontinuous flow in alluvial fans is a common natural phenomenon in this region, and it does result in periodic fish kills in undisturbed areas. In several locations, however, excavation of granular material may have aggravated this problem. Since baseline data are lacking, an assessment of this problem cannot be made without more precise data describing the hydrology and the characteristics of intergravel flow in these locations.

In the fall, discontinuous flow in Holden, Trevor, and Spike Camp creeks and the North Fork Chandalar River sometimes results in small fish kills. In some years, major kills exceeding 1,000 grayling occur in the North Fork Chandalar River. When summer stream flows are low, and when stream temperatures decline gradually in late August, few fish are trapped. Only when stream flows drop off rapidly as a result of an abrupt weather change does entrapment in alluvial fans become a serious concern.

Based on our observations of changes in alluvial fans resulting from instream mining, it appears that the Sten Creek pit has affected the hydraulics of Spike Camp Creek. In Holden Creek, deposition of loose cobble material appears to have resulted from instream mining. In 1983, this latter problem corrected itself, but may recur in future. To date, fish kills in Trevor Creek have been small and cannot be clearly attributed to instream mining, though mining may have resulted in reduced channel stability and damage to the surface armor of this stream.

In the North Fork Chandalar River, entrapment of fish is difficult to attribute entirely to instream mining. The occurrence of similar entrapment in the undisturbed East Branch of the river, and the broad area affected by discontinuous flow in the West Branch, well outside of the area originally mined, suggest that the North Fork may have been subject to discontinuous flow prior to mining.

With the possible exception of the North Fork Chandalar River, fish entrapment is having negligible effects on fish populations in the study area. The small losses at low water crossings, materials sites, and in other areas of discontinuous flow are relatively insignificant compared to natural losses during years of limited summer precipitation. Recruitment and re-invasion from adjacent undisturbed areas are probably adequate to replace these losses.

7.10 Habitat Modifications

Minor habitat modifications at stream crossings, access roads, and other linear forms of disturbance have had little effect on the localized distribution of fish. In many locations, this disturbance enhances the natural habitat. Elsewhere, the amount of modified habitat is extremely small compared with the amount of habitat available in any single stream. As a rule, overhead crossings have resulted in less habitat modification than buried crossings have.

Materials sites and stream training structures have resulted in the most widespread habitat changes. Of these, only habitat modifications associated with the mining of materials sites were assessed in detail. Studies of the habitat preferences of grayling, round whitefish, and char indicate that habitat changes in these large-scale disturbed areas are generally detrimental to habitat quality, and that the reduced numbers of fish present and changes in population structures have resulted from these habitat modifications.

Within the study area, Falcon Creek, Holden Creek, Trevor Creek, and Airstrip Creek all contain materials sites where mining has substantially altered habitat to the detriment of fish using these streams. Study sites in the North Fork Chandalar River mainstem, Snowden Creek, and Brockman Creek do not appear to have been changed by instream mining. The use of large quantities of rip-rap (eg. in Brockman Creek) has created some new habitat, but overall, these new habitats support average densities only about equal to the habitats they replaced. Juvenile grayling appear to select more for these man-made habitats than adult grayling, char, or round whitefish.

Changes in Falcon Creek, Holden Creek, Trevor Creek, and Airstrip Creek have resulted in the elimination of habitat for an estimated 340 grayling and 50 round whitefish in all size classes larger than 75 mm. Undoubtedly, instream mining in other stable single channel streams not included in our Detailed Studies has also resulted in the elimination of habitat for grayling and round whitefish. Within the pipeline corridor, char appear to be too restricted in their distribution to have been affected by these habitat changes.

The types of changes which result from instream mining in tributary streams include increased braiding, channelization, reduced substrate and bank stability, changes in channel configuration, increased velocity, reduced depth, reduced pool habitat, reduction in average substrate size, loss of banks, elimination of bank vegetation, elimination of cover, increased turbulence and elimination of velocity barriers. These changes are responsible for the reduced numbers of fish using mined sections of stream.

Mining in highly braided streams (eg. North Fork Chandalar River), which are already subject to severe scour and instability, has much less effect on fish habitat (Woodward Clyde Consultants 1980b). In some instances, the creation of ponded areas in or adjacent to streams has resulted in the creation of new habitat. Where scour is severe, these new habitats are temporary (eg. Dietrich River) and may be eliminated by sedimentation and channel migration. The changes in most tributary streams appear to be long-term. Outside the pipeline corridor, Woodward Clyde Consultants (1980a) observed that changes were still apparent in some mined areas which had been disturbed 15 years prior to their studies. There is little evidence that mined areas in tributary streams have recovered significantly since abandonment.

While these habitat modifications have resulted in localized reductions in summer fish densities, habitat preference studies indicate a large surplus of under-utilized habitat throughout the study area. Since fish populations in these disturbed streams are highly migratory and were not present during the actual mining operations, the overall effect of instream mining has been a displacement of fish to alternate habitats in undisturbed areas. In any specific stream within the study area, the availability of overwintering habitat appears to be the most important factor controlling fish densities. Instream mining was concentrated in alluvial fans, deposition areas and other locations where no water was present in winter. While there were instances where instream mining encountered groundwater (MS-106-2, Dietrich River), in general, overwintering areas were not affected by instream mining.

There is no evidence that the localized habitat modifications caused by instream mining have had any adverse effect on regional population levels of grayling, char, and round whitefish in the corridor. Similarly, the modification of habitats as a result of stream training structures has resulted in displacement rather than elimination of fish from the population.

8.0 LITERATURE CITED

Alaska Department of Fish and Game. 1980. Fish resource areas of the Northwest Gas Pipeline corridor. Phase I: status and packaging study. Alaska Department of Fish and Game, Pipeline Surveillance Office, Anchorage.

Alaska Department of Natural Resources. 1982. Fish stream identification forms. Field forms collected for: "List of fish streams between Prudhoe Bay and the Canadian border along the proposed Northwest Alaskan Pipeline Company gas pipeline route." Northwest Alaskan Pipeline Company, Anchorage. 31 pp.

Alyeska Pipeline Service Company. 1969. Preliminary aerial photographs along the route of proposed Trans Alaska Pipeline System (Sagavanirktok and Dietrich regions). Alyeska Pipeline Service Company, Bellevue, Washington. Ms. 10 pp + maps.

Alyeska Pipeline Service Company. Undated. Northern District aerials. Alyeska Pipeline Service Company, Anchorage. Aerial photographs.

American Public Health Association. 1971. Standard Methods for the Examination of Water and Wastewater. 13th ed. APHA, New York.

Anctil, D., N. Grinich, and M. Haddix. 1978. Aquatic habitat evaluation, data summary report. Habitat Protection Section, Alaska Department of Fish and Game, Anchorage.

Baumann, R.W. 1975. Revision of the stonefly family Nemouridae (Plecoptera): A Study of the World Fauna at the Generic Level. Smithsonian Contributions to Zoology, No. 211. 75 pp.

Binns, N.A. and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Amer. Fish. Soc. 108:215-228.

Borror, D.J. and D.M. DeLong. 1971. An Introduction to the Study of Insects. 3rd Ed. Holt, Rinehart and Windsor. New York. 812 pp.

Bovee, K.O. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper No. 12. USDI Fish and Wildlife Service, Office of the Biological Services. FWS/OBS-82/26. 248 pp.

Bovee, K.D. and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability of use curves for instream flow. Info. Paper No. 3, FWS/OBS-77/63. 39 pp.

Bureau of Land Management. 1981. Report of post breakup inspection Trans Alaska Pipeline and haul road, June 16-19 and 23-25, 1981. Office of Special Projects, Bureau of Land Management, Anchorage. Mimeo.

Burgar, C. and L. Swenson. 1977. Environmental surveillance of gravel removal on the Trans-Alaska Pipeline System with recommendations for future gravel mining. JFWAT, Anchorage. Special Rept. No. 13.

Cairns, J., Jr. 1968. Suspended solids standards for the protection of aquatic organisms. Purdue University. Engineering Bull. No. 129.

Campbell, P., J. Dentry, G.W. Morden, S.E. Elliott, G.J. Brunskill, R. Wagemann, and B.W. Graham. 1975. General physical and chemical data for water and sediments of the Mackenzie and Porcupine watersheds and rates of transport at dissolved and suspended elements at selected stations in the Mackenzie and Porcupine watersheds, 1971-1974. Fish. and Mar. Serv. Res. Div. Tech. Bull. No. 545. 18 pp.

Chihuly, M. 1982. Fish stream identification forms, fall 1981 and winter 1982. Unpublished Alaska Department of Fish and Game data forms. Alaska Department of Natural Resources, Anchorage. 26 pp.

Craig, P.C. and P.J. McCart. 1975. Classification of stream types in Beaufort Sea drainages between Prudhoe Bay, Alaska, and the Mackenzie Delta, NWT, Canada. Arct. Alp. Res. 7(2):183-198.

Cummins, K.W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. Amer. Mid. Nat. 67:477-504.

DenBeste, J. and P. McCart (In prep.) Final report Atigun River oil spill study. Report to Groh, Eggers, Robinson, Price, and Johnson Law Offices, Anchorage.

Edmondson, W.T. (ed.) 1959. Freshwater Biology. John Wiley and Sons, New York. 1248 pp.

Edmunds, G.F., S.L. Jensen, and L. Berner. 1976. The Mayflies of North and Central America. University of Minnesota Press, Minneapolis. 330 pp.

Elliott, J.M. 1971. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biological Association Scientific Publ. No. 25. 148 pp.

Elliott, G.V. 1982. Final report on the evaluation of stream crossings and effects at channel modification on fishery resources along the route of the Trans-Alaska Pipeline. US Fish and Wildlife Service, Special Studies, Anchorage. 110 pp.

Gustafson, J. 1977. An evaluation of low water crossings at fish streams along the Trans-Alaska Pipeline System. JFWAT, Anchorage. Special Rept. No. 16.

Hallberg, J. 1975. Second interim report of the sport fish technical evaluation study. JFWAT, Anchorage. Special Rept. No. 7.

Hamilton, A.L. and O.A. Saether. Undated. Unpublished key to the Chironomids. Environment Canada, Freshwater Institute, Winnipeg.

Harman, H.H. 1976. Modern Factor Analysis. 3rd ed. University of Chicago Press, Illinois. 487 pp.

Hemming, C. 1982. Fish stream identification forms, fall 1981 and winter 1982. Unpublished Alaska Department of Fish and Game data forms. Alaska Department of Natural Resources, Anchorage. 26 pp.

Hess, A.D. 1941. New limnological sampling equipment. Limn. Soc. of Amer. Spec. Pub. 6:1-5.

Hubbard, M.D. and W.L. Peters. 1978. Environmental requirements and pollution tolerance of Ephemeroptera. Environ. Prot. Agency Rept. No. EPA-600/4-78-061. 218 pp.

Johnson, R.L. and J. Rockwell, Jr. 1981. List of streams and other waterbodies along the Trans-Alaska Oil Pipeline route. Fourth Revision (draft). USDI, Alaska Pipeline Office, Anchorage.

Joint Federal/State Fish and Wildlife Advisory Team. 1975. Zones of restricted activity for fish and wildlife along the Trans-Alaska Pipeline. Unpub. Ms. 21 pp.

Lackey, R.T. and B.E. May. 1971. Use of sugar flotation and dye to sort benthic samples. Trans. Amer. Fish. Soc. 4:794-797.

Lloyd, M. and R.J. Ghelardi. 1964. A table for calculating the "equitablity" component of species diversity. J. Anim. Ecol. 33:217-225.

Lloyd, M., J.H. Zar, and J.R. Karr. 1968. On the calculation of information-theoretical measures of diversity. Amer. Midland Natur. 79:257-272.

MacArthur, R.H. 1957. On the relative abundance of bird species. Proc. Nat. Acad. Sci., Washington, D.C. 43:293-295.

Margalef, R. 1974. Sampling techniques and methods for estimating quantity and quality of biomass; 2:12 counting. In R.A. Vollenweider (ed.), A Manual on Methods for Measuring Primary Production in Aquatic Environments. IBP Handbook 12. Blackwell Scientific Publications, Oxford. 225 pp.

McCart, P.J. 1980. A review of the systematics and ecology of Arctic char (Salvelinus alpinus) in the western Arctic. Canadian Tech. Rept. Fish. and Aquat. Sci. No. 935. 89 pp.

McCart, P. and P. Craig. 1971. Meristic differences between anadromous and freshwater resident Arctic char (Salvelinus alpinus) in the Saganavirktok River drainage, Alaska. J. Fish. Res. Board Can. 28:115-118.

McCart, P.J., P.C. Craig, and H. Bain. 1972. Report on fisheries investigations in the Sagavanirktok River and neighboring drainages. Report to the Alyeska Pipeline Service Company, Bellevue. 83 pp.

McCart, P. and V. Pepper. 1970. Report on fish investigations along part of the proposed route of the Trans-Alaska Pipeline, June to August 1969. Pages 21 to 64 In A preliminary report of the ecology survey along the proposed pipeline route, June through October, 1969. Trans-Alaska Pipeline System, Anchorage.

McPhail, J.D. 1961. A systematic study of the Salvelinus alpinus complex in North America. J. Fish. Res. Board Can. 18(5):793-816.

McPhee, C. and J.J. Watts. 1976. Swimming performance of Arctic grayling in highway culverts. Final report to US Fish and Wildlife Service, Anchorage. 41 pp.

Merritt, R.W. and K.W. Cummins. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co. Dubuque. 441 pp.

Michael Baker Inc. 1977. Accounting of sale-free use permit materials. Prepared for Alyeska Pipeline Service Company, Anchorage.

Miller, M.C., P. Spatt, and P.A. Lewis. (In Prep.) A report on the effects of the Atigun River oil spill on macroinvertebrates. Department of Biology, University of Cincinnati, Ohio.

Morehouse, A., Robert A. Childers, and Linda E. Leask. 1978. Fish and wildlife protection in the planning and construction of the Trans-Alaska Oil Pipeline. US Department of Commerce, Nat. Tech. Info. Svc. PB-298614.

Nauman, J.W. and D.R. Kernodle. 1975. The effect of a fuel oil spill on benthic invertebrate and water quality on the Alaska Arctic slope, Happy Valley Creek near Sagwon, Alaska. J. Res. US Geol. Surv. 3(4):495-500.

Nauman, J.W. and D.R. Kernodle. 1977. Aquatic organisms from selected sites along the Trans-Alaska Pipeline Corridor, September 1970 to September 1972. US Geological Survey, Anchorage. Open-File Rept. 77-634.

Netsch, N. 1975. Fishery resources of waters along the route of the Trans-Alaska Pipeline between Yukon River and Atigun Pass in north central Alaska. US Fish and Wild. Serv. Res. Pub. 124.

Netsch, N.F., T.O. Renschler, and E.C. Wadlow. 1972. Supplement to "A progress report on fish surveys along the route of the proposed Trans-Alaska Pipeline between the Yukon River and Atigun Pass during 1971. USDI Bureau of Sport Fish and Wildlife, Anchorage. 202 pp.

Northern Engineering Services Company Ltd. and Aquatic Environments Limited. 1975. Reconnaissance of the Alyeska Pipeline --material source borrow methods and an evaluation of these methods with respect to aquatic habitats. Canadian Arctic Gas Study Ltd., Calgary, Alberta.

Northwest Alaskan Pipeline Company. 1982. List of fish streams. Alaska Department of Fish and Game, Anchorage. Mimeo. 29 pp.

Oliver, D.R., D. McClymont, and M.E. Roussel. 1978. A key to some larvae of Chironomidae (Diptera) from the Mackenzie and Porcupine river watersheds. Fish. and Mar. Serv. Tech. Rept. No. 791. 73 pp.

Pankratova, V. 1970. Larvae and pupae of midges of the subfamily Orthocladiinae of the fauna of the USSR. Inst. Akad. Nauk. SSSR 102. 343 pp. (In Russian.)

Pennak, R.W. 1978. Fresh-water Invertebrates of the United States. 2nd Ed. Wiley, New York. 803 pp.

Poole, R.W. 1974. An Introduction to Quantitative Ecology. McGraw-Hill, New York. 532 pp.

Prewitt, C.G. 1982. The effect of depth-velocity correlations on aquatic physical habitat usability estimates. PhD Thesis, Colorado State University. 83 pp.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. No. 191:153-155.

Rockwell, J., Jr. 1978. Criteria for crossing small drainages containing fish. Alaska Pipeline Office Narrative Surveillance Report. Attach G. USDI, Alaska Pipeline Office, Anchorage.

Saether, O.A. 1969. Some Nearctic Podonominae, Diamesinae, and Orthocladiinae (Diptera: Chironomidae). Fish. Res. Baord Can. Bull. 170. 154 pp.

Saether, O.A. 1976. Revision of Hydrobaenus, Tressocladius, Zalutschia, Paratrissocladius, and some related genera (Diptera: Chironomidae). Fish. Res. Board Can. Bull. 195. 287 pp.

Shannon, C.E. and W. Weaver. 1949. The Mathematical Theory of Communication. University of Illinois Press, Urbana. 117 pp.

Slack, K.V., J.W. Nauman, and L.J. Tilley. 1979. Benthic invertebrates in a north-flowing stream and a south-flowing stream, Brooks Range, Alaska. Water Res. Bull. 15(1):108-135.

Sokal, R.R. and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco. 776 pp.

Tack, Steven L. 1980. Migrations and distributions of Arctic grayling, Thymallus arcticus (Pallas), in interior and Arctic Alaska. Alaska Department of Fish and Game, Sport Fish Division, FAIFR No. R-1, Volume 21. 32 pp.

Tilley, L.J. Undated. Some larvae of Orthocladiinae, Chironomidae from Brooks Range, Alaska with provisional key (Diptera). Pan-Pacific Entomologist. Volume 55:127-146.

University of California Press. 1977. BMDP Biomedical Computer Programs, P-Series. University of California, Berkeley.

Voos, K.A. 1981. Simulated use of the exponential polynomial/maximum likelihood technique in developing suitability of use functions for fish habitat. PhD Thesis, Utah State University. 85 pp.

US Department of Interior. 1974. Agreement and grant of right-of-way for Trans-Alaska Pipeline between United States of America and Amerada Hess Corp., ARCO Pipeline Co., Exxon Pipeline Co., Mobil Alaska Pipeline Co., Phillips Petroleum Co., Sohio Pipeline Co., and Union Alaska Pipeline Co. US Government Printing Office, Washington, DC.

Usinger, R.L. (ed.) 1963. Aquatic Insects of California. University of California Press, Berkeley. 508 pp.

Weber, C.I. 1973. Biolgical Field and Laboratoy Methods for Measuring the Quality of Surface Waters and Effluents. Analytical Quality Control Laboratory, National Environmental Research Center, Cincinnati. EPA-670/4-73-001.

Wiggins, G.B. 1977. Larvae of the North American Caddisfly Genera (Trichoptera). University of Toronto Press, Toronto. 401 pp.

Wilhm, J.L. 1970. Range of diversity index in benthic macroinvertebrate populations. JWPCF 42:R221-R224.

Winer, B.J. 1971. Statistical Principles in Experimental Design. 2nd Ed. McGraw-Hill, Inc., New York. 907 pp.

Woodward Clyde Consultants. 1980a. Gravel removal studies in Arctic and Subarctic floodplains in Alaska. USDI Fish and Wildlife Service. Bio. Ser. Prog. FWS/OBS-80/08.

Woodward Clyde Consultants. 1980b. Gravel removal guidelines manual for Arctic and Subarctic floodplains. USDI Fish and Wildlife Service. Biol. Ser. Prog. FWS/OBS-80/09.

Wright, D.G. 1978. Observations on the environmental monitoring and surveillance of the Alyeska or Trans-Alaska Pipeline. Fish. and Mar. Serv. Ms. Rept. No. 1451.

Yoshihara, H.T. 1972. Monitoring and evaluation of Arctic waters with emphais on the North Slope drainages. Alaska Department of Fish and GAme. Federal Aid In Fish Restoration 13(G-III-A):1-49.

Yoshihara, H.T. 1973a. Monitoring and evaluation of Arctic waters with emphasis on the North Slope drainages. Part A. Some life history aspects of Arctic char. Alaska Department of Fish and Game. Federal Aid in Fish Restoration 14(G-III-A):1-63.

Yoshihara, H.T. 1973b. Monitoring and evaluation of Arctic waters with emphasis on the North Slope drainages. Part B: Pipeline and haul road crossing surveys. Alaska Department of Fish and Game. Federal Aid in Fish Restoration 14(G-III-A)64-83.

Zippin, C. 1956. The removal method of estimating animal populations. Biometrics 12:163-189.

Zippin, C. 1958. The removal method of population estimation. J. Wildl. Mgmt. 22:82-90.

TABLES

Table 1 Fish species captured or observed along the TAPS alignment north of the Yukon River during the period 1981 to 1983. Specimens from the Dietrich and Koyukuk River systems have been identified as Dolly Varden (*Salvelinus malma*) by previous workers. Specimens of these fish have been subjected to taxonomic examination by Aquatic Environments Inc. and found to be the Western Form of Arctic char (*Salvelinus alpinus*).

Common Name	Scientific Name	Four Letter Code	Major Drainage				
			Sagavanirktok	Atigun	Chandalar	Dietrich	Koyukuk
Chum salmon	*Oncorhynchus keta*	CHUM	X				X
Chinook salmon	*Oncorhynchus tshawytscha*	CHIN					X
Pink salmon	*Oncorhynchus gorbuscha*	PINK	X				
Arctic char	*Salvelinus alpinus*	CHAR	X	X		X	X
Lake trout	*Salvelinus namaycush*	LKTR	X	X			
Least cisco	*Coregonus sardinella*	LSCS	X				
Arctic cisco	*Coregonus autumnalis*	ARCS	X				
Lake whitefish	*Coregonus clupeaformis*	LKWT					X
Broad whitefish	*Coregonus nasus*	BDWT	X				
Round whitefish	*Prosopium cylindraceum*	RDWT	X	X		X	X
Arctic grayling	*Thymallus arcticus*	GRAY	X	X	X	X	X
Northern pike	*Esox lucius*	PIKE					X
Longnose sucker	*Catostomus catostomus*	LNSK				X	X
Burbot	*Lota lota*	BURB	X	X		X	X
Ninespine stickleback	*Pungitius pungitius*	NSSB	X				
Slimy sculpin	*Cottus cognatus*	SLSC	X	X	X	X	X

Table 2 Methods used to collect physical and chemical data during General Surveys and Detailed Studies.

Physical Parameters	Equipment	Units	Accuracy
Water Temperature	Fisher Hand Held Pocket Thermometer	°C	±0.5°C
Air Temperature	As above		
Max-Min Temperature	U.S. Weather Bureau Mercury-Alcohol Max-Min	°C	±0.1°C
Dissolved Oxygen	Bausch and Lomb Spectrokit Reagent	ppm	±0.2 ppm
pH	Merck Non-Bleeding pH Strips	pH units	±0.2 pH
Conductivity	Labline Lechro MHO-meter	µmhos	±1 µmho @ 50 µmhos
Turbidity	HS Shaban Turbid Meter DRT 100	Formazin Turbidity Units (FTU)	±0.1 FTU
Gradient	Carpenter's level and 50 m sight line	degrees	±0.1°
Substrate Size	25 unit-1 m^2 grid	%	±10%
Discharge/Velocity	Marsh-McBirney Portable Discharge Meter, Model No. 201 & Wading Rod	m/s	±0.01 m/s
Water Depth	Marsh-McBirney Wading Rod	cm	±1 cm

Table 3 Methods used to collect biological data during General Surveys and Detailed Studies.

Biological Parameters	Equipment
Benthic Invertebrate Samples	
Colonization	6.25 dm^3 Chicken barbecue baskets filled with fist sized rocks (washed)
Drift	45 cm x 45 cm Drift Nets (300 μ mesh)
Substrate	a) Modified Hess Sampler (0.1 m^2 with 300 μ mesh) b) Standard Surber Sampler (0.093 m^2 with 300 μ mesh) c) Kick Nets (1.0 m^2 with 1.6 mm mesh)
Fish Studies	
Distribution and Abundance	a) Smith Root Type VII backpack electrofisher b) 20 m marquisette beach seine c) 5 m marquisette pole seine
Downstream Movements (Young-of-the-year)	45 cm x 45 cm Drift Nets (300 μ mesh)
Egg Surveys	Kick Nets (1.0 m^2 with 1.6 mm mesh)
Young-of-the-Year Collection	a) 30 cm diameter long handled dipnet (300 μ mesh) b) 5 m marquisette pole seine
Density	a) 20 m marquisette beach seine or 1.3 cm^2 mesh wire fence and electrofisher b) 20 m marquisette beach seine
Angling	No. 1 Mepps Spinner
Biomass	O'Haus Triple Beam Balance equipped with fish weighing bucket

Table 4 Summary of Detailed Study streams, forms of disturbance, reported concerns and the types of studies conducted from 1981 through 1983.

Stream	MP	Form of Disturbance(s)	Reported Concern(s)	Type of Studies
Oksrukuyik Creek	103.5	Overhead Crossing Light Angling Pressure	Undisturbed	Fish Density/Habitat
Kuparuk River	126.4	Overhead Crossing Light Angling Pressure	Undisturbed	Fish Density/Habitat
Falcon Creek	uncrossed	Instream Materials Site	Habitat Modification	Benthic Invertebrate Fish Density/Habitat
Holden Creek	145.7	Overhead Crossing Instream Materials Site Stream Channelization	Fish Entrapment Habitat Modification	Benthic Invertebrate Fish Density/Habitat Migration Monitoring
Trevor Creek	154.1	Overhead Crossing Instream Materials Site Extensive Armoring	Fish Entrapment Habitat Modification	Benthic Invertebrate Fish Density/Habitat Migration Monitoring
Spike Camp Creek	163.0	Adjacent Materials Site	Fish Entrapment	Fish Density/Habitat Migration Monitoring
Atigun River	150-164.0	Instream Burial Materials Site Oil Spill Ongoing Maintenance	Fish Entrapment Thermal Irregularities Sediment Introductions Oil Damage	Benthic Invertebrate Fish Distribution Sedimentation Migration Monitoring Fish Density/Habitat Temperature Monitoring
North Fork Chandalar River	167-173.0	Instream Burial Materials Site Ongoing Maintenance	Fish Entrapment Thermal Irregularities Sediment Introductions Habitat Modification	Benthic Invertebrate Fish Density/Habitat Sedimentation Temperature Monitoring Migration Monitoring
Snowden Creek	198.5	Overhead Crossing Extensive Armoring Adjacent Materials Site	Habitat Modification	Benthic Invertebrate Fish Density/Habitat
Brockman Creek	204.1	Overhead Crossing Extensive Armoring Instream Materials Site	Habitat Modification	Benthic Invertebrate Fish Density/Habitat Migration Monitoring
Minnie Creek	225.6	Overhead Crossing Bank Armor	Undisturbed	Benthic Invertebrate Fish Density/Habitat
Marion Creek	233.2	Buried Crossing Extensive Bank Armor Long-term Impassible Culverts	Reduced Fish Use Habitat Modification	Benthic Invertebrate Fish Density/Habitat

Table 5 Summary of coded variables and explanation of codes used for available habitat, habitat use, and habitat preference studies. Coded categories are explained in detail in Volume III, Appendices A and B.

Parameter	Units	Code 0	1	2	3	4	5	6	7	8	9
Stream Gradient	%	0-0.5	0.6-1.0	1.1-2.0	>2.0						
Food Availability	mean organisms/m^2	<500	501-1000	1001-2000	2001-5000	>5000					
Food Diversity	mean no. taxa	1-5	6-10	11-15	16-20	>20					
Sustrate Size	cm	Organic	<0.2	0.2-1.0	1.1-2.5	2.6-6.0	6.1-12.0	12.1-25	56-40	>40	Bedrock
Habitat Type	class	Pool	Riffle	Run	Low Velocity Area	Boulder Controlled Pool					
Bank Type	class	Midstream	Rock or Gravel Bar	Cutbank	Slumping Earth	Sloping Loose Gravel or Rock	Rip-Rap	Boulder	Stable Vegetated Earth	Bedrock	
Cover Type											
Depth		Absent	Present								
Bank Vegetation		Absent	Present								
Instream Vegetation		Absent	Present								
Rock Cover		Absent	Present								
Bank Cover		Absent	Present								
Slumps		Absent	Present								
Shade		Absent	Present								
Turbulence		Absent	Present								
Turbidity or Color		Absent	Present								
Adjacent Velocity	m/s		0.0	0.01-0.5	>0.5						

Table 6 Locations of observed fish entrapment resulting from declining stream discharge. Size range codes are: YOY = Young-of-the-year; J = Juvenile-sized; A = Adult-sized. Species codes are: CHAR = Arctic char; GRAY = Arctic grayling; RDWT = round whitefish.

Waterbody	Source	Species	Number (estimate)	Size Range
Trans Alaska Pipeline				
Sagavanirktok River	9	GRAY, RDWT	hundreds	YOY to A
North Fork Chandalar River	2	GRAY	700 to 1200	120 to 350 mm
Upper Atigun River	6	GRAY	200 to 300	100 to 300 mm
Spike Camp Creek	6	GRAY	100	150 to 300 mm
Trevor Creek	6	GRAY, RDWT	50	J
Holden Creek	6	GRAY, RDWT	200	150 to 350 mm
Dietrich River	9	GRAY	no estimate	YOY and J
Koyukuk River	9	GRAY	no estimate	YOY and J
Northern Alaska				
Anaktuvuk River	7	GRAY, RDWT	no estimate	J
Anaktuvuk River Tributaries	7	GRAY, RDWT	no estimate	J and A
Upper Kuparuk River	1,2	GRAY	100	YOY
Ivishak River	1,7	GRAY, RDWT	no estimate	75 to 300 mm
Ribdon River	2	GRAY	no estimate	J
Accomplishment Creek Tributary	1	GRAY, CHAR	300	<200 mm
Canning River (Marsh Fork)	1,2	GRAY, RDWT	1000	65 to 400 mm
Upper Atigun River (1971)	5	GRAY	hundreds	45 to 65 mm
East Fork Chandalar River	6	GRAY, CHAR	125 +	100 to 200 mm
Lupine River	2	CHAR	200	80 to 150 mm
Sagavanirktok River (1971)	1	GRAY	hundreds	45 to 65 mm
Oksrukuyik Creek	9	GRAY	no estimate	YOY to 400 mm

Continued

Table 6 Concluded

Waterbody	Source	Species	Number (estimate)	Size Range
Yukon Territory				
Firth River	8	GRAY	1000	150 mm+
Blackstone River at headwaters	2,3	GRAY	5000	200 to 375 mm
Stoney Creek (Peel Tributary)	2,3	CHAR	100	about 200 mm
Northwest Territories				
Peel River Tributaries	2,3	GRAY, RDWT	150 each	80 to 175 mm
Vermilion Creek	4	GRAY	2000	65 to 220 mm
Nota Lake	4	GRAY	5000	65 to 300 mm
Prohibition Creek	4	GRAY	1000 to 2000	80 to 175 mm

Sources:
1. Dr. P.J. McCart, Aquatic Environments Inc.
2. J. Den Beste, Aquatic Enironments Inc.
3. G. Mann, Esso Resources Ltd
4. D. Tripp and P. McCart Biological Consultants
5. Dr. P. Craig, LGL Consultants
6. Ken Durley, Alyeska Pipeline Service Co.
7. Terry Bendock, Alaska Department of Fish and Game
8. Dr. G. Glova, Aquatic Environments Limited
9. Woodward Clyde Consultants Ltd. (1980)

Table 7 Summary of observed fish entrapment in North Slope streams during 1982 studies in the TAPS corridor. Species codes are: BURB = burbot; CHAR = Arctic char; GRAY = Arctic grayling; RDWT = round whitefish; SLSC = slimy sculpin. Estimated numbers code is: P = present.

Location	MP	Date	Species	Estimated Numbers	Size Range (mm)	Comments
Happy Valley Creek	51.0	Aug 2	GRAY	100	fry	Stranded in isolated pools along edge of main channel
Sagavanirktok River	69.0	Aug 3	GRAY	26	35 to 195	Stranded in small side channel pools
			RDWT	2	175	
			SLSC	>50	55 to 90	
Sagavanirktok River	81.0	Aug 2	GRAY	45	125 to 200	Stranded in perched pool at lower end of dry side channel
			SLSC	P	50 to 70	
			CHAR	2	120	
Arthur Creek	95.8	Aug 2	GRAY	80	fry	Stranded in isolated pools in lowest 1 km of stream
			GRAY	55	188 to 267	
Sagavanirktok River	96.0	Sep 9	GRAY	7	54 to 190	Stranded in perched pool french draining into side channel
			CHAR	4	79 to 185	
			BURB	3	150 to 195	
			SLSC	7	70 to 90	
Gustafson Gulch	96.1	Aug 2	GRAY	200	35 to 120	Stranded in isolated pools
Polygon Creek	99.0	Aug 3	GRAY	300	29 to 190	Stranded in isolated pools over first 1 km of stream; all perished
Poison Pipe Creek	100.0	Aug 2	GRAY	50	33 to 145	Stranded in isolated pools near haul road

Continued

Table 7 Concluded

Location	MP	Date	Species	Estimated Numbers	Size Range (mm)	Comments
Rudy Creek	102.5	Jul 26	GRAY	>100	24 to 100	Stranded in isolated pools below pipeline crossing
Oksrukuyik Creek	103.0	Jul 26	GRAY	>200	23 to 38	Stranded in isolated pools along main channel above haul road
			SLSC	30	35 to 55	
Kuparuk River	126.4	Jul 26	GRAY	30	fry	Stranded in pools french draining into main channel
			GRAY	10	190 to 295	
Holden Creek	145.8	Jul 28	GRAY	44	94 to 292	Creek french draining in lowest 200 m of materials site
Trevor Creek	154.1	Sep 3	GRAY	29	86 to 290	Creek dried up near mouth fish perished by Sept 12
			CHAR	3	142 to 167	
Spike Camp Creek	163.0	Jul 28	GRAY	16	210 to 261	Creek dried up 100m below haul road
North Fork Chandalar River	172.0	Sep 12	GRAY	70	135 to 290	Stranded in flowing water above area of discontinuous flow
			SLSC	P	45 to 90	

Table 8 Summary of observed fish entrapment in North Slope streams during 1983 studies in the TAPS corridor. Species codes are: BURB = burbot; CHAR = Arctic char; GRAY = Arctic grayling; RDWT = round whitefish; SLSC = slimy sculpin.

Location	MP	Date	Species	Estimated Number	Size Range (mm)	Comments
Stout Creek	H/R340.0	Aug 1	GRAY	46	130 to 254	Stranded in 2 shallow isolated pools below haul road. Outwash from haul road is partially responsible
Happy Valley Creek	51.0	Jul 20	GRAY	5000	fry	Stranded in isolated pools
		Aug 1	GRAY	17	120 to 350	1 km above haul road
Clarke Lake Outlet (Stump Creek)	91.9	Jul 20	GRAY	19	juvenile	Stranded between dense growths of grass in non-flowing channel
Sagavanirktok River Side Channel	93.0	Jul 20 Aug 1	GRAY	200	150 to 250	Culvert has no flow at haul road. Fish in 100 m area above haul road
Arthur Creek	95.8	Jul 20	GRAY	200	fry	Stranded in isolated pools
			GRAY	26	90 to 300	in lowest 1 km of stream
Gustafson Gulch	96.1	Jul 20	GRAY	50	fry	Isolated pool at LWC.
			SLSC	2	fry	Stream has no continuous flow

Continued

Table 8 Concluded

Location	MP	Date	Species	Estimated Number	Size Range (mm)	Comments
Polygon Creek	99.0	Jul 20	GRAY	12	juvenile	Above haul road 250 m. Stranded in isolated pools above haul road
Poison Pipe Creek	100.0	Jul 20	GRAY	600	fry	Blocked by grass and no flow
			GRAY	8	100 to 175	
			GRAY	1	275	
Trevor Creek	154.1	Jun 15	GRAY	500	90 to 350	Stream abruptly dewatered crew installing new haul haul road bridge
			RDWT		80 to 300	
			SLSC		50 to 90	
North Fork Chandalar River	172.0	Sep 9	GRAY	6	153 to 269	Stranded above an area of discontinuous flow
North Fork Chandalar River	172.5	Sep 9	GRAY	37	120 to 195	Stranded in isolated pools 400 m below MS.
			SLSC	12	40 to 90	

Table 9 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in Brockman Creek on July 20 and September 13, 1981 and June 6, July 23, and September 13, 1982. Standing crop is transformed as log (x+1).

Date	Source of Variation	Sum of Squares	df	Mean Square	F	P
81/7/20	Station	1.62131	3	0.54044	4.67	<0.05
	Station Ia vs. II	0.58872	1	0.58872	5.08	<0.05
	Station II vs. III	0.04490	1	0.04490	0.39	>0.05
	Error	1.38920	12	0.11577		
	Total	**3.01051**	**15**			
81/9/13	Station	0.15522	3	0.05174	2.69	>0.05
	Station Ia vs. II	0.03173	1	0.03173	1.65	>0.05
	Station II vs. III	0.09159	1	0.09159	4.77	<0.05
	Error	0.23304	12	0.01920		
	Total	**0.51148**	**15**			
82/6/6	Station	0.37226	3	0.12409	1.51	>0.05
	Station I vs. II	0.00014	1	0.00014	0.00	>0.05
	Station II vs. III	0.09920	1	0.09920	1.21	>0.05
	Error	0.98385	12	0.08199		
	Total	**1.35611**	**15**			
82/7/23	Station	1.50133	3	0.50044	40.78	<0.01
	Station I vs. II	0.68067	1	0.68067	55.46	<0.01
	Station II vs. III	0.13837	1	0.13837	11.28	<0.01
	Error	0.14726	12	0.01227		
	Total	**1.64829**	**15**			

Table 9 Concluded

Date	Source of Variation	Sum of Squares	df	Mean Square	F	P
82/9/13	Station	0.39494	3	0.13165	2.32	>0.05
	Station I vs. II	0.16523	1	0.16523	2.91	>0.05
	Station II vs. III		1	0.01607	0.28	>0.05
	Error	0.68119	12	0.05677		
	Total	1.07613	15			

Table 10 Multiple comparisons of benthic invertebrate standing crop at four stations in Brockman Creek using Newman-Keuls procedure with log (x+1) original counts. Numbers in the table body are the studentized range statistic, q. Values significant at the 0.05 level are indicated by an asterisk. Values significant at the 0.01 level are indicated by a double asterisk. Only those dates where ANOVA shows an overall significant value (Table 9) are included.

Date	Station	n	Mean log(x+1) Number/ Sample	Station			
				IV	III	II	Ia
81/7/20	IV	4	0.595				
	III	4	0.746				
	II	4	0.896	1.769			
	Ia	4	4.961*	4.073*	3.192*		
Station				IV	III	II	Ia

Date	Station	n	Mean log(x+1) Number/ Sample	Station			
				III	II	IV	I
82/7/23	III	4	1.094				
	II	4	1.358	4.766**			
	IV	4	1.470	6.790**	2.022		
	I	4	1.941	15.29**	10.52**	8.504**	
Station				III	II	IV	I

Table 11 Statistical comparison of mean benthic invertebrate standing crop (as number of organisms/m2) in samples collected from Brockman Creek in July 1981 and 1982, and in September 1981 and 1982. Student's t-test value was calculated from the total counts in each individual sample.

	July		September	
Parameter	**1981**	**1982**	**1981**	**1982**
Mean Standing Crop				
Station Ia	293	888	205	770
Station II	78	118	175	405
Station III	40	288	153	665
Station IV	73	225	273	388
Total Mean Standing Crop	**112**	**380**	**202**	**557**
SD	115.90	346.02	52.21	190.35
t-value	2.405		3.612	
df	30		30	
P	<0.05		<0.05	

Table 12 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in Snowden Creek on July 25 to 26 and September 11, 1981 and June 2, 1982. Standing crop is transformed as log (x+1).

Date	Source of Variation	Sum of Squares	df	Mean Square	F	P
81/7/25 -26	Station	0.03394	3	0.01133	0.09	>0.05
	Station I vs. II	0.02442	1	0.02442	0.20	>0.05
	Station II vs. III	0.00542	1	0.00542	0.04	>0.05
	Error	1.46564	12	0.12214		
	Total	1.49963	15			
81/9/11	Station	0.24332	3	0.08111	3.43	>0.05
	Station I vs. II	0.18626	1	0.18626	7.88	<0.05
	Station II vs. III	0.00104	1	0.00104	0.04	>0.05
	Error	0.28347	12	0.02362		
	Total	0.52678	15			
82/6/1	Station	0.29236	3	0.09746	0.58	>0.05
	Station I vs. II	0.22379	1	0.22379	1.32	>0.05
	Station II vs. III	0.05334	1	0.05334	0.32	>0.05
	Error	2.02775	12	0.16898		
	Total	2.32012	15			

Table 13 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in Minnie Creek on July 18 and September 15, 1981 and June 3, 1982. Standing crop is transformed as log (x+1).

Date	Source of Variation	Sum of Squares	df	Mean Square	F	P
81/7/18	Station	1.20987	3	0.40329	4.74	<0.05
	Station I vs. II	0.20305	1	0.20305	2.38	>0.05
	Station II vs. III	0.37892	1	0.37892	4.45	>0.05
	Error	1.02169	12	0.08514		
	Total	**2.23156**	**15**			
81/9/15	Station	0.15795	3	0.05265	2.71	>0.05
	Station I vs. II	0.00066	1	0.00066	0.03	>0.05
	Station II vs. III	0.05251	1	0.05251	2.70	>0.05
	Error	0.23294	12	0.01941		
	Total	**0.39089**	**15**			
82/6/3	Station	2.14690	3	0.71563	20.92	<0.01
	Station I vs. II	0.05932	1	0.05932	0.58	>0.05
	Station II vs. III	1.41009	1	1.41009	13.74	<0.01
	Error	1.23121	12	0.10260		
	Total	**3.37811**	**15**			

Table 14 Multiple comparisons of benthic invertebrate standing crop at four stations in Minnie Creek using Newman-Keuls procedure with log (x+1) original counts. Numbers in the table body are the studentized range statistic, q. Stations joined by lines do not differ significantly. Values significant at the 0.05 level are indicated by an asterisk. Values significant at the 0.01 level are indicated by a double asterisk. Only those dates where ANOVA shows an overall significant value (Table 13) are included.

Date	Station	n	Mean log(x+1) Number/ Sample	Station I	II	IV	III
81/7/18	I	4	1.204				
	II	4	1.523				
	IV	4	1.708	3.454^{-}			
	III	4	1.958	5.168*	2.982^{-}		
Station				I	II	IV	III

Date	Station	n	Mean log(x+1) Number/ Sample	Station I	II	IV	III
82/3/6	IV	4	1.181				
	II	4	1.281				
	I	4	1.453	1.698^{-}			
	III	4	2.121	5.869**	5.245**	4.171*	
Station				IV	II	I	III

Table 15 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in Marion Creek on July 22 and September 18, 1981 and June 4, 1982. Standing crop is transformed as log (x+1).

Date	Source of Variation	Sum of Squares	df	Mean Square	F	P
81/7/22	Station	0.70022	3	0.23341	4.63	<0.05
	Station I vs. II	0.56718	1	0.56718	11.25	<0.01
	Station II vs. III	0.02268	1	0.02268	0.45	>0.05
	Error	0.60516	12	0.05043		
	Total	**1.30538**	**15**			
81/9/18	Station	1.47808	3	0.49269	7.04	<0.01
	Station I vs. II	0.00822	1	0.00822	0.12	>0.05
	Station II vs. III	0.96325	1	0.96325	13.76	<0.01
	Error	0.84005	12	0.07000		
	Total	**2.31813**	**15**			
82/6/4	Station	0.68148	3	0.22716	7.99	<0.01
	Station I vs. II	0.26365	1	0.26365	9.27	<0.05
	Station II vs. III	0.04531	1	0.04531	1.59	>0.05
	Error	0.34132	12	0.02844		
	Total	**1.02280**	**15**			

Table 16 Multiple comparisons of benthic invertebrate standing crop at four stations in Marion Creek using Newman-Keuls procedure with log (x+1) original counts. Numbers in the table body are the studentized range statistic, q. Values significant at the 0.05 level are indicated by an asterisk. Values significant at the 0.01 level are indicated by a double asterisk. Only those dates where ANOVA shows an overall significant value (Table 15) are included.

Date	Station	n	Mean log(x+1) Number/ Sample	Station III	Station II	Station IV	Station I
81/7/22	III	4	0.588				
	II	4	0.739	1.345			
	IV	4	1.027	3.910*			
	I	4	1.102	4.578*	3.233		
Station				III	II	IV	I

Date	Station	n	Mean log(x+1) Number/ Sample	Station III	Station II	Station IV	Station I
81/9/18	I	4	0.646				
	II	4	0.646				
	IV	4	1.066	3.175			
	III	4	1.404	5.730**	5.730**	2.555	
Station				I	II	IV	III

Date	Station	n	Mean log(x+1) Number/ Sample	Station II	Station III	Station IV	Station I
82/6/4	II	4	0.433				
	III	4	0.540	1.269			
	IV	4	0.770	3.996*	2.728		
	I	4	0.966	6.321**	5.052**	2.324	
Station				II	III	IV	I

Table 17 Selected turbidity and settleable solids data for sampling sites in the Atigun River receiving runoff from disturbances on Atigun Pass. Turbidity sampling sites are shown on Figures 16 and 17. Turbidity values are presented in Formazin turbidity units (FTU) and settleable solids are presented as mg/L. SH = Shaken turbidity; ST = Settled turbidity; SF = Settleable fraction (ST:SH); SS = Settleable solids.

Sampling Site	Location	July 16 1981				June 8 1982			June 9 1982			June 1 1983			
		SH	ST	SF	SS	SH	ST	SF	SH	ST	SF	SH	ST	SF	SS
A	South branch above haul road (control)	360	85	0.23	32	620	90	0.15	220	76	0.35	900	110	0.12	144
B	East branch (control)	440	90	0.20	41	840	150	0.18	--	--	--	1300	260	0.20	29
C	West branch above workpad (control)	400	85	0.21	30	940	100	0.11	--	--	--	1300	180	0.14	161
D	Workpad runoff	6600	300	0.05	1240	3800	300	0.08	7300	400	0.05	800	240	0.30	25
E	Haul road runoff	3700	400	0.11	304	1050	240	0.22	--	--	--	4100	320	0.08	991
F	Atigun River below Atigun Pass	4350	320	0.07	344	700	100	0.14	5000	280	0.06	1500	180	0.12	137
G	West branch with workpad runoff	--	--	--	--	--	--	--	--	--	--	1650	205	0.12	156
H	Atigun River at Atigun Bridge 1	4350	400	0.09	317	3300	450	0.13	2800	400	0.14	2100	420	0.2	151

Table 18 Mean total standing crop, taxonomic diversity, mean standing crop of Chironomidae, Shannon-Weaver diversity index, and MacArthur equitability of samples collected by Hess sampler at sampling stations in the Atigun River, 1982. Locations which are significantly higher than the control using Student's t-test are indicated with an asterisk ($P < 0.05$, df=6). Bracketed values are mean chironomid standing crop as a percentage of mean total standing crop. Locations of sampling stations are shown on Figure 16 (Roman numerals).

Date	Station Number	Mean Total Standing Crop (n/m2)	Mean Chironomidae Standing Crop (n/m2)	(%)	Mean Taxonomic Diversity (s)	Species Diversity (d)	Equitability (e)
82/6/2	V	495.0	411.6	(83.1)	24	3.22	0.58
82/7/17	I	116.2	96.0	(82.6)	7	1.92	0.71
	II	487.4	470.7	(96.6)	14	2.44	0.57
	III	507.6	444.4	(87.5)	20	3.02	0.60
	IV	399.0*	315.7	(79.1)*	16*	2.28	0.44
	V	285.4	252.5	(88.5)	13	1.84	0.38
82/9/2	I	1201.9	1148.9	(95.6)	15	2.19	0.47
	II	3032.6*	2891.2	(95.3)*	21*	3.16	0.29
	III	2030.2*	1494.8	(73.6)	32*	2.14	0.41
	IV	1472.2	1169.1	(79.4)	25*	2.87	0.44
	V	3211.9*	2628.6	(81.8)*	29*	2.47	0.28
	VI	3214.4*	1340.8	(41.7)	33*	3.58	0.55
	VII	1585.8	694.4	(43.8)	32	3.64	0.59

Table 19 Selected turbidity and settleable solids data for sampling sites in the West branch North Fork Chandalar River receiving runoff from disturbances in Atigun Pass. Turbidity sampling sites are shown on Figures 17 and 19. Turbidity values are presented in Formazin turbidity units (FTU) and settleable solids are presented as mg/L. SH = Shaken turbidity; ST = Settled turbidity; SF = Settleable fraction (ST:SH); SS = Settleable solids.

Sampling Site	Location	July 16 1981				June 9 1982			June 1 1983			
		SH	ST	SF	SS	SH	ST	SF	SH	ST	SF	SS
I	100 m above haul road	4100	550	0.13	1048	400	120	0.30	1500	220	0.15	490
J	Upstream of settling ponds	4300	600	0.14	808	600	105	0.18	3300	280	0.08	322
K	Outlet of settling ponds	4950	490	0.10	1411	580	140	0.24	3200	240	0.08	287
L	100 m below settling pond confluence	4000	550	0.14	929	480	180	0.38	3000	240	0.08	182
M	East branch above airport	650	180	0.28	--	310	100	0.32	--	--	--	--
N	3 km downstream of settling ponds	3300	290	0.09	420	300	100	0.33	--	--	--	--
O	At Airport Bridge 5 km downstream	1400	300	0.21	188	520*	220	0.42	--	--	--	--

Note: * indicates receiving silt from small undisturbed west side tributary

Table 20 Mean total standing crop, mean standing crop of Chironomidae, Shannon-Weaver species diversity index, and MacArthur equitability of samples collected by Hess sampler at Benthic Invertebrate Sampling Stations in the North Fork Chandalar River, 1982. Locations which are significantly lower than the control using Student's t-test are indicated with an asterisk (P <0.05, df=6). Bracketed values are mean chironomid standing crop as a percentage of mean total standing crop. Locations of sampling stations are shown on Figure 19 (Roman numerals).

Date	Sampling Station	Mean Total Standing Crop (n/m2)	Mean Chironomidae Standing Crop (n/m2)	Mean Chironomidae Standing Crop (%)	Mean Taxonomic Diversity (s)	Species Diversity (d)	Equitability (e)
82/6/6	I	12	12	(100.0)	2	0.40	0.75
	II	32	15	(46.9)	4	1.15	0.67
	III	115	65	(56.5)	18	2.36	0.38
	IV	340	325	(95.6)	16	1.37	0.20
	V	88	65	(73.9)	13	2.12	0.45
82/7/22	I	2170	1563	(72.0)	19	1.86	0.25
	II	3150	2805	(89.1)	19	1.76	0.23
	III	875*	313	(35.8)	28	2.19	0.22
	IV	3630	3303	(91.0)	24	1.35	0.13
	V	1728	1575	(91.2)	21	1.44	0.16
82/9/7	I	3080	1760	(57.1)	26	1.22	0.14
	II	1940	1770	(91.2)	19	0.64	0.09
	III	2620	1110	(42.4)	25	1.32	0.12
	IV	5450	4140	(76.0)	28	1.67	0.14
	V	3340	2610	(78.1)	21	1.01	0.11

Table 21 One-way analysis of variance (ANOVA) for benthic invertebrate standing crop values (as numbers/sample) in samples from four stations in North Fork Chandalar River on June 9, July 22, and September 7, 1982. Standing crop is transformed as log (x+1).

Date	Source of Variation	Sum of Squares	df	Mean Square	F	P
82/6/9	Station	1.73947	4	0.43487	2.23	>0.05
	Station I vs. II	0.07936	1	0.07936	0.41	>0.05
	Error	2.92612	15	0.19507		
	Total	**4.66559**	19			
82/7/22	Station	0.98896	4	0.24724	7.27	<0.01
	Station I vs. II	0.05274	1	0.05274	1.55	>0.05
	Error	0.50988	15	0.03399		
	Total	**1.49884**	19			
82/9/7	Station	0.49721	4	0.12430	4.53	<0.01
	Station I vs. II	0.10241	1	0.10241	3.73	>0.05
	Error	0.41185	15	0.02746		
	Total	**0.90906**	19			

Table 22 Multiple comparisons of benthic invertebrate standing crop at four stations in North Fork Chandalar River using Newman-Keuls procedure with log (x+1) original counts. Numbers in the table body are the studentized range statistic, q. Values significant at the 0.05 level are indicated by an asterisk. Values significant at the 0.01 level are indicated by a double asterisk. Only those dates where ANOVA shows an overall significant value (Table 21) are included.

Date	Station	n	Mean log(x+1) Number/ Sample	Station				
				III	V	I	II	IV
82/7/22	III	5	1.900					
	V	5	2.234	3.623*				
	I	5	2.294	4.274*				
	II	5	2.476	6.248**				
	IV	5	2.530	6.834**	3.211			
Station				III	V	I	II	IV

Date	Station	n	Mean log(x+1) Number/ Sample	Station				
				III	V	I	II	IV
82/9/7	II	5	2.249					
	III	5	2.406					
	I	5	2.475					
	V	5	2.513	3.186				
	IV	5	2.733	5.842**	3.947			
Station				II	III	I	V	IV

Table 23 Streams sampled during fish habitat preference studies including length of study reach and total length of representative 100m study sections, gradient code, benthic diversity code and standing crop code. Benthic invertebrate codes based on samples collected in mid July using Hess sampler. Representative study sections included in descriptions of available habitat are indicated with an asterisk. F = Foothills Stream; M = Mountain Stream.

Location	Computer Location Code	Stream Type	Length of Study Reach (m)	Total Length of Representative Sections (m)	Gradient Code	Mean Benthic Diversity	Mean Standing Crop
Happy Valley Creek	01	F	400		2	3	3
Dan Creek	02	F	400		1	2	2
Rudy Creek	06	F	400		3	3	3
Oksrukuyik Creek MP 103	03	F	3000	200*	1	4	3
Oksrukuyik Creek MP 109	04	F	2000	200*	2	4	3
Oksrukuyik Creek MP 117	05	F	2000	200	1	4	3
Ribdon River	25	M	1000	100	2	1	1
Kuparuk River	07	F	2000	200*	1	4	3
Falcon Creek	27	M	1500	200	1	2	3
Atigun River Mouth	08	M	2000	200	2	1	1
Holden Creek	10	M	2800	300*	3	2	2
Roche Montonnee Creek	11	M	600	300*	3	2	2
Tyler Creek	12	M	1050	200*	2	2	2
Trevor Creek	13	M	1050	300*	3	2	2
Atigun River (upper)	09	M	950	200*	2	2	2
North Fork Chandalar River	14	M	1550	300*	2	3	2
Airstrip Creek	15	M	1700	300*	2	3	2
Dietrich River	16	M	2000	200	2	2	2
Snowden Creek	17	M	850	300*	3	0	0
Brockman Creek	18	M	2350	300*	3	2	1
Minnie Creek	19	M	2000	300*	2	3	2
Marion Creek	20	M	1000	300*	2	1	1
Slate Creek	21	M	300	100*	2	2	2
Rosie Creek	22	M	200		2	2	2
Jim River	26	F	400		1	3	3
Bonanza Creek (North Fork)	23	F	400		0	3	3
Bonanza Creek (South Fork)	24	F	400		0	3	3
Total Length			34 300	4700			

Notes:
1. Gradient codes are 0 = 0 to 0.5%; 1 = 0.6 to 1.0%; 2 = 1.1 to 2.0%; 3 = > 2.0%.
2. Benthic diversity codes are 0 = 1 to 5 species; 1 = 6 to 10 species; 2 = 11 to 15 species; 3 = 16 to 20 species; 4 = > 20 species.
3. Standing crop codes are 0 = < 500/m2; 1 = 501 to 1000/m2; 2 = 1001 to 2000/m2; 3 = 2001 to 5000/m2; 4 = > 5000/m2.

Table 24 Summary of available habitat characteristics for 15 representative streams (unweighted), for all 27 study stream reaches providing fish habitat data (weighted) and for selected Foothills Streams and Mountain Streams as described by McCart et al. (1972). Measurements were made at typical midsummer discharge levels. Coded variables are described in Volume III, Appendix B and summarized in Table 5.

Parameter	Units	All Study Streams Unweighted Mean	All Study Streams Weighted Mean	Min	Max	Foothills Streams[1] Unweighted Mean	Mountain Streams[2] Unweighted Mean
Channel Width	m	7.4	9.0	1.0	26.6	19.5	8.2
Cell Area	m2	36.5	50.6	7.7	163.0	98.7	28.5
Gradient	%slope	1.38	1.20	0.10	4.75	0.90	1.48
Discharge	m3/s	2.15	2.64	0.10	9.40	5.25	1.99
Water Temperature	°C	6.7	6.9	3.0	10.0	8.0	6.5
Conductivity	µmhos	229	229	56	840	65	235
Turbidity	FTU	37	32	1.0	100	24	40
Benthic Standing Crop	code	1.55	1.71	0.0	3.0	2.90	1.50
Benthic Diversity	code	1.83	2.20	0.0	4.0	3.30	1.78
Depth	m	0.30	0.35	0.01	2.28	-	-
Velocity	m/s	0.52	0.48	0.00	2.20	-	-
Substrate	code	5.46	5.76	0.84	8.00	-	-
Habitat Type	code	2.22	2.11	1	5	-	-
Bank Type	code	1.22	1.17	1	8	-	-
Bank Height	m	0.34	0.40	0.00	2.00	-	-
Bank Vegetation	code	0.12	0.18	0	1	-	-
Bank Cover	code	0.13	0.17	0	1	-	-
Rock Cover	code	0.15	0.15	0	1	-	-
Depth Cover	code	0.30	0.34	0	1	-	-
Instream Vegetation Cover	code	0.03	0.05	0	1	-	-
Shade Cover	code	0.06	0.08	0	1	-	-
Slump Cover	code	0.04	0.05	0	1	-	-
Turbulence Cover	code	0.88	0.86	0	1	-	-
Turbidity Cover	code	0.22	0.22	0	1	-	-

Notes: 1. Includes data from physical measurements on Foothills Streams not included in the 15 representative streams.

2. Calculated by deleting Oksrukuyik Creek and Kuparuk River data from unweighted data set.

Table 25 Summary of habitat features used by juvenile grayling, adult grayling, juvenile Arctic char, and adult round whitefish in 27 stream reaches listed in Table 23. n = number of locations observed. Coded variables are described in Volume III, Appendix A, and summarized in Table 5.

		Juvenile Grayling (n = 634)			Adult Grayling (n = 439)			Juvenile Arctic Char (n = 72)			Adult Round Whitefish (n = 67)		
Parameter	Units	Mean	Range	S.D.	Mean	Range	S.D.	Mean	Range	S.D.	Mean	Range	S.D.
Depth at Collection Point	m	0.5	0.1-1.6	0.2	0.6	0.1-2.1	0.3	0.3	0.1-1.1	0.2	0.8	0.1-2.1	0.5
Velocity at Mean Depth	m/s	0.23	0-0.8	0.2	0.21	0-0.6	0.1	0.05	0-0.8	0.1	0.17	0-0.5	0.1
Velocity at Collection Point	m/s	0.10	0-0.5	0.1	0.10	0-0.7	0.1	0.03	0-0.4	0.1	0.08	0-0.5	0.1
Habitat Area	m^2	125.6	1.0-1000	139.8	169.4	1.5-1250	191.7	23.1	1.0-200	37.2	333.9	2.0-450	338.1
Habitat Length	m	18.3	0.5-24	15.9	18.5	1.0-100	13.0	7.1	1.0-40	7.0	27.1	2.0-50	13.4
Habitat Width	m	5.1	0.5-20	2.9	7.3	0.5-26	5.2	2.1	1.0-6	1.4	10.5	1.0-26.0	6.7
Number of Cover Features	n	2.2	0-5	1.3	2.3	0-5	1.2	1.8	0-5	0.7	2.3	1-5	1.0
Channel Width	m	7.8	2.0-2.6	4.8	10.0	2.0-40	5.7	4.5	2.0-22	3.0	11.3	4.0-20	4.8
Distance From Bank	m	1.5	0-6.0	1.4	1.8	0-8.0	1.8	0.7	0-5.0	0.8	1.9	0-5.0	1.3
Bank Height	m	0.9	0->5.0	0.9	1.0	0->5.0	0.9	0.9	0-2.0	0.9	1.4	0-2.0	0.9
Adjacent Velocity	coded	2.5	1-3	0.6	2.7	1-3	0.5	2.6	1-3	0.5	2.7	1-3	0.5
Food Availability	coded	1.1	0-3	0.7	1.7	0-3	0.9	1.7	0-3	0.5	1.6	0-3	1.0
Food Diversity	coded	1.7	0-4	0.7	2.3	0-4	1.1	1.9	1-4	0.4	2.4	1-4	1.1
Turbidity	FTU	17.7	0-150	30.8	20.2	0-100	27.9	4.0	0-30	6.1	11.0	0-100	25.0
Water Temperature	°C	5.6	0-11.0	3.1	6.0	0-12.0	3.0	6.1	1.0-9.0	1.7	5.9	2.0-11.0	2.9
Bank Types			%			%			%			%	
Gravel or Rock Bar			23.0			11.8			41.7			13.4	
Cutbanks			28.4			54.7			37.5			46.3	
All Others			48.6			33.5			20.8			40.3	
Habitat Types													
Pool			51.4			65.4			87.5			83.6	
Riffle			1.1			0.2			2.8			0.0	
Run			26.4			21.0			2.8			7.5	
Boulder Controlled Pool			9.9			7.1			2.8			6.0	
Low Velocity Area			11.2			6.4			4.2			3.0	
Cover Types													
Depth			55.2			59.7			9.7			77.6	
Bank Vegetation			22.4			28.7			45.8			26.9	
Instream Vegetation			11.4			16.9			36.1			17.9	
Banks			29.3			38.3			4.2			59.7	
Slumps			16.1			23.2			23.6			3.0	
Rocks			49.8			29.6			27.8			16.4	
Shade			17.7			26.7			29.2			23.9	
Turbulence			26.2			16.9			4.2			4.5	
Turbidity			3.9			6.6			1.4			0.0	

Table 26 Bank height and bank type as a percentage of available habitat and as a percentage of fish use for juvenile grayling, adult grayling, juvenile Arctic char, and adult round whitefish. Relative Suitability Index (RSI) is the ratio of percent fish use vs. percent of available habitat (brackets).

Parameter	Available Habitat	Juvenile Grayling		Adult Grayling		Juvenile Char		Adult Round Whitefish	
	%	%	RSI	%	RSI	%	RSI	%	RSI
Bank Height (m)									
0 (none)	31.1	24.0	(0.8)	8.0	(0.3)	41.7	(1.3)	4.5	(0.1)
0.2	37.3	3.7	(0.1)	6.8	(0.2)	9.7	(0.3)	11.9	(0.3)
0.4	5.9	8.3	(1.4)	4.8	(0.8)	1.4	(0.2)	0.0	(0.0)
0.6	3.8	11.0	(2.9)	24.8	(6.5)	2.8	(0.7)	1.5	(0.4)
0.8	2.0	4.3	(2.6)	6.2	(3.1)	4.2	(2.1)	0.0	(0.0)
1.0	8.1	14.1	(1.7)	21.6	(2.7)	1.4	(0.2)	40.3	(5.0)
1.5	5.5	3.1	(0.6)	2.3	(0.4)	1.4	(0.3)	1.5	(0.3)
2.0	6.3	30.1	(4.8)	22.8	(3.6)	37.4	(5.9)	35.8	(5.7)
4.5	<0.1	0.7	(>1.0)	0.2	(>1.0)	0.0	(0.0)	3.0	(>1.0)
>5.0	<0.1	1.0	(>1.0)	2.5	(>1.0)	0.0	(0.0)	1.5	(>1.0)
Bank Type (coded)									
1 rock or gravel bar	61.9	26.8	(0.4)	11.8	(0.2)	41.7	(0.7)	13.4	(0.2)
2 cutbank	22.4	33.0	(1.5)	54.6	(2.4)	37.5	(1.7)	46.3	(2.1)
3 slumping earth	0.4	8.3	(20.8)	5.5	(13.8)	1.4	(3.5)	4.5	(11.3)
4 sloping loose gravel or rock	11.3	20.9	(1.8)	8.4	(0.7)	12.5	(1.1)	0.0	(0.0)
5 rip-rap	1.8	1.3	(0.7)	3.9	(2.2)	1.4	(0.8)	4.5	(2.5)
6 boulder	0.4	2.4	(6.0)	7.1	(17.8)	4.2	(10.5)	3.0	(7.5)
7 stable vegetated earth	1.2	7.2	(6.0)	8.7	(7.3)	1.4	(1.2)	28.3	(23.6)
8 bedrock	0.4	0.1	(0.3)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)

Table 27 Summary of habitat preference features developed by comparing the percentage of fish using a habitat feature with the percent availability in the study area. For increasing values, those parameters listed as + are positively selected for and those listed as - are negatively selected for. 0 values indicate no effect. Species codes are: CHAR = Arctic char; GRAY = Arctic grayling; RDWT = round whitefish.

Parameter	GRAY Juvenile	GRAY Adults	CHAR Juvenile	RDWT Adults
Turbidity	-	-	-	-
Depth	+	+	-	+
Velocity	-	-	-	-
Channel Width	-	+	-	+
Bank Height	+	+	0	+
Bank Type				
Gravel Bar	-	-	-	-
Cutbank	+	+	+	+
Other	+	+	+	+
Habitat Type				
Pool	+	+	+	+
Riffle	-	-	-	-
Run	+	-	-	0
Boulder Controlled Pool	+	+	0	0
Low Velocity Area	+	+	0	0
Cover Type				
Depth	+	+	-	+
Bank Vegetation	+	+	+	+
Instream Vegetation	+	+	+	+
Banks	+	+	-	+
Slumps	-	0	+	-
Rocks	+	+	+	0
Shade	+	+	+	+
Turbulence	-	-	-	-
Turbidity	-	-	-	-
Food Availability	0	0	0	0
Food Diversity	0	+	0	0
Adjacent Velocity	0	+	+	+
Gradient	-	-	-	-

Table 28 Comparison of available habitat sites, with and without fish, based on relative suitability for adult and juvenile grayling using Kruskal-Wallis one way analysis of variance (ANOVA) and Mann-Whitney test statistics.

Number of Variable	Category	n	Mean Relative Suitability	SD	Max	Min	Rank Sum	Mean Rank
1	Juveniles absent	177	0.009	0.011	0.065	0.000	17 876.0	100.99
2	Some juveniles	50	0.058	0.108	0.482	0.002	8002.0	160.04
3	Adults absent	177	0.004	0.013	0.160	0.000	17 876.5	101.00
4	Some adults	50	0.014	0.024	0.128	0.000	8001.5	160.03

	Value (Juveniles)	Value (Adults)	DF	Level of Significance (Adults and Juveniles)
Kruskal-Wallis	28.24	31.50	1	$P < 0.0001$
Mann-Whitney	2246.00	2123.50	-	$P < 0.0001$

Table 29 Sorted rotated factor loadings (pattern) for physical habitat availability characters. The factor loading matrix (below) has been rearranged so that the columns appear in decreasing order of variance explained by factors. The rows have been rearranged so that for each successive factor, loadings greater than 0.5000 appear first. Loadings less than 0.2500 have been replaced by zero. VP = sum of squares of the elements of the column of the factor pattern matrix for each factor (Variance Explained).

	Factor 1 (Banks)	Factor 2 (Food)	Factor 3 (Scour/ Stability)	Factor 4 (Cover)	Factor 5 (Width)
Bank Vegetation Cover	0.830	0.000	0.000	0.000	0.000
Overhanging Vegetation (%)	0.820	0.000	-0.260	0.000	0.000
Bank Cover	0.809	0.000	0.000	0.000	0.000
Cover (%)	0.771	0.000	0.000	0.000	0.000
Maximum Bank Height	0.547	0.000	0.000	0.532	0.000
Food Availability	0.000	0.897	0.000	0.000	0.000
Food Diversity	0.000	0.852	0.000	0.000	0.000
Conductivity	0.000	-0.732	0.267	0.000	0.000
Turbidity	0.000	-0.643	0.434	0.000	0.000
Unstable (%)	0.000	0.000	0.792	0.000	0.000
Gradient	0.000	0.000	0.703	0.361	0.000
Rock Cover	0.000	0.000	0.000	0.901	0.000
Width	0.000	0.000	0.000	0.000	0.961
Cum. % Variance Explained	33.125	47.364	58.761	67.294	74.912
VP	3.064	2.716	1.502	1.388	1.069

Table 30 Analysis of variance comparison of physical habitat factors at sites with no juvenile grayling compared to sites with at least one juvenile grayling present and sites with no adult grayling compared to sites with at least one adult grayling present. Acceptance Probability (P)=0.05; df=1 and 225. Asterisk indicates significant difference between means.

	Mean Fish Absent	Mean Fish Present	SS Between	SS Among	F Value	P
Juvenile Grayling						
F1	-0.047	0.264	3.775	225.189	3.77	0.053
F2	0.075	-0.233	3.705	232.803	3.58	0.060
F3	0.049	0.058	0.003	221.163	<0.01	0.957
F4	-0.031	-0.057	0.027	222.582	0.03	0.870
F5	0.031	-0.106	2.181	204.067	2.40	0.122
Adult Grayling						
F1	-0.148	0.621	23.075	205.818	25.23*	0.000
F2	-0.021	0.105	0.621	235.887	0.59	0.442
F3	0.002	0.226	1.966	219.200	2.02	0.157
F4	-0.082	0.125	1.671	220.938	1.70	0.193
F5	0.055	0.160	0.429	205.000	0.47	0.494

Table 31 Comparison of mean physical characteristics for locations supporting at least one grayling with 50 selected locations in the same streams which supported no fish. Coded parameters are described in Table 5.

Parameter	Units	Supporting Grayling	Sites with No Fish
Channel Width	m	8.7	8.3
Distance From Bank	m	1.8	1.5
Bank Height	m	0.8	0.8
Bank Type	code	2.04	2.65
Point Depth	m	0.47	0.45
Minimum Depth	m	0.24	0.23
Maximum Depth	m	0.67	0.59
Point Velocity	m/s	0.11	0.09
Minimum Velocity	m/s	0.03	0.02
Maximum Velocity	m/s	0.32	0.30
Mean Velocity	m/s	0.17	0.17
Depth of Fish	code	bottom	-
Distance to Control	code	4.6	4.0
Discharge	m3/s	1.3	1.2
Habitat Length	m	14.0	10.7
Habitat Width	m	5.7	4.4
Habitat Area	m2	109.0	80.0
Habitat Type (%)	code	(63, 13, 15, 2, 3)	(48, 4, 18, 13, 17)
Control	code	0.2	0.4
Adjacent Velocity	code	2.8	2.7
Substrate	code	4.96	4.89
Unstable	%	20.0	20.0
Depth Range	m	0.42	0.35
Velocity Range	ms	0.28	0.27
Total Cover	code	1.95	1.97
Depth Cover	%	39.3	56.5
Bank Vegetation	%	26.4	26.0
Stream Vegetation	%	14.6	8.7
Bank Cover	%	27.8	30.4
Slump Cover	%	7.5	8.7
Rock Cover	%	42.4	32.6
Shade Cover	%	21.0	13.0
Turbulence Cover	%	14.6	8.7
Turbidity Cover	%	3.7	6.5

Table 32 Multiple regression analysis for adult grayling habitat preference factors for all locations. F to enter 2.5; F to remove 2.496. Terms indicated by an asterisk were forced into equation to accommodate non-normal distribution. Adult suitability index was calculated as described in Section 6.6.5.

Step No. 6

Multiple R	0.4945
Multiple RSQ	0.2446
Adjusted RSQ	0.2240
Standard Error of Est.	0.2362

ANALYSIS OF VARIANCE

	SS	DF	Mean Square	F Ratio
Regression	3.9725	6	0.6620	11.87
Residual	12.2708	220	0.5578	

Variables in Equation

Variable	Coefficient	Standard Error of Coefficient	F to Remove	R	RSQ	Increase in RSQ
(Y intercept	-0.03263)					
$F_4 2$	0.06730	0.0201	11.23	0.1569	0.0246	0.0246
F_4	-0.02421	0.0200	*1.46	0.1695	0.0287	0.0041
Adult suitability	0.04107	0.0077	28.49	0.4304	0.1852	0.1565
F_1	0.05068	0.0165	9.42	0.4665	0.2176	0.0324
F_3	0.03156	0.0163	3.76	0.4829	0.2332	0.0156
F_5	-0.03016	0.0166	3.31	0.4945	0.2446	0.0114

Variables Not in Equation

Variable	Partial Correlation	F to Enter
F_2	0.02416	0.13

Table 33 Multiple regression analysis for adult grayling habitat preference factors for only those locations with fish. F to enter 2.5; F to remove 2.496. Terms indicated by an asterisk were forced into equation to accommodate non-normal distribution. Adult suitability index was calculated as described in Section 6.6.5.

Step No. 3

Multiple R	0.6926
Multiple RSQ	0.4797
Adjusted RSQ	0.4458
Standard Error of Est.	0.2159

ANALYSIS OF VARIANCE

	SS	DF	Mean Square	F Ratio
Regression	1.9771	3	0.6590	14.14
Residual	2.1442	46	0.4661	

Variables in Equation

Variable	Coefficient	Standard Error of Coefficient	F to Remove	R	RSQ	Increase in RSQ
(Y intercept	0.50604)					
F_4^2	0.06877	0.0441	*2.43	0.1597	0.0255	0.0255
F_4	-0.02939	0.0549	*0.29	0.4367	0.1907	0.1652
F_5	-0.18020	0.0356	25.55	0.6926	0.4797	0.2890

Variables Not in Equation

Variable	Partial Correlation	F to Enter
Adult Suitability	0.06870	0.21
F_1	-0.03290	0.05
F_2	0.09270	0.39
F_3	0.02587	0.03

Table 34 Multiple regression analysis for juvenile grayling habitat preference factors for all locations. F to enter 2.5; F to remove 2.496. Juvenile suitability index was calculated as described in Section 6.6.5.

Step No. 5

Multiple R	0.6153
Multiple RSQ	0.3786
Adjusted RSQ	0.3646
Standard Error of Est.	0.2237

ANALYSIS OF VARIANCE

	SS	DF	Mean Square	F Ratio
Regression	6.7375	5	1.3475	26.93
Residual	11.0573	221	0.5003	

Variables in Equation

Variable	Coefficient	Standard Error of Coefficient	F to Remove	R	RSQ	Increase in RSQ
(Y intercept	-0.07284)					
Juvenile suitability	0.03796	0.0037	103.36	0.5571	0.3104	0.3104
$F_4 2$	0.04582	0.0185	6.10	0.5613	0.3151	0.0047
F_4	-0.04376	0.0189	5.34	0.5774	0.3333	0.0183
F_5	-0.04660	0.0158	8.72	0.5982	0.3578	0.0245
F_2	-0.03974	0.0146	7.39	0.6153	0.3786	0.0208

Variables Not in Equation

Variable	Partial Correlation	F to Enter
F_1	0.05235	0.60
F_3	-0.07119	1.12

Table 35 Multiple regression analysis for juvenile grayling habitat preference factors for only those locations with fish. F to enter 2.5; F to remove 2.496. Terms indicated by an asterisk were forced into equation to accomodate non-normal distribution. Juvenile suitability index was calculated as described in Section 6.6.5.

Step No. 5

Multiple R	0.7251
Multiple RSQ	0.5258
Adjusted RSQ	0.4719
Standard Error of Est.	0.2111

ANALYSIS OF VARIANCE

	SS	DF	Mean Square	F Ratio
Regression	2.1740	5	0.4348	9.76
Residual	1.9606	44	0.4456	

Variables in Equation

Variable	Coefficient	Standard Error of Coefficient	F to Remove	R	RSQ	Increase in RSQ
(Y intercept	0.39498)					
Juvenile suitability	0.01411	0.0047	9.09	0.4582	0.2100	0.2100
F_4	-0.07010	0.0401	3.05	0.5543	0.3072	0.0973
F_4^2	0.04411	0.0384	*1.32	0.5616	0.3154	0.0081
F_5	-0.14777	0.0336	19.34	0.7026	0.4937	0.1783
F_2	-0.08043	0.0466	2.98	0.7251	0.5258	0.0321

Variables Not in Equation

Variable	Partial Correlation	F to Enter
F_1	-0.05622	0.14
F_3	-0.00449	0.00

Table 36 Density and size range of Arctic grayling and round whitefish in two study sections in Oksrukuyik Creek. Section 1 (Control) receives low angling pressure while Section 2 receives moderate pressure. The locations of both 1 km sections are indicated on Figure 34. Arctic char, slimy sculpin, burbot and Arctic grayling young-of-the-year were also present but were not censused.

		Arctic Grayling			Round Whitefish		
Date	Section No	n	Mean Length (mm)	Range	n	Mean Length (mm)	Range
81/7/29	1	120	292	244-370	33	369	337-381
	2	94	305	258-371	13	396	353-415
81/9/4-5	1	89	307	181-364	9	414	405-423
	2	120	308	114-373	33	415	406-419
83/7/31	1	87	294	227-347	42	378	306-435
	2	66	315	214-395	27	372	294-422

Table 37 Arctic grayling relative habitat suitability indices (derived from Polynomial Suitability of Use Functions) for representative study sections in the TAPS corridor. The suitability index (PSI) is based on depth, velocity, and substrate composition. J = Juvenile suitability; A = Adult suitability. Disturbance codes are: A = Armored; MS = Materials site; N = None; S = Scoured.

Stream Name	Stream Section	Type of Disturbance	Mean Suitability		Mean of 10 Highest Suitabilities		Mean Maximum per Transect	
			J	A	J	A	J	A
Falcon Creek	1	MS	.0116	.0001	.0240	.0004	.0139	.0004
	2	control	.0333	.0040	.0871	.0588	.0542	.0355
Holden Creek	1	MS	.0035	.0006	.0074	.0013	.0063	.0010
	2	control	.0083	.0015	.0200	.0035	.0144	.0030
	3	control	.0039	.0005	.0083	.0011	.0077	.0010
Trevor Creek	1	control	.0044	.0009	.0109	.0027	.0107	.0025
	2	MS	.0037	.0008	.0096	.0010	.0084	.0007
	3	MS	.0033	.0011	.0090	.0003	.0071	.0002
North Fork Chandalar River								
Airstrip Creek	1	control	.0253	.0038	.0652	.0107	.0404	.0062
	2	MS	.0017	.0002	.0037	.0005	.0035	.0004
Mainstem Channels	1	S	.0066	.0010	.0120	.0023	.0099	.0016
	2	N	.0313	.0047	.0932	.0141	.0639	.0108
	3	MS	.0094	.0009	.0142	.0019	.0104	.0014
Brockman Creek	1	A, MS	.0081	.0018	.0198	.0043	.0206	.0044
	2	MS (control)	.0288	.0080	.0735	.0210	.0708	.0206

Table 38 Summary of fish displaced by habitat modification in seven streams mined for granular material during TAPS construction. Estimate of fish numbers based on average late July densities. Displaced fish codes are: A = Adult; J = Juveniles; V = various. Species codes are: CHAR = Arctic char; GRAY = Arctic grayling; RDWT = round whitefish. ND = not determined.

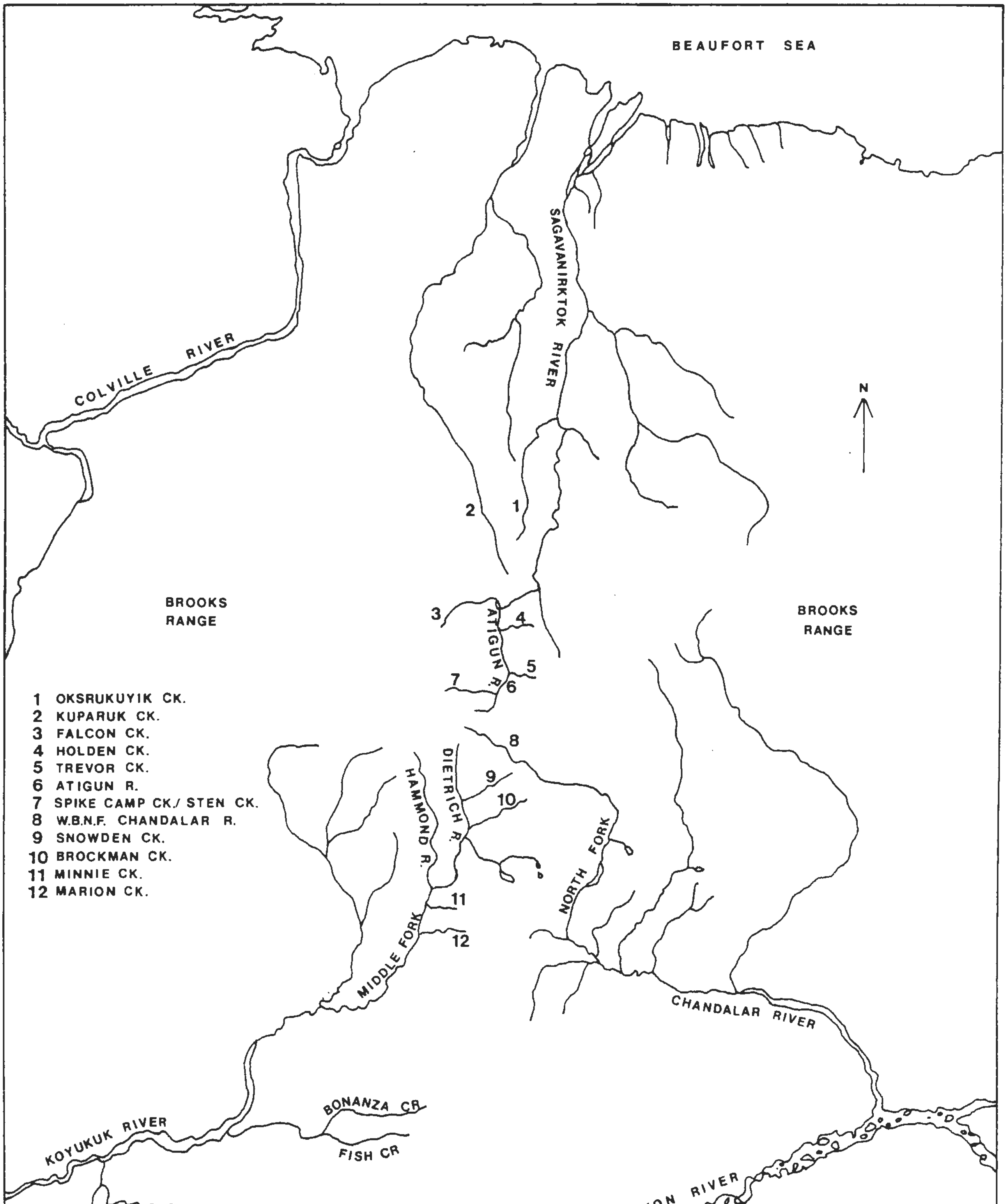
Stream Name	Fish Displaced By Habitat Modification (n)			Size of Displaced Fish			Total Area Disturbed (m2)	Other Effects
	GRAY	RDWT	CHAR	GRAY	RDWT	CHAR		
Falcon Creek	60	20	0	A	A	-	15 600	spawning habitat reduced
Holden Creek	100	27	0	V	J	-	5600	mean size of remaining fish reduced
Trevor Creek	70	0	0	V	-	-	7700	spawning habitat reduced
North Fork Chandalar River								
Airstrip Creek	108	0	0	J	-	-	4640	habitat enhancement in excavated ponds
Mainstem Channels	0	0	0	-	-	-	2400	
Snowden Creek	0	0	0	-	-	-	3000	
Brockman Creek	ND	ND	ND	-	-	-	30 000	reduced stability increased fluvial deposition
Totals	338	47	0				68 940	

Table 39 Summary of habitat modifications in seven streams in the northern portion of the TAPS corridor. Each habitat parameter is rated according to the effect of any habitat modification on grayling habitat quality. Only the effect of rip-rap is assessed in Brockman Creek; not the effect of instream mining. C = channelized; I = improved; NE = no effect; R = reduced.

Parameter	Falcon	Holden	Trevor	Airstrip	North Fork Chandalar	Snowden	Brockman	No of R	No of I
Stream Stability	R(C)	R(C)	R	R(C)	NE	NE	R	5	0
Water Quality	NE	NE	NE	NE	NE	NE	NE	-	-
Channel Width	NE	R	R/NE	NE	NE	R	NE	3	0
Mean Depth	R	R	R	R	NE	I	I	4	2
Mean Velocity	NE	NE	NE	R	NE	NE	I	1	1
Mean Substrate Size	R	I	R	R	NE	NE	NE	3	1
Pool Habitat	R	R	R	R	NE	NE	I	4	1
Food Availability	R	NE	NE	I	NE	NE	NE	1	1
Bank Height	R	I	R	R	R	NE	I	4	2
Bank Type	R	R	R	R	R	R	I	6	1
Percent Unstable Bank	I	I	R	I	R	I	I	2	5
Cover									
Depth	R	R	R	R	NE	I	I	4	2
Bank Vegetation	R	R	R	R	R	R	NE	6	0
Stream Vegetation	R	R	R	R	NE	NE	NE	4	0
Banks	R	R	R	R	R	R	I	6	1
Slumps	R	R	NE	R	NE	NE	NE	3	0
Rocks	NE	I	I	I	NE	I	NE	0	4
Shade	R	R	R	R	NE	NE	I	4	1
Turbulence	NE	R	I	I	NE	NE	I	1	3
Turbidity	NE	NE	NE	NE	NE	NE	NE	-	-
Total Cover	R	NE	I	R	R	NE	I	3	2
Adult Suitability	R	R/NE	R	R	NE	NE	R	5	0
Juvenile Suitability	R	R/NE	R	R	NE	NE	R	5	0

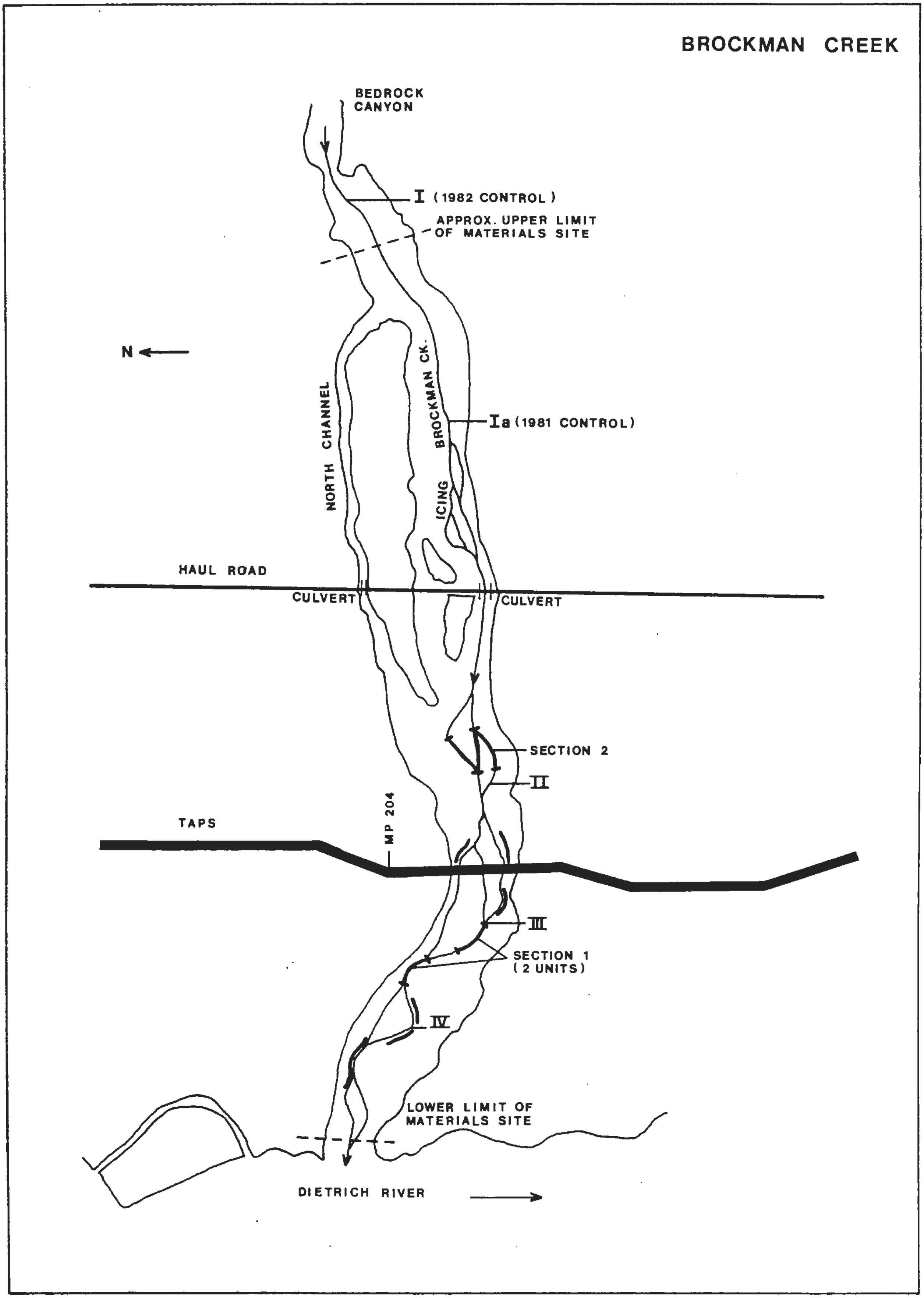
FIGURES

Figure 1 Map of the study area showing the locations of 12 Detailed Study Streams examined in 1981 through 1983.



BEAUFORT SEA
SAGAVANIRKTOK RIVER
COLVILLE RIVER
N
BROOKS RANGE
BROOKS RANGE
ATIGUN R.
1
2
3
4
5
6
7
8
9
10
11
12
1 OKSRUKUYIK CK.
2 KUPARUK CK.
3 FALCON CK.
4 HOLDEN CK.
5 TREVOR CK.
6 ATIGUN R.
7 SPIKE CAMP CK./ STEN CK.
8 W.B.N.F. CHANDALAR R.
9 SNOWDEN CK.
10 BROCKMAN CK.
11 MINNIE CK.
12 MARION CK.
DIETRICH R.
HAMMOND R.
NORTH FORK
MIDDLE FORK
CHANDALAR RIVER
BONANZA CR
FISH CR
KOYUKUK RIVER
YUKON RIVER
50
0
50
KM

Figure 2 Sketch map of Brockman Creek including the approximate boundaries of an instream materials site (dashed line), two fish density study sections (bracketed dark bars), and five benthic invertebrate sampling stations (Roman numerals). Other dark bars are locations of rip-rap banks. The approximate locations of the haul road and the TAPS alignment are also indicated. Not to scale.



BROCKMAN CREEK
BEDROCK CANYON
I (1982 CONTROL)
APPROX. UPPER LIMIT OF MATERIALS SITE
N
NORTH CHANNEL
BROCKMAN CK.
Ia (1981 CONTROL)
ICING
HAUL ROAD
CULVERT
CULVERT
SECTION 2
II
TAPS
MP 204
III
SECTION 1 (2 UNITS)
IV
LOWER LIMIT OF MATERIALS SITE
DIETRICH RIVER

Figure 3 Benthic invertebrate standing crop (as organisms/m^2), composition of dominant taxa (>50 organisms/m^2) and functional group composition in Hess samples collected in Brockman Creek in July and September 1981. Locations of sampling stations are shown on Figure 2.

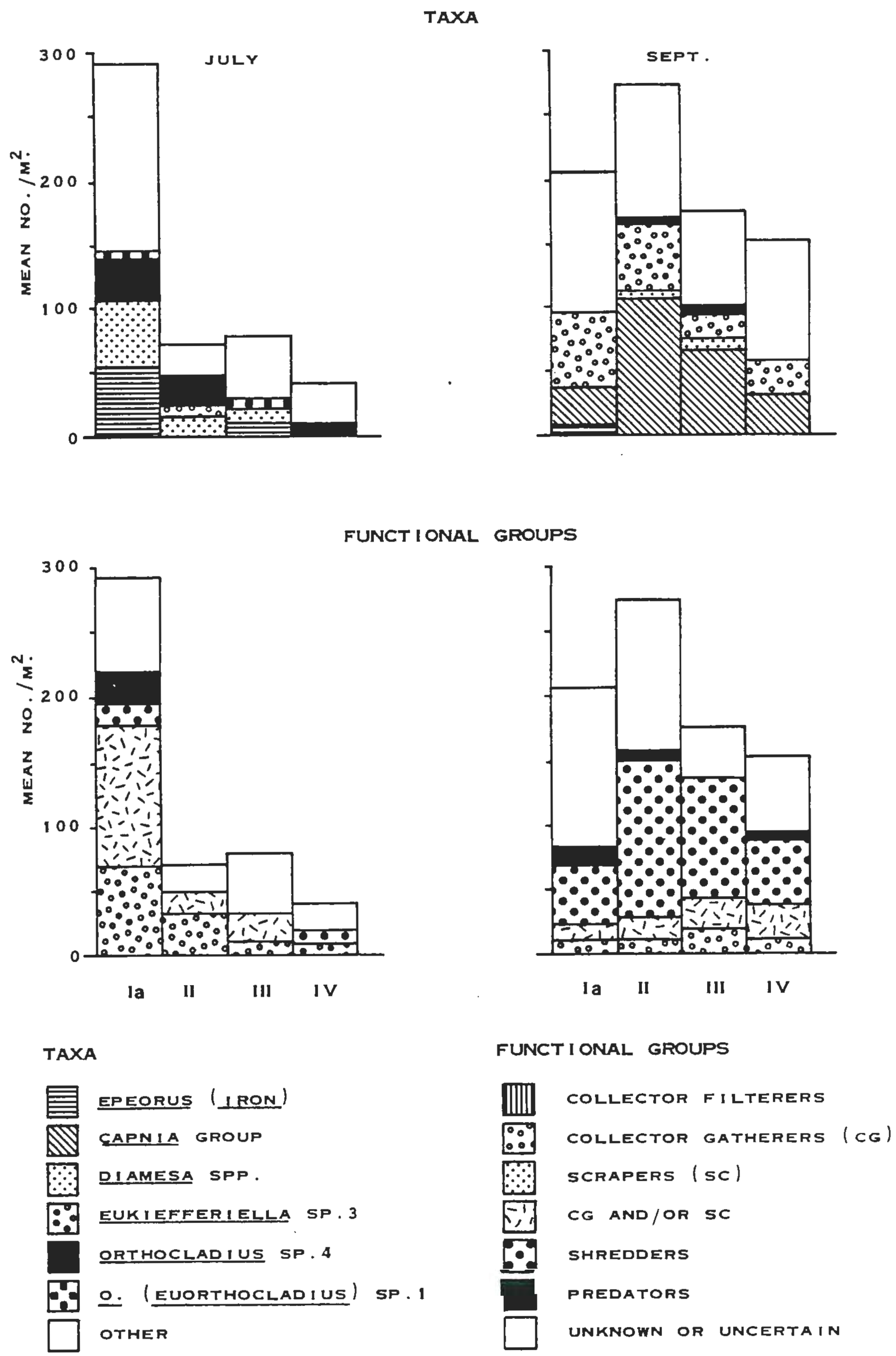

TAXA
JULY
SEPT.
MEAN NO./M.2
300
200
100
0
FUNCTIONAL GROUPS
MEAN NO./M.2
300
200
100
0
Ia II III IV
Ia II III IV
TAXA
EPEORUS (IRON)
CAPNIA GROUP
DIAMESA SPP.
EUKIEFFERIELLA SP.3
ORTHOCLADIUS SP.4
O. (EUORTHOCLADIUS) SP.1
OTHER
FUNCTIONAL GROUPS
COLLECTOR FILTERERS
COLLECTOR GATHERERS (CG)
SCRAPERS (SC)
CG AND/OR SC
SHREDDERS
PREDATORS
UNKNOWN OR UNCERTAIN

Figure 4 Benthic invertebrate standing crop (as organisms/m^2), composition of dominant taxa (>50 organisms/m^2) and functional group composition in Hess samples collected in Brockman Creek in June, July, and September 1982. Locations of sampling stations are shown on Figure 2.

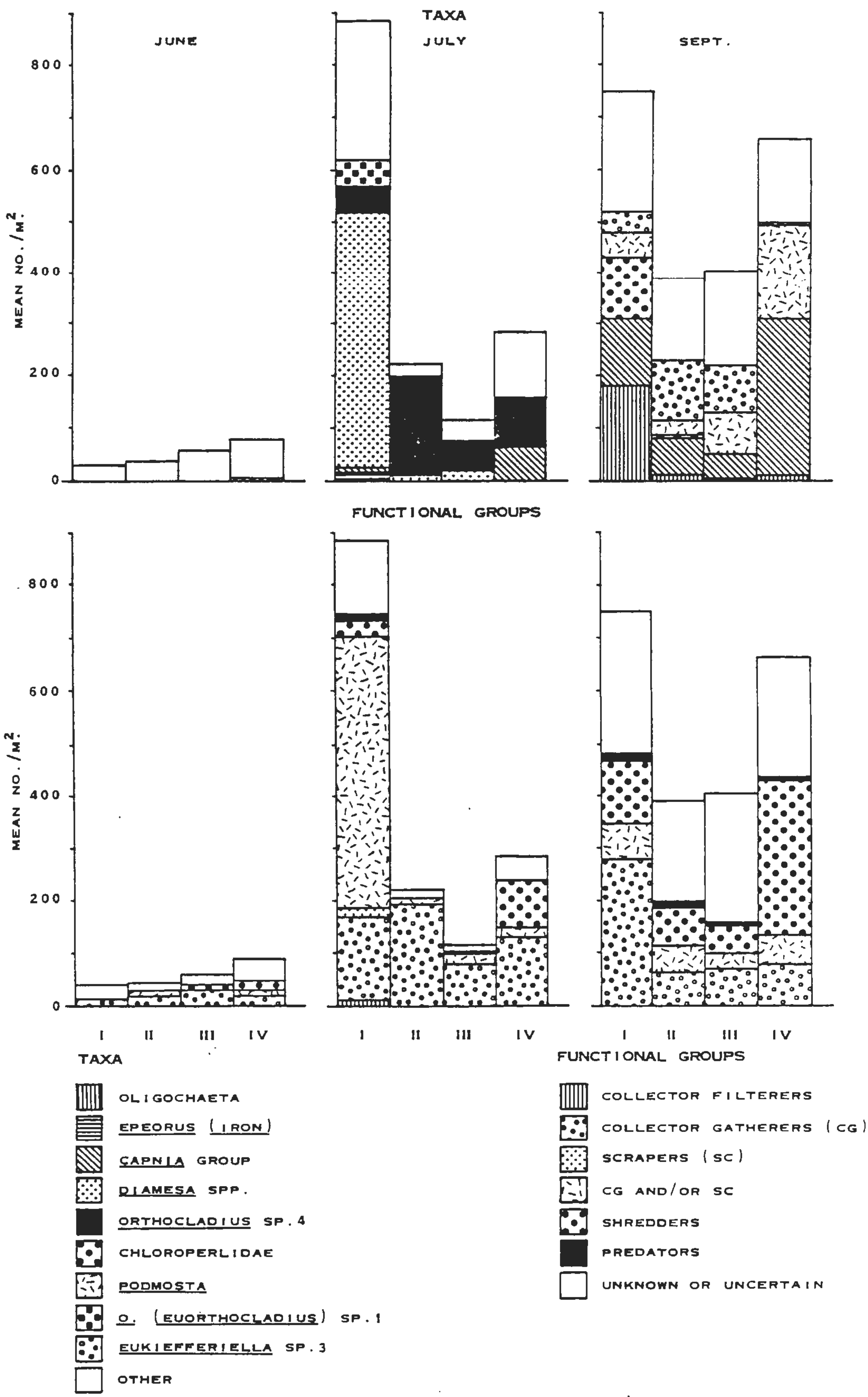

TAXA
JUNE
JULY
SEPT.
MEAN NO./M.²
800
600
400
200
0
FUNCTIONAL GROUPS
I
II
III
IV
TAXA
OLIGOCHAETA
EPEORUS (IRON)
CAPNIA GROUP
DIAMESA SPP.
ORTHOCLADIUS SP.4
CHLOROPERLIDAE
PODMOSTA
O. (EUORTHOCLADIUS) SP.1
EUKIEFFERIELLA SP.3
OTHER
FUNCTIONAL GROUPS
COLLECTOR FILTERERS
COLLECTOR GATHERERS (CG)
SCRAPERS (SC)
CG AND/OR SC
SHREDDERS
PREDATORS
UNKNOWN OR UNCERTAIN

Figure 5 Shannon-Weaver species diversity index (dots) ±SE (bracketed bars) for benthic invertebrate communities in Brockman Creek in July and September 1981. Number above the bar is the number of taxa (s), and the number below the bar is the equitability index (e). Locations of sampling stations are shown on Figure 2.

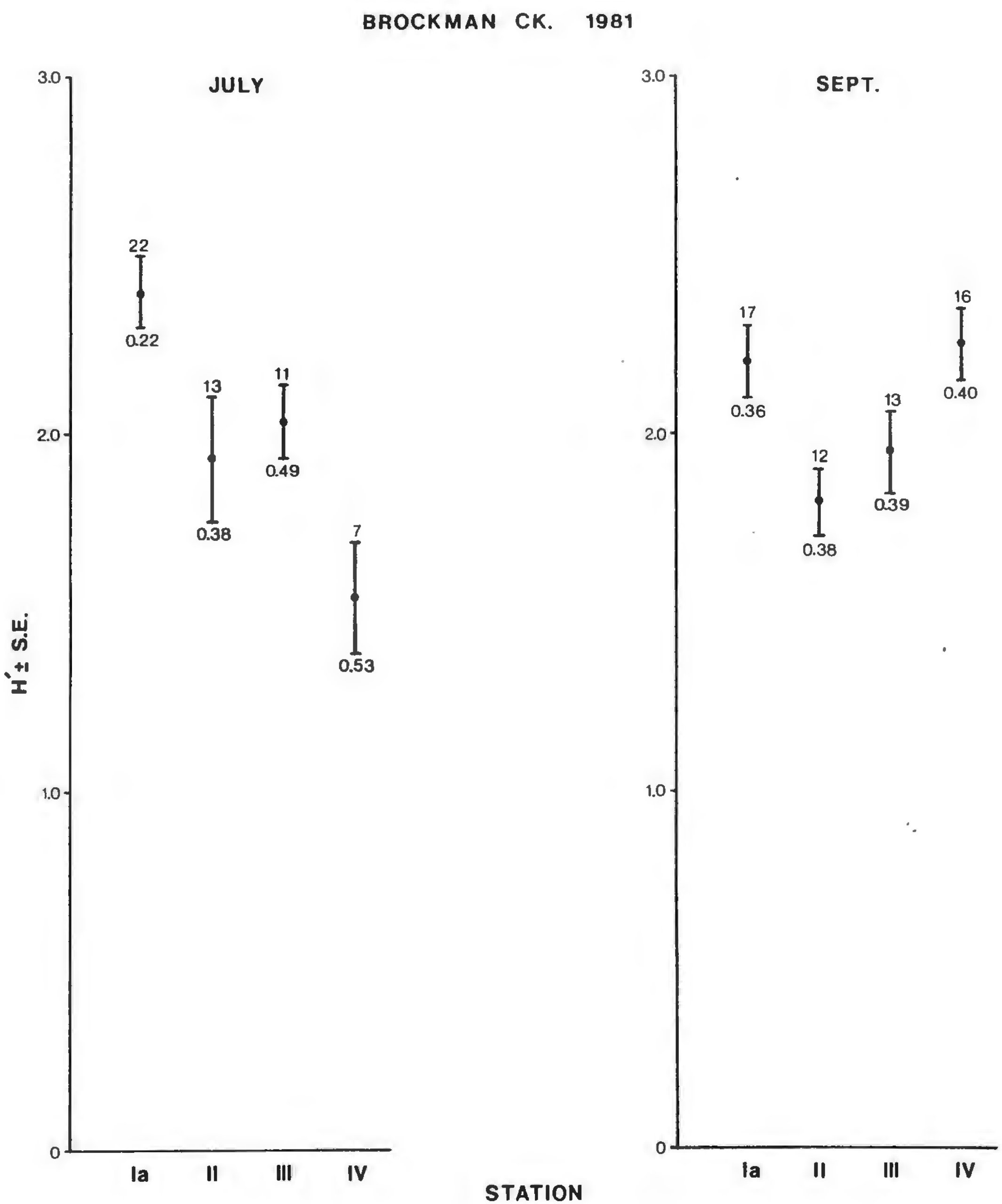
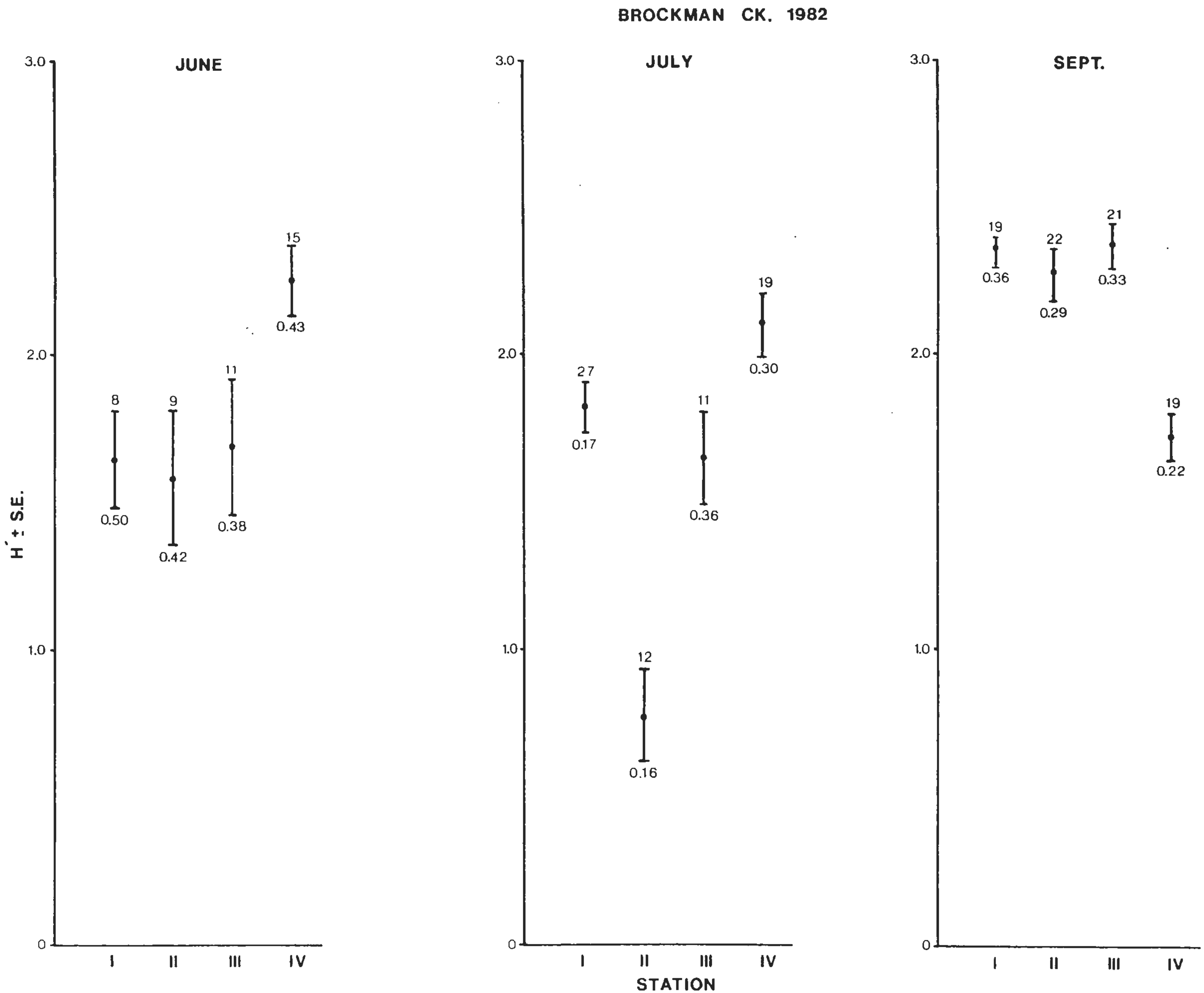

BROCKMAN CK. 1981
JULY
SEPT.
H' ± S.E.
3.0
2.0
1.0
0
22
0.22
13
0.38
11
0.49
7
0.53
17
0.36
12
0.38
13
0.39
16
0.40
Ia
II
III
IV
STATION

Figure 6 Shannon-Weaver species diversity index (dots ±SE (bracketed bars) for benthic invertebrate communities in Brockman Creek in June, July, and September 1982. Number above the bar is the number of taxa (s) and the number below the bar is the equitability index (e). Sampling stations are shown on Figure 2.



BROCKMAN CK. 1982
JUNE
JULY
SEPT.
H´ ± S.E.
3.0
2.0
1.0
0
8
0.50
9
0.42
11
0.38
15
0.43
27
0.17
12
0.16
11
0.36
19
0.30
19
0.36
22
0.29
21
0.33
19
0.22
I
II
III
IV
STATION

Figure 7 Sketch map of Snowden Creek near its confluence with the Dietrich River including the location of an adjacent materials site and armored bank, two fish study test sections (bracketed bars) and four benthic invertebrate sampling stations (Roman numerals). The approximate locations of the haul road and the TAPS alignment are indicated. Not to scale.

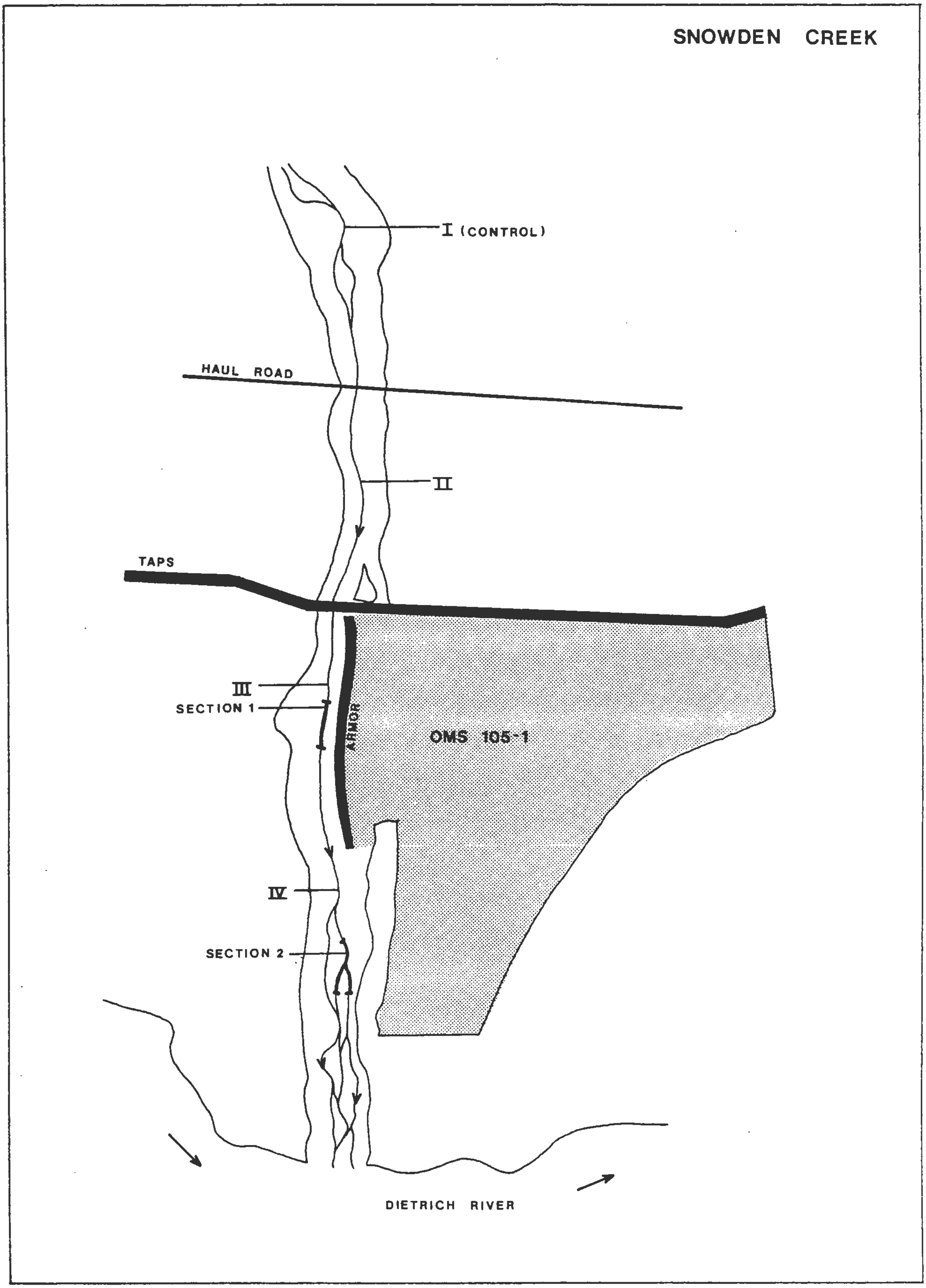

SNOWDEN CREEK
I (CONTROL)
HAUL ROAD
II
TAPS
III
SECTION 1
ARMOR
OMS 105-1
IV
SECTION 2
DIETRICH RIVER

Figure 8 Benthic invertebrate standing crop (as organisms/m^2), composition of dominant taxa (>25 organisms/m^2), and functional group composition in Hess samples collected in Snowden Creek in July and September 1981 and June 1982. Locations of sampling stations are shown on Figure 7.

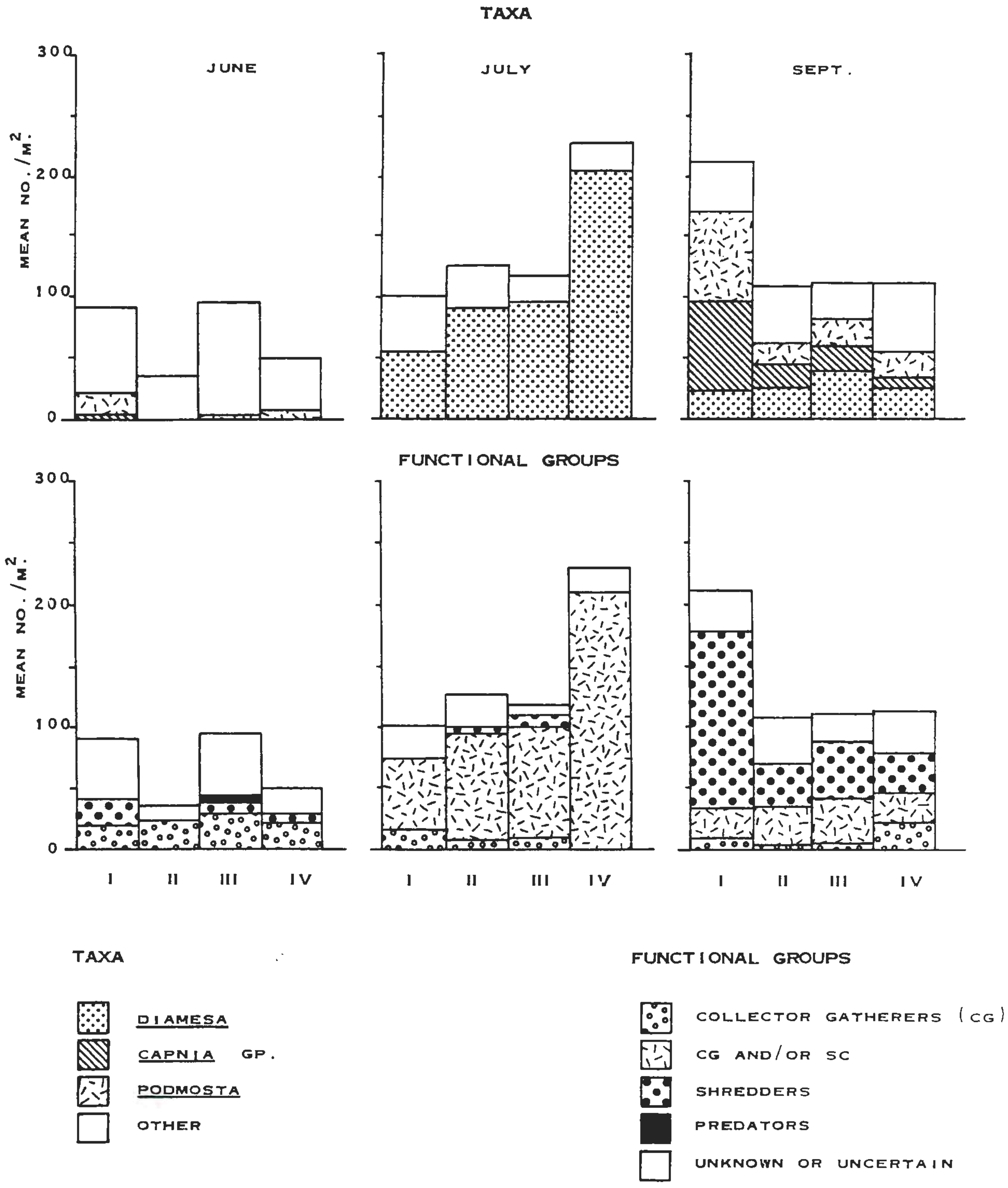
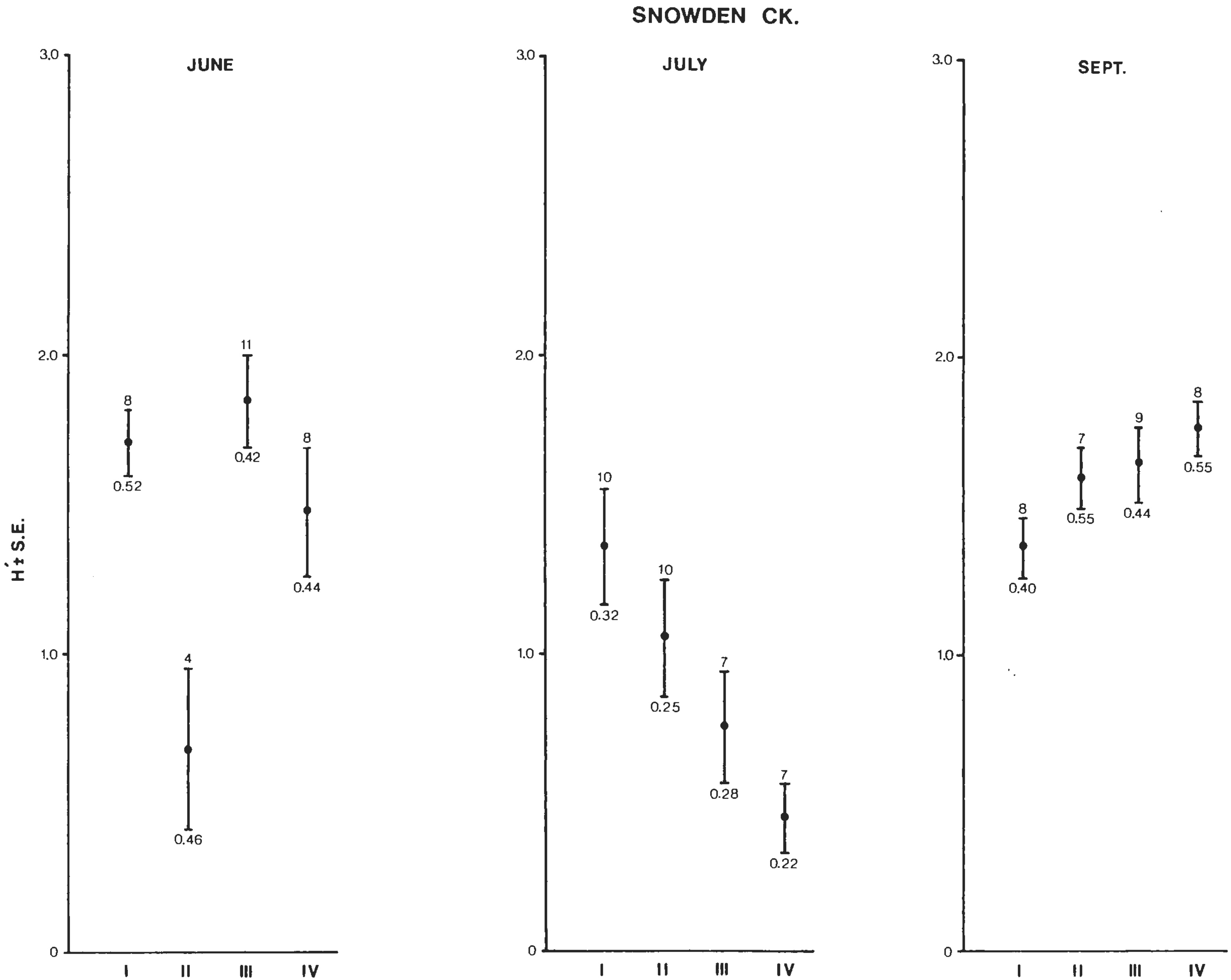
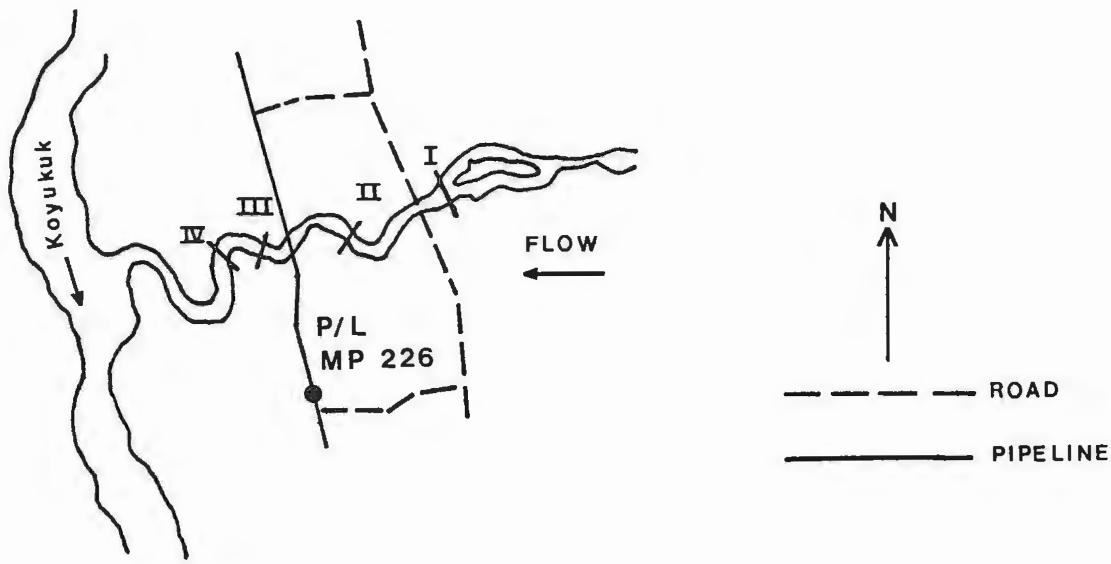

TAXA
JUNE
JULY
SEPT.
MEAN NO. /M.2
300
200
100
0
FUNCTIONAL GROUPS
I
II
III
IV
TAXA
DIAMESA
CAPNIA GP.
PODMOSTA
OTHER
FUNCTIONAL GROUPS
COLLECTOR GATHERERS (CG)
CG AND/OR SC
SHREDDERS
PREDATORS
UNKNOWN OR UNCERTAIN

Figure 9 Shannon-Weaver species diversity index (dots) $\pm$SE (bracketed bars) for benthic invertebrate communities in Snowden Creek in July and September 1981 and June 1982. Number above bars is the number of taxa (s) and the number below the bar is the equitability index (e). Sampling stations are shown on Figure 7.

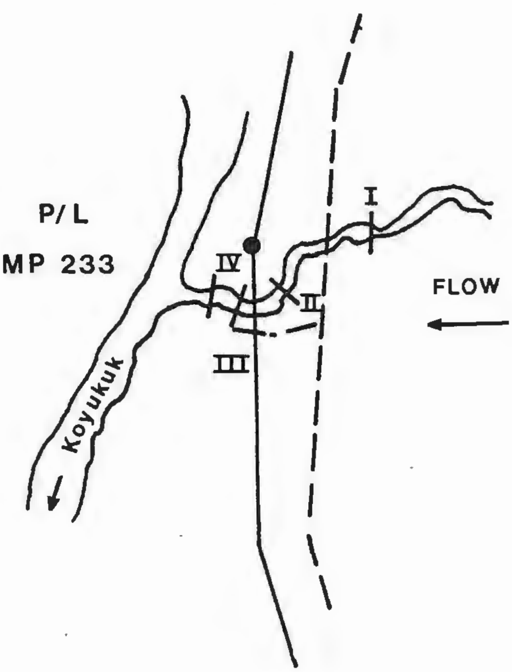


SNOWDEN CK.
JUNE
JULY
SEPT.
H' ± S.E.
3.0
2.0
1.0
0
I
II
III
IV
8
0.52
4
0.46
11
0.42
8
0.44
10
0.32
10
0.25
7
0.28
7
0.22
8
0.40
7
0.55
9
0.44
8
0.55

Figure 10 Sketch maps of Minnie Creek and Marion Creek near their confluence with the Middle Fork Koyukuk River showing the location of four benthic invertebrate sampling stations (Roman numerals) in each stream. The approximate locations of the haul road (dashed line) and the TAPS alignment (solid line) are indicated. Not to scale.

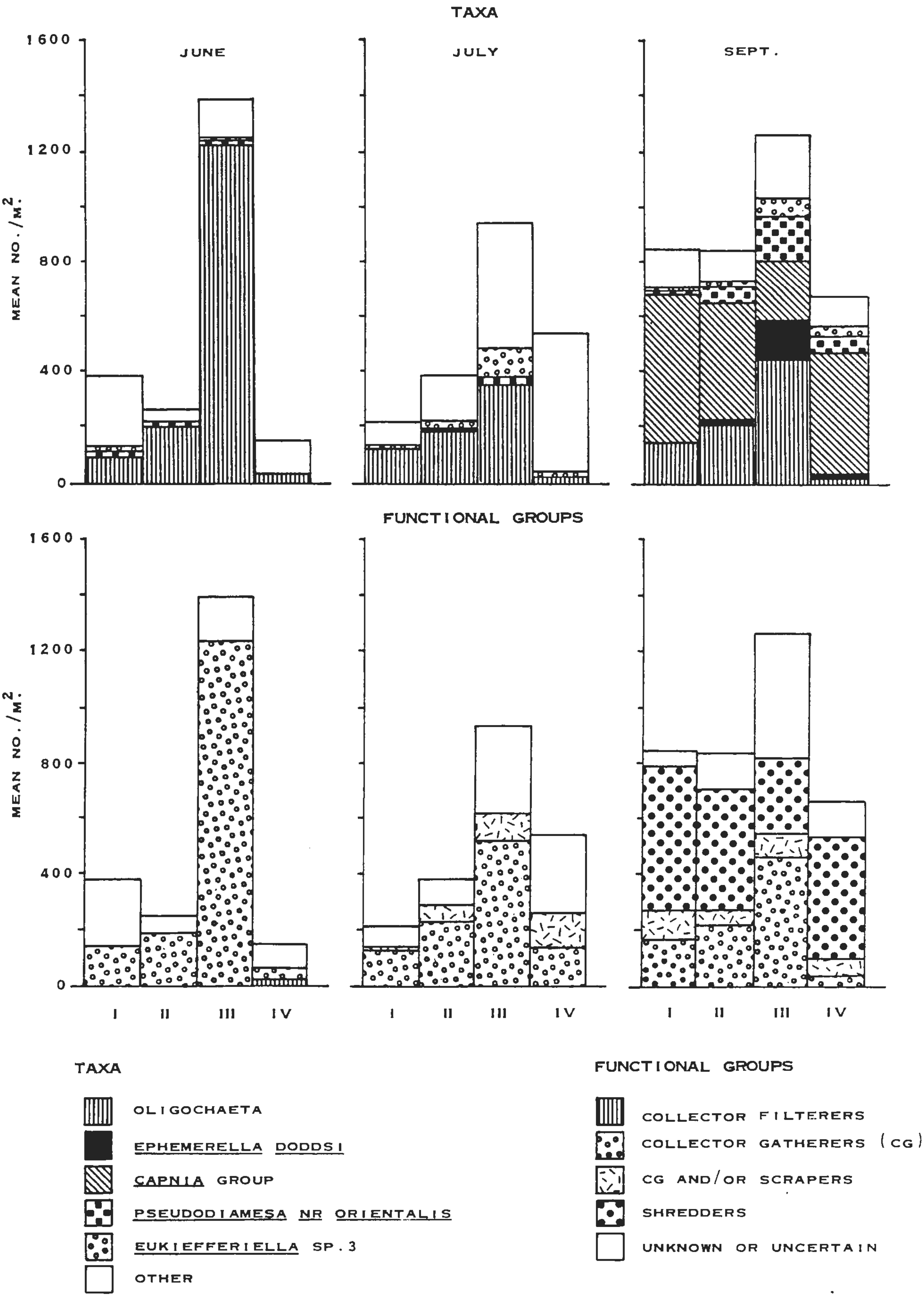


MINNIE
CREEK



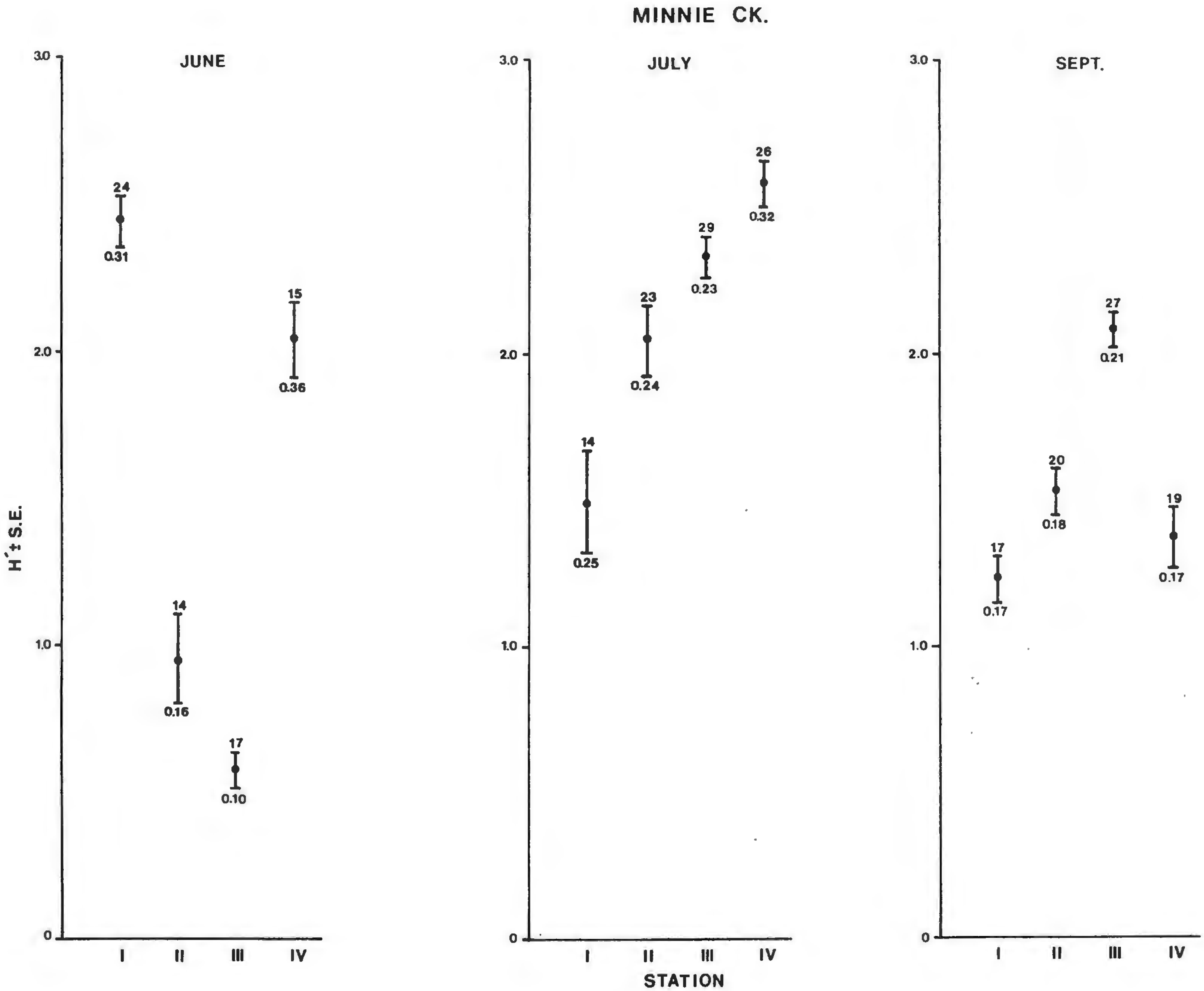
MARION
CREEK

Figure 11 Benthic invertebrate standing crop (as organisms/m^2), composition of dominant taxa (>50 organisms/m^2), and functional group composition in Hess samples from Minnie Creek collected in July and September 1981 and June 1982. Locations of sampling stations are shown on Figure 10.



TAXA
JUNE
JULY
SEPT.
MEAN NO./M.2
1600
1200
800
400
0
FUNCTIONAL GROUPS
I
II
III
IV
TAXA
OLIGOCHAETA
EPHEMERELLA DODDSI
CAPNIA GROUP
PSEUDODIAMESA NR ORIENTALIS
EUKIEFFERIELLA SP. 3
OTHER
FUNCTIONAL GROUPS
COLLECTOR FILTERERS
COLLECTOR GATHERERS (CG)
CG AND/OR SCRAPERS
SHREDDERS
UNKNOWN OR UNCERTAIN

Figure 12 Shannon-Weaver species diversity index (dots) $\pm$SE (bracketed bars) for benthic invertebrate communities in Minnie Creek in July and September 1981 and June 1982. Number above the bar is the number of taxa (s) and the number below the bar is the equitability index (e). Sampling stations are shown on Figure 10.



MINNIE CK.
JUNE
JULY
SEPT.
H' ± S.E.
3.0
2.0
1.0
0
24
0.31
14
0.16
17
0.10
15
0.36
14
0.25
23
0.24
29
0.23
26
0.32
17
0.17
20
0.18
27
0.21
19
0.17
I
II
III
IV
STATION

Figure 13 Benthic invertebrate standing crop (as organisms/m^2), composition of dominant taxa (>25 organisms/m^2), and functional group composition in Hess samples from Marion Creek collected in July and September 1981 and June 1982. Locations of sampling stations are shown on Figure 10.

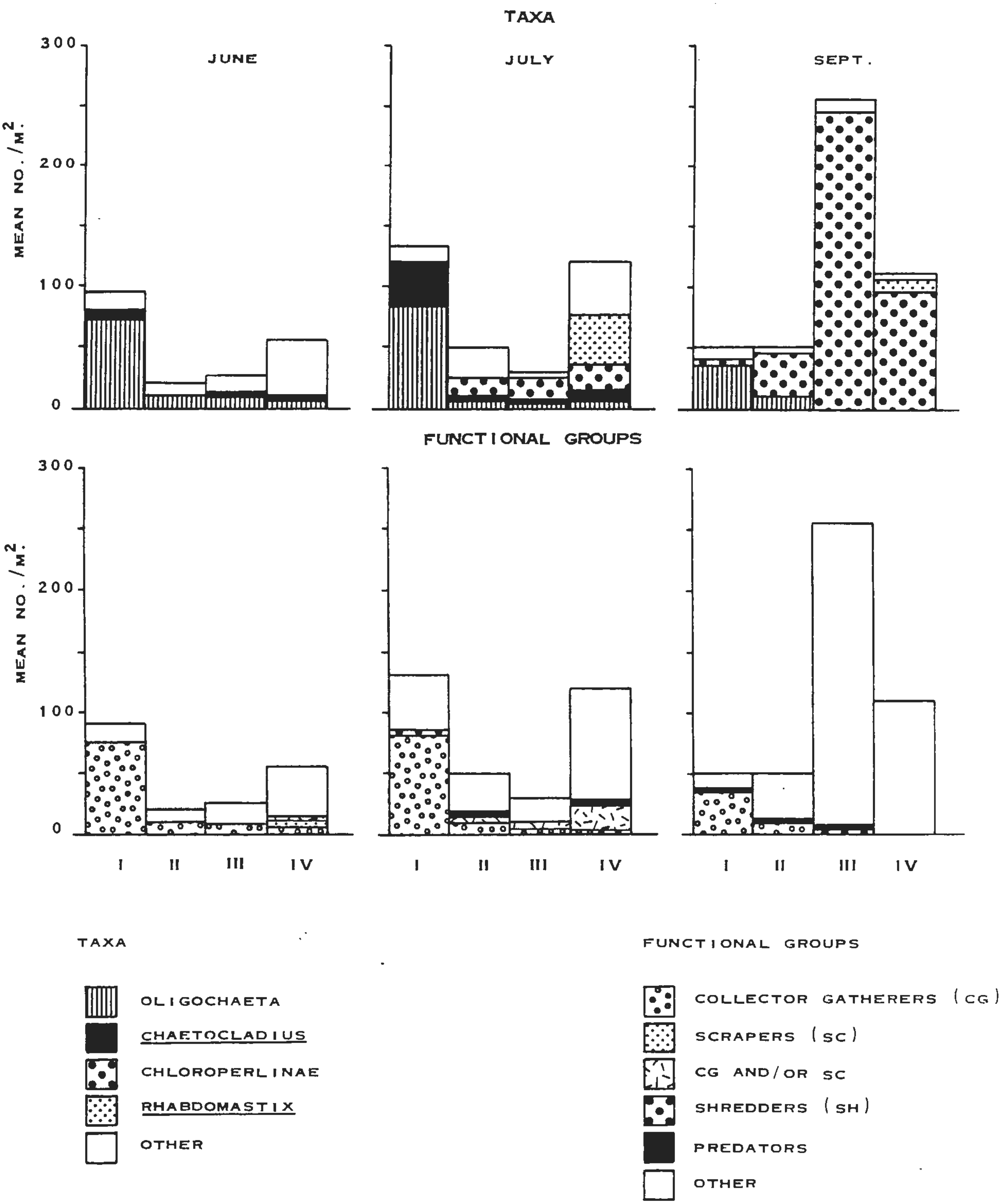

TAXA
JUNE
JULY
SEPT.
MEAN NO. /M.2
300
200
100
0
FUNCTIONAL GROUPS
I
II
III
IV
TAXA
OLIGOCHAETA
CHAETOCLADIUS
CHLOROPERLINAE
RHABDOMASTIX
OTHER
FUNCTIONAL GROUPS
COLLECTOR GATHERERS (CG)
SCRAPERS (SC)
CG AND/OR SC
SHREDDERS (SH)
PREDATORS
OTHER

Figure 14 Shannon-Weaver species diversity index (dots) $\pm$SE (bracketed bars) for benthic invertebrate communities in Marion Creek in July and September 1981 and June 1982. Number above the bar is the number of taxa (s) and the number below the bar is the equitability index (e). Sampling stations are shown on Figure 10.

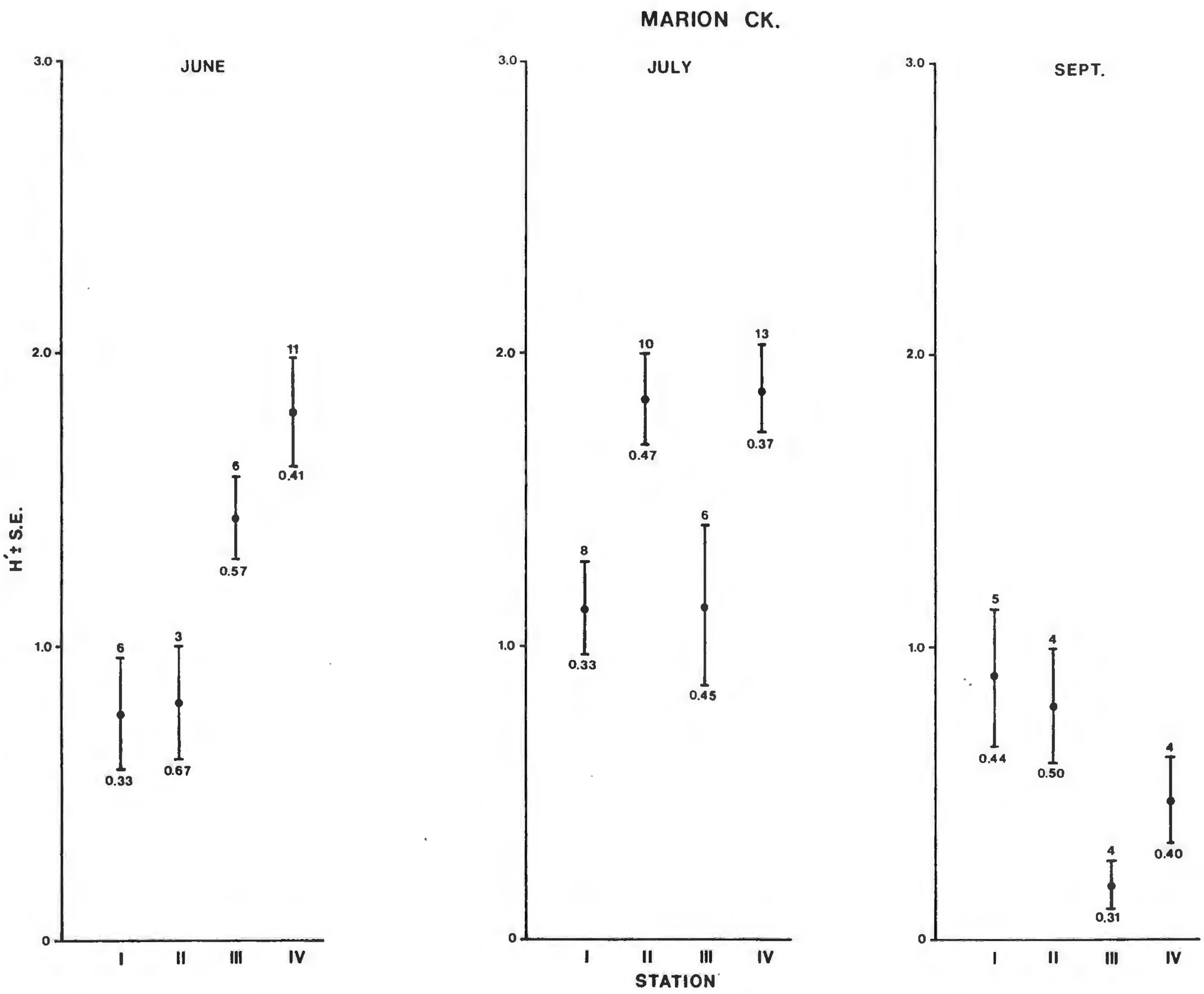

MARION CK.
JUNE
JULY
SEPT.
H'± S.E.
3.0
2.0
1.0
0
I
II
III
IV
STATION
6
3
6
11
0.33
0.67
0.57
0.41
8
10
6
13
0.33
0.47
0.45
0.37
5
4
4
4
0.44
0.50
0.31
0.40

Figure 15 Benthic invertebrate drift (as organisms/24 hr drift set), composition of major taxa and total number of taxa in 2000 m^3 samples from materials site and control sampling sites in Falcon Creek and Airstrip Creek. The total number of taxa is divided into terrestrial and aquatic fauna.

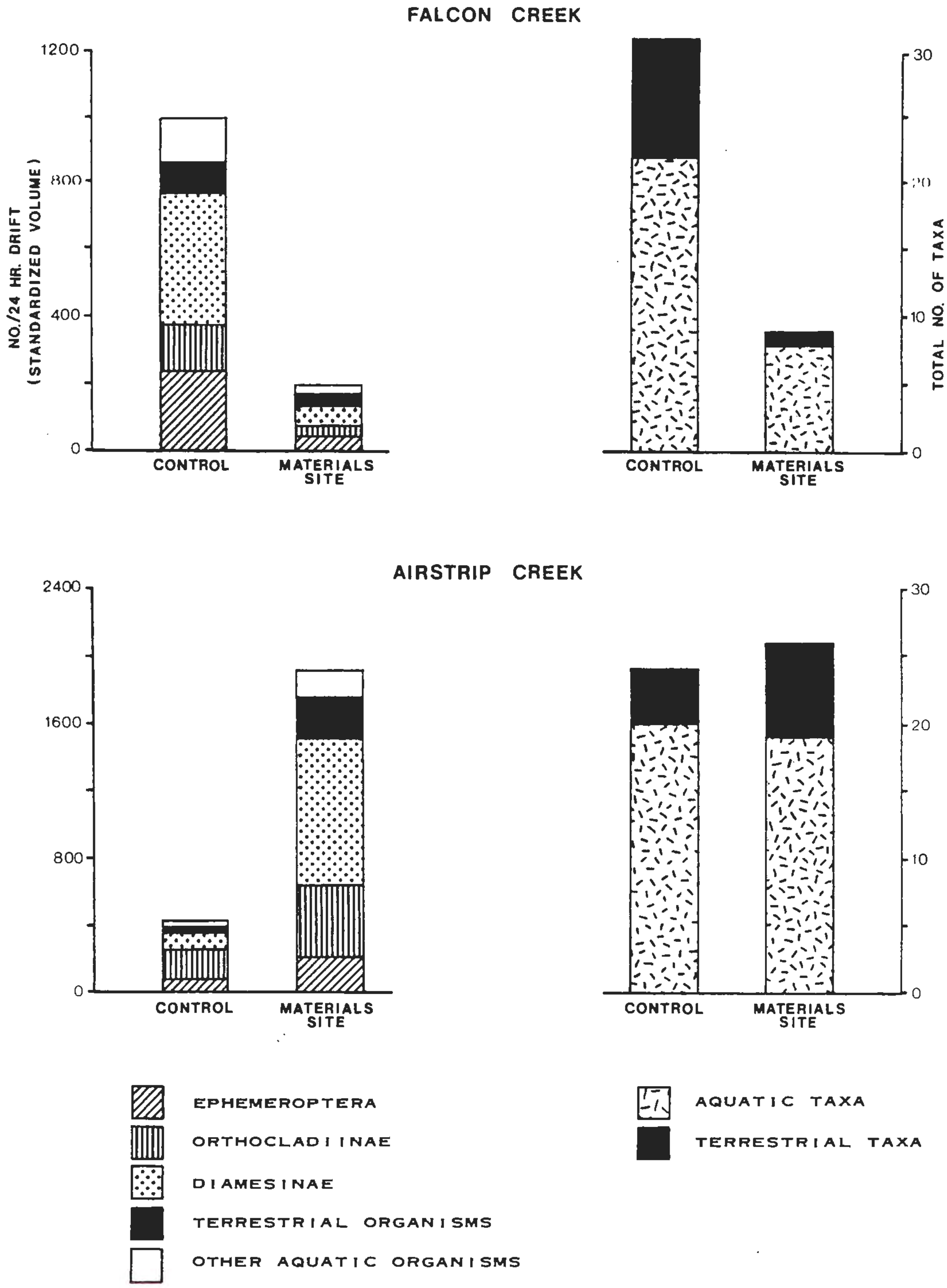

FALCON CREEK
AIRSTRIP CREEK
NO./24 HR. DRIFT (STANDARDIZED VOLUME)
TOTAL NO. OF TAXA
1200
800
400
0
2400
1600
800
0
30
20
10
0
CONTROL
MATERIALS SITE
EPHEMEROPTERA
ORTHOCLADIINAE
DIAMESINAE
TERRESTRIAL ORGANISMS
OTHER AQUATIC ORGANISMS
AQUATIC TAXA
TERRESTRIAL TAXA

Figure 16 Map of the upper Atigun River showing Atigun Pass, the source of sediments entering the East Fork Atigun River at Atigun Pass, benthic invertebrate sampling stations (Roman numerals), and turbidity sampling sites (capital letters).

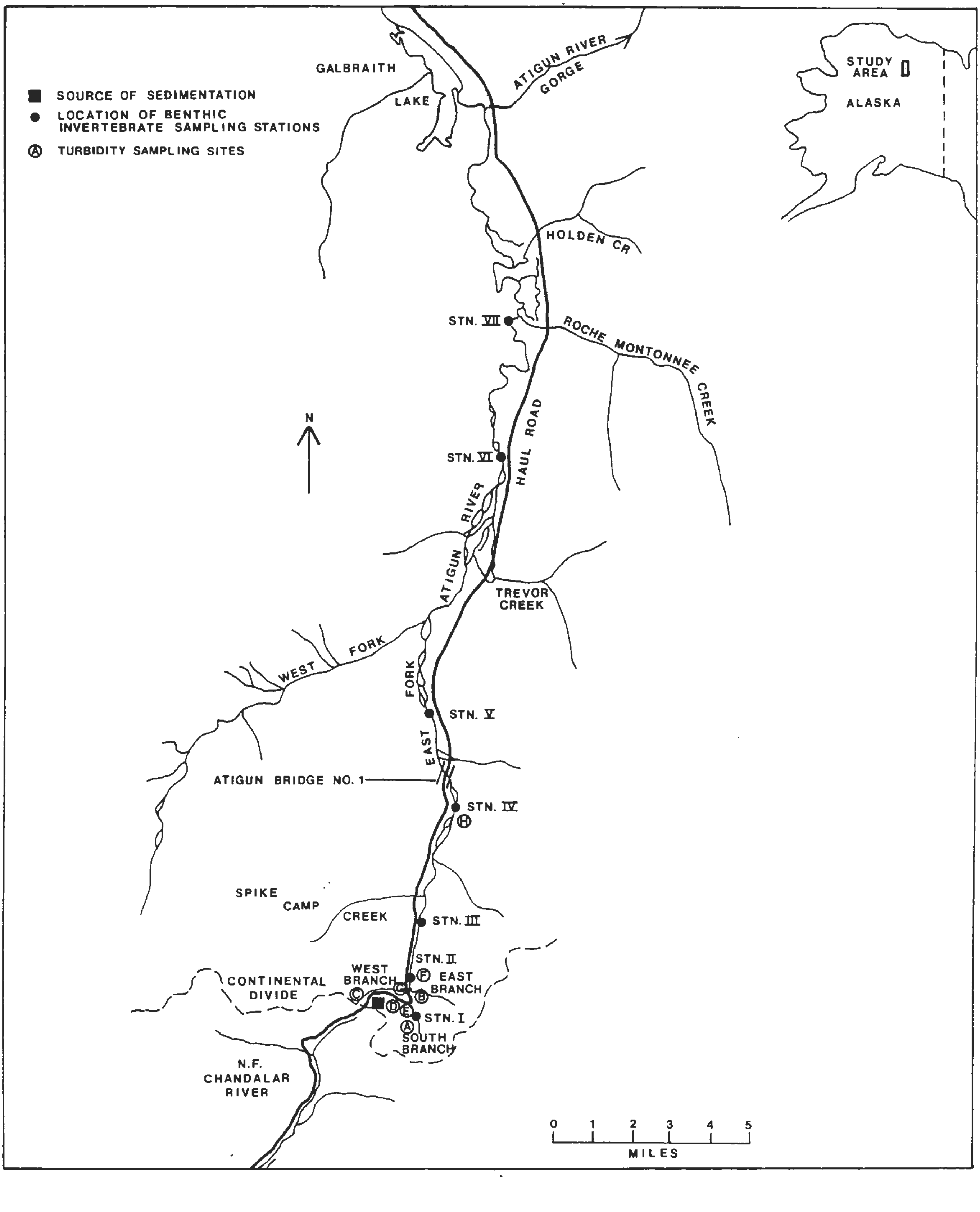
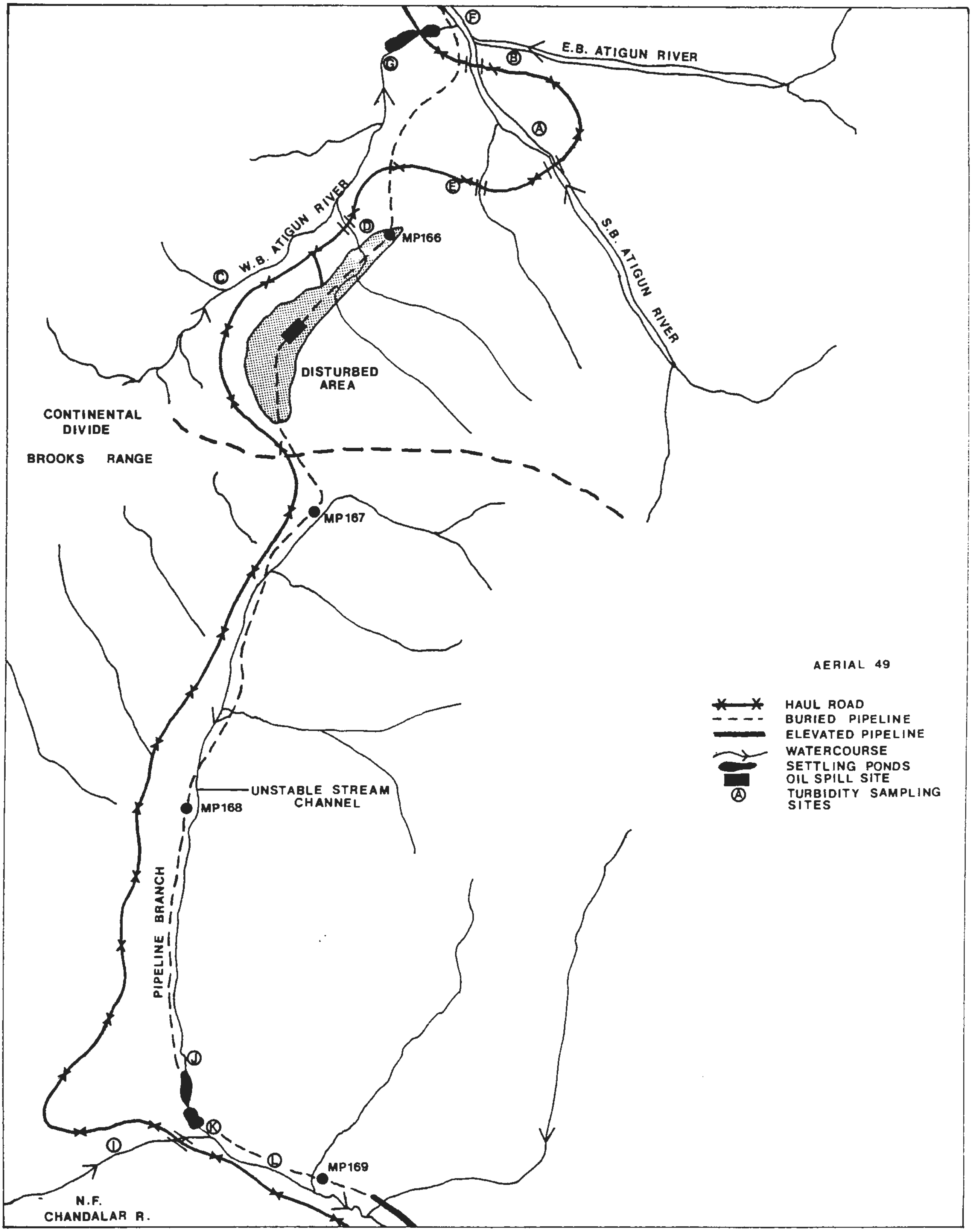
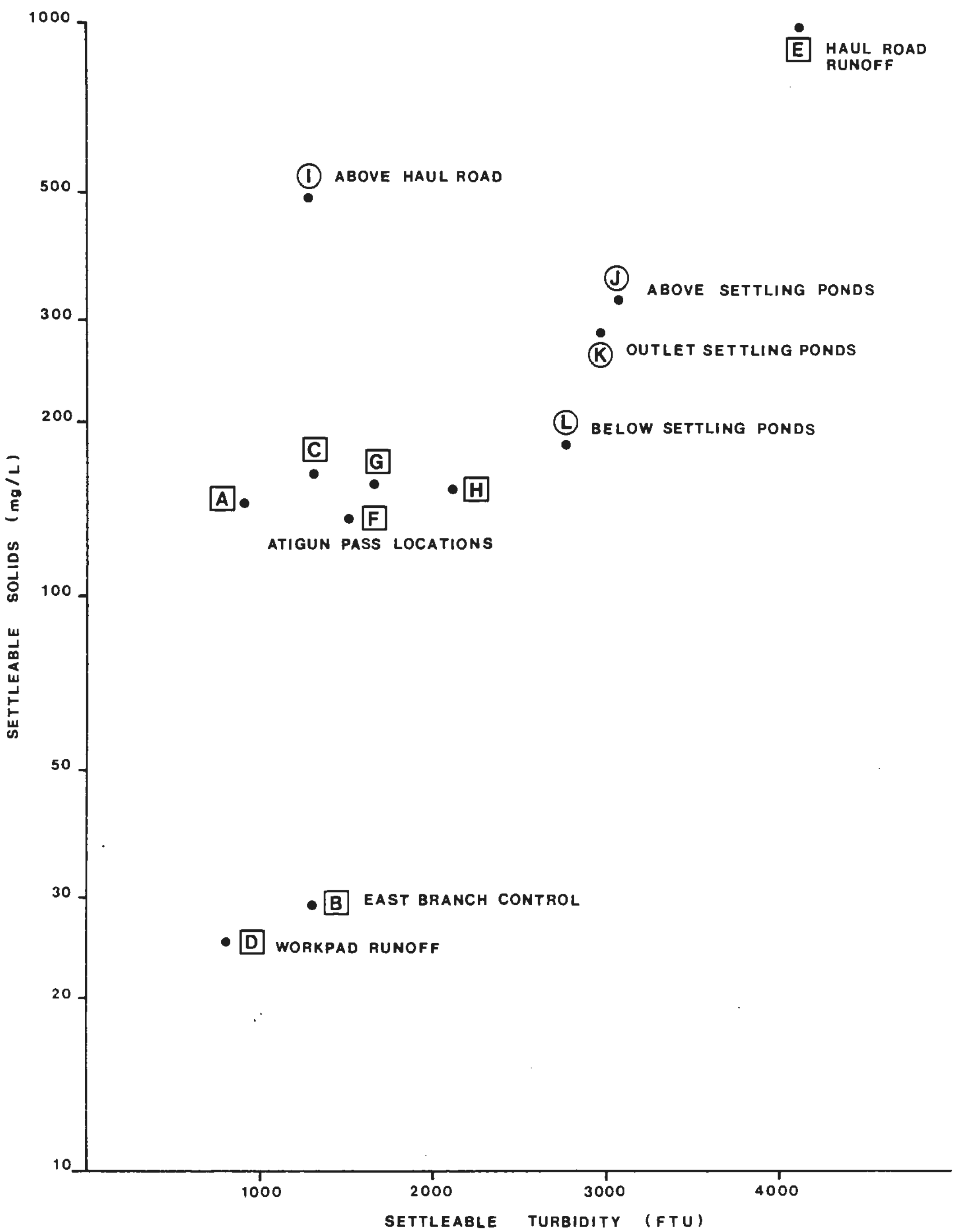

SOURCE OF SEDIMENTATION
LOCATION OF BENTHIC INVERTEBRATE SAMPLING STATIONS
TURBIDITY SAMPLING SITES
GALBRAITH
LAKE
ATIGUN RIVER
GORGE
STUDY AREA
ALASKA
HOLDEN CR
STN. VII
ROCHE MONTONNEE
CREEK
N
STN. VI
HAUL ROAD
RIVER
ATIGUN
TREVOR
CREEK
WEST
FORK
FORK
STN. V
EAST
ATIGUN BRIDGE NO. 1
STN. IV
SPIKE
CAMP
CREEK
STN. III
STN. II
WEST
BRANCH
EAST
BRANCH
CONTINENTAL
DIVIDE
STN. I
SOUTH
BRANCH
N.F.
CHANDALAR
RIVER
0 1 2 3 4 5
MILES

Figure 17 Sketch map of Atigun Pass area showing the disturbed area north of the Continental Divide, the unstable stream channel and settling ponds south of the Continental Divide (Pipeline Branch), and the location of turbidity sampling sites (capital letters). From Northern District Aerial Photograph No. 49. Not to scale.



E.B. ATIGUN RIVER
W.B. ATIGUN RIVER
S.B. ATIGUN RIVER
MP166
DISTURBED AREA
CONTINENTAL DIVIDE
BROOKS RANGE
MP167
UNSTABLE STREAM CHANNEL
MP168
PIPELINE BRANCH
MP169
N.F. CHANDALAR R.
AERIAL 49
HAUL ROAD
BURIED PIPELINE
ELEVATED PIPELINE
WATERCOURSE
SETTLING PONDS
OIL SPILL SITE
TURBIDITY SAMPLING SITES

Figure 18 Settleable turbidity (FTU) and settleable solids concentrations at sites in the North Fork Chandalar River (circles) and Atigun River (squares) during a freshet, June 1, 1983. Site locations are shown on Figures 16 and 17.



1000
500
300
200
100
50
30
20
10
SETTLEABLE SOLIDS (mg/L)
1000
2000
3000
4000
SETTLEABLE TURBIDITY (FTU)
E HAUL ROAD RUNOFF
I ABOVE HAUL ROAD
J ABOVE SETTLING PONDS
K OUTLET SETTLING PONDS
L BELOW SETTLING PONDS
A
C
G
H
F
ATIGUN PASS LOCATIONS
B EAST BRANCH CONTROL
D WORKPAD RUNOFF

Figure 19 Map of the West Branch North Fork Chandalar River showing settling ponds (dark rectangle), benthic invertebrate sampling stations (Roman numerals), turbidity sampling sites (capital letters) and six 100 m long fish density study sections (Bracketed dark bars). The locations of Airstrip Creek and materials site MS-109-3 (expansions 1 to 3) are also shown.

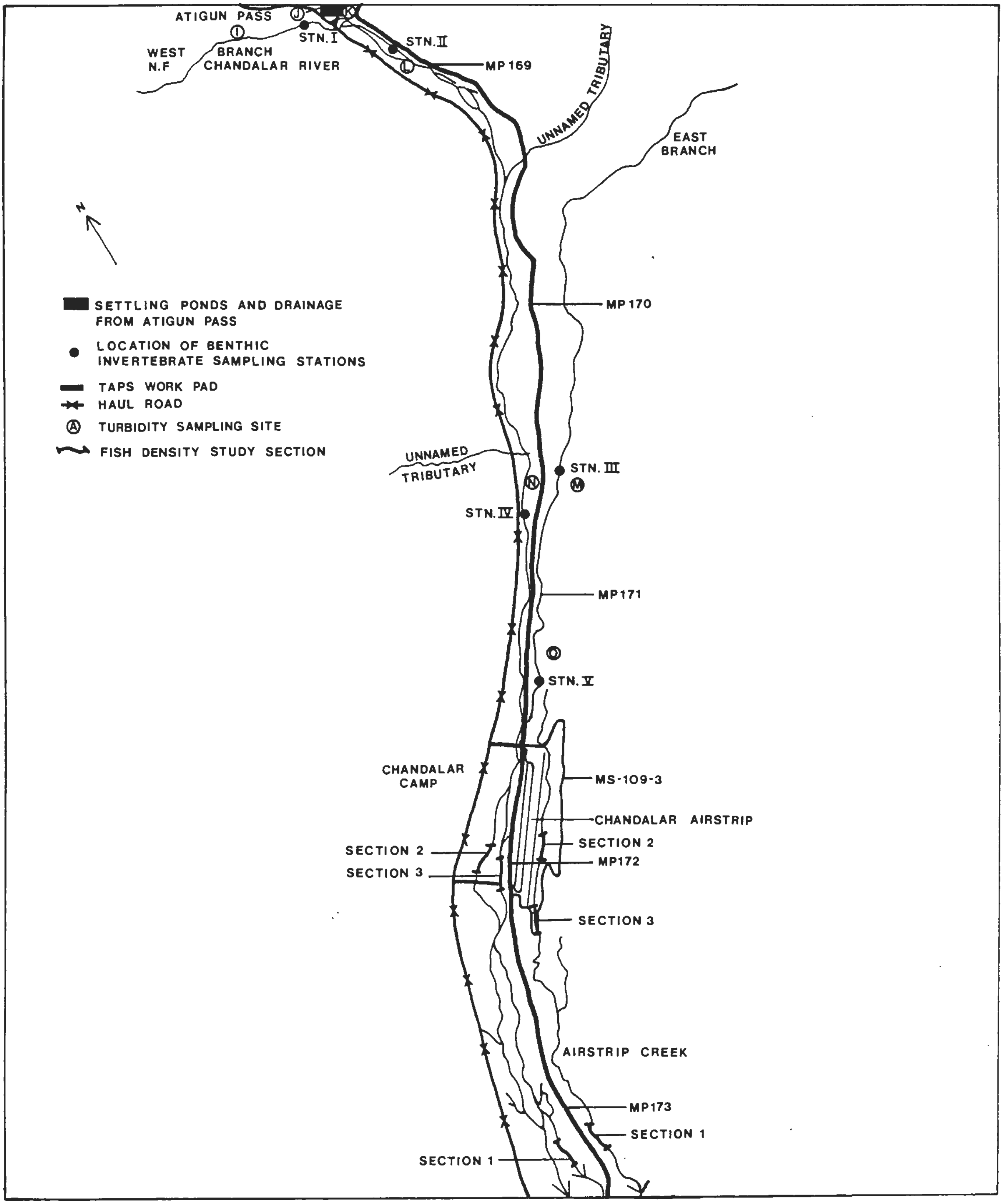

ATIGUN PASS
WEST N.F
BRANCH CHANDALAR RIVER
STN. I
STN. II
MP 169
UNNAMED TRIBUTARY
EAST BRANCH
N
SETTLING PONDS AND DRAINAGE FROM ATIGUN PASS
LOCATION OF BENTHIC INVERTEBRATE SAMPLING STATIONS
TAPS WORK PAD
HAUL ROAD
TURBIDITY SAMPLING SITE
FISH DENSITY STUDY SECTION
MP 170
UNNAMED TRIBUTARY
STN. III
STN. IV
MP 171
STN. V
CHANDALAR CAMP
MS-109-3
CHANDALAR AIRSTRIP
SECTION 2
SECTION 3
SECTION 2
MP172
SECTION 3
AIRSTRIP CREEK
MP173
SECTION 1
SECTION 1

Figure 20 Benthic invertebrate standing crop (as organisms/m^2), composition of dominant taxa (>25 organisms/m^2), and functional group composition in Hess samples from five stations in the North Fork Chandalar River in June and July 1982. Locations of sampling stations are shown in Figure 19.

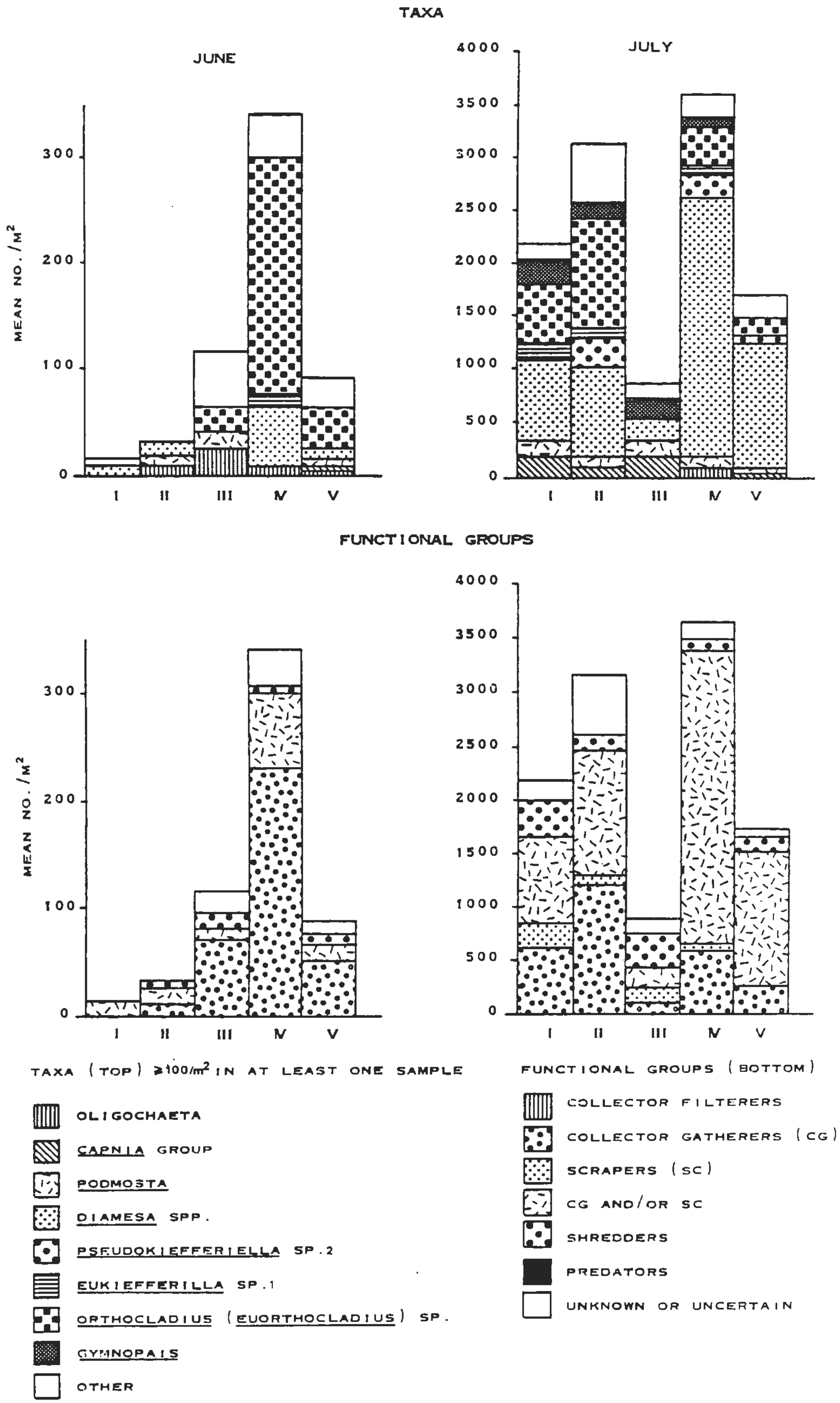
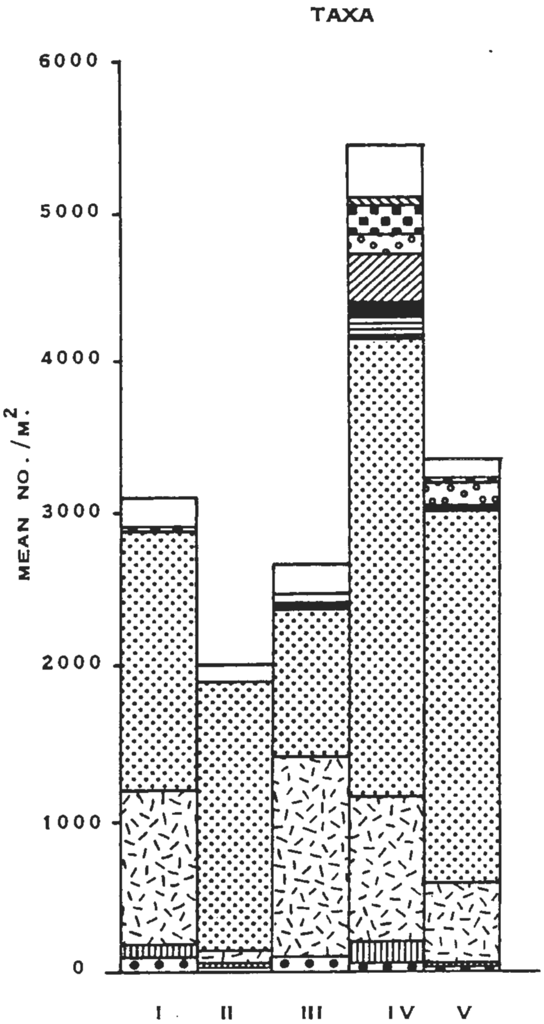
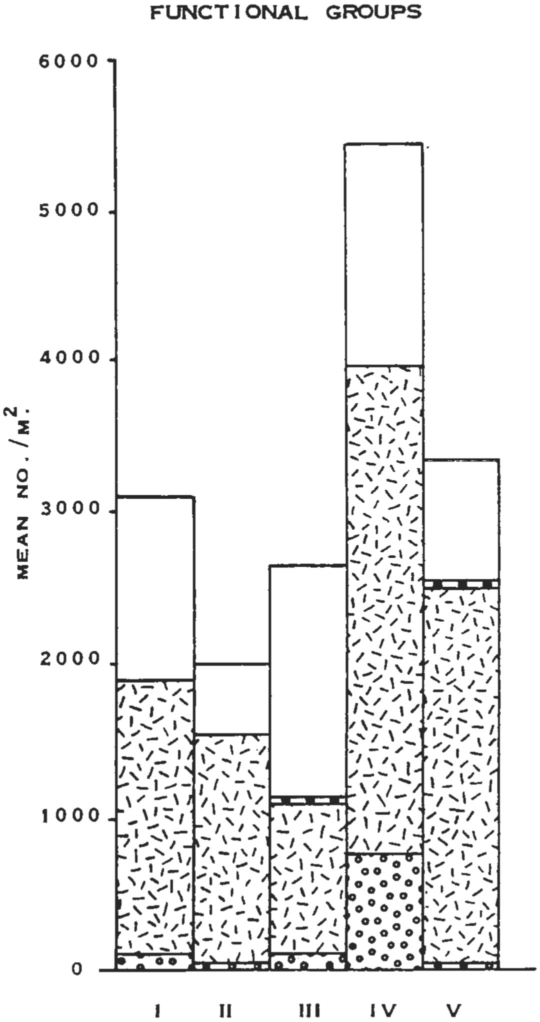

TAXA
JUNE
JULY
MEAN NO. /M²
0
100
200
300
500
1000
1500
2000
2500
3000
3500
4000
I
II
III
IV
V
FUNCTIONAL GROUPS
TAXA (TOP) ≥100/m² IN AT LEAST ONE SAMPLE
OLIGOCHAETA
CAPNIA GROUP
PODMOSTA
DIAMESA SPP.
PSEUDOKIEFFERIELLA SP.2
EUKIEFFERILLA SP.1
ORTHOCLADIUS (EUORTHOCLADIUS) SP.
GYMNOPAIS
OTHER
FUNCTIONAL GROUPS (BOTTOM)
COLLECTOR FILTERERS
COLLECTOR GATHERERS (CG)
SCRAPERS (SC)
CG AND/OR SC
SHREDDERS
PREDATORS
UNKNOWN OR UNCERTAIN

Figure 21 Benthic invertebrate standing crop (as organisms/m^2), composition of dominant taxa (>100 organisms/m^2), and functional group composition in Hess samples from five stations in the North Fork Chandalar River in September 1982. Locations of sampling stations are shown in Figure 19.

SEPTEMBER





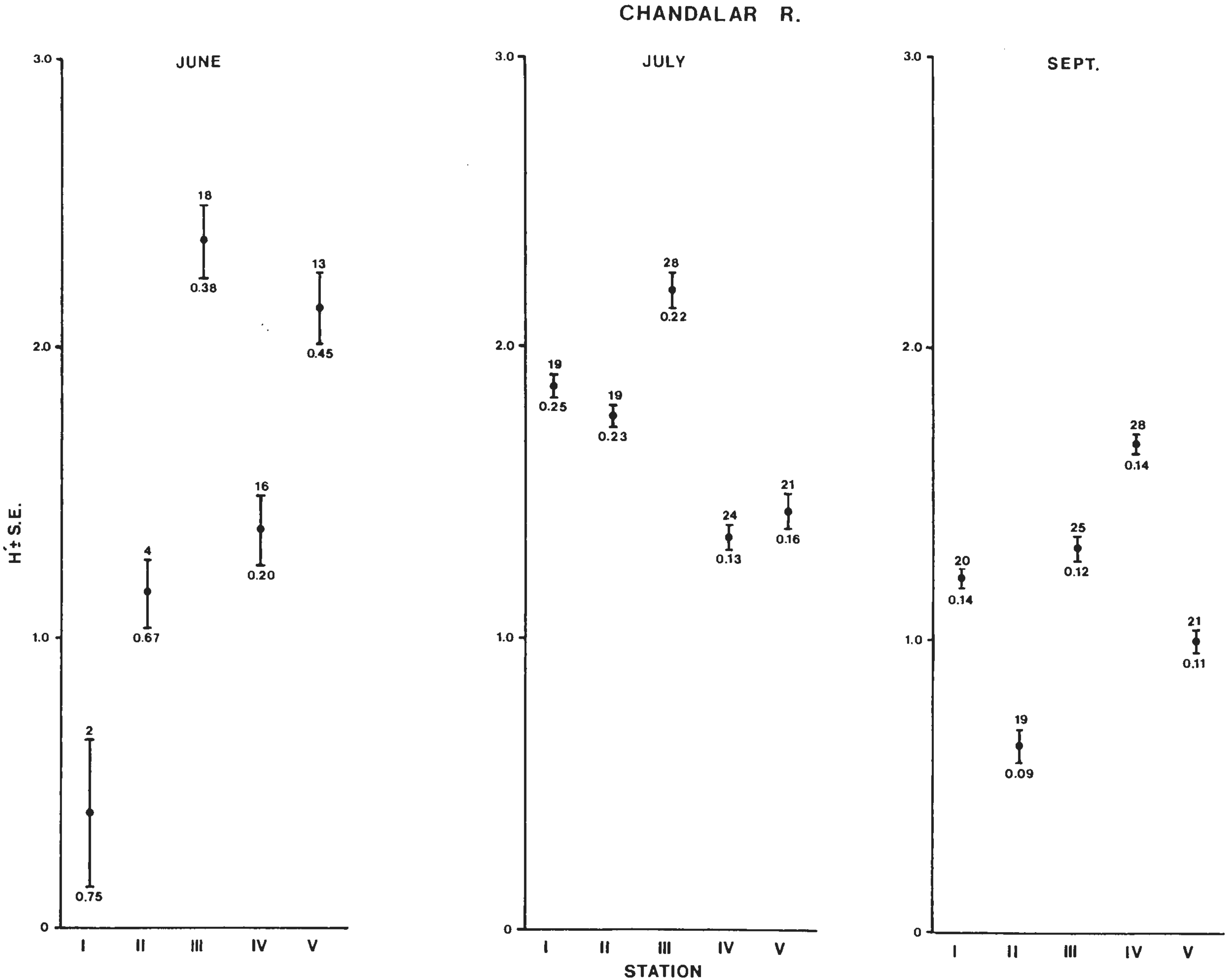
TAXA

- TURBELLARIA
- CINYGMULA
- PODMOSTA
- DIAMESA
- CRICTOPUS
- CR. OR ORTHOCLADIUS SPP.
- CR. OR ORTHOCLADIUS SP. 1
- EUKIEFFERIELLA SP. 1
- EUKIEFFERIELLA SP. 3
- ORTHOCLADIUS (EUORTHOCLADIUS) SP. 3
- OTHER

FUNCTIONAL GROUPS

- COLLECTOR FILTERERS (CF)
- COLLECTOR GATHERERS (CG)
- SCRAPERS (SC)
- CG AND/OR SC
- SHREDDERS
- PREDATORS
- UNKNOWN OR UNCERTAIN

Figure 22 Shannon-Weaver species diversity index (dots) $\pm$SE (bracketed bars) for benthic invertebrate communities in the North Fork Chandalar River in June, July, and September 1982. Number above the bar is the number of taxa (s) and the number below the bar is the equitability index (e). Sampling stations are shown on Figure 19.



CHANDALAR R.
JUNE
JULY
SEPT.
H' ± S.E.
STATION
3.0
2.0
1.0
0
I
II
III
IV
V
2
0.75
4
0.67
18
0.38
16
0.20
13
0.45
19
0.25
19
0.23
28
0.22
24
0.13
21
0.16
20
0.14
19
0.09
25
0.12
28
0.14
21
0.11

Figure 23 Sketch map of Holden Creek drainage showing the location of the haul road, the TAPS alignment, materials site MS-114-1, and three 100 m long fish density study sections (bracket dark bars). Not to scale.

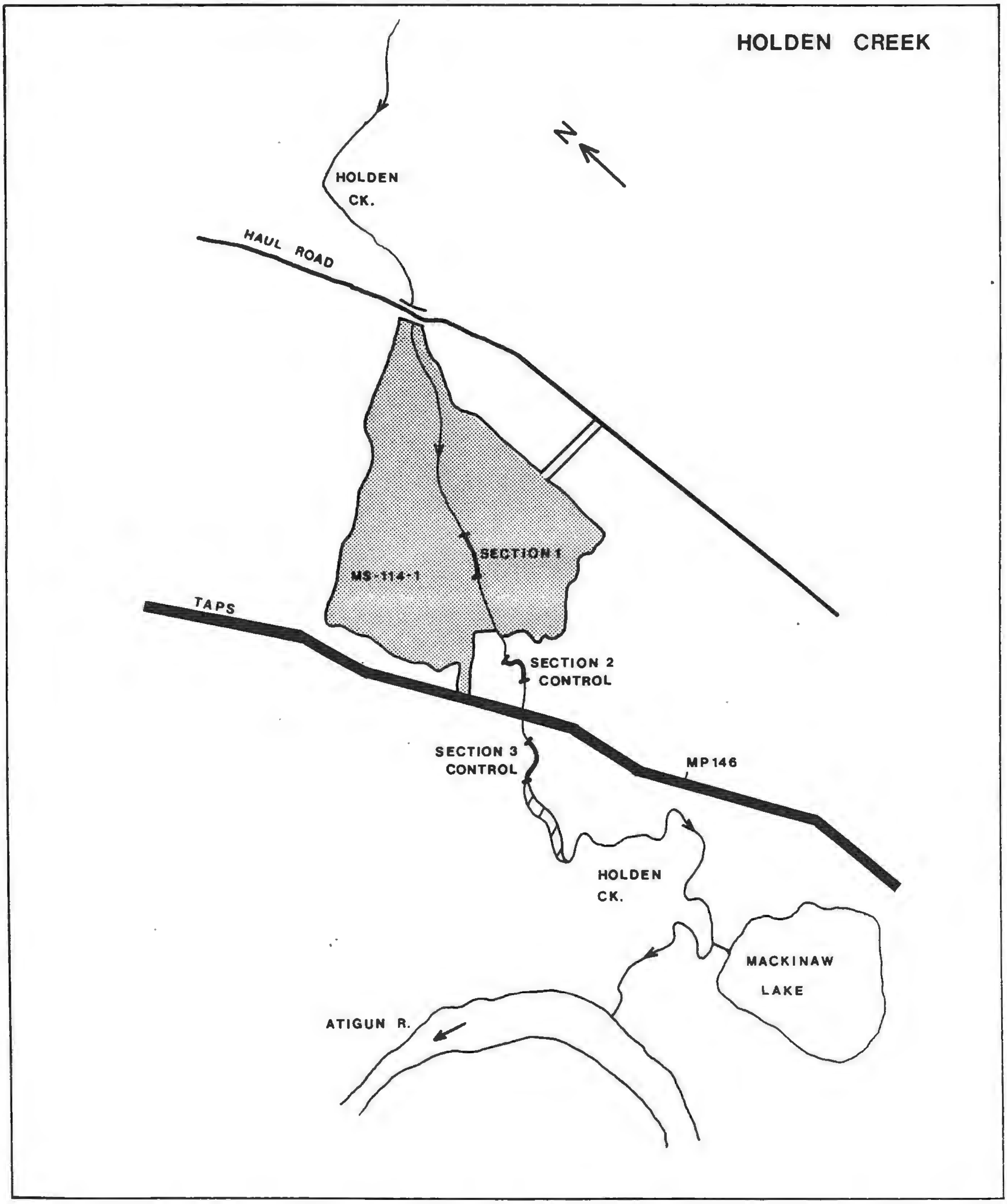
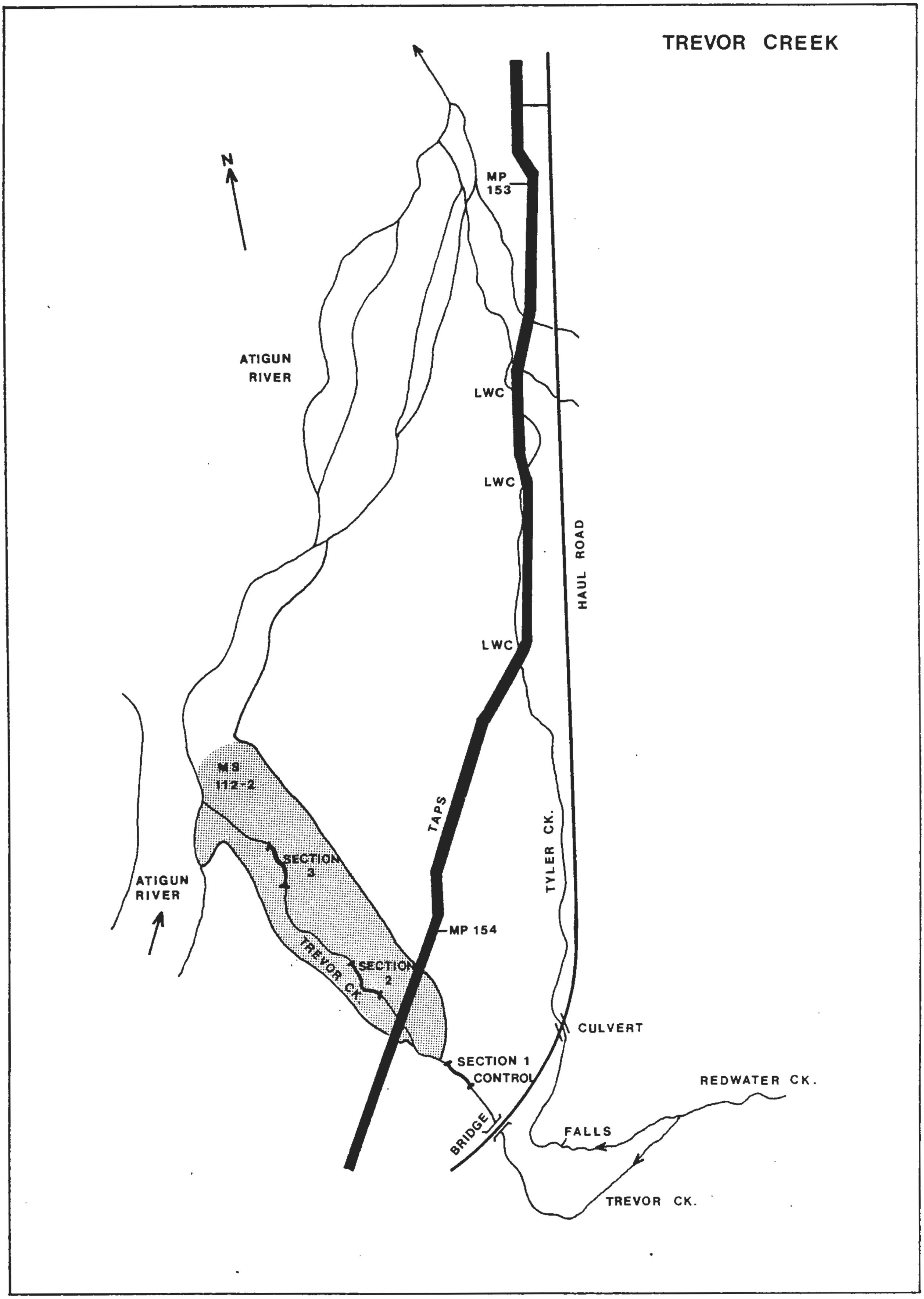

HOLDEN CREEK
N
HOLDEN
CK.
HAUL ROAD
SECTION 1
MS-114-1
TAPS
SECTION 2
CONTROL
SECTION 3
CONTROL
MP146
HOLDEN
CK.
MACKINAW
LAKE
ATIGUN R.

Figure 24 Sketch map of Redwater Creek drainage including the two major distributaries, Trevor Creek and Tyler Creek. The locations of the haul road, the TAPS alignment, materials site MS-112-2, and three 100 m long fish density study sections (bracketed dark bars) are shown. Not to scale.



TREVOR CREEK
N
MP 153
ATIGUN RIVER
LWC
LWC
LWC
HAUL ROAD
MS 112-2
TAPS
TYLER CK.
SECTION 3
ATIGUN RIVER
MP 154
TREVOR CK.
SECTION 2
CULVERT
SECTION 1 CONTROL
REDWATER CK.
FALLS
BRIDGE
TREVOR CK.

Figure 25 Sketch map of the upper Atigun River at Atigun Camp including Spike Camp Creek and Sten Creek. The locations of materials site MS-111-1 and a section of buried pipeline on the TAPS alignment are also illustrated. Not to scale.

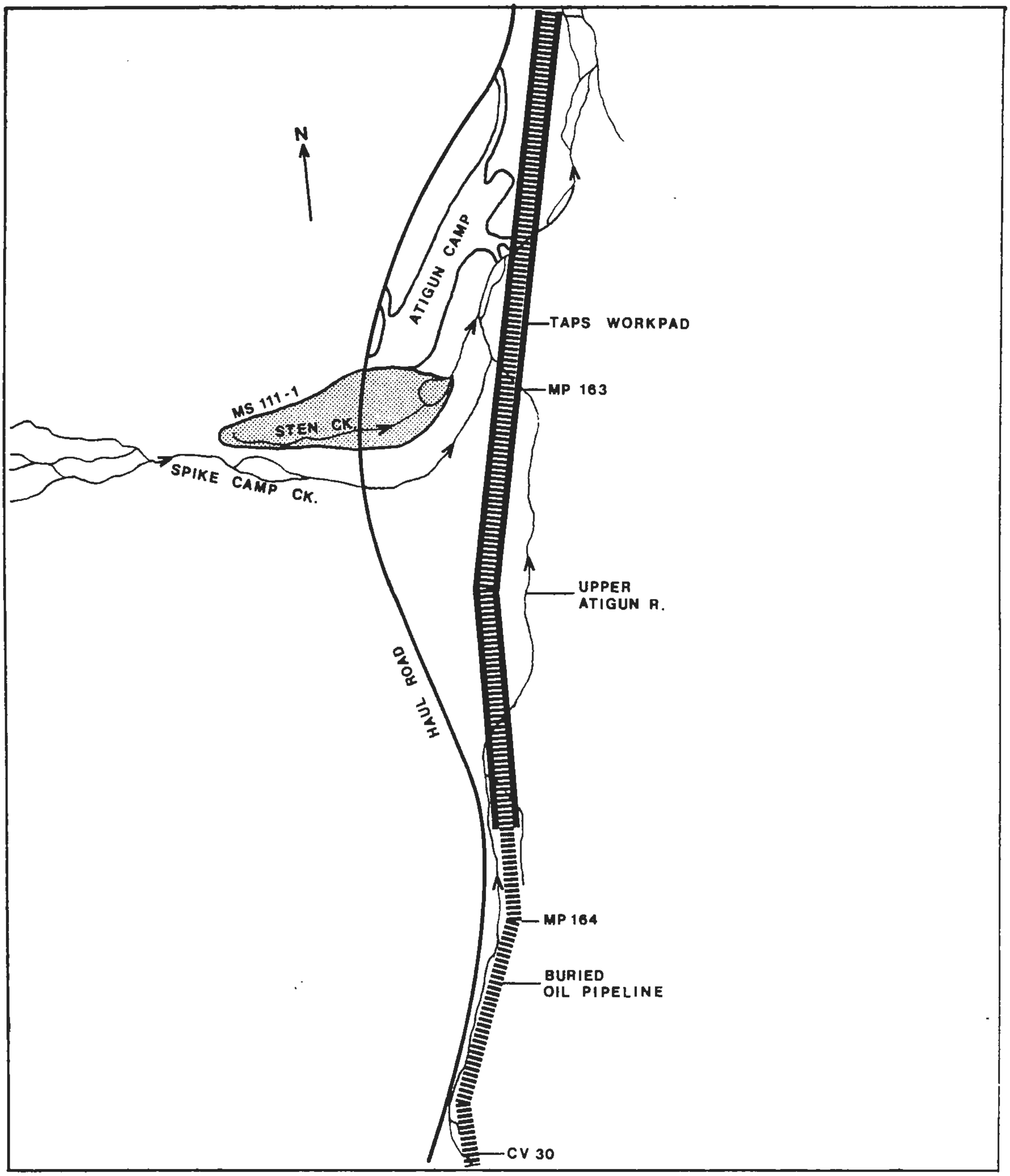
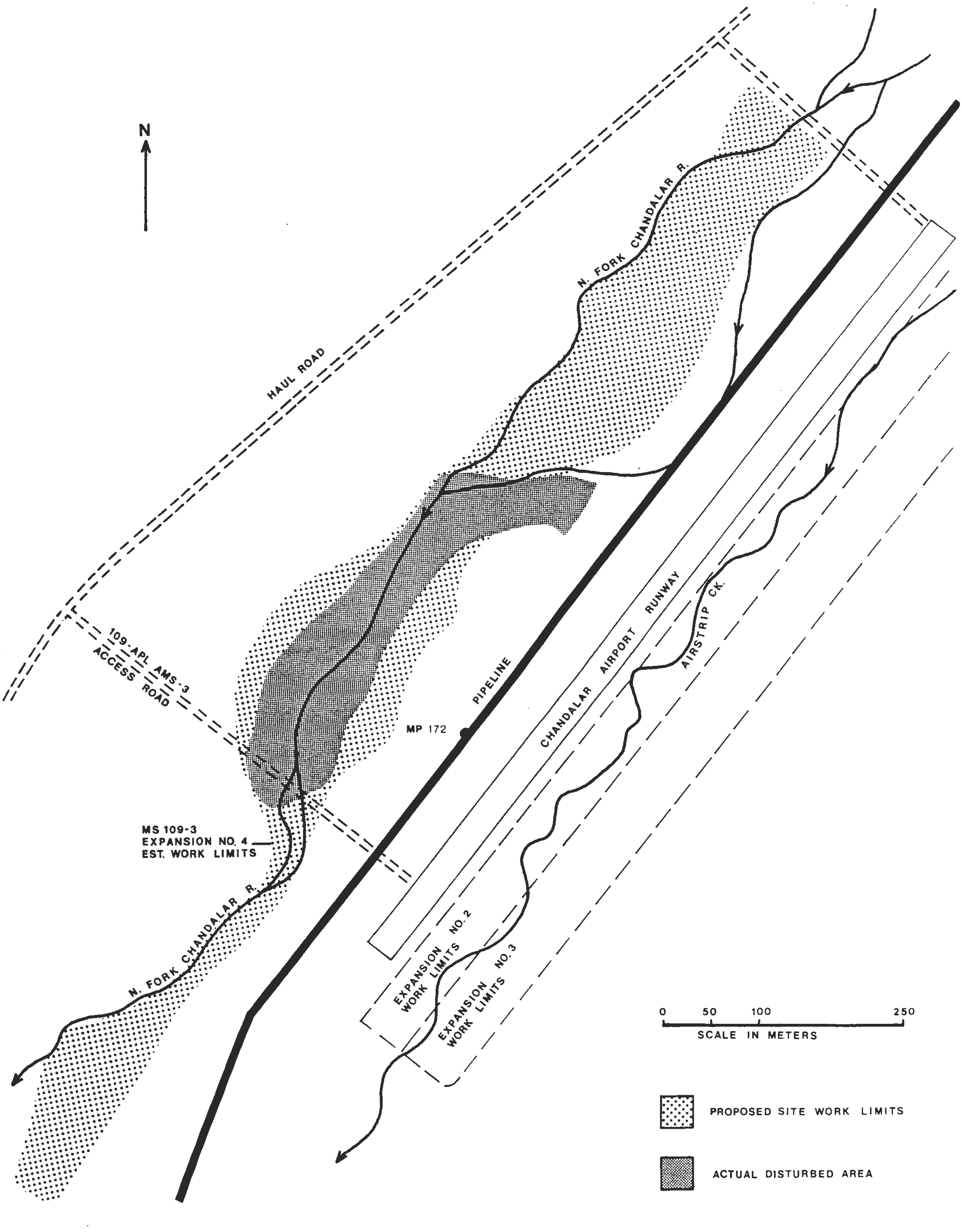
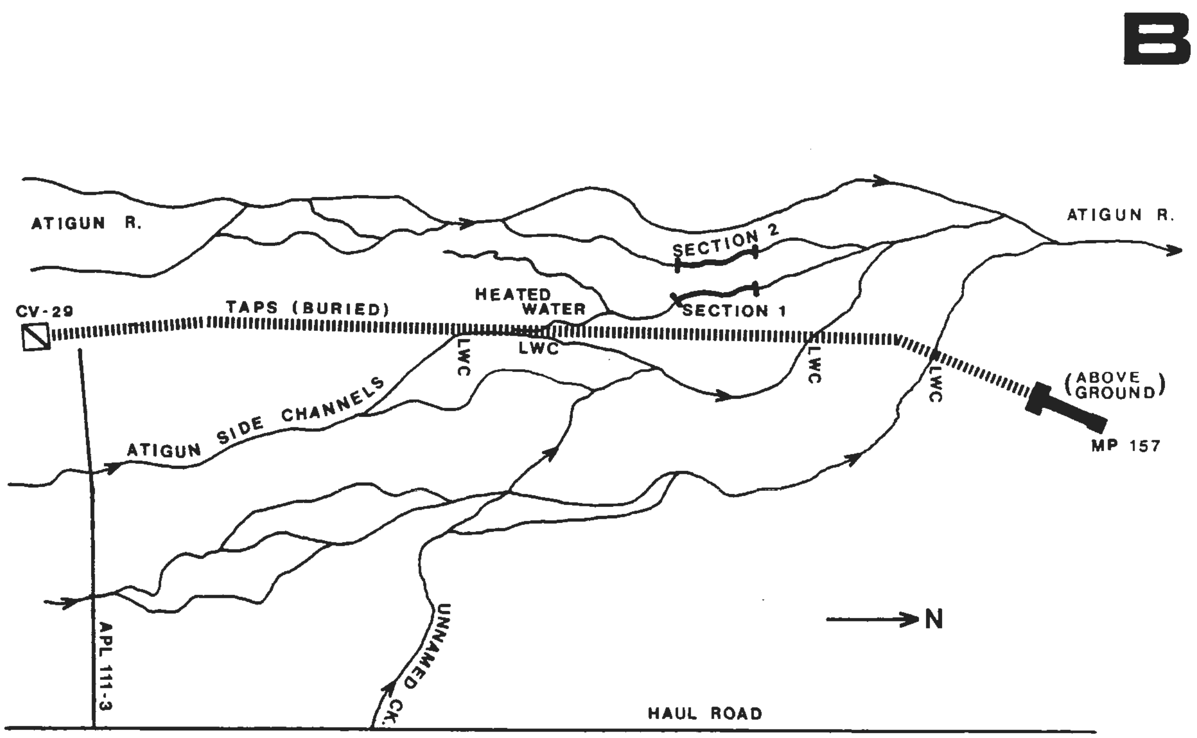

N
ATIGUN CAMP
TAPS WORKPAD
MP 163
MS 111-1
STEN CK.
SPIKE CAMP CK.
UPPER
ATIGUN R.
HAUL ROAD
MP 164
BURIED
OIL PIPELINE
CV 30

Figure 26 Map of materials site MS 109-3 (expansion 4) in the North Fork Chandalar River including the original boundaries of the proposed site as submitted by Alyeska Pipeline Service Company on August 21, 1975 (stippled area) and the actual area disturbed by instream activity (shaded area). Also shown are the approximate locations of the TAPS alignment, the haul road, Chandalar Airport runway, Airstrip Creek, and the airstrip access road (upper right corner). APL-109 AMS 3 access road is blocked.



N
HAUL ROAD
N. FORK CHANDALAR R.
109-APL AMS-3
ACCESS ROAD
PIPELINE
MP 172
CHANDALAR AIRPORT RUNWAY
AIRSTRIP CK.
MS 109-3
EXPANSION NO. 4
EST. WORK LIMITS
N. FORK CHANDALAR R.
EXPANSION NO. 2
WORK LIMITS
EXPANSION NO. 3
WORK LIMITS
0 50 100 250
SCALE IN METERS
PROPOSED SITE WORK LIMITS
ACTUAL DISTURBED AREA

Figure 27 Sketch map of the location of two thermal irregularities in the Atigun River near MP161.0 (A) and near MP 157.2 (B). The locations of two 100 m long fish density study sections in each location (bracketed dark bars) and the TAPS alignment are shown.


B
ATIGUN R.
ATIGUN R.
SECTION 2
SECTION 1
HEATED
WATER
CV-29
TAPS (BURIED)
LWC
LWC
LWC
LWC
(ABOVE GROUND)
MP 157
ATIGUN SIDE CHANNELS
N
APL 111-3
UNNAMED CK.
HAUL ROAD

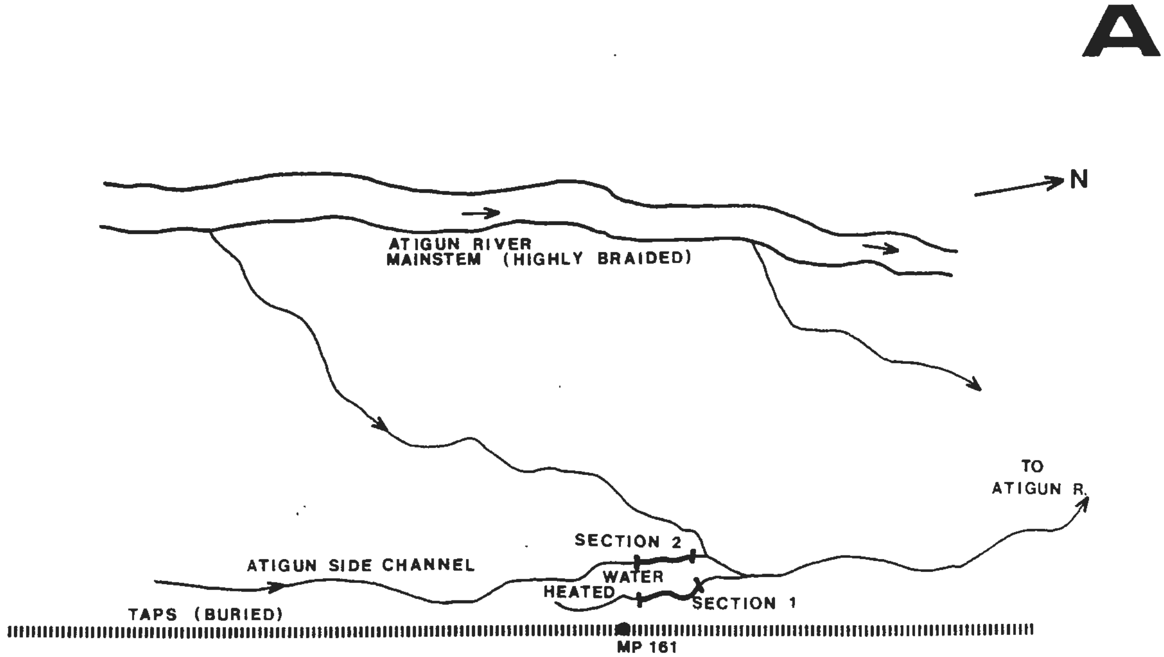
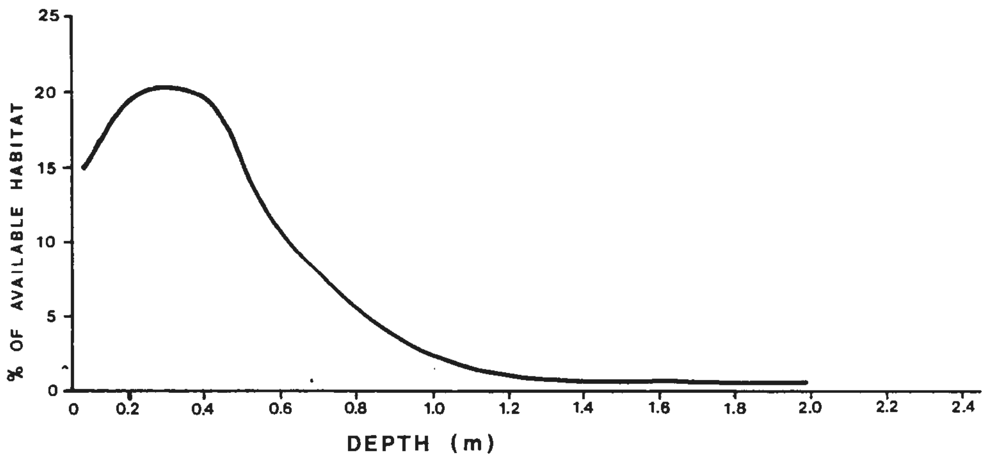
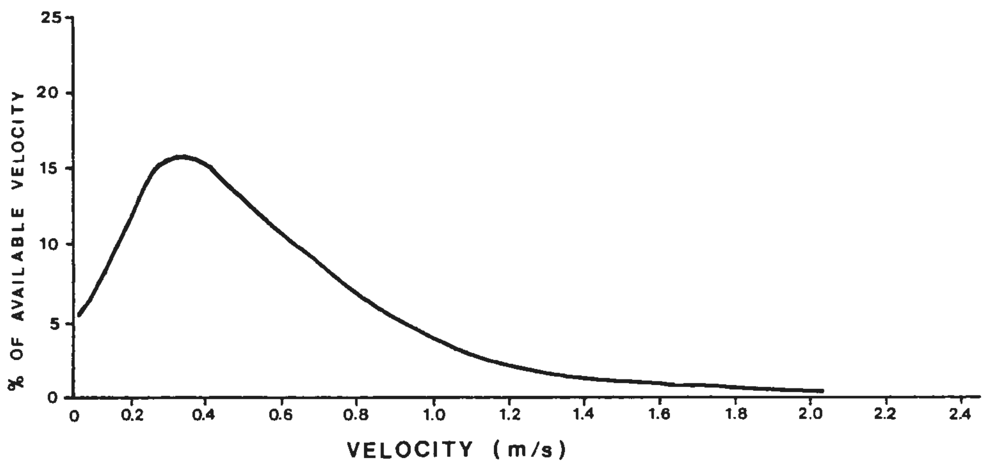

A
N
ATIGUN RIVER
MAINSTEM (HIGHLY BRAIDED)
TO
ATIGUN R.
SECTION 2
ATIGUN SIDE CHANNEL
WATER
HEATED
SECTION 1
TAPS (BURIED)
MP 161

Figure 28 Depth, mean velocity, and substrate (weighted average code) as a percentage of total available habitat, based on weighted habitat availability in 27 study streams.


% OF AVAILABLE HABITAT
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
DEPTH (m)


% OF AVAILABLE VELOCITY
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
VELOCITY (m/s)

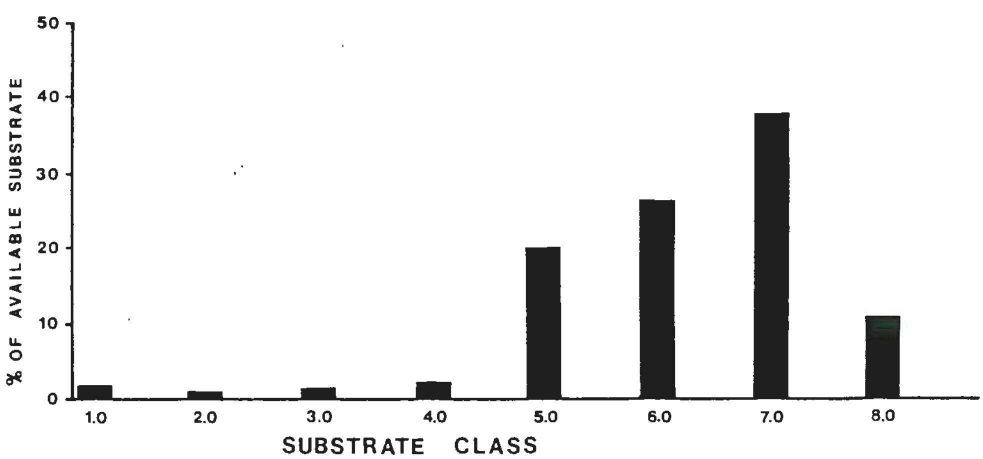
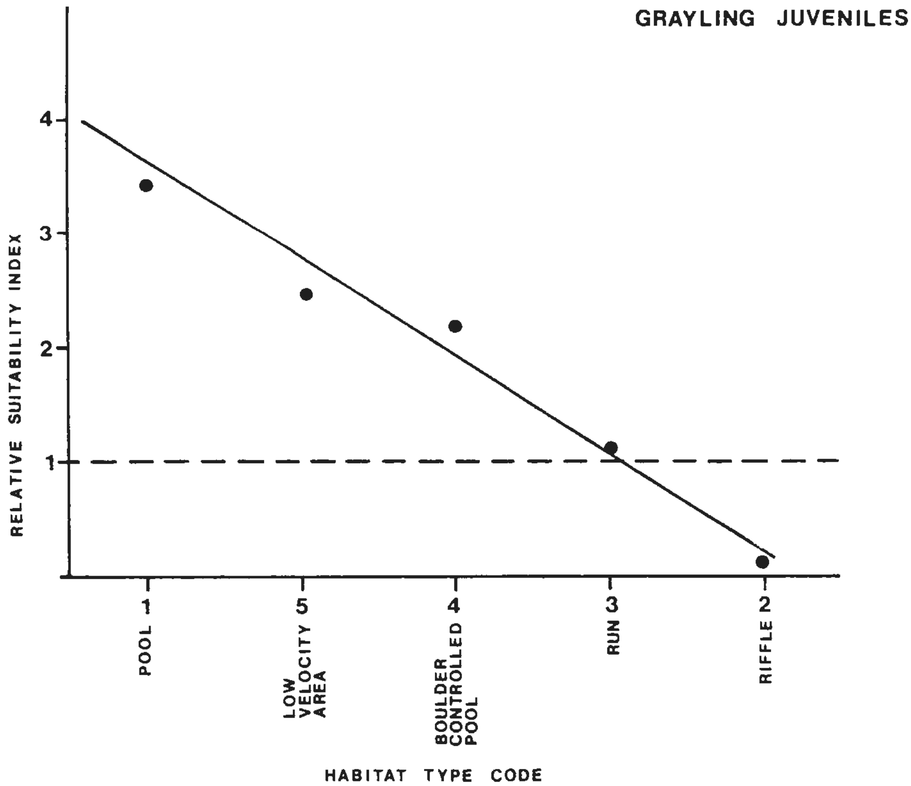

% OF AVAILABLE SUBSTRATE
50
40
30
20
10
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
SUBSTRATE CLASS

Figure 29 Relative Suitability Index (RSI) of five coded habitat types for juvenile and adult grayling in northern portions of the TAPS corridor. RSI values were obtained by dividing the percentage of fish found in a habitat type by the percent availability of that habitat type in the study area. Coded variables are arranged according to decreasing depth and increasing velocity.


GRAYLING JUVENILES
RELATIVE SUITABILITY INDEX
4
3
2
1
1
5
4
3
2
POOL
LOW VELOCITY AREA
BOULDER CONTROLLED POOL
RUN
RIFFLE
HABITAT TYPE CODE

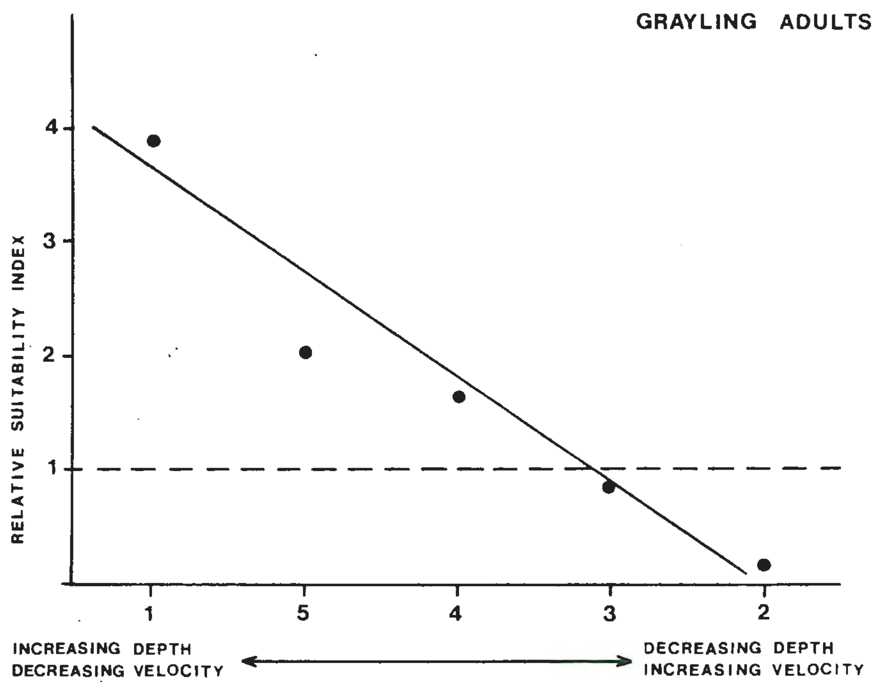
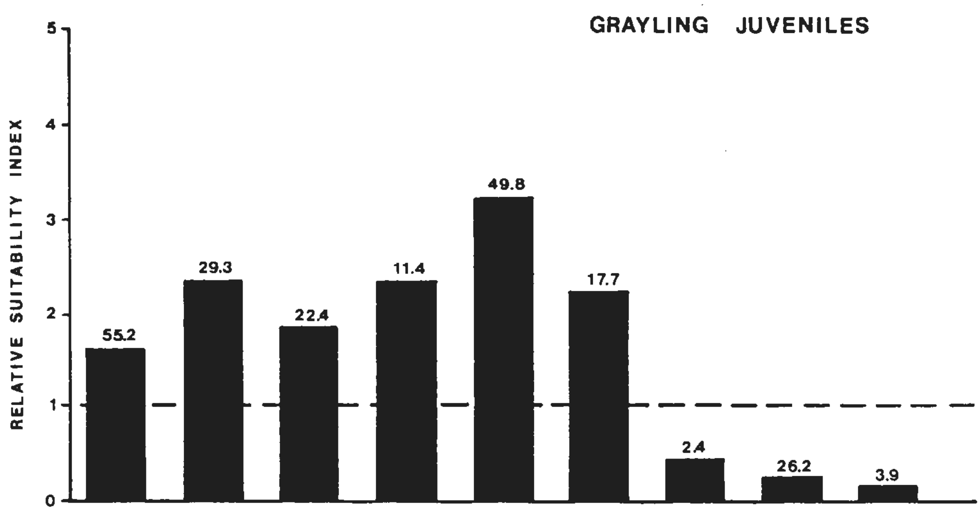

GRAYLING ADULTS
RELATIVE SUITABILITY INDEX
4
3
2
1
1
5
4
3
2
INCREASING DEPTH
DECREASING VELOCITY
DECREASING DEPTH
INCREASING VELOCITY

Figure 30 Relative Suitability Index (RSI) for nine types of cover used by juvenile and adult grayling. The percent frequency of fish using each cover type is indicated above each bar. Fish may use more than one type of cover.


GRAYLING JUVENILES
RELATIVE SUITABILITY INDEX
0
1
2
3
4
5
55.2
29.3
22.4
11.4
49.8
17.7
2.4
26.2
3.9

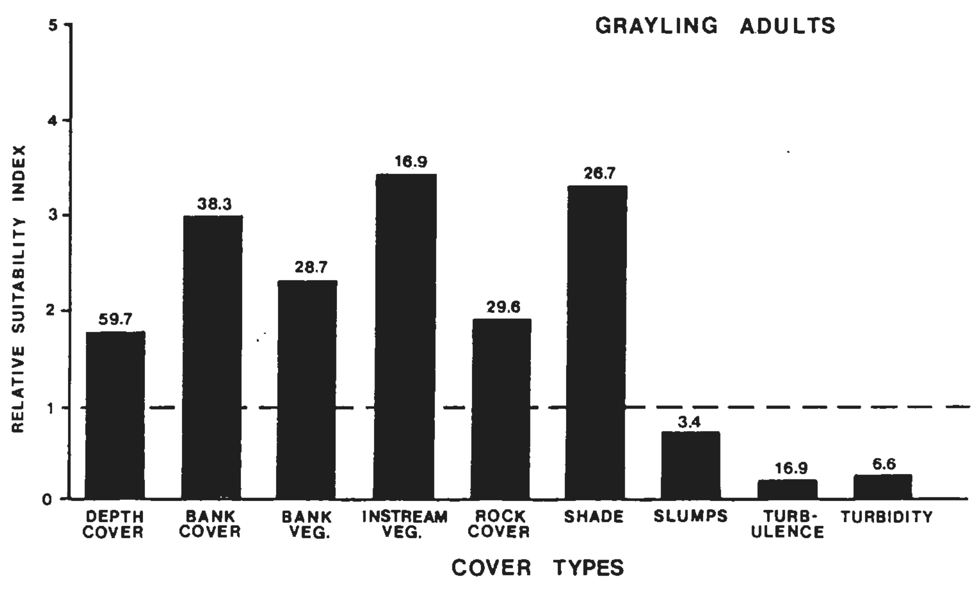
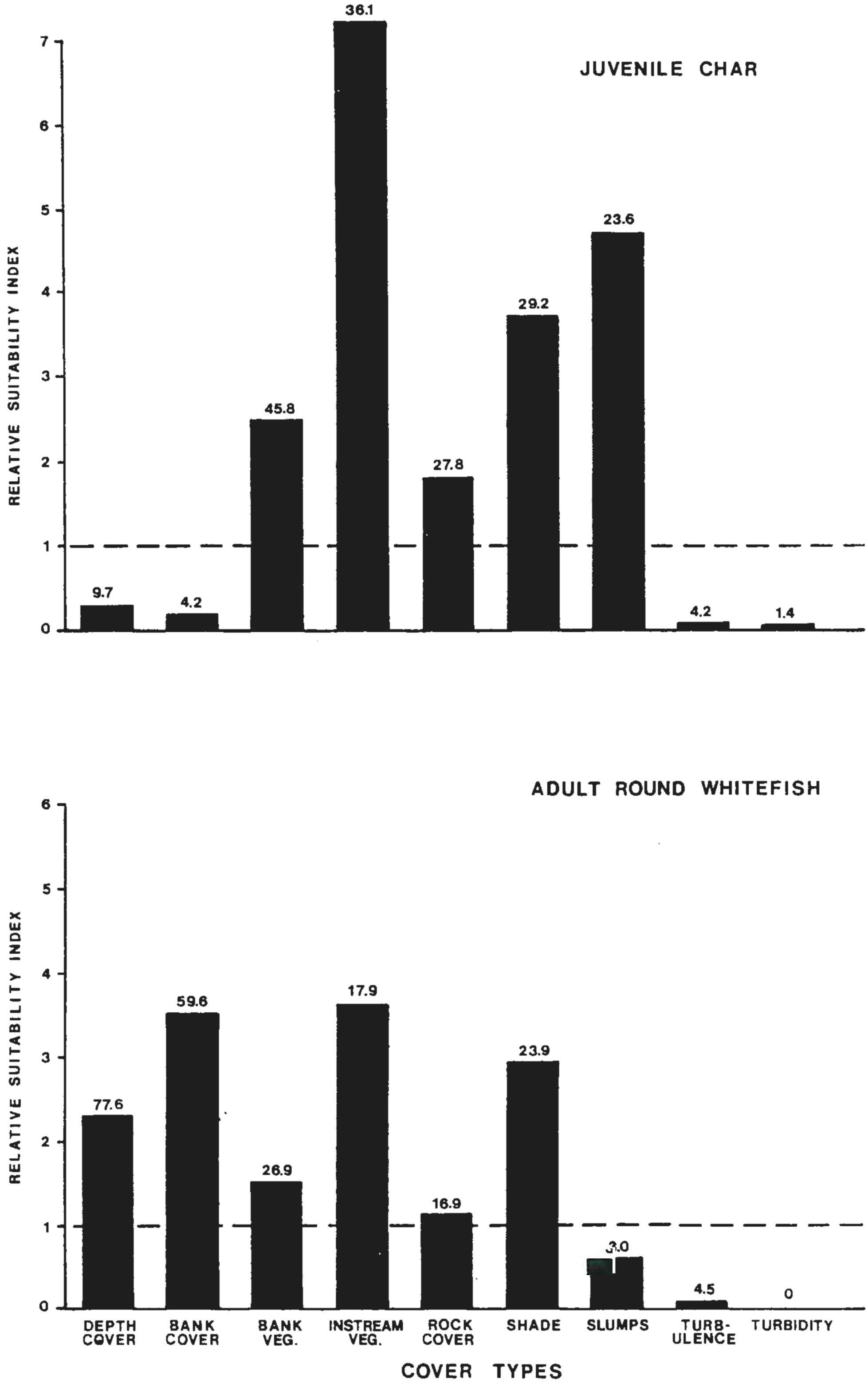
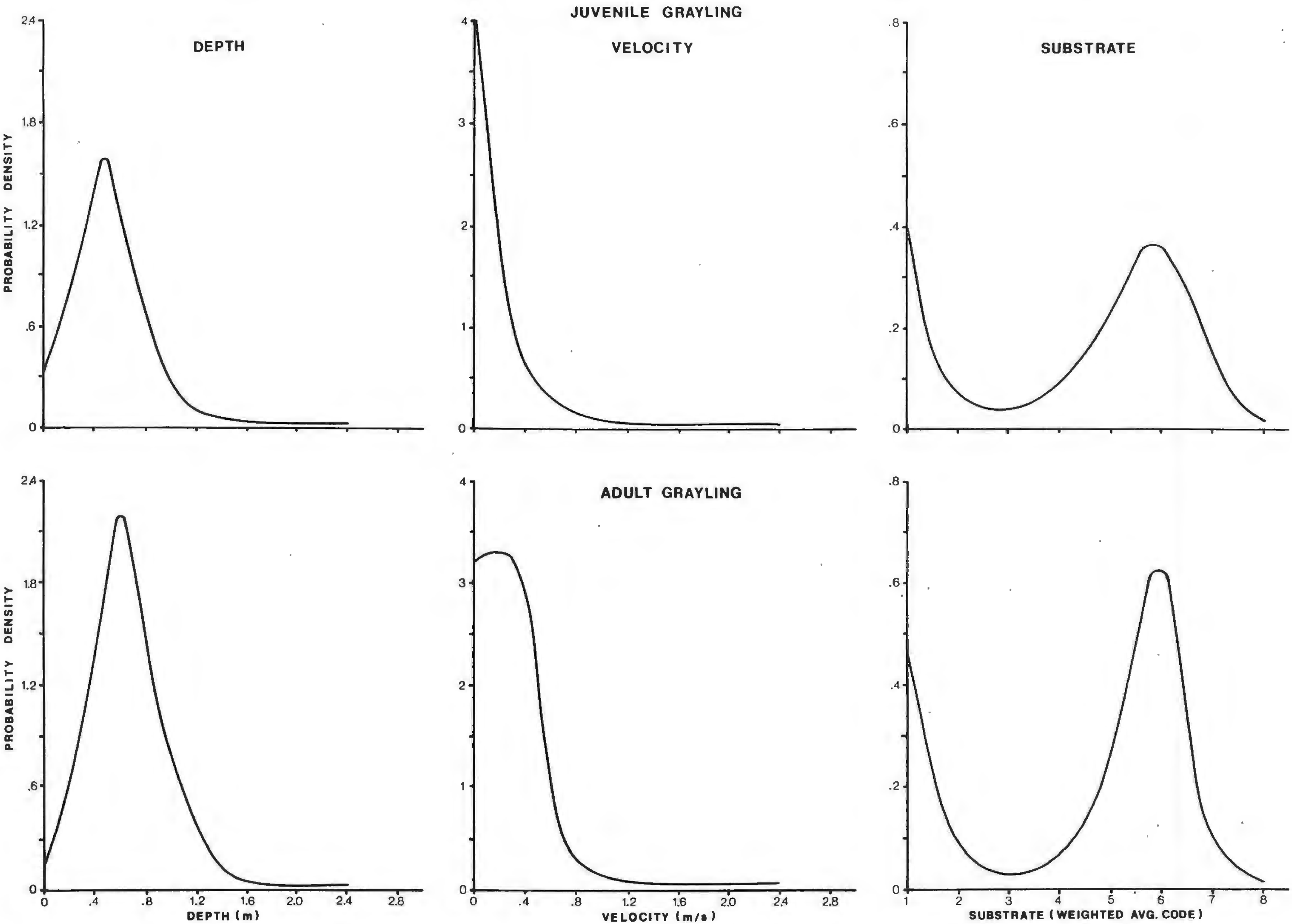

GRAYLING ADULTS
RELATIVE SUITABILITY INDEX
0
1
2
3
4
5
59.7
38.3
28.7
16.9
29.6
26.7
3.4
16.9
6.6
DEPTH COVER
BANK COVER
BANK VEG.
INSTREAM VEG.
ROCK COVER
SHADE
SLUMPS
TURB-ULENCE
TURBIDITY
COVER TYPES

Figure 31 Relative Suitability Index (RSI) for nine types of cover used by juvenile Arctic char and adult round whitefish. The percent frequency of fish using each cover type is indicated above each bar. Fish may use more than one type of cover.



JUVENILE CHAR
RELATIVE SUITABILITY INDEX
0
1
2
3
4
5
6
7
9.7
4.2
45.8
36.1
27.8
29.2
23.6
4.2
1.4
ADULT ROUND WHITEFISH
RELATIVE SUITABILITY INDEX
0
1
2
3
4
5
6
77.6
59.6
26.9
17.9
16.9
23.9
3.0
4.5
0
DEPTH COVER
BANK COVER
BANK VEG.
INSTREAM VEG.
ROCK COVER
SHADE
SLUMPS
TURB-ULENCE
TURBIDITY
COVER TYPES

Figure 32	Probability density functions for depth, mean velocity, and substrate (weighted average code) for juvenile and adult grayling.



JUVENILE GRAYLING
DEPTH
VELOCITY
SUBSTRATE
ADULT GRAYLING
PROBABILITY DENSITY
2.4
1.8
1.2
.6
0
4
3
2
1
.8
.6
.4
.2
0 .4 .8 1.2 1.6 2.0 2.4 2.8
DEPTH (m)
VELOCITY (m/s)
1 2 3 4 5 6 7 8
SUBSTRATE (WEIGHTED AVG. CODE)

Figure 33 Weighted suitability of use curves for depth, mean velocity, and substrate (weighted average code) for juvenile and adult grayling.

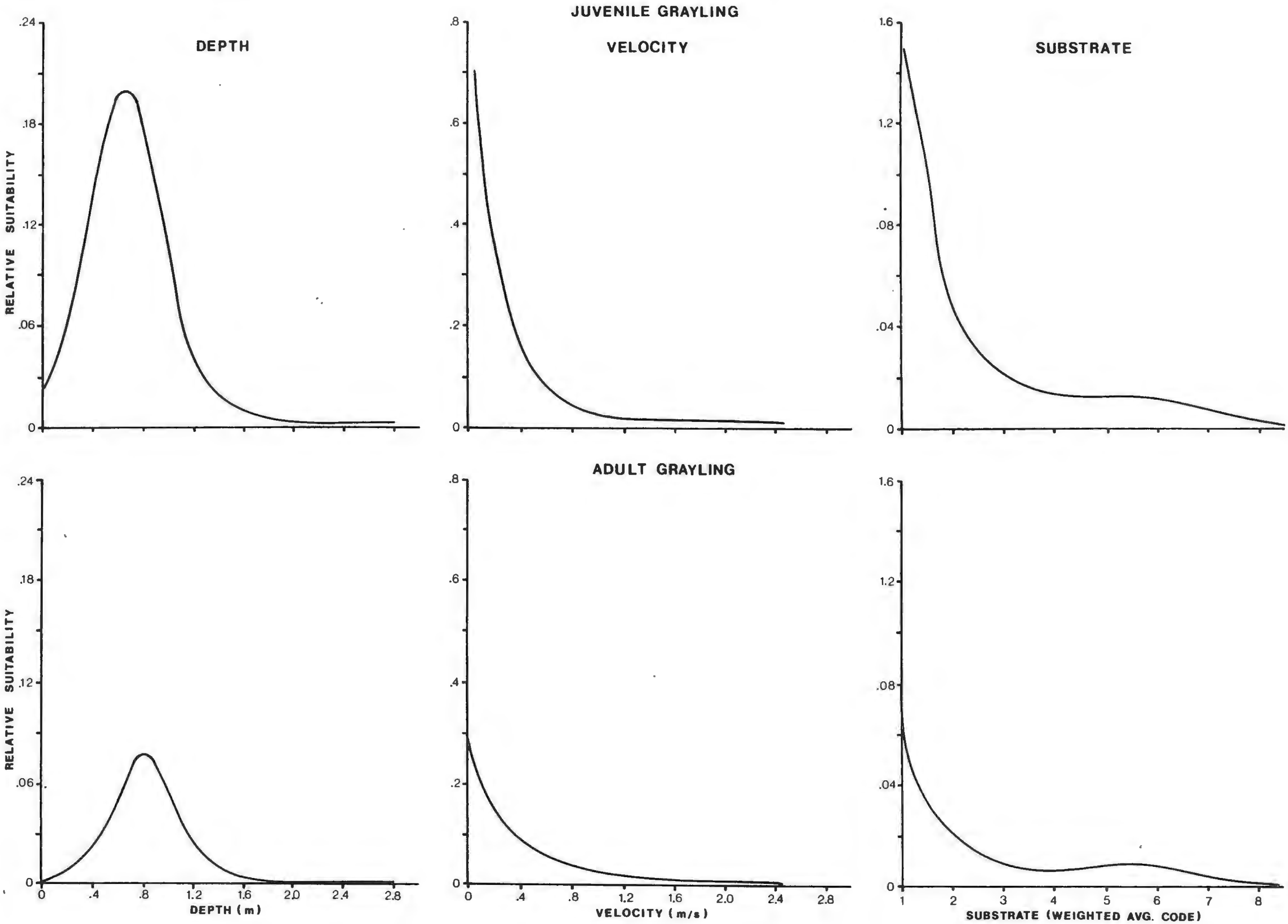
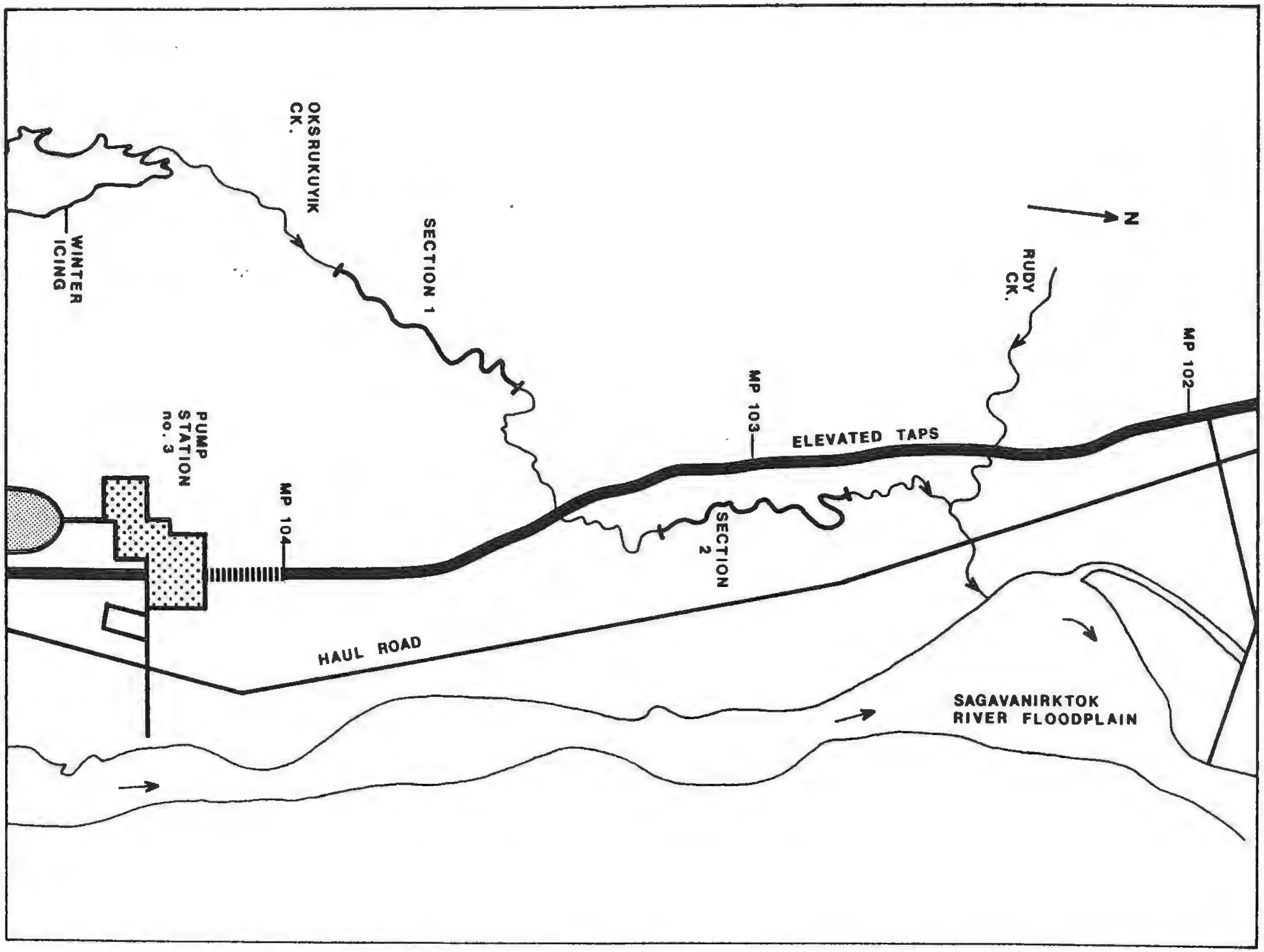

JUVENILE GRAYLING
DEPTH
VELOCITY
SUBSTRATE
RELATIVE SUITABILITY
ADULT GRAYLING
RELATIVE SUITABILITY
DEPTH (m)
VELOCITY (m/s)
SUBSTRATE (WEIGHTED AVG. CODE)

Figure 34 Sketch map of lower Oksrukuyik Creek between the winter icing and stream mouth. The locations of the haul road, the TAPS alignment, and two 1 km long fish density study sections (bracketed dark bars) are illustrated. Not to scale.



OKSRUKUYIK
CK.
WINTER
ICING
SECTION 1
PUMP
STATION
no. 3
MP 104
MP 103
ELEVATED TAPS
SECTION
2
RUDY
CK.
MP 102
N
HAUL ROAD
SAGAVANIRKTOK
RIVER FLOODPLAIN

Figure 35 Sketch map of Falcon Creek showing the locations of materials site MS-114A-5, the access road, Galbraith Airport, and two 100 m fish density study sections (bracketed dark bars). Not to scale.

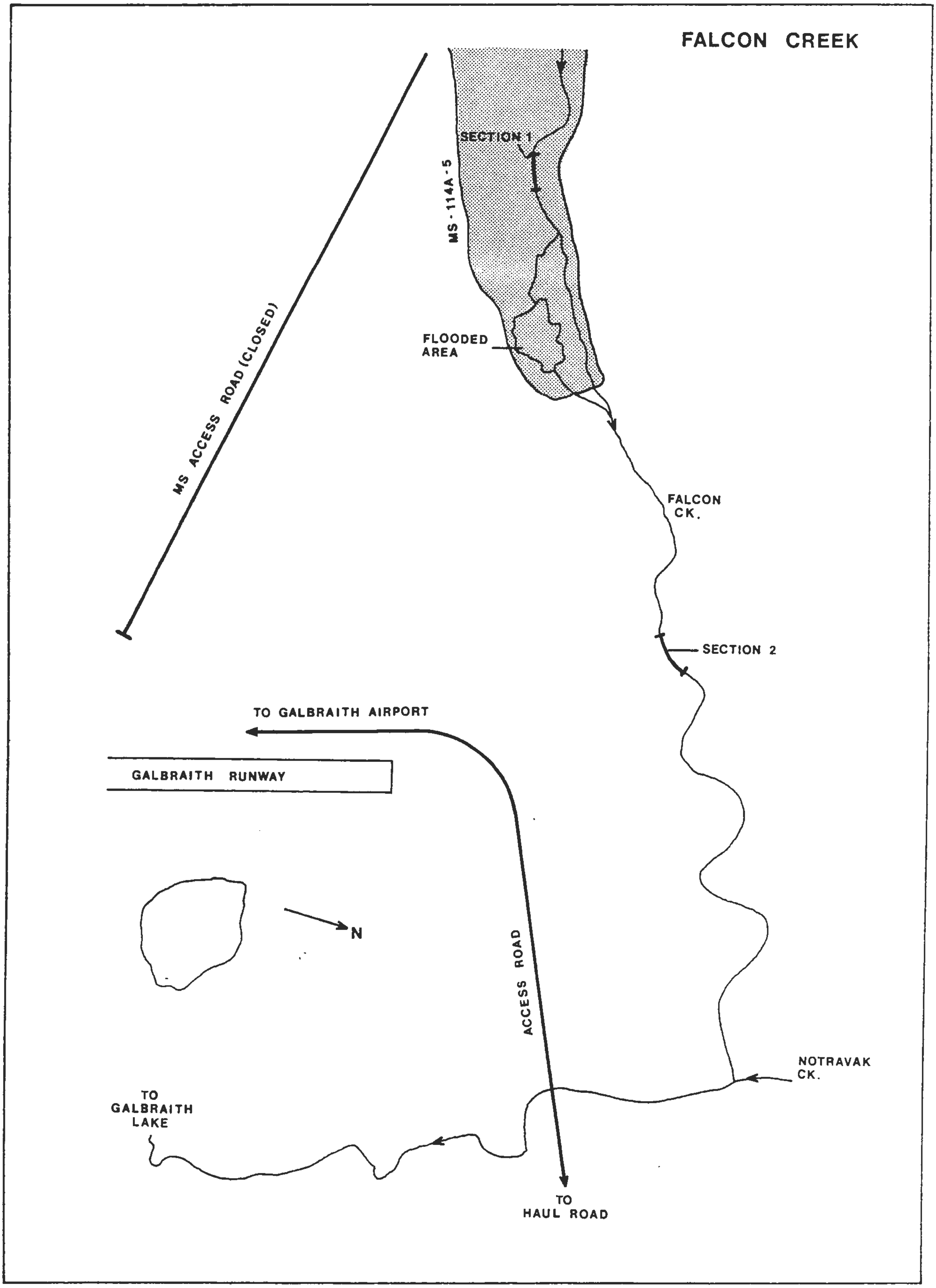

FALCON CREEK
SECTION 1
MS-114A-5
MS ACCESS ROAD (CLOSED)
FLOODED
AREA
FALCON
CK.
SECTION 2
TO GALBRAITH AIRPORT
GALBRAITH RUNWAY
N
ACCESS ROAD
NOTRAVAK
CK.
TO
GALBRAITH
LAKE
TO
HAUL ROAD

Figure 36 Depth, velocity, substrate composition, and gradient profiles for two study sections in Falcon Creek.

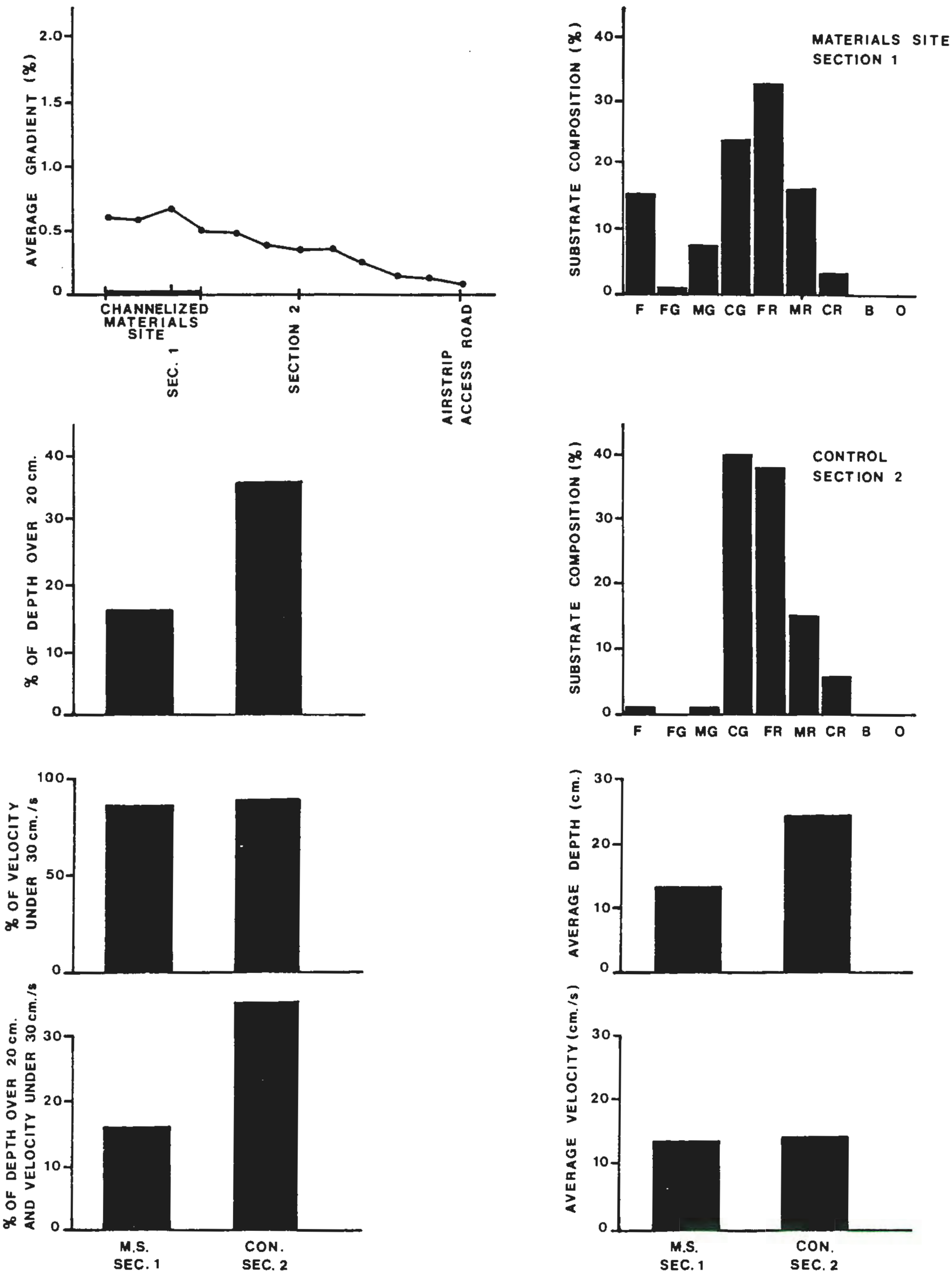
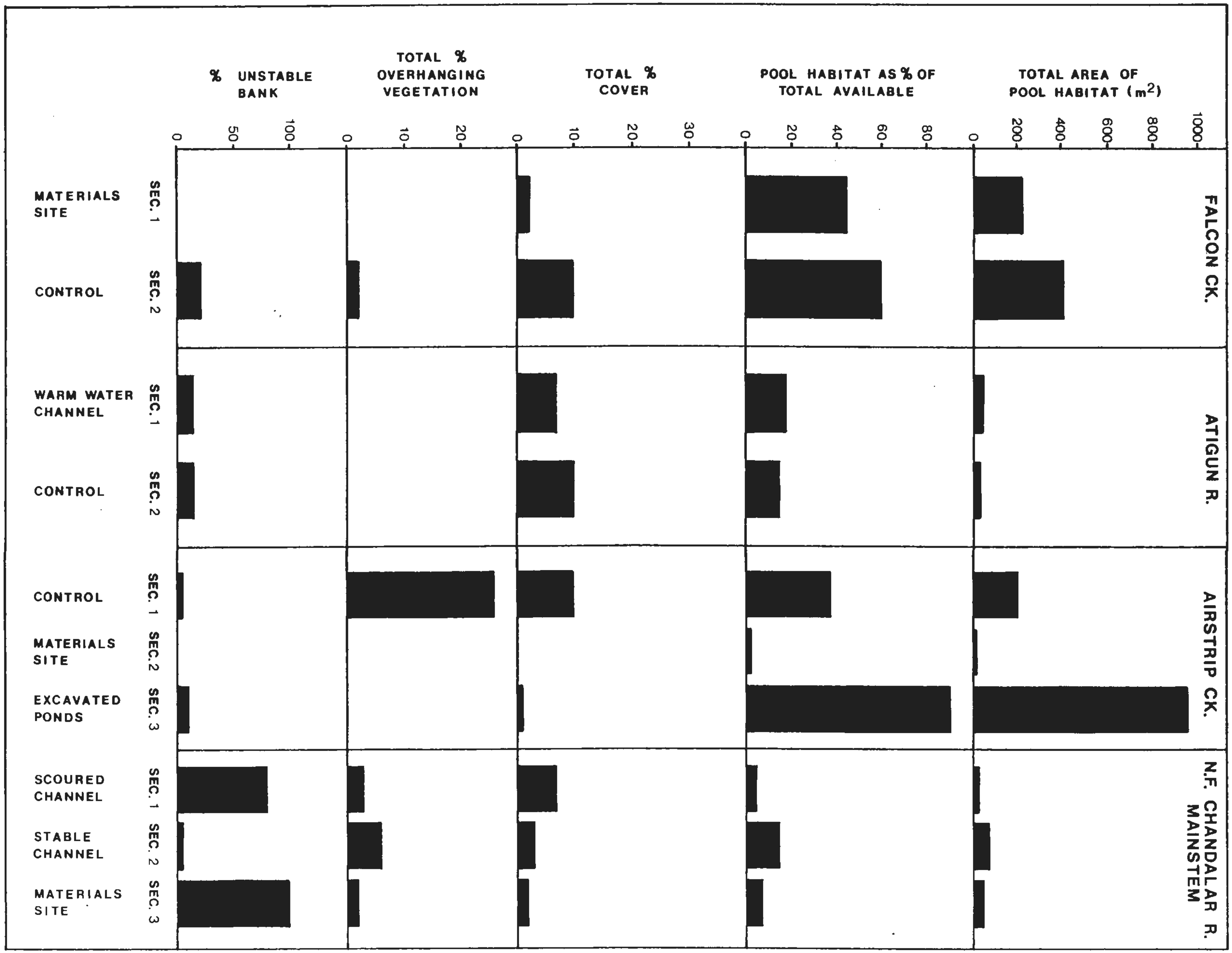
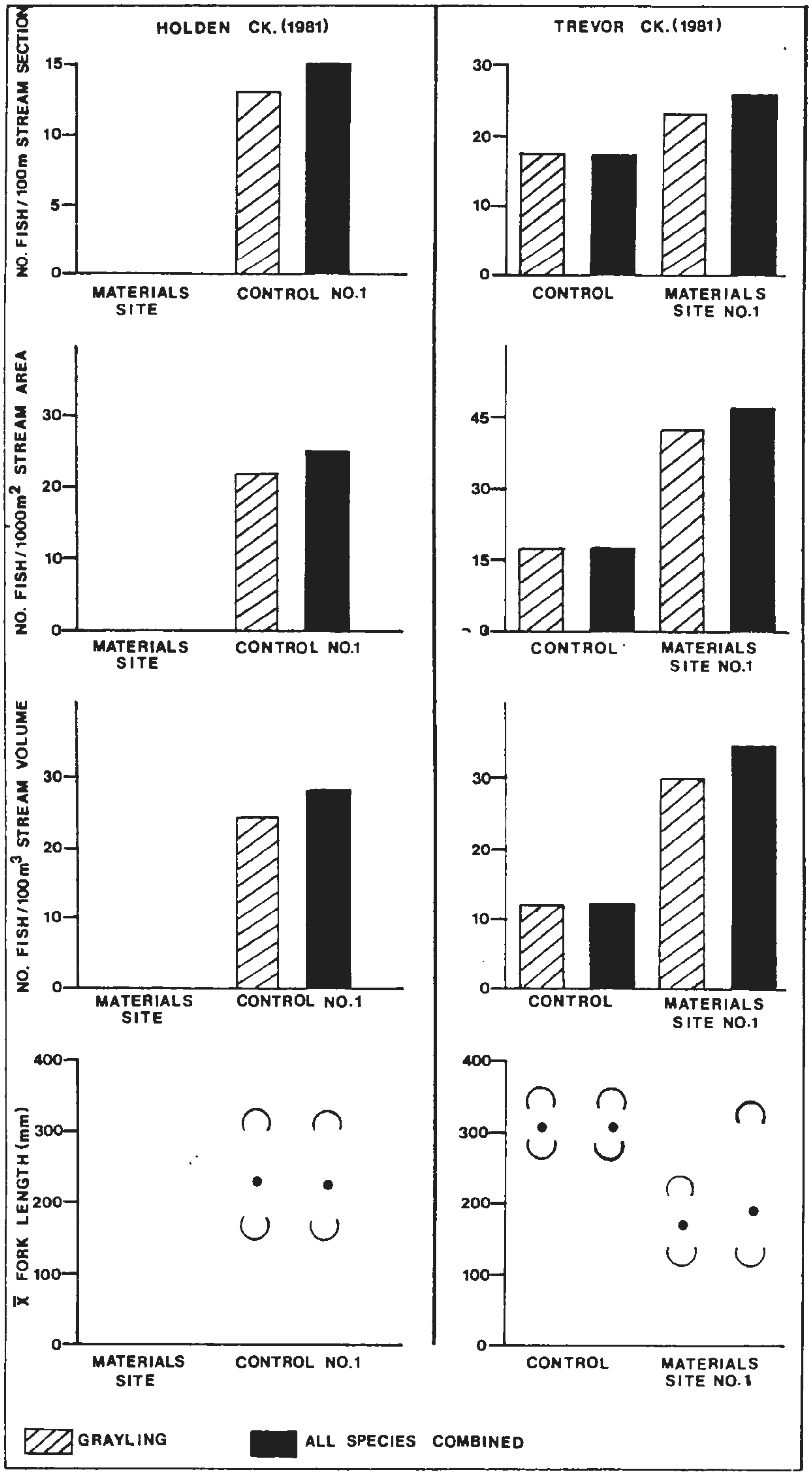

AVERAGE GRADIENT (%)
2.0
1.5
1.0
0.5
0
CHANNELIZED MATERIALS SITE
SEC. 1
SECTION 2
AIRSTRIP ACCESS ROAD
SUBSTRATE COMPOSITION (%)
MATERIALS SITE SECTION 1
40
30
20
10
0
F FG MG CG FR MR CR B O
% OF DEPTH OVER 20 cm.
SUBSTRATE COMPOSITION (%)
CONTROL SECTION 2
F FG MG CG FR MR CR B O
% OF VELOCITY UNDER 30 cm./s
100
50
0
AVERAGE DEPTH (cm.)
% OF DEPTH OVER 20 cm. AND VELOCITY UNDER 30 cm./s
AVERAGE VELOCITY (cm./s)
M.S. SEC. 1
CON. SEC. 2

Figure 37 Area of pool habitat, percent pool habitat, percent cover, percent overhanging vegetation, and percent unstable bank for study sections in Falcon Creek, the Atigun River, Airstrip Creek, and the North Fork Chandalar River mainstem.



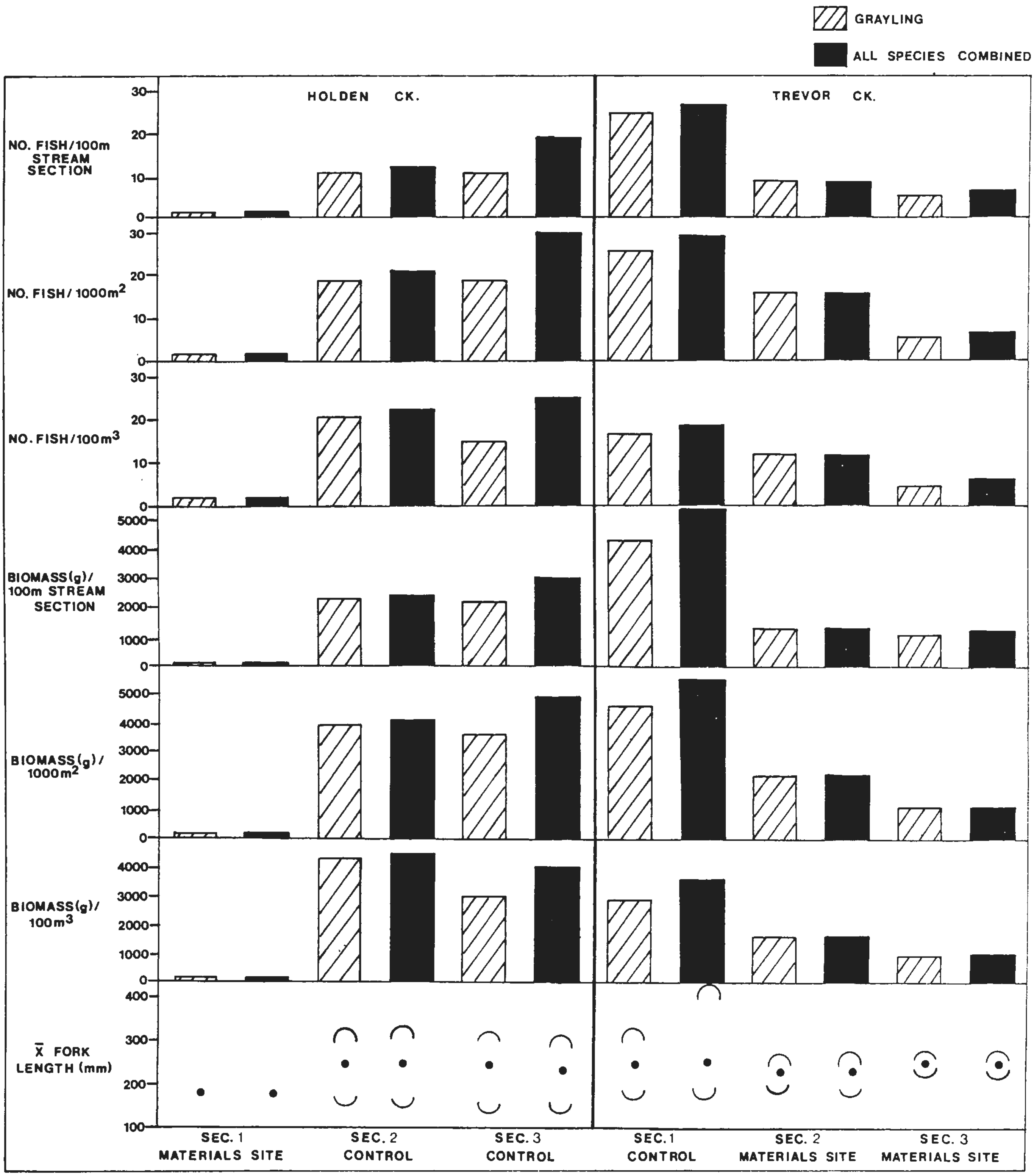
% UNSTABLE BANK
TOTAL % OVERHANGING VEGETATION
TOTAL % COVER
POOL HABITAT AS % OF TOTAL AVAILABLE
TOTAL AREA OF POOL HABITAT (m2)
0 50 100
0 10 20
0 10 20 30
0 20 40 60 80
0 200 400 600 800 1000
MATERIALS SITE
SEC. 1
CONTROL
SEC. 2
FALCON CK.
WARM WATER CHANNEL
SEC. 1
CONTROL
SEC. 2
ATIGUN R.
CONTROL
SEC. 1
MATERIALS SITE
SEC. 2
EXCAVATED PONDS
SEC. 3
AIRSTRIP CK.
SCOURED CHANNEL
SEC. 1
STABLE CHANNEL
SEC. 2
MATERIALS SITE
SEC. 3
N.F. CHANDALAR R. MAINSTEM

Figure 38 Density of Arctic grayling and all fish species combined expressed as numbers per unit stream length (100 m), unit stream area (1,000 m^2), and unit stream volume (100 m^3) in disturbed and control sections of Holden and Trevor creeks in July 1981. Mean fork length (mm) and the range of lengths (brackets) are shown for each study section.



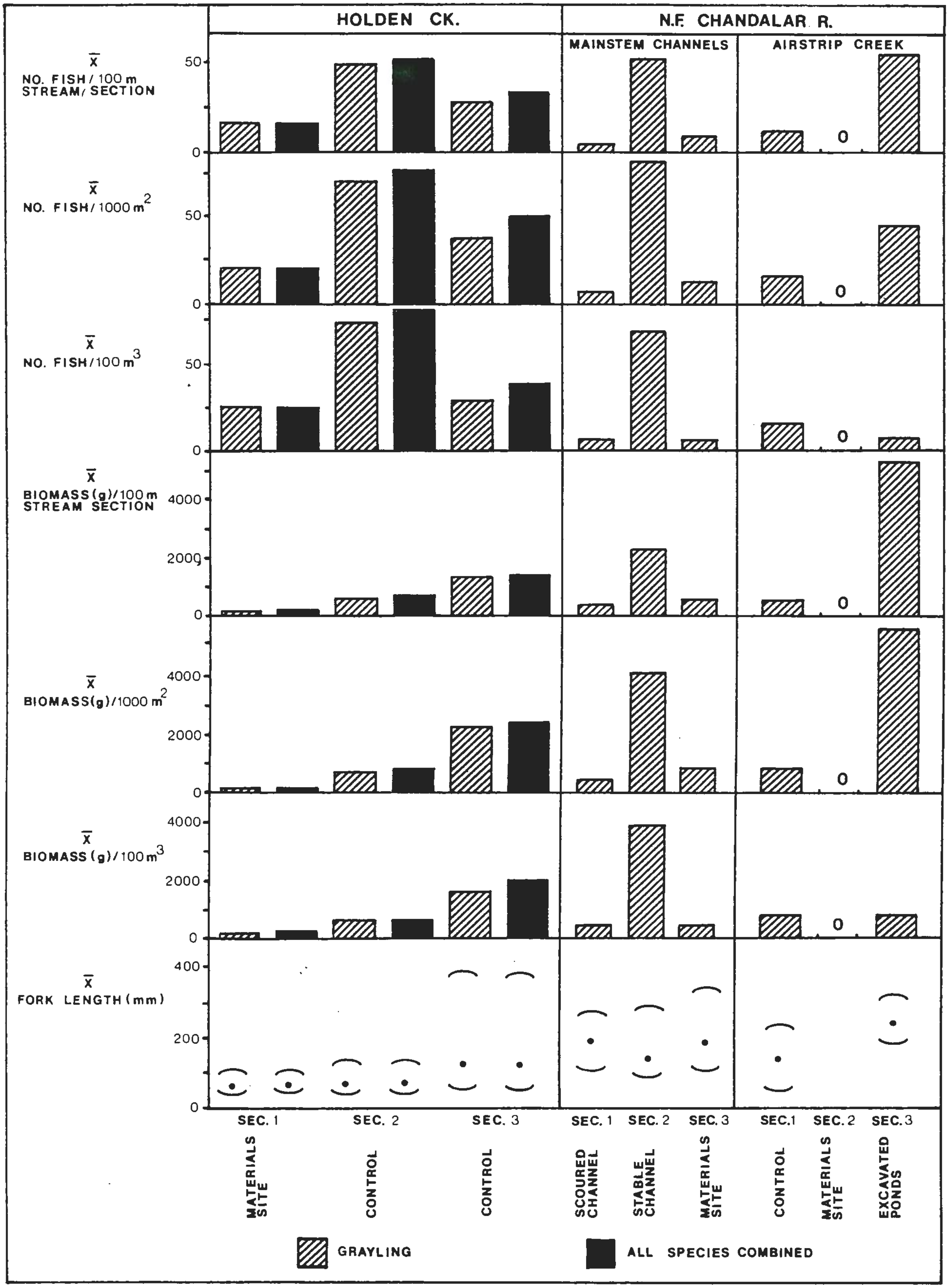
HOLDEN CK. (1981)
TREVOR CK. (1981)
NO. FISH / 100m STREAM SECTION
NO. FISH / 1000m2 STREAM AREA
NO. FISH / 100m3 STREAM VOLUME
X̄ FORK LENGTH (mm)
MATERIALS SITE
CONTROL NO.1
CONTROL
MATERIALS SITE NO.1
GRAYLING
ALL SPECIES COMBINED

Figure 39 Density and biomass (g) of Arctic grayling and all fish species combined expressed per unit of stream length (100 m), unit stream area (1,000 m^2), and unit stream volume (100 m^3) in disturbed and control sections of Holden and Trevor creeks in July 1982. Mean fork length (mm) and the range of lengths (bracketed) are shown for each study section.



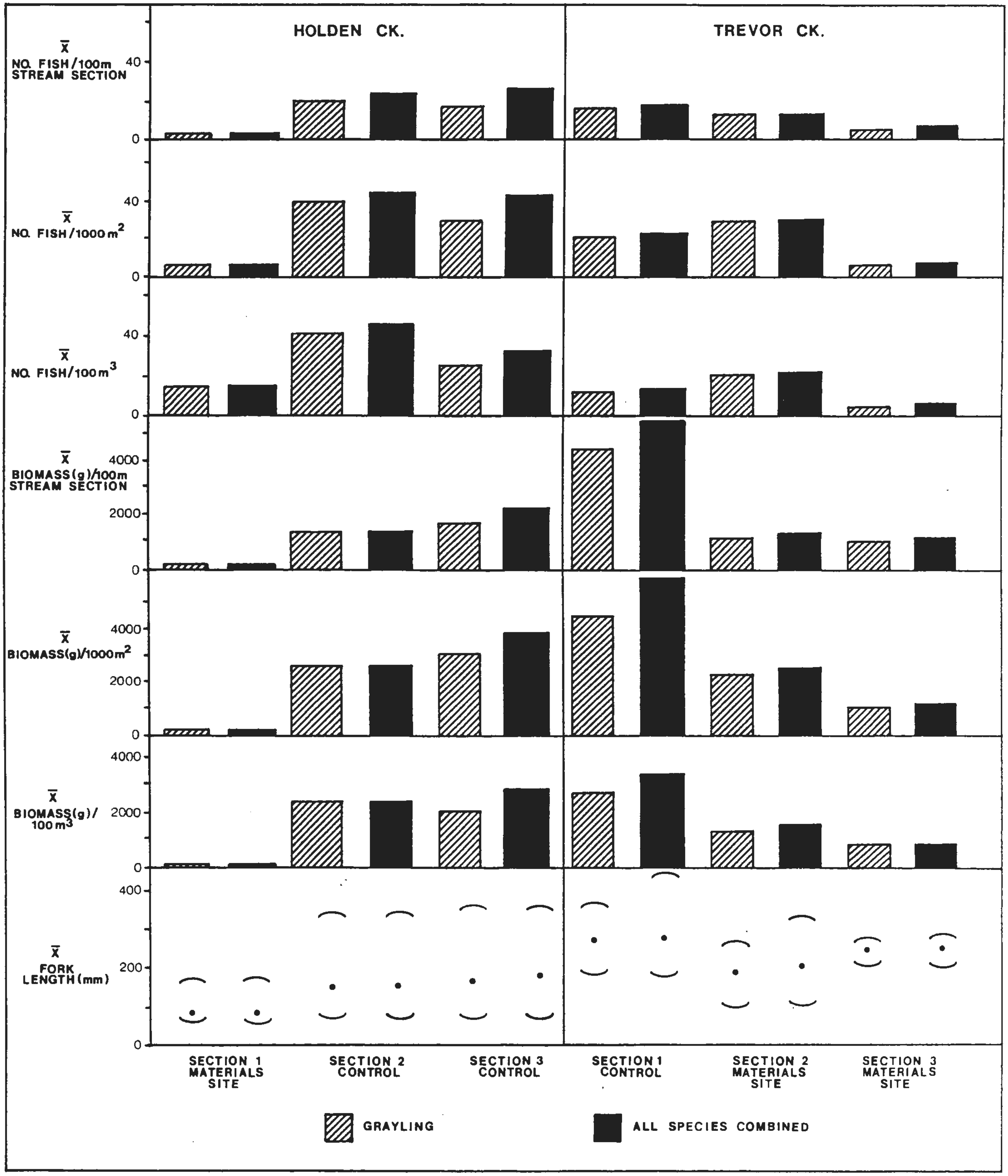
GRAYLING
ALL SPECIES COMBINED
HOLDEN CK.
TREVOR CK.
NO. FISH/100m STREAM SECTION
NO. FISH/1000m²
NO. FISH/100m³
BIOMASS(g)/100m STREAM SECTION
BIOMASS(g)/1000m²
BIOMASS(g)/100m³
X̄ FORK LENGTH (mm)
SEC. 1 MATERIALS SITE
SEC. 2 CONTROL
SEC. 3 CONTROL
SEC. 1 CONTROL
SEC. 2 MATERIALS SITE
SEC. 3 MATERIALS SITE

Figure 40 Density and biomass (g) of Arctic grayling and all fish species combined expressed per unit of stream length (100 m), unit stream area (1,000 m^2), and unit stream volume (100 m^3) in disturbed and control sections of Holden Creek, Airstrip Creek, and the North Fork Chandalar River mainstem in July 1983. Mean fork length (mm) and the range of lengths (bracketed) are shown for each study section.



HOLDEN CK.
N.F. CHANDALAR R.
MAINSTEM CHANNELS
AIRSTRIP CREEK
X̄ NO. FISH / 100 m STREAM / SECTION
X̄ NO. FISH / 1000 m2
X̄ NO. FISH / 100 m3
X̄ BIOMASS (g) / 100 m STREAM SECTION
X̄ BIOMASS (g) / 1000 m2
X̄ BIOMASS (g) / 100 m3
X̄ FORK LENGTH (mm)
0
50
2000
4000
200
400
SEC. 1
SEC. 2
SEC. 3
MATERIALS SITE
CONTROL
CONTROL
SCOURED CHANNEL
STABLE CHANNEL
MATERIALS SITE
CONTROL
MATERIALS SITE
EXCAVATED PONDS
GRAYLING
ALL SPECIES COMBINED

Figure 41 Density and biomass (g) of Arctic grayling and all fish species combined expressed per unit of stream length (100 m), unit stream area (1,000 m^2), and unit stream volume (100 m^3) in disturbed and control sections of Holden Creek (1981 through 1983) and Trevor Creek (1981 and 1982). Mean fork length (mm) and the range of lengths (bracketed) are shown for each study section.



HOLDEN CK.
TREVOR CK.
X̄ NO. FISH/100m STREAM SECTION
X̄ NO. FISH/1000 m2
X̄ NO. FISH/100 m3
X̄ BIOMASS(g)/100m STREAM SECTION
X̄ BIOMASS(g)/1000m2
X̄ BIOMASS(g)/ 100 m3
X̄ FORK LENGTH (mm)
0
40
2000
4000
200
400
SECTION 1 MATERIALS SITE
SECTION 2 CONTROL
SECTION 3 CONTROL
SECTION 1 CONTROL
SECTION 2 MATERIALS SITE
SECTION 3 MATERIALS SITE
GRAYLING
ALL SPECIES COMBINED

Figure 42 Substrate composition, depth, velocity, and gradient profiles for three study sections in Holden Creek.

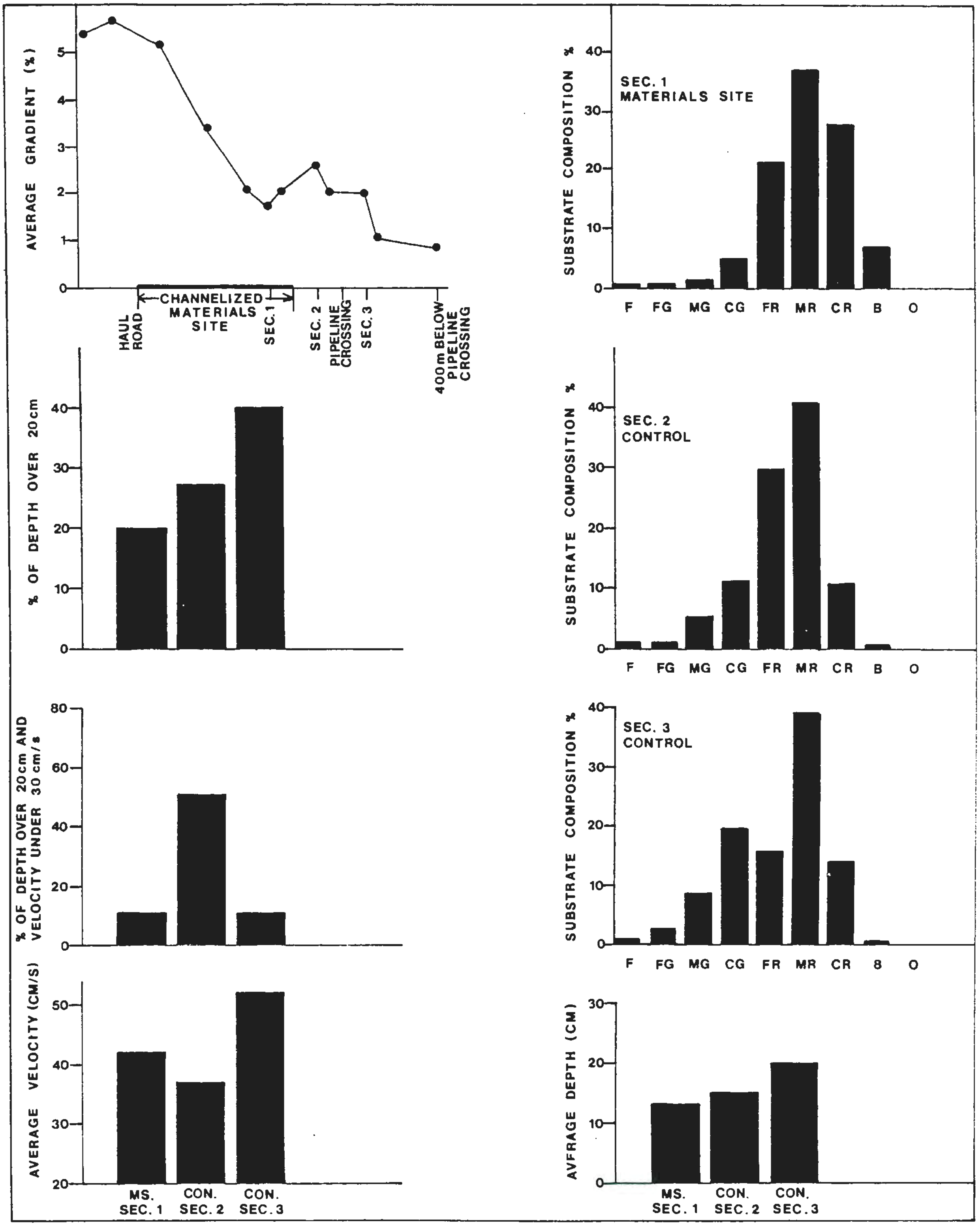
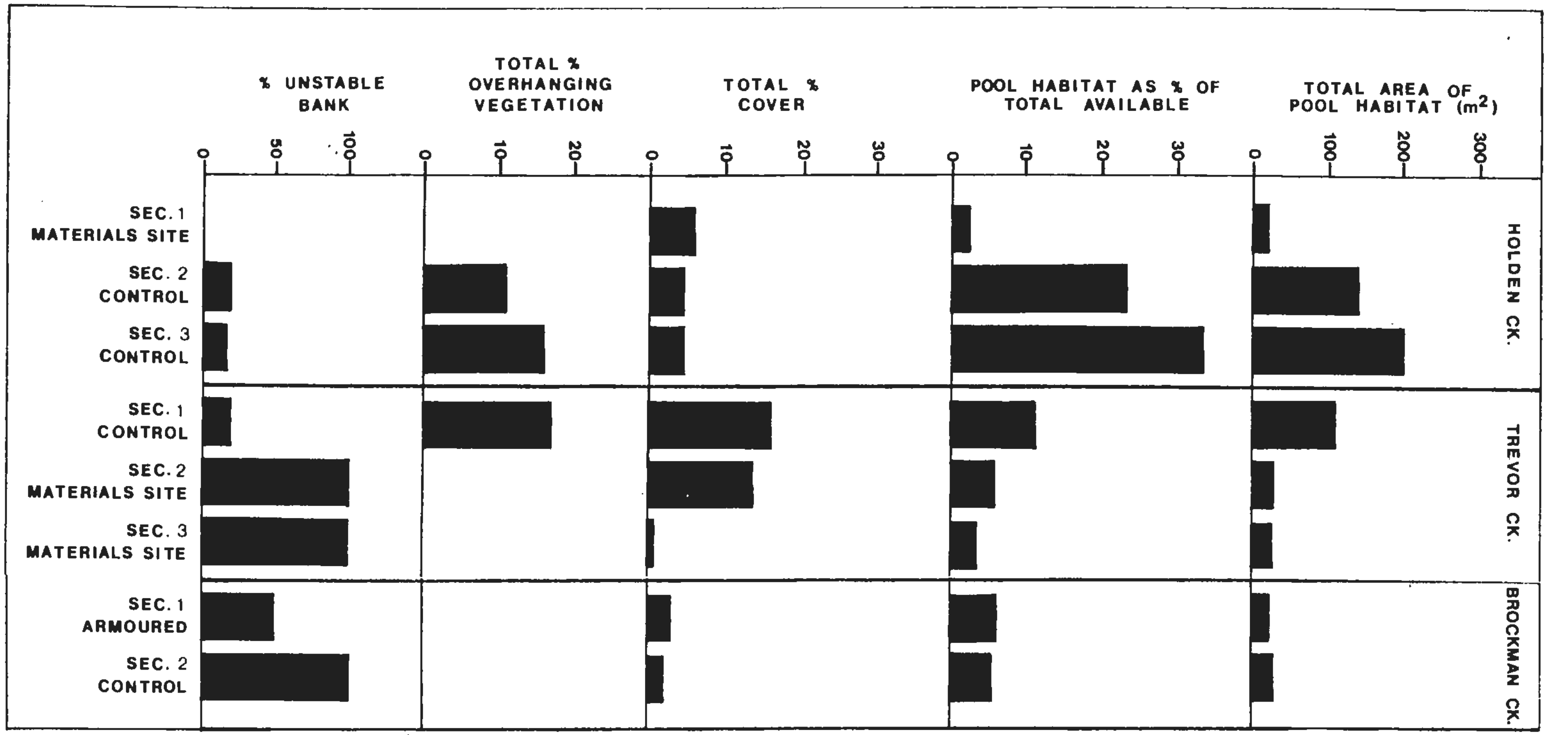

AVERAGE GRADIENT (%)
CHANNELIZED MATERIALS SITE
HAUL ROAD
SEC. 1
SEC. 2
PIPELINE CROSSING
SEC. 3
400 m BELOW PIPELINE CROSSING
SUBSTRATE COMPOSITION %
SEC. 1 MATERIALS SITE
SEC. 2 CONTROL
SEC. 3 CONTROL
F FG MG CG FR MR CR B O
% OF DEPTH OVER 20cm
% OF DEPTH OVER 20cm AND VELOCITY UNDER 30 cm/s
AVERAGE VELOCITY (CM/S)
AVERAGE DEPTH (CM)
MS. SEC. 1
CON. SEC. 2
CON. SEC. 3

Figure 43 Area of pool habitat, percent pool habitat, percent cover, percent overhanging vegetation, and percent unstable bank for study sections in Holden Creek, Trevor Creek, and Brockman Creek.



% UNSTABLE BANK
TOTAL % OVERHANGING VEGETATION
TOTAL % COVER
POOL HABITAT AS % OF TOTAL AVAILABLE
TOTAL AREA OF POOL HABITAT (m2)
0
50
100
0
10
20
0
10
20
30
0
10
20
30
0
100
200
300
SEC. 1 MATERIALS SITE
SEC. 2 CONTROL
SEC. 3 CONTROL
SEC. 1 CONTROL
SEC. 2 MATERIALS SITE
SEC. 3 MATERIALS SITE
SEC. 1 ARMOURED
SEC. 2 CONTROL
HOLDEN CK.
TREVOR CK.
BROCKMAN CK.

Figure 44 Substrate composition, depth, velocity, and gradient profile for three study sections in Trevor Creek.

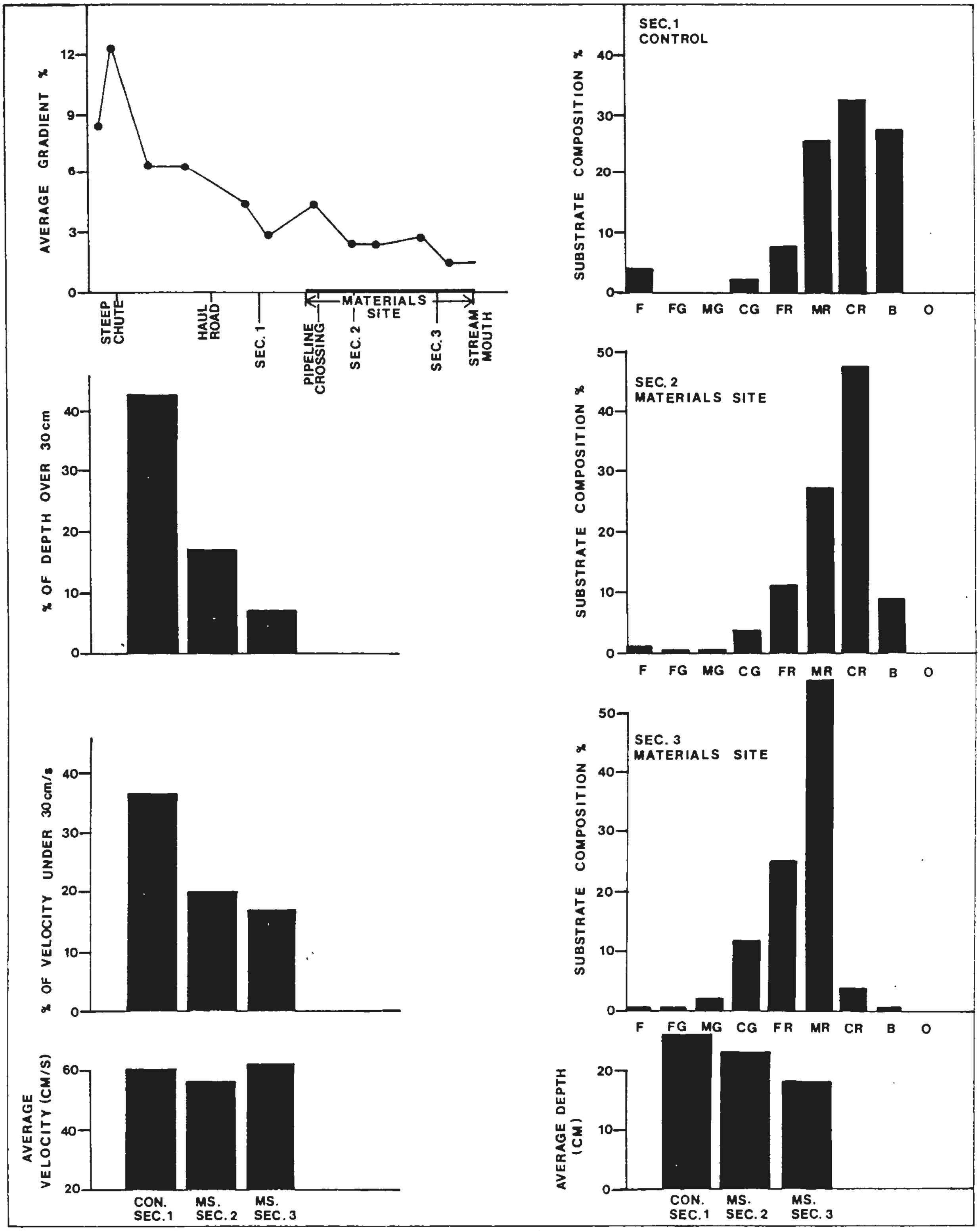
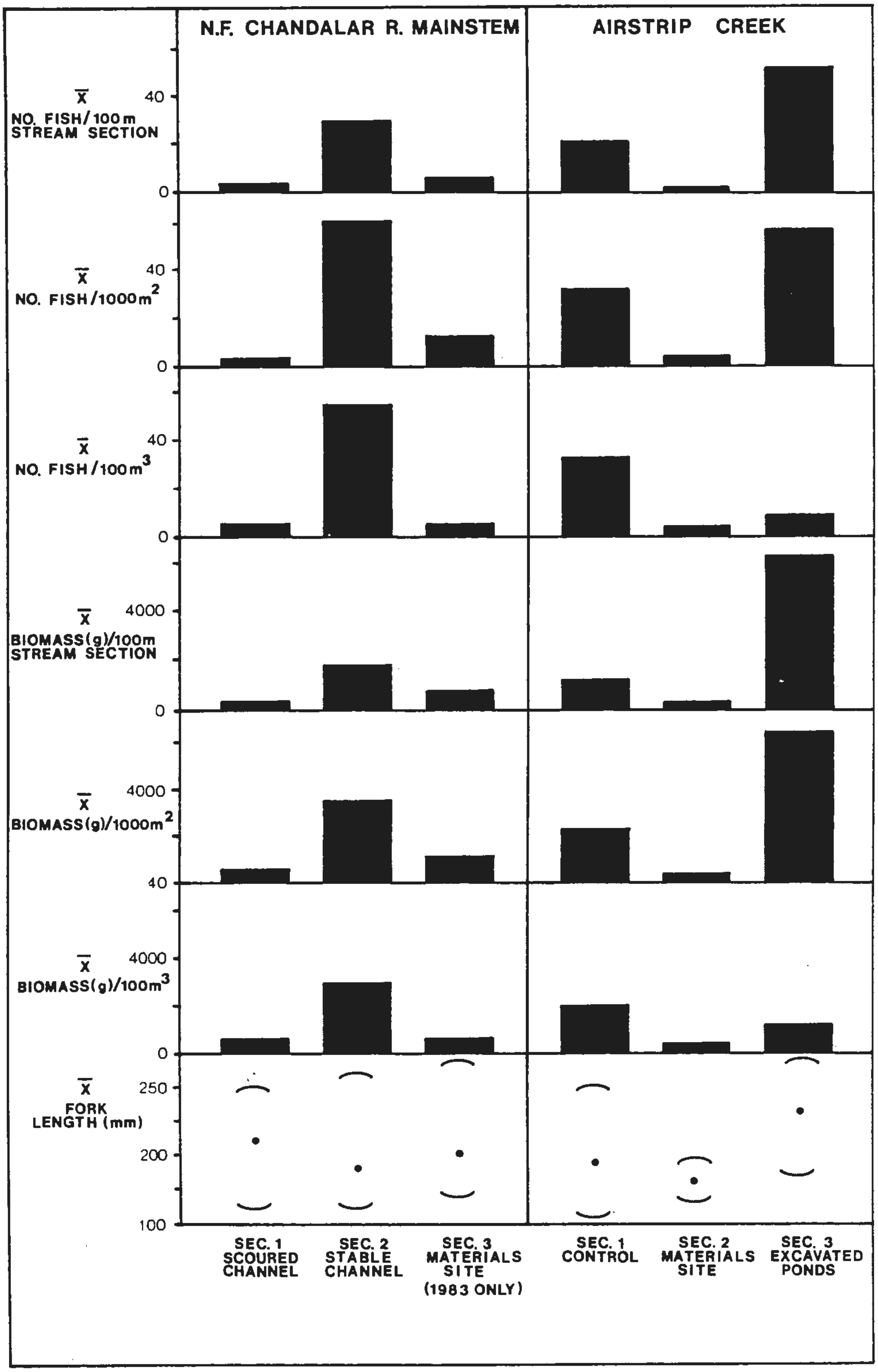

AVERAGE GRADIENT %
STEEP CHUTE
HAUL ROAD
SEC. 1
PIPELINE CROSSING
MATERIALS SITE
SEC. 2
SEC. 3
STREAM MOUTH
SEC. 1
CONTROL
SUBSTRATE COMPOSITION %
F FG MG CG FR MR CR B O
% OF DEPTH OVER 30 cm
SEC. 2
MATERIALS SITE
% OF VELOCITY UNDER 30 cm/s
SEC. 3
MATERIALS SITE
AVERAGE VELOCITY (CM/S)
CON. SEC. 1
MS. SEC. 2
MS. SEC. 3
AVERAGE DEPTH (CM)

Figure 45 Density and Biomass (g) of Arctic grayling expressed per unit stream length (100 m), unit stream area (1,000 m^2), and unit stream volume (100 m^3) in disturbed and control sections of the North Fork Chandalar River mainstem and Airstrip Creek in July 1982. Mean fork length (mm) and the range of lengths (bracketed) are shown for each study section.



N.F. CHANDALAR R. MAINSTEM
AIRSTRIP CREEK
X̄ NO. FISH/100 m STREAM SECTION
X̄ NO. FISH/1000m²
X̄ NO. FISH/100m³
X̄ BIOMASS(g)/100m STREAM SECTION
X̄ BIOMASS(g)/1000m²
X̄ BIOMASS(g)/100m³
X̄ FORK LENGTH (mm)
0
40
4000
100
200
250
SEC. 1 SCOURED CHANNEL
SEC. 2 STABLE CHANNEL
SEC. 3 MATERIALS SITE (1983 ONLY)
SEC. 1 CONTROL
SEC. 2 MATERIALS SITE
SEC. 3 EXCAVATED PONDS

Figure 46 Average density and biomass (g) of Arctic grayling expressed per unit of stream length (100 m), unit stream area (1,000 m^2), and unit stream volume (100 m^3) om disturbed and control sections of the North Fork Chandalar River mainstem and Airstrip Creek, a small tributary stream (1981 and 1983). Mean fork length (mm) and the range of lengths (brackets) are shown for each study section.

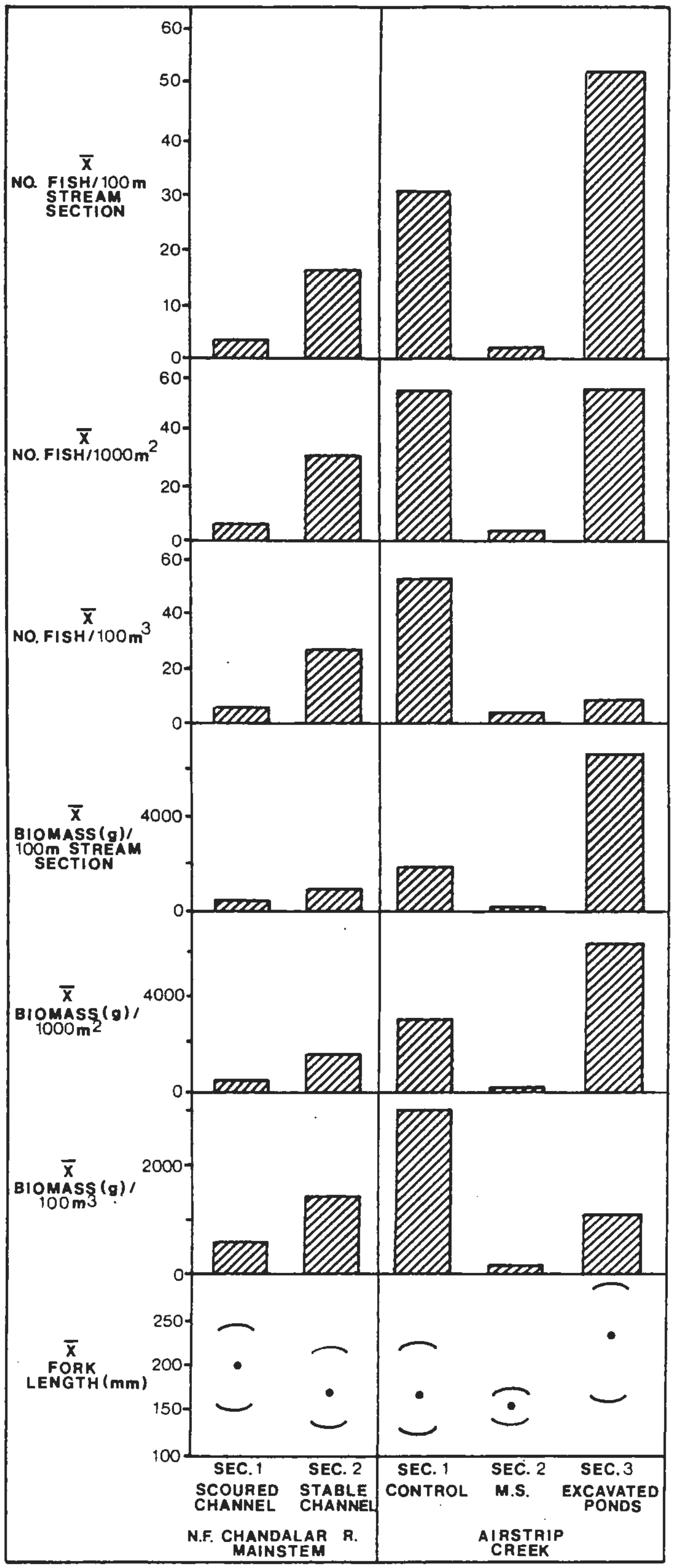

X̄ NO. FISH/100m STREAM SECTION
X̄ NO. FISH/1000m²
X̄ NO. FISH/100m³
X̄ BIOMASS(g)/ 100m STREAM SECTION
X̄ BIOMASS(g)/ 1000m²
X̄ BIOMASS(g)/ 100m³
X̄ FORK LENGTH (mm)
0
10
20
30
40
50
60
4000
2000
100
150
200
250
SEC. 1
SCOURED CHANNEL
SEC. 2
STABLE CHANNEL
SEC. 1
CONTROL
SEC. 2
M.S.
SEC. 3
EXCAVATED PONDS
N.F. CHANDALAR R. MAINSTEM
AIRSTRIP CREEK

Figure 47 Substrate composition, depth, velocity, and gradient profiles for two study sections in Airstrip Creek, a tributary of the North Fork Chandalar River. MS = materials site; CON = control; SEC = section.

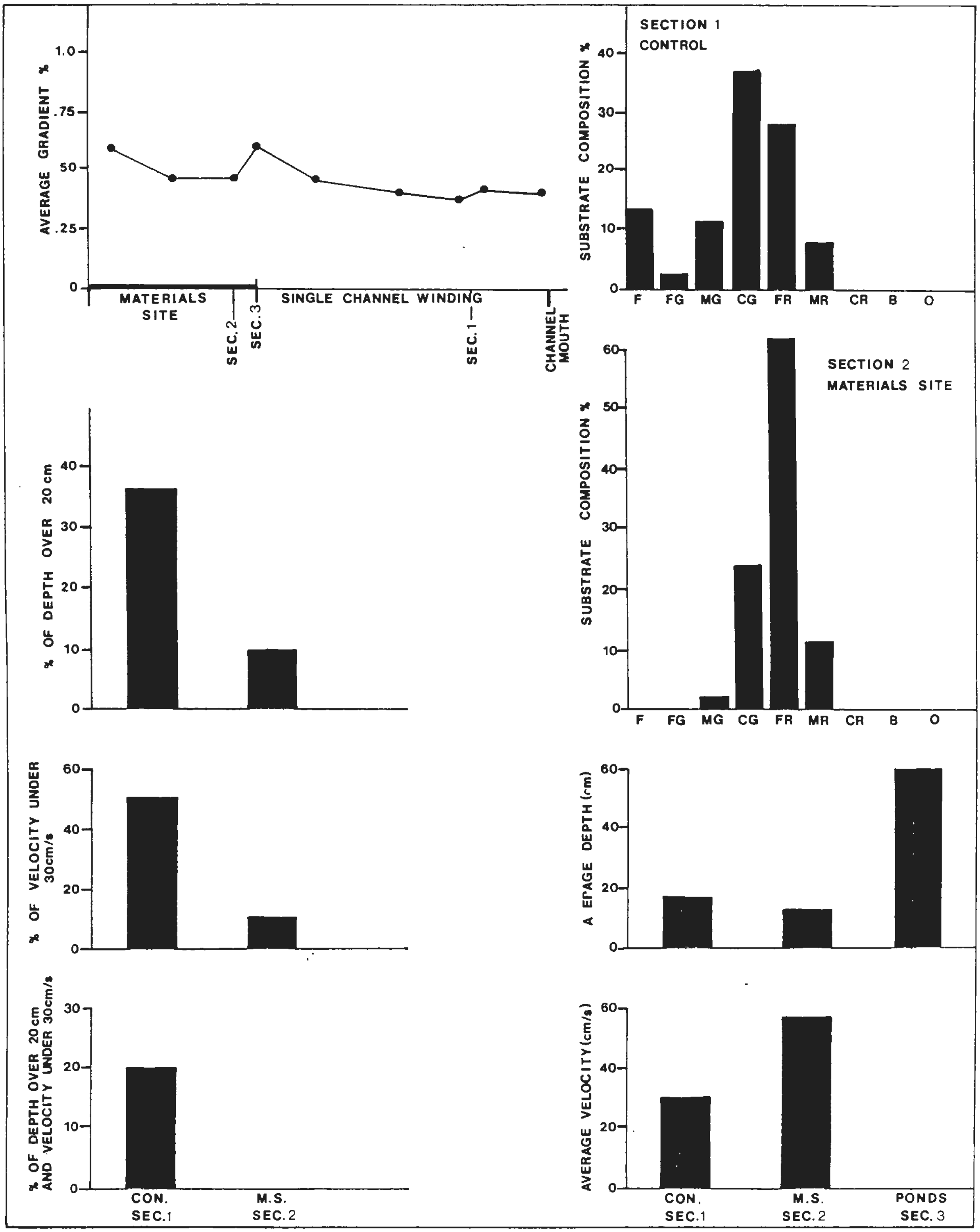
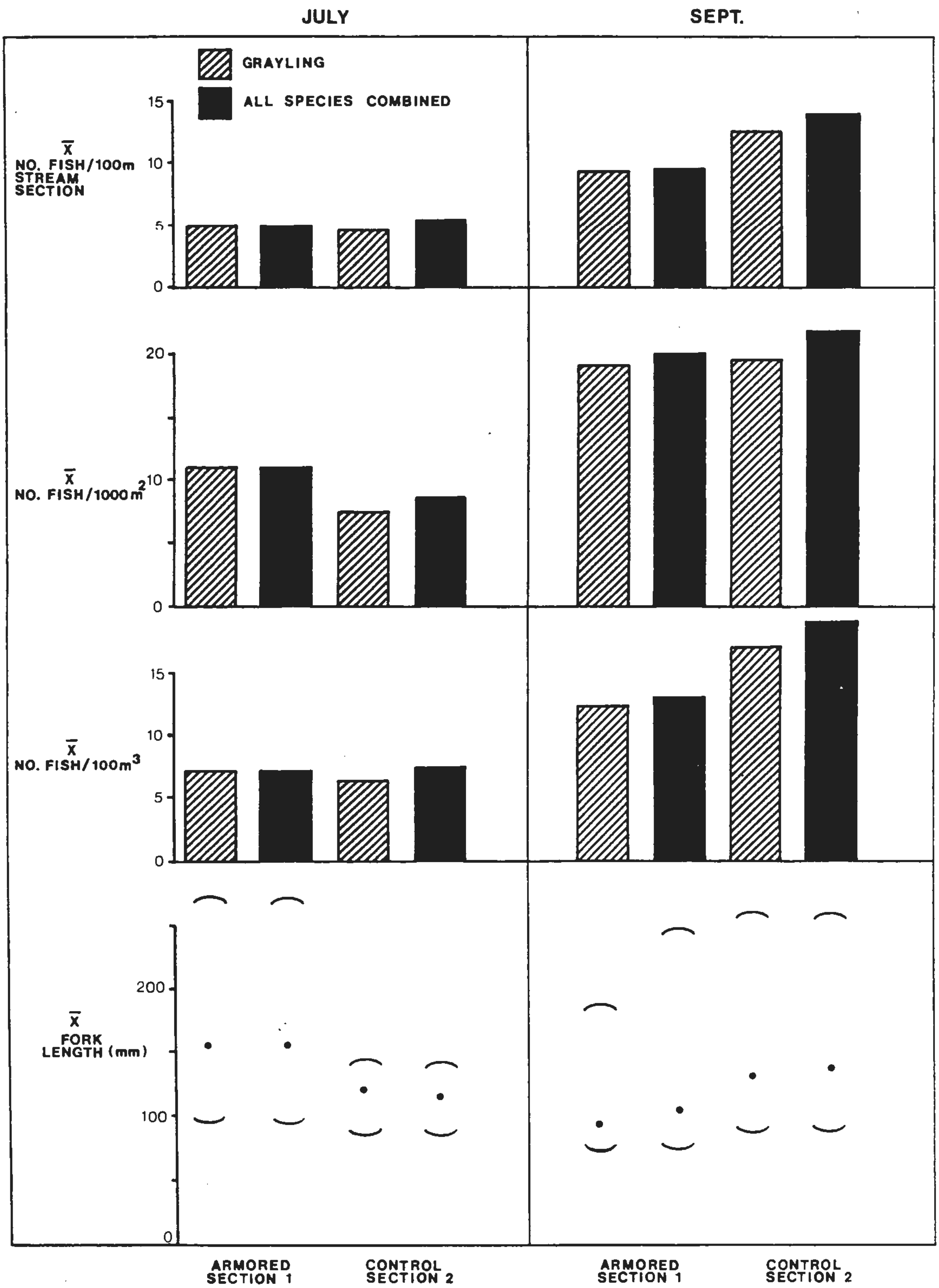
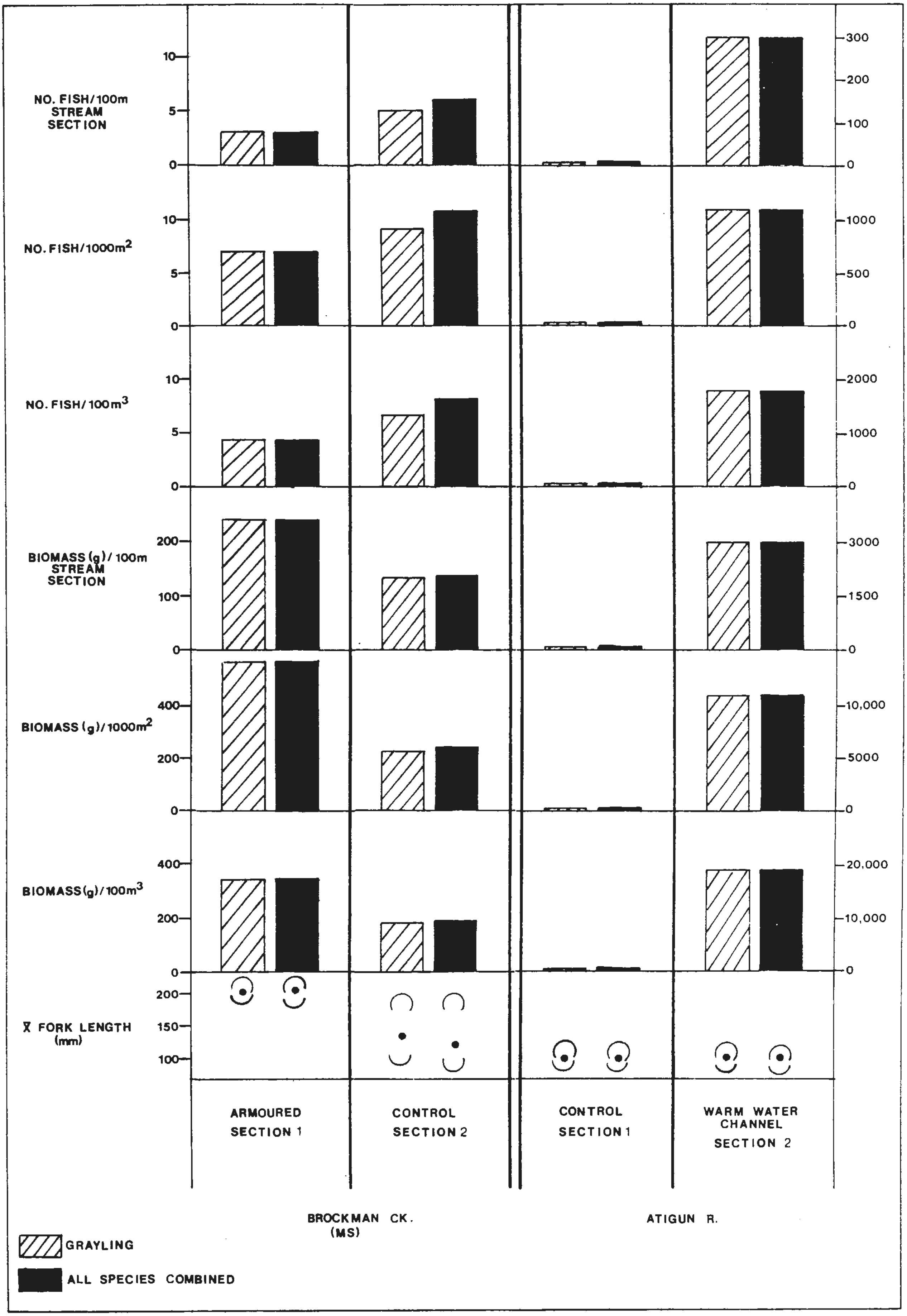

AVERAGE GRADIENT %
1.0
.75
.50
.25
0
MATERIALS SITE
SINGLE CHANNEL WINDING
SEC.2
SEC.3
SEC.1
CHANNEL MOUTH
SECTION 1
CONTROL
SUBSTRATE COMPOSITION %
F FG MG CG FR MR CR B O
SECTION 2
MATERIALS SITE
% OF DEPTH OVER 20 cm
% OF VELOCITY UNDER 30cm/s
% OF DEPTH OVER 20 cm AND VELOCITY UNDER 30cm/s
CON. SEC.1
M.S. SEC.2
A ERAGE DEPTH (cm)
AVERAGE VELOCITY (cm/s)
PONDS SEC. 3

Figure 48 Density of Arctic grayling and all fish species combined expressed as numbers per unit stream length (100 m), unit stream area (1,000 m^2), and unit stream volume (100 m^3) in disturbed and control sections of Brockman Creek in July and September 1981. Mean fork length (mm) and the range of lengths (brackets) are shown for each study section.



JULY
SEPT.
GRAYLING
ALL SPECIES COMBINED
X̄ NO. FISH/100m STREAM SECTION
X̄ NO. FISH/1000m²
X̄ NO. FISH/100m³
X̄ FORK LENGTH (mm)
0
5
10
15
20
100
200
ARMORED SECTION 1
CONTROL SECTION 2
ARMORED SECTION 1
CONTROL SECTION 2

Figure 49 Density and biomass (g) of Arctic grayling and all fish species combined expressed per unit stream length (100 m), unit stream area (1,000 m^2), and unit stream volume (100 m^3) in disturbed and control sections of Brockman Creek and the Atigun River in 1982. Mean fork length (mm) and the range of lengths (brackets) are shown for each study section. MS = materials site.



NO. FISH/100m STREAM SECTION
NO. FISH/1000m^2
NO. FISH/100m^3
BIOMASS (g)/100m STREAM SECTION
BIOMASS (g)/1000m^2
BIOMASS(g)/100m^3
$\bar{X}$ FORK LENGTH (mm)
0
5
10
100
200
400
150
300
500
1000
2000
1500
3000
5000
10,000
20,000
ARMOURED SECTION 1
CONTROL SECTION 2
CONTROL SECTION 1
WARM WATER CHANNEL SECTION 2
BROCKMAN CK. (MS)
ATIGUN R.
GRAYLING
ALL SPECIES COMBINED