[redacted]

# AQUATIC ENVIRONMENTS INCORPORATED

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

VOLUME I

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 PLATES

# 1.0 INTRODUCTION

During the years 1981, 1982, and 1983, Aquatic Environments Incorporated conducted a series of studies of aquatic environments and fish populations along the Trans Alaska Pipeline System (TAPS) north of the Yukon River. The report of these studies is presented in four volumes, of which this is Volume I. 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. |

The purpose of the study, which was commissioned by Alyeska Pipeline Service Company, was to document the present status of fish populations in the study area, to examine their responses 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 several years.

A preliminary survey of the literature and discussions with individuals knowledgeable about the pipeline and its effects on the aquatic environment revealed that most concerns centered on locations inside the Arctic Circle. For this reason, studies conducted by Aquatic Environments Incorporated were concentrated on streams located within the Northern District, and emphasized the most important concerns identified to date--that is, those concerns which have the greatest potential to affect regional populations of fish, cause long-term modification of fish habitat, or cause persistent long-term problems at a single location.

Where possible, this report references pre-construction baseline studies and the observations of regulatory agencies made during the construction period; however, much of the available information from existing sources is anecdotal in nature, and does not provide the data necessary for temporal comparisons with existing benthic invertebrate and fish populations in the corridor. To generate the information required for comparisons of disturbed and undisturbed habitats, the present study made use of spatial controls, which were established in relatively undisturbed areas of nearby stream sections.

Many of the concerns addressed during the construction period involved short-term problems (eg. sedimentation, fuel spills, instream equipment operation) which are much less of a concern now that TAPS is in operation. While our study sought to provide an overview of these concerns, emphasis was placed on the effects of long-term habitat modification, particularly large-scale modification associated with materials sites in active streambeds. Since this topic was addressed to a limited extent in earlier studies (Woodward Clyde Consultants 1980a, 1980b; Elliott 1982), our research was designed to complement that done previously. It was the overall goal of the study to obtain sufficient information on the habitat requirements of the three most common fish species (Arctic grayling, round whitefish, and

Arctic char) that the effects of habitat modifications on populations of these species could be assessed quantitatively.

The study was conducted in three parts. The first part was a Review of Existing Information, including both published and unpublished literature, and interviews with over 100 individuals knowledgeable about the construction process and the effects of the project on aquatic environments. The second part was a General Survey of Selected Streams, and was designed to provide an overall assessment of the status of stream habitats and fish populations north of the Yukon River. Most of the General Survey was conducted in 1981, but numerous incidental observations made during 1982 and 1983 have been included. The third part of the study, by far the largest and most important component, consisted of Detailed Studies of Representative Stream in the Northern District. During this part of the study, a dozen streams were studied intensively over the course of the three-year study period, enabling comparison among years of the effects of different weather conditions and variations in biological parameters.

Because they were designed to address concerns identified during the Review of Existing Information and the General Survey, 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).

In the following sections, an overview of the most important results of these studies is presented. Study results are presented in more detail in Volume II.

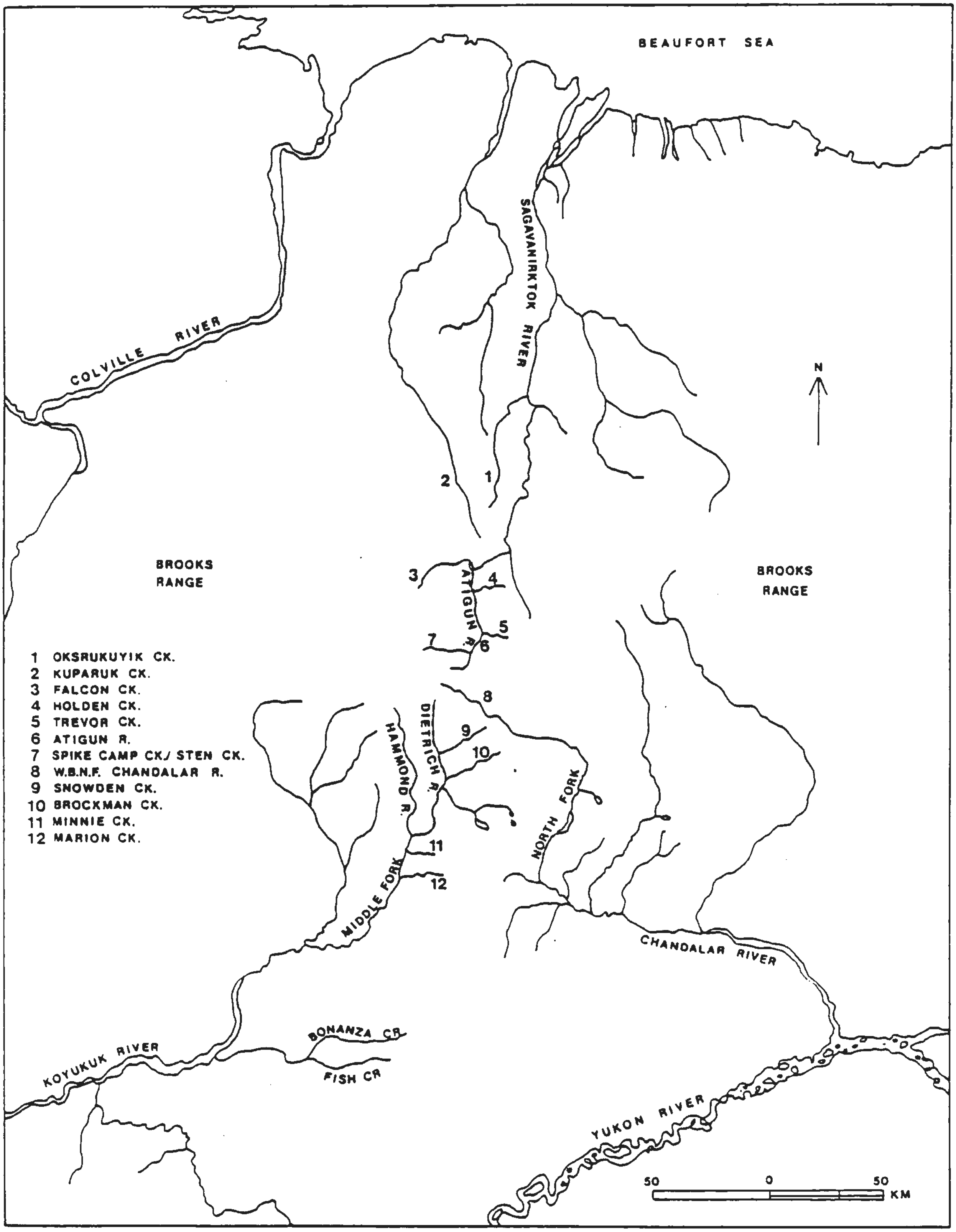
## 2.0 THE TAPS STUDY AREA

The TAPS Study Area was located within the Northern District, and extended from Prudhoe Bay to the Yukon River, an area where the TAPS right-of-way crosses more than 400 streams and intermittent watercourses (Figure 1). Many of these waterbodies support substantial migrating populations of Arctic grayling (Plate 1), the most abundant species in the area, and smaller numbers of Arctic char and round whitefish.

In this region, the pipeline route generally parallels portions of the Sagavanirktok, Atigun, North Fork Chandalar, Dietrich, and Middle Fork Koyukuk rivers, and is buried in the floodplains of each of these streams for considerable distances. In these areas, stream training structures (spur dykes) have been used to promote hydraulic stability and prevent channel migration over the buried pipeline. At those locations where the pipeline crosses a river or a stream, the pipeline has been either elevated or buried. Most of these crossings are overhead crossings, which were installed during the winter months when streams were dry or frozen to the bottom, and consequently had little effect on the instream environment.

Within the TAPS Study Area, the most extensive forms of instream disturbance occurs in materials sites (granular borrow sources) located within the historic floodplains both of major rivers and of some tributary streams. Surface scraping and pit excavation at these sites has affected areas up to 1 to 2 km in length, and necessitated the removal of both stream banks and bank vegetation (Plate 2). Such materials sites in the Sagavanirktok, Dietrich, and Middle Fork Chandalar rivers were studied by Woodward Clyde

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.
DIETRICH R.
HAMMOND R.
NORTH FORK
MIDDLE FORK
CHANDALAR RIVER
BONANZA CR
FISH CR
KOYUKUK RIVER
YUKON RIVER
50 0 50 KM
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.

Consultants (1980a, 1980b). Sites in the Atigun River drainage were examined by Elliott (1982). Both authors concluded that the effects of instream mining were still readily apparent following site abandonment.

The streams of the region were classified by McCart et al. (1972), according to their physical and biological characteristics, as Foothills Streams, Mountain Streams, and Spring Streams. Within the TAPS Study Area, most streams can be classified as either Foothills Streams or Mountain Streams. Spring Streams, which provide important fall spawning and overwintering habitat, particularly in tributaries along the east bank of the Sagavanirktok River, are uncommon inside the pipeline corridor.

Foothills Streams, typified by Oksrukuyik Creek (Plate 3), generally originate within 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. Springs are rare in Foothills Stream drainages; but, where they do occur (eg. in Oksrukuyik Creek near Pump Station 3), braiding and icing formation in the winter usually coincide. Most of these streams cease flowing in winter, and receive only seasonal use by fish. Beaded pools and small intermittent lakes are common, the latter often providing the only fish overwintering habitat available in the watercourse.

Mountain Streams, typified by the Atigun River (Plate 4), originate in the Brooks Range, and include all the larger streams within the TAPS study area (eg. Sagavanirktok, North Fork Chandalar, Dietrich, and Koyukuk rivers), as well as the numerous smaller tributaries draining the Mountain Physiographic Province. These streams usually have high gradients and tend to become highly braided wherever valley floors are broad and flat. Groundwater from small springs is common, and generally forms substantial icings when flow persists into 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.

Fish inhabiting most streams in the TAPS Study Area are highly migratory, moving into tributary streams following breakup, remaining there for a three-month summer feeding period, and returning to deep pools in large streams, lakes, and groundwater sources to overwinter. The majority of the 400 stream channels crossed by the pipeline are either dry or frozen to the bottom in winter, and support no fish from early September until Late May. As a result, with the exception of the major rivers, pipeline routing has avoided most important overwintering areas in the region.

The locations of the 12 Detailed Study Streams are shown on Figure 1. Table 1 summarizes information concerning the types of studies conducted in each of these 12 streams. Of the 12 streams, seven (from north to south, Falcon Creek, Holden Creek, Trevor Creek, Spike Camp Creek, North Fork Chandalar River, Snowden Creek, and Brockman Creek), are associated with major materials sites; two (Oksrukuyik Creek and the Kuparuk River) are typical Foothills Streams with overhead crossings; and two (Minnie Creek and Marion Creek) are typical Mountain Streams, the former with an overhead crossing and the latter with a buried crossing. The 12th stream, the upper Atigun River, was the site of reported fish entrapments, thermal irregularities, sediment introduction, and, in 1979, a crude oil spill. The effects of the spill are discussed in a separate report (DenBeste and McCart, In Preparation).

During the course of these studies, there was high variability in weather conditions, so that each of the streams was observed under a wide range of discharge conditions. In 1981, heavy rains during much of the summer caused high water levels and frequent freshets. The following two years were characterized by extremely low water levels, infrequent rains, and few, though relatively severe,

Table 1 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<br>Light Angling Pressure | Undisturbed | Fish Density/Habitat |
| Kuparuk River | 126.4 | Overhead Crossing<br>Light Angling Pressure | Undisturbed | Fish Density/Habitat |
| Falcon Creek | uncrossed | Instream Materials Site | Habitat Modification | Benthic Invertebrate<br>Fish Density/Habitat |
| Holden Creek | 145.7 | Overhead Crossing<br>Instream Materials Site<br>Stream Channelization | Fish Entrapment<br>Habitat Modification | Benthic Invertebrate<br>Fish Density/Habitat<br>Migration Monitoring |
| Trevor Creek | 154.1 | Overhead Crossing<br>Instream Materials Site<br>Extensive Armoring | Fish Entrapment<br>Habitat Modification | Benthic Invertebrate<br>Fish Density/Habitat<br>Migration Monitoring |
| Spike Camp Creek | 163.0 | Adjacent Materials Site | Fish Entrapment | Fish Density/Habitat<br>Migration Monitoring |
| Atigun River | 150-164.0 | Instream Burial<br>Materials Site<br>Oil Spill<br>Ongoing Maintenance | Fish Entrapment<br>Thermal Irregularities<br>Sediment Introductions<br>Oil Damage | Benthic Invertebrate<br>Fish Distribution<br>Sedimentation<br>Migration Monitoring<br>Fish Density/Habitat<br>Temperature Monitoring |
| North Fork Chandalar River | 167-173.0 | Instream Burial<br>Materials Site<br>Ongoing Maintenance | Fish Entrapment<br>Thermal Irregularities<br>Sediment Introductions<br>Habitat Modification | Benthic Invertebrate<br>Fish Density/Habitat<br>Sedimentation<br>Temperature Monitoring<br>Migration Monitoring |
| Snowden Creek | 198.5 | Overhead Crossing<br>Extensive Armoring<br>Adjacent Materials Site | Habitat Modification | Benthic Invertebrate<br>Fish Density/Habitat |
| Brockman Creek | 204.1 | Overhead Crossing<br>Extensive Armoring<br>Instream Materials Site | Habitat Modification | Benthic Invertebrate<br>Fish Density/Habitat<br>Migration Monitoring |
| Minnie Creek | 225.6 | Overhead Crossing<br>Bank Armor | Undisturbed | Benthic Invertebrate<br>Fish Density/Habitat |
| Marion Creek | 233.2 | Buried Crossing<br>Extensive Bank Armor<br>Long-term Impassible Culverts | Reduced Fish Use<br>Habitat Modification | Benthic Invertebrate<br>Fish Density/Habitat |

freshets. Except for 1983, breakup occurred during the last week of May and the 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 period 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 7 to 10 days earlier in 1983. In early September 1981, the abrupt onset of cold weather caused a rapid decline in water levels which had previously remained high all summer. In late August 1983, an even more severe cold spell (-10°C) caused considerable ice formation and loss of flow in both North and South Slope streams. This ice persisted until streams ceased to flow in early to mid September.

# 3.0 RESULTS AND DISCUSSION

## 3.1 Effects on Benthic Invertebrates

Detailed benthic invertebrate studies were conducted in eight streams, at locations typifying several forms of disturbance. In Snowden, Brockman, Minnie, and Marion creeks, a Hess sampler (Hess 1941) was used to compare benthic invertebrate populations along transects located above and below various forms of disturbance. The effects of sedimentation in the Atigun and North Fork Chandalar rivers were also assessed, using Hess samples collected above and below the sediment sources. Studies of invertebrate stream drift were conducted in two major instream materials sites, Falcon Creek and Airstrip Creek, as a means of assessing whether removal of banks and overhanging vegetation has adversely affected drift of terrestrial invertebrates (those associated with land) and aquatic invertebrates (those which spend some portion of their life history in water). Both are an important component of the diet of Arctic grayling, round whitefish, Arctic char, and slimy sculpin, all species which are common in the streams of the TAPS Study Area.

Benthic invertebrates are the bottom organisms, many of them insects, which inhabit the substrates of streams. These organisms are considered useful indicators of change in aquatic environments, and their responses to alterations in water quality and stream hydrology are well documented. Typical responses include shifts in standing crop, species diversity, functional group composition, taxonomic diversity, and species composition. In general, because benthic invertebrates occupy lower levels in the food chain and have shorter life histories than fish, they display a more rapid response to and recovery from changes to their immediate environment. Fish are more able to alter their behavior, move to other locations, or even change their feeding habits to adapt to environmental change. As a result, it is often possible to document the effects of changes in stream environments by studying benthic invertebrate populations when effects on fish populations are not apparent.

Near watercourses, pipeline construction and its associated activities often result in localized sedimentation or erosion of streams, alterations in channel configuration, modification of granular deposition patterns, and localized changes to hydraulic configuration. All of these changes result in localized short-term shifts in the composition of the benthic invertebrate community. Most of these effects become less apparent with time, particularly when the source of disturbance (eg. instream equipment operation) ceases, and the watercourse stabilizes in a configuration comparable to that of the pre-construction environment.

In the TAPS Study Area, most areas where streams were disturbed during the construction phase have been stabilized, and little erosion is now apparent. The majority of pipeline stream crossings, at least in the Northern District, are overhead crossings with stable armored banks, and were installed with little instream disturbance. In most instances, stream crossings were installed during the winter months when watercourses were dry or frozen to the bottom. Buried pipeline crossings, which are similarly well-armored, displayed little evidence of instability during the three years of the present study.

The most extensive streambed modifications occurred within the floodplain materials sites used to supply granular material for the construction of the pipeline and the haul road, and in areas where extensive bank armor or stream training structures had been installed to prevent scouring and subsequent exposure of the pipeline. The latter were used in highly unstable streams where an alternative to deep burial was required. In their natural state, these streams have highly braided floodplains, carry heavy sediment loads, undergo frequent channel migration, and support comparatively impoverished benthic invertebrate communities. In such areas, instream activity is less likely to have an adverse effect on benthic invertebrate populations than it is in clear, stable tributary streams, where organisms are not subjected to the rigors of the large braided mainstem streams.

In Snowden Creek, a stream with a nearly 300 m long channelized section separated from an adjacent materials site by an armored bank, benthic invertebrate studies indicated that disturbance in this high-gradient stream had had no effect on the benthic invertebrate community. In streams with high gradients (>2.0%), the naturally severe scour, high sediment loads, and unstable substrates combine to limit benthic invertebrate productivity. Compared to the effect of natural events such as freshets, stream channelization and bank armor have little effect on such streams.

In Brockman Creek, the area upstream of the haul road is apparently more stable than the rest of the mined area, in part due to less mining activity, and in part due to the existence of an unmined north channel which diverts freshet water around the materials site and through a second haul road culvert. No attempt was made to stabilize the area above the haul road, but extensive areas of rip-rap were installed downstream of the haul road in the hopes of returning the stream to a more winding configuration. Much of this rip-rap has been washed out or has been partially buried by the highly unstable streambed. The disturbance of the original surface armor on the streambed by mining is responsible for the reduced stability, and the apparent adverse effects on the benthic invertebrate community.

Minnie Creek is crossed by a typical overhead pipeline crossing. There are three armored banks in the area, one at the pipeline crossing, and two at the haul road bridge. Otherwise, the stream is undisturbed. Sampling above and below the armored areas indicated that armoring has limited disturbance without altering the streambed, and had no effects on benthic invertebrate communities. Immediately downstream of the pipeline crossing, a slight increase in standing crop was apparent on all three sampling dates, but was attributable to a natural and unexplained increase in the density of algae on substrates in the vicinity of the sampling stations.

Marion Creek is crossed by a typical buried pipeline with extensive armor along the south bank. At the haul road crossing, both banks are armored, and formerly supported a bridge which was replaced immediately following the present sampling program. The benthic invertebrate community in Marion Creek was the most impoverished of any stream sampled during this study. (Benthic invertebrate samples were obtained from a total of 34). Compared to most other streams in the vicinity, Marion Creek is relatively clear, and sedimentation does not play a significant role in the low benthic invertebrate standing crop.

Scour in Marion Creek adjacent to armored areas has resulted in deposition of granular material immediately downstream of both the haul road and pipeline crossing. This appears to have resulted in an increased in the abundance of Chloroperlinae (midges) at stations located immediately downstream of the pipeline crossing, and a significant reduction in standing crop at stations located immediately downstream of both the haul road the pipeline crossing. Chloroperlinae characteristically inhabit actively eroding areas where substrate compaction is reduced. The disturbed area is limited to only a few hundred metres of stream channel.

Benthic invertebrate drift studies in a large materials site in Falcon Creek, located near Galbraith Airstrip, revealed that the materials site was responsible for reduced drift of both terrestrial and truly aquatic taxa. Both the total numbers of organisms and the taxonomic diversity of organisms in the drift within the materials site were lower in midsummer than the corresponding values at a station located downstream of the materials site. The Falcon Creek materials site, which was one of the longest instream materials sites studied, was characterized by a low gradient, streambanks and vegetation which have been removed, and some sediment deposition.

In contrast, adjacent undisturbed areas were characterized by cutbanks, considerable amounts of overhanging dwarf willow, and relatively little evidence of sediment deposition. Disturbance within the materials site had reduced the number of terrestrial insects falling from overhanging vegetation, and had adversely affected the standing crop of aquatic organisms. As a result, the availability of stream drift as a source of food for fish had been reduced in the materials site, making the area less attractive to summer feeding fish.

Similar studies in Airstrip Creek, a tributary of the North Fork Chandalar River, which contains a 700 m long materials site, indicated that stream drift was higher in the materials site than it was in undisturbed areas downstream. Gradient in the highly channelized Airstrip Creek materials site is steeper than in Falcon Creek, and no deposition of sediments has occurred except at the extreme lower end of the materials site and areas downstream. As was the case with Falcon Creek, all streambanks and overhanging vegetation have been removed by instream mining. Despite the high stream drift, fish utilization of the materials site was low. It is suggested that sediment deposition downstream of the materials site, resulting from occasional high-water floods from the silt-laden mainstem, may be reducing standing crop in the undisturbed portions of Airstrip Creek. The presence of groundwater in the materials site may also play a role in the increased stream drift.

Overall, drift studies in materials sites were inconclusive. Instream mining appears to have reduced instream drift in some locations, and increased it in a few others. In most smaller tributary streams, the effect of instream mining on stream drift is minimal, and probably has no direct effect on fish distribution. Habitat modification associated with these materials sites is a more serious concern, and will be discussed below.

## 3.2 Effects of Stream Crossings

Stream crossings in the TAPS Study Area include bridges, pipeline crossings, culverts, and low-water crossings (Plate 5). In this section, the post-construction status of each of these crossings is discussed.

The most criticized stream crossing technique along the pipeline and its access roads is the low-water crossing, which is frequently used to cross small streams along the workpad. A review of JFWAT field surveillance reports from the construction period makes it apparent that these crossings were inadequate to handle heavy construction traffic without causing sedimentation, rutting of the streambed, deposition of cobble downstream of the crossing, blockage of fish passage, and habitat modification. Gustafson (1977) and Rockwell (1978) provide summaries of the extent of this problem during the construction period, and both concluded that low-water crossings created a continuous problem throughout the open water season.

During the course of the present study, most observers interviewed agreed that, with the completion of construction, the number of problems associated with low-water crossings declined dramatically. The main reason for this decline was a decrease in vehicular and heavy equipment traffic along the workpad. Alyeska Pipeline Service Company does not allow vehicles to travel on the workpad during and immediately following breakup, a ban which prevents many of the rutting problems within streams. Moreover, now that the pipeline is operating, traffic is light, generally consisting only of those vehicles required for the inspection and maintenance of pipeline facilities.

At the more than 250 low-water crossings examined during the course of this study, fish entrapment was observed at only two, Union Creek (MP224.2) and Wood Creek (MP51.8 access MS-129-1). In both cases, entrapment occurred as a result of low stream flows french-draining through accumulated loose cobble, and the number of fish stranded was small, most of them young-of-the-year or juvenile grayling. While stranded fish were observed above several other low-water crossings during this study, in all cases the streams had ceased to flow downstream of the low-water crossing, and fish were stranded in equal numbers in undisturbed areas. Two successive dry summers (1982 and 1983) were responsible for this extensive natural stranding.

At a few low-water crossings, there was some evidence of cobble accumulation on the downstream side, and of rutting caused by vehicular traffic. These effects were most apparent in Foothills Streams, where low-water crossings tend to flatten out as a result of bank compaction. During low flow periods, routine removal of these cobble accumulations with a shovel is all that is required to maintain adequate fish passage. The vast majority of low-water crossings were stable, and produced little sedimentation even when crossed by vehicles. Though erosion of the workpad was noted at Snowden Creek (MP 198.5), Brockman Creek (MP204.1), and at a few locations on Foothills Streams, in all cases, the erosion was minor and was quickly repaired to allow vehicles to move through these streams. The larger and more important fish streams have all been provided with rip-rap block points, which prevent instream vehicular traffic.

Bridge crossings rarely cause problems with fish passage; however, in 1981, and to a lesser extent in 1983, a bridge on the workpad at Dan Creek (MP85.0) caused a serious blockage of fish. In those years, an icing, the result of groundwater flow in winter, blocked the channel on the upstream side of the bridge, causing a stream diversion over the tundra. To prevent this problem recurring in the future, Alyeska Pipeline Service Company has initiated the installation of heat-tracing wire under the bridge.

Pipeline crossings are posing few problems during the operational phase of the TAPS Project. During an intial survey of 72 stream crossings located north of the Yukon River (Volume IV of this report), no signs of significant fish passage problems, erosion, or instability were found. At all stream crossings examined, stream turbidity levels above and below the crossing were comparable. Where the pipeline was buried in large unstable floodplains, instream trenching did not appear to have increased instability, and stream training structures seemed to have limited channel migration in the most unstable areas. The liberal use of bank armor (rip-rap) on potentially unstable banks has also minimized problems. Although there were substantial washouts at MS-106-2, and at an unnamed stream (MP176.6) during this study, in neither case were the pipeline or its facilities the cause of the instability.

Culverts associated with the TAPS facilities are used at only a few locations along the workpad and on access roads, primarily to provide cross drainage. In general, these culverts posed no problems to fish passage, and were well-maintained and routinely de-iced during the present study. Culverts associated with the haul road were not specifically examined during this study; however, it was sometimes necessary to assess them in order to separate their effects from those of the pipeline and its ancillary facilities. Though there are still numerous impassible culverts along the haul road, an intensive program to replace the most troublesome culverts with bridges has been undertaken by the State of Alaska. Several culverts which were impassible in 1981 were replaced during 1982 and 1983, resulting in dramatically improved fish passage. In the Northern District, the majority of culverts where problems have been identified are slated to be replaced by bridges over the next three years.

### 3.3 Effects of Erosion and Sedimentation

Overall, sedimentation has not been a serious problem along the TAPS alignment since most access roads and the workpad are relatively stable with only a few localized erosion problems reported. Minor erosion was observed along the workpad at a few locations as previously noted, but generally only during severe freshets, primarily those associated with ice breakup in the spring. The Bureau of Land Management Office of Special Projects also noted a few minor erosion problems in their annual post-breakup inspection reports for 1981 through 1983. In no case do they indicate that these isolated incidents pose a serious environmental concern. In most instances, Alyeska has been prompt to respond to reported instability at stream crossings or along the workpad.

Instability along the pipeline corridor within the Atigun Pass has resulted in increased sediment loadings in both the North Fork Chandalar River and the Atigun River (Plate 6). During the course of this three-year study, periodic freshets associated with breakup and summer storms caused the movement of substantial quantities of sediments from disturbance along both the haul road and the workpad. Settling ponds were established on Pipeline Branch on the south side of Atigun Pass in an attempt to limit the amount of sediment reaching the headwaters of the North Fork Chandalar River. Additional ponds were installed on the north side of Atigun Pass as a temporary oil spill containment measure after the 1979 crude oil spill, though the latter were not designed to have any effect on sediment levels entering the Atigun River. In any case, most observers (eg. Elliott 1982) have suggested that the sediment problem is most serious on the south side of the Pass, where sediments may be adversely affecting the North Fork Chandalar River for a considerable distance downstream.

The potentially adverse effects of inorganic sediments on benthic invertebrates, fish eggs, and newly emergent fish fry are well documented (Cairns 1968). While it is often speculated about in the scientific literature, there is little evidence that suspended sediment levels as high as 10,000 mg/L affect fish over 50 mm in size. In northern Canada, suspended sediment levels in the Mackenzie River commonly exceed these levels without apparent adverse effects (Campbell et al. 1975).

Typically, increased sediment levels result in reduced standing crop, reduced species diversity, changes in functional group composition and overall changes in the species composition of benthic invertebrate communities. With respect to fish, both spawning success and egg survival are reduced by the coating of spawning beds with sediment, and the survival of the newly emergent fry of coldwater fish species can also be affected by the clogging or abrasion of gill filaments by sediment. Nevertheless, fish species inhabiting streams north of the Arctic Circle are well adapted to tolerating naturally occurring high sediment levels. In order to locate the clear tributary streams, side channels, and groundwater sources commonly used for spawning, these species must migrate through steams with suspended sediment loads which occasionally exceed 5,000 mg/L.

### 3.3.1 Atigun River

Turbidity and settleable solids data collected from the vicinity of Atigun Pass indicate that, during 1981, the majority of sediments originating from disturbed areas were originating from recent maintenance activity on the workpad and, to a lesser extent, from the haul road. With reduced activity on the workpad in 1982 and 1983, and extensive grading on the haul road, the haul road became the principal source of sediments during the later portions of the study. Apparently the workpad on the north side of the Atigun Pass tends to stabilize when it is left undisturbed.

Sediments originating from disturbed areas tend to increase turbidity and settleable solids levels in the Atigun River only during the declining stages of freshets. At low discharge levels, sediment concentrations in waters originating from disturbed areas are lower than background levels in undisturbed tributaries. During peak freshets, natural background turbidity levels often exceed 3,000 FTU, higher than the levels recorded in disturbed areas. The major effect of disturbance within Atigun Pass seems to be to prolong the duration of high turbidity levels following freshets.

Benthic invertebrate sampling conducted in 1981 and 1982 indicated that sediments and other forms of disturbance affecting the Atigun River have not caused a significant reduction in standing crop. In fact, total standing crop, species composition, functional group composition, and species diversity are comparable to those of communities found in undisturbed tributaries of the Atigun River.

There is no evidence that grayling, the only species spawning in the upper Atigun River, spawn upstream of MP158.0, about 7 km downstream of the major sources of sediment. Extensive sampling of the fish population revealed that most spawning occurs in lakes, clear side channels, and tributary streams where the stream gradient and scour are less severe. It is unlikely that sediments originating from disturbed areas within the Atigun Pass have any effect on spawning success downstream.

### 3.3.2 North Fork Chandalar River

Turbidity and settleable solids sampling in the North Fork Chandalar River and Pipeline Branch indicated that large sediment loads were originating from along the buried pipeline in Pipeline Branch. Despite the presence of two or three small settling ponds, these sediments were entering the North Fork Chandalar River during freshets and for periods of up to one week following freshets. During peak freshets, sediment levels were seldom higher than background levels upstream in the North Fork Chandalar River; however, turbidity levels quickly declined in the undisturbed stream as the freshet subsided. This was not the case in runoff from disturbed areas in Pipeline Branch.

Settling ponds at the base of Pipeline Branch are undersized for the quantities of sediment originating in Atigun Pass and, overall, are ineffective in reducing sediment loading downstream. The problem is particularly severe when portions of these ponds wash out during freshets, releasing large quantities of accumulated sediments in a short period.

Benthic invertebrate sampling in the North Fork Chandalar River indicated that the effect of sediments originating in Atigun Pass was localized and relatively limited. Only samples collected during the fall, when sediment levels in the undisturbed stream had declined, displayed significant changes in species composition 100 m downstream of the confluence of Pipeline Branch. There was no reduction in standing crop, and no change in functional group composition or taxonomic diversity. Species diversity was, however, significantly reduced. These effects were not apparent 2.5 and 3.5 km downstream.

There was no evidence of spawning in the North Fork Chandalar River upstream of MP173.0, about 4 km downstream of the major sources of sediment. Grayling dominated the study area from mid to late summer, but were rare in June when spawning occurs. No young-of-the-year have been caught upstream of MP173.0, including the unnamed tributary at MP170.7 and Airstrip Creek (opposite MP171.5 to 173.5), both clear tributaries unaffected by sediment loading from Atigun Pass. It seems unlikely that sediment introductions are having a significant effect on spawning success of grayling in the downstream North Fork Chandalar River.

Overall, while disturbance in Atigun Pass has contributed to the total sediment load in both the Atigun River and the North Fork Chandalar River, the effects on fish and fish food organisms have been minimal. The need to maintain the mechanical stability of the pipeline in Atigun Pass will ensure that efforts will continue to improve erosion control.

## 3.4 Effects of Fish Entrapment

The fish entrapment study period included two relatively dry summers, and entrapment of fish in streams above areas of discontinuous flow or stranding of fish in isolated pools where all flow had ceased was a widespread phenomenon in both disturbed and undisturbed areas. Numerous natural entrapments of up to 300 fish, primarily grayling, were documented during the course of this study. In addition, there was entrapment of large numbers of fish above areas of discontinuous flow associated with instream materials sites in alluvial fans of streams.

While discontinuous flow in alluvial fans is a common natural phenomenon in the Brooks Range, there is evidence that instream mining has aggravated the flow problem, at least in some locations. Unfortunately, baseline data from the pre-construction period are inadequate to determine the extent of discontinuous flow prior to instream mining. In some instances, the extensive area of discontinuous flow, and the pattern of dewatering suggested that the alluvial fans had some predisposed tendency toward discontinuous flow prior to instream mining.

No new areas of discontinous flow in materials sites, other than those previously reported in the literature, were discovered during this study, despite monitoring of numerous instream materials sites in Sagavanirktok River side channels, and in the Atigun, North Fork Chandalar, Dietrich, and Middle Fork Koyukuk river drainages.

Known areas of discontinuous flow were monitored in Holden Creek, Trevor Creek, Spike Camp Creek, and the North Fork Chandalar River. Substantial fish kills have previously been reported in low-gradient alluvial fan areas in all four of these streams (Elliott 1982).

### 3.4.1 Holden Creek

Discontinuous flow occurred in the lower portion of the Holden Creek materials site in 1981 and 1982, but a freshet at breakup 1983 scoured out much of the accumulated loose cobble, and no discontinuous flow was observed in 1983. Up to 44 grayling, primarily juveniles, were observed trapped above the discontinuous flow at various times during this study. Most, however, were able to escape during timely freshets. Elliott (1982) reported that 31 grayling and char died in the materials site in 1980; however, the maximum number of fish which died there during our study was only five juvenile grayling.

While the alluvial fan in Holden Creek was undoubtedly relatively porous and subject to some discontinuous flow even prior to instream mining, the scour resulting from its present linear configuration is responsible for the deposition of loose cobble at the lower end of the materials site. Since this was the first location to dry up in both 1981 and 1982, the evidence indicates that instream mining has added to the problem. Even though most of this accumulated cobble was scoured out in 1983, there is a strong possibility that scour in the 700 m of nearly straight channelized stream will result in a new deposition of loose material in the future. Over the last four years, the average number of fish lost in Holden Creek has been relatively small, and any action to eliminate these small losses may actually make them worse.

### 3.4.2 Trevor Creek

Discontinuous flow in Trevor Creek occurs in late August or early September in the lowermost 100 m near the stream mouth. The dry area gradually expands upstream, until it encompasses the lowermost 500 m of stream. Elliott (1982) reported a similar pattern of dewatering in 1980. The lowermost 700 m of Trevor Creek, from a point 50 m above the pipeline crossing to the stream mouth, was mined for granular material (Plate 2). The band of discontinuous flow is wholly contained within the area disturbed by instream mining. The alluvial fan in Trevor Creek is located at approximately the same distance from the east canyon wall as the alluvial fan in Holden Creek. Dewatering does not occur until discharge, measured at the haul road, drops below 0.15 $m^3/s$.

The largest entrapment recorded in Trevor Creek was 91 grayling found by Elliott (1982) in early September 1980. During our three-year study, the only fish which died as a result of discontinuous flow were 29 grayling and three char found trapped on September 3, 1982. As a result of the persistent high water levels in 1981, all fish were able to emigrate prior to the first discontinuous flow. Trevor Creek was diverted into Tyler Creek for most of the 1983 open water season to accommodate bridge installation. This diversion would have killed any fish present during the intial mid-June diversion, and prevented use of the stream for the remainder of the season.

Elliott reported that the 91 grayling trapped in 1980 represented 75% of the maximum number of fish using Trevor Creek. Our own estimates of the maximum number of fish in Trevor Creek were much higher, a maximum of about 900, with as many as 60 grayling, mostly adults, caught in a single 100 m length of stream. This difference may have been due to year-to-year variability in fish density, or it may have been because the population estimate technique used by Elliott was less accurate than the technique used in this study.

The presence of discontinuous flow in two other undisturbed streams located near Trevor Creek (Waterhole Creek near MP152.4, and an unnamed west side tributary opposite MP151.0), strongly suggests that the alluvial fans of all streams in this area are subject to periodic discontinuous flow. There are insufficient baseline data to determine whether discontinuous flow in Trevor Creek is the result of instream mining, or even whether instream mining is contributing to the problem.

### 3.4.3 Spike Camp Creek

During the construction of TAPS, a large pit was excavated in the Spike Camp Creek floodplain to provide granular material. While the pit (MS-111-1) did not affect the wetted perimeter of Spike Camp Creek, water emerging near the upper end of the pit created a small stream named Sten Creek. Downstream of the haul road, this new stream enters a deeper pit in the materials site, creating a small pond which is used by grayling during the summer months. In the reach which parallels the Sten Creek watercourse, Spike Camp Creek displays discontinuous flow during late August and early September. Elliott (1982) has suggested that the Sten Creek pit may be intercepting flow from the Spike Camp Creek water table, causing the premature loss of surface flow.

From 1981 through 1983, Spike Camp Creek initially lost surface flow at a point 200 m downstream of the haul road. Repeated measurements of the decline in surface flow in Spike Camp Creek adjacent to the Sten Creek pit confirmed that the proportionate loss of surface flow was nearly identical to the discharge of Sten Creek. While these measurements do not include intergravel flow, which may comprise a significant portion of the Spike Camp Creek discharge, they do provide strong circumstantial evidence that the excavation of the Sten Creek pit is contributing to the problem of discontinuous flow.

While Elliott (1982) documented the entrapment of at least 132 fish in Spike Camp Creek in 1981, during three years of study we found only one trapped grayling upstream of the discontinuous flow. The difference in the number of trapped fish is probably the result of timely freshets in 1981 and 1982, and early cold weather in 1983, which encouraged most fish to emigrate prior to the first discontinuous flow.

Based on conductivity and temperature comparisons alone, it is unlikely that Sten Creek represents a distinct groundwater source. Consideration has been given to the possibility of combining the two streams in the hope of preventing any future entrapment; however, the extent of channel modifications necessary to combine both streams would be substantial and might result in an even worse entrapment problem.

### 3.4.4 North Fork Chandalar River

By far the largest entrapments of fish in an area of discontinuous flow have been reported in the North Fork Chandalar River (MP172.0) in the vicinity of a small instream materials site (MS-109-3, expansion 4). A large area of discontinuous flow occurs in this area, including up to 2 km of stream (MP171.6 to MP173.0). Fish have been documented stranded in all portions of the dry area, but the two largest entrapments documented to date occurred upstream of the materials site near the airstrip access bridge. The location of the initial dewatering varies from year to year, ranging from a point 300 m below the material site upstream through the materials site as far upstream as 100 m below the airstrip access bridge. Discharge at the airstrip access bridge ranges from 0.18 to 0.32 $m^3/s$ when discontinuous flow first appears.

Elliott (1982) reported that an estimated 5,000 grayling were stranded in the vicinity of the airstrip access bridge in early September 1979, and an estimated 1,650 grayling were rescued three days later and transplanted downstream. The largest entrapment documented during our studies was an estimated 1,000 grayling, 525 of which were rescued and transplanted downstream. Many of these fish (more than 300) were found in isolated pools downstream of any instream disturbance. Timely freshets prevented entrapment of small numbers of fish in 1980 (Elliott 1982), 1982, and 1983.

Disturbance during instream mining in the North Fork Chandalar River was minor compared to all other instream materials sites studied. Prior to abandonment of the site, only 6,600 cubic yards of surface material had been scraped from an area 200 to 300 m in length. The widespread area affected by discontinuous flow both above and below the materials site suggests that this area was subject to problems with discontinuous flow long before instream mining occurred.

The occurrence of a nearly identical area of discontinuous flow in the East Branch North Fork Chandalar River, where no disturbance had occurred, strongly suggests that these streams are naturally subject to discontinuous flow. In the absence of adequate baseline data covering the period prior to instream mining, we cannot conclude that fish entrapment in the North Fork Chandalar River is the result of disturbance associated with TAPS.

### 3.4.5 Atigun River Headwaters

Elliott (1982) reported that the pipeline trench appeared to intercept surface flow in the Atigun River between MP162.2 and MP163.4. In the fall of 1980, this interception of flow resulted in the entrapment of 59 fish, primarily grayling; however, observations made in 1982 and 1983 revealed no problems with discontinuous flow and evidence of fish entrapment in this area. Low discharge levels in 1982 and 1983 probably caused the early emigration of the few fish using the upper Atigun River for summer feeding. Minor channel migration may have temporarily reduced or eliminated the problem at this location. On several occasions when no flow was present at MP163.0, there was a small trickle of surface flow present at MP165.0. At no time, however, were fish caught in the area. No similar areas were found in the Sagavanirktok, Atigun, North Fork Chandalar, Dietrich, or Koyukuk rivers, despite extensive ground surveys.

## 3.5 Effects of Thermal Irregularities

Various observers have reported the existence of heated water emerging over the buried pipeline trench during the fall and winter months. This heated water, originally either surface or intergravel flow, flows parallel to the buried pipeline for some distance, and then emerges at temperatures exceeding the ambient temperature of the receiving waters. During summer, when stream discharge is high, these locations are difficult to discern and are of little consequence. During fall, as stream discharge declines, these locations attract downstream emigrating fish seeking suitable overwintering habitat. Should fish remain at these sites, they will eventually die as the pools become anoxic or freeze to the bottom.

During September, numerous locations with thermal irregularities can be found in the Atigun, North Fork Chandalar, Dietrich, and Middle Fork Koyukuk rivers. An abundance of algae makes most of these locations readily discernible at low stream discharges. From the standpoint of fish attraction, the greatest concern is for locations in the Atigun River, where the number of fish attracted is alarmingly high. Other streams may also be adversely affected by this problem, but the timing of the completion of our studies (late

September) was such that stream discharges in the Dietrich and Middle Fork Koyukuk rivers remained too high for significant attraction of fish to occur.

One location in the Atigun River was investigated by Alaska Department of Fish and Game, who 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 (Hemming 1982). These fish were apparently attracted by warm water as stream discharge declined, and they became trapped and died as the stream froze.

Two locations in the Atigun River floodplain, investigated in the fall of 1982 and 1983 are of particular concern. In early September 1983, a warm water source at MP161.0 was flowing at 10.5°C, compared with water temperatures of 1.0°C in unheated water nearby. A 100 m long section of this side channel contained a total of 206 juvenile grayling (82 to 134 mm) while a 100 m long section of an adjacent unheated channel contained no fish.

The largest numbers of fish concentrated in a warm water channel have been observed at MP175.2. In 1982, the number of juvenile grayling (47 to 123 mm) in a 435 m long side channel was estimated at 700. Water temperatures near the buried pipeline averaged 9.5°C in the 1 to 2 m wide channel. Temperature in adjacent unheated channels, where no fish were present, measured 4.0°C. Similar results were obtained in this same location in 1983, when water temperatures in the heated channel averaged 5.0°C, while water temperatures in adjacent channels ranged from 1.0 to 3.0°C. A 100 m test section in the heated channel contained 407 juvenile grayling (84 to 156 mm) while an adjacent unheated channel contained only eight juvenile grayling and two char. This location is near a major icing in the Atigun River which may provide overwintering habitat for some of these fish. It is emphasized, however, that fish were not yet trapped at either of these locations, and all may have emigrated to areas with groundwater flow after completion of our studies. Studies by Hemming (1982) suggest that, at least at MP162.2, some do not escape.

Chihuly (1982) described an extreme example of a thermal irregularity in the Middle Fork Koyukuk River (MP208.5) where, on March 16, 1981, the water temperature measured 33.3°C. In April 1981, Chihuly observed a "...school of small fish (>30) 2"-4" [51 to 102 mm] in total length, possibly grayling." During the present study, 97 juvenile grayling were observed in this area on September 13, 1982. On September 14, 1983, the water temperature at the source of the thermal irregularity was 25.0°C, compared with an ambient water temperature of only 4.0°C in an adjacent stream channel. No fish were present.

From the results of our own and other studies, it is apparent that small numbers of fish are being lost in all streams where there are thermal irregularities associated with extensive instream burial.

## 3.6 Fish Habitat Preference Studies

Studies of fish habitat preference were designed to fulfill three purposes:

1. To define the habitat preferences of the most common fish species;

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

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

Descriptions of both the available habitat in 27 streams within the TAPS study area and the typical habitat types selected by the most abundant species (Arctic grayling, Arctic char, and round whitefish) are presented in Volume II. Based on a comparison of the physical features in available habitats with the physical features of habitats actually occupied by fish, fish habitat preferences were determined. This was accomplished using three different techniques:

1. Histograms for available habitat were compared with similar histograms for habitats occupied by each species or life history group of fish to develop a Relative Suitability Index;

2. Comparisons of depth, velocity, and substrate composition were made between data for all sample locations and data for only those locations which supported fish, using a polynomial suitability-of-use function (Bovee and Cochnauer 1977, Voos 1981);

3. Factor analysis was performed on a selected group of 13 physical habitat features to produce five independent factors. These factors, along with the index obtained from the polynomial suitability-of-use function were included in a multiple regression comparing each factor with fish density.

Data describing the physical characteristics of the available stream habitat were obtained at a total of 7,233 sampling points at locations in 27 streams. At each sampling point, a total of 28 physical characteristics was measured. In addition, data were obtained describing the characteristics of more than 500 habitat sampling sites actually supporting fish. At each fish habitat sampling site, 42 separate data items were recorded. These included physical parameters, as well as a description (species and length) of the fish present.

Arctic grayling dominated the study area, comprising 83.5% of the 1,934 fish observed during these 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 was the slimy sculpin which, due to difficulty in accurately censusing this species with the methods used in this study, were not included in the analysis. Although some data are included on grayling and Arctic char young-of-the-year, fish under 75 mm were generally excluded from the analysis for similar reasons. Because few of the disturbed habitats studied in detail provide spawning habitat, there are few observations of habitat used by young-of-the-year.

Grayling were present in sufficient numbers to allow for a separate analysis of both juveniles (75 to 220 mm) and adults (>180 mm). The overlap in fish lengths included in each group was used to accommodate variability in size at maturity. Arctic char and round whitefish were sufficiently rare in the study area that only portions of the analysis were performed for the juveniles and adults of these species. No adult anadromous Arctic char were caught in the vicinity of the pipeline. The following section summarizes the habitat preferences of each of the three species studied.

### 3.6.1 Juvenile Grayling

Habitat preference studies indicated that juvenile grayling select habitats with the lowest possible velocity (often where there is no detectable current), pools with an average depth of 0.65 m, and fine-grained substrates. Of nine cover features studied, juvenile grayling select most strongly for rock cover, but to a lesser extent, use habitats with cutbanks or loose gravel or rock banks providing cover, overhanging vegetation, deep water, instream vegetation, and shade. Juvenile grayling prefer pool habitats, often with adjacent swift water (>0.5 m/s) to provide a steady supply of stream drift for food (59.8% of habitats fit this description). The presence of adjacent swift water is slightly less important to juvenile habitat selection than to adults. Juvenile grayling also appear to select for narrow channel widths (1 to 8 m wide) and, although they are found in channels of average width, tend to select against channels wider than 14 m.

The average habitat area used by individual juvenile grayling was 125 $m^2$, although habitats as small as 1 $m^2$ were used in boulder-controlled pools in some Mountain Streams. Except while feeding, a high percentage of juvenile grayling (56.8%) were observed within 10 cm of the bottom. This is in part a response to the lower velocity near the stream bottom, and in part a tendency to use both depth and the stream bottom as cover.

While histogram analysis indicated that juvenile grayling do not select for streams with high food availability, factor analysis suggested that the density of fish is slightly higher in areas with higher benthic invertebrate standing crop and diversity, and low stream turbidity. Juvenile suitability, as determined by the polynomial suitability-of-use function, was found to be the most useful factor for predicting both juvenile and adult density in the study area; however, the predictive capability of any formula based on habitat features alone is relatively low, due to an abundance of unused high quality summer feeding habitat. It appears that some other factor, most likely overwintering habitat, is probably limiting the number of fish in most areas.

### 3.6.2 Adult Grayling

Habitat preference studies indicated that the depth, velocity, and substrate requirements of adult grayling are similar to those of juveniles. Adults prefer near zero velocity water with an average depth of 0.8 m. While adults display a preference for fine-grained substrates, coarse substrates are also selected for. Only the medium-grained gravel substrates are avoided. Adult grayling prefer habitats with cover features typically associated with banks (eg. cutbanks, overhanging vegetation, instream vegetation, and shade), but use rock cover to some extent, and the deepest water available to an even greater extent than juveniles. Adults display a strong preference for pool habitat, but an even higher percentage (69.7%) of these habitats were located adjacent to swift water (>0.5 m/s) than were juvenile habitats (59.8%). The average channel width used by adults was is 10m, but channels less than 6 m wide are selected against. Confirming the importance of banks as cover, adult grayling prefer habitats with bank heights of 0.6 m or greater.

The average habitat area used by adult grayling is 170 $m^2$, but habitats as small as 1.5 $m^2$ are used in a few Mountain Streams. Adults, like juveniles, prefer to remain near the stream bottom where velocity is lowest, and the most efficient use of both depth and substrate as cover is possible. Of grayling adults observed during this study, 53.8% were found within 10 cm of the stream bottom.

Factor analysis revealed that adult suitability as predicted by the polynomial suitability-of-use function is the most useful factor for predicting adult density. Bank and cover-related factors were also of some value in predicting density. While histogram analysis suggested that adults select for habitats with higher benthic invertebrate standing crop and diversity, factor analysis indicated that food-related parameters have little or no value in predicting fish density. As with juveniles, there appears to be an abundance of high quality habitat which is unoccupied, and an irregular distribution of fish in the study area, which suggests that factors other than the availability of summer feeding habitat are controlling numbers (eg. overwintering habitat, distance from overwintering habitat, periodic stream dewatering).

### 3.6.3 Arctic Char

Only juvenile Arctic char were observed in sufficient numbers for an analysis of their habitat preferences; adults were rare in the study area. All of the char observed were of the stream-resident type, and no adult anadromous char were observed either spawning or overwintering in any of the study streams.

Habitat preference studies indicated that juvenile char (75 to 220 mm) prefer shallow pools with low current velocities, generally below 0.3 m/s, with medium to coarse rock substrates. The majority of these habitats (85.2%) are located adjacent to swift flowing water (>0.5 m/s). The strong preference for pools can be seen in the fact that 87.5% of juveniles were found in this habitat type.

Instream vegetation, bank vegetation, shade, instream tundra slumps, and rock cover are the most important cover features for juvenile char. Depth and bank cover, so important to grayling, are selected against by juvenile char. While a high percentage of char (37.5%) was found in the vicinity of cutbanks, this figure probably reflects a tendency for char to use streams with cutbanks rather than an affinity for cutbanks themselves. Where cutbanks are present in juvenile char habitat, they tend not to provide cover. While vegetation as cover is important to juvenile char, these fish are also common in braided floodplains with unvegetated channels 6.0 m or less in width. Predation or competition with larger fish may cause juvenile char to seek these habitats. Juvenile char were the only group of fish that did not select against habitats with gravel and rock bar banks, and displayed a positive selection for habitats with banks of 0.2 m or less in height.

The average habitat area used by juvenile char is only 23 $m^2$, and some fish use habitats 1 $m^2$ or less in boulder-controlled pools of high gradient streams. Juvenile char, unlike grayling, tend to select habitats with higher-than-average benthic invertebrate standing crops.

### 3.6.4 Round Whitefish

Habitat preference studies indicated that round whitefish adults (>220 mm) prefer deep pools in large streams with relatively low velocities (mean=0.17 m/s) and coarse substrates. The cover requirements of adult round whitefish are similar to those of adult grayling. The two species are often found in mixed schools, particularly in Foothills Streams with large beaded pools. The average habitat size of adult round whitefish (335 $m^2$, nearly twice the size of habitats used by adult grayling) reflects this preference for large pools. Of the five habitat types studied, adult round whitefish were found most often in pools (83.6% of habitats used). Depth was used as cover in 77.6% of habitats observed. Cutbanks, typical of Foothills Streams, were present in 46.3% of adult round whitefish habitats observed.

The average bank height in round whitefish habitats is 1.4 m, the highest of the three species studied. Average channel width is 11.4 m, but all channel widths greater than 10 m are selected for positively. Round whitefish adults, like grayling adults, appear to select for streams with higher-than-average benthic invertebrate standing crop and diversity. Since these streams tend to be Foothills Streams, this feature is probably of little value in predicting fish density.

Data are presented for juvenile round whitefish (<220 mm) in Volume III; but, in general, the numbers observed were too small for detailed analysis.

## 3.7 Effects of Habitat Modification

Fish habitat modification resulted from instream construction at pipeline crossings, access roads, culverts, low-water crossings, armored banks, stream-training structures, and materials sites. With the exception of the latter two, the amount of habitat lost or modified at any single location is extremely small. In many instances, minor modifications which increased stream depth, reduced velocity, created pool habitat, increased cover along banks (with rip-rap), or created uniform cobble substrates appear to have enhanced habitat in relation to the habitat preferences of the most common fish species. Indeed, many of these small disturbed areas (eg. low-water crossings, culvert plunge pools, pools created in armored banks) support a disproportionately high number of fish compared with adjacent undisturbed areas.

In a few high-gradient streams (eg. Snowden Creek), large pools created by rip-rap at the pipeline crossing and the haul road culvert plunge pool occasionally support more fish than all other accessible habitats in the stream combined. Low-water crossings were frequently used by spawning grayling, since they provide low-velocity pool habitat during high discharge periods, and generally have uniform cobble substrates.

Of greater concern are the large-scale habitat modifications resulting from use of extensive bank armor, spur dykes, and instream mining of granular material. Woodward Clyde Consultants (1980a) have already demonstrated that habitat modifications in instream materials sites located in the largest streams have caused changes in fish distribution and size composition (eg. Sagavanirktok River, Dietrich River, Middle Fork Koyukuk River). Elliot (1982) suggests that some of these same types of habitat modifications may affect fish distributions and size composition in materials sites in the Atigun River drainage, and in the vicinity of spur dykes in the Middle Fork Koyukuk River drainage.

Investigations conducted in the vicinity of spur dykes in the Dietrich and Middle Fork Koyukuk rivers in 1981 revealed that there are a few locations where intrusions of silt-laden water, sedimentation, channel diversion, and scour have modified habitats and where fish densities appear to be low. However, because of the complete absence of baseline data for the period prior to construction, and the general absence of spatial controls, quantifying these changes is virtually impossible. In systems as unstable as the Dietrich and Middle Fork Koyukuk rivers, channel migrations occur frequently, resulting in natural habitat modification which appears similar to the habitat modification associated with spur dykes.

The migration of the Dietrich River through a major floodplain materials site (MS-106-2) during a freshet in 1982 is a good example of the magnitude of natural channel movements. Clear channels arising in the materials site were completely buried by granular material and sediments and mixed with silt-laden water. In such a naturally unstable system, minor differences in the abundance of fish in adjacent channels near spur dykes are of little significance to fish populations. Elliott (1982), for instance, states that the impact of altered flow regime in Jackson Slough (Middle Fork Koyukuk River drainage, MP244.5) is uncertain. He indicates that fish densities were 1.65/100 m in a channelized reach, and 2.2/100 m in a natural reach. This kind of difference is insignificant, since natural variability in undisturbed areas is dramatically greater.

The conclusion of the studies summarized here is that, while there is some evidence of minor habitat modifications and localized reductions in fish density associated with a few spur dykes, there is no evidence that these modifications have had an adverse effect on overall fish population levels in the area.

Extensive habitat modifications in instream materials sites in Falcon Creek, Holden Creek, Trevor Creek, Airstrip Creek, the North Fork Chandalar River, and Brockman Creek are documented in Volume II of this report. Modifications in Snowden Creek associated with an adjacent materials site are also described. Overall, instream mining in tributary streams has resulted in increases in braiding, turbulence, and channelized areas; decreases in depth, average substrate size, and amount of pool habitat; and the elimination of banks, bank vegetation, cover, and velocity barriers (Plates 7 and 8). The effects of instream mining on fish habitat are generally less severe in highly scoured braided floodplains without highly developed banks or overhanging vegetation. Streams with steep gradients (eg. Snowden Creek) are also less affected by instream disturbance because habitat quality is already relatively poor.

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 larger than 75 mm. Undoubtedly, instream mining in stable single-channel streams has eliminated some habitat for grayling and round whitefish. Arctic char appear to be too restricted in their distribution within the pipeline corridor to have been affected by these habitat changes.

Sites in the North Fork Chandalar River, Snowden Creek, and Brockman Creek do not appear to have been sufficiently altered to affect the distribution of fish. The use of rip-rap in Snowden and Brockman creeks has created some new habitat, but this new habitat generally appears to support average fish densities comparable to those of the original undisturbed habitat it replaced. Juvenile grayling appear to select more for these man-made habitats than adult grayling, char, or round whitefish.

Mining adjacent to watercourses, but within the historical floodplain, has resulted in the creation of several new pond habitats which are used by substantial numbers of summer feeding fish (eg. Prospect Creek, Dietrich River, Sten Creek). Where scour is severe, these new habitats are temporary (eg. Dietrich River), and may be eliminated by sedimentation and channel migration.

The types of habitat modifications caused by instream mining in single-channel tributary streams appear to be long-term. There is little evidence of any return to the original complex stream habitat in most locations observed during these studies. Channelization prior to site abandonment (eg. Holden Creek, Airstrip Creek) has aggravated the problem by delaying the return of streams to a winding configuration. Where attempts have been made to restore this configuration (eg. Brockman Creek), the inherent instability of newly mined areas has negated the effort.

Woodward Clyde Consultants (1980a) observed that changes in some mined areas located outside the pipeline corridor have persisted for 15 years with little evidence of recovery. Sites inside the corridor, mined between 1974 and 1977, generally retained a disturbed appearance and show little sign of recovery. An exception to this pattern occurs in areas of high inherent instability, where natural scour and channel migration have removed all evidence of instream mining (eg. North Fork Chandalar River). Even in these areas, there is little evidence of the restoration of bank vegetation (ie. dwarf willow) removed during mining.

While these habitat modifications have resulted in localized reductions in the density of summer feeding fish, habitat preference studies indicate a large surplus of under-utilized habitat throughout the study area. Since fish populations in the disturbed streams are highly migratory, and were not present during the actual mining operations, which took place in winter, the overall effect of instream mining has been a displacement of fish to alternate habitats in undisturbed areas.

The availability of overwintering habitat appears to be the most important factor controlling fish densities in streams within the study area. Less than 1% of total habitat in the study area supports the entire fish population for up to eight months annually, and the quality and location of overwintering habitat is likely to be the single most important factor affecting both fish density and fish distribution. All of the tributary streams containing materials sites are dry from mid-September until late May. Of necessity, instream mining is conducted in alluvial flans and deposition areas, which are unlikely to have winter flow. While there were a few instances where instream mining encountered groundwater (eg. MS-106-2, Dietrich River), in general, instream mining has had no impact on overwintering areas.

## 4.0 CONCLUSIONS

Overall, fish populations in streams along the TAPS alignment in the Northern District appear comparable to populations reported prior to construction. With a few exceptions, principally associated with spur dykes and materials sites, species composition and distribution have been largely unaffected by TAPS facilities. There is still some restriction of fish passage due to inadequate haul road culverts, but measures are being taken by the State of Alaska to alleviate this concern.

With the exceptions already noted in this report, fish densities are comparable to those reported prior to construction, and to densities reported for undisturbed habitats located outside the pipeline corridor. Populations in selected streams appear to have a normal length-frequency structure, indicating the presence of a wide range of year classes, including those produced during and since the construction period. Exploitation of fish populations by anglers has increased with improved access, but, to date, most angling is of the catch-and-release type and, at worst, is causing only localized reductions in the immediate vicinity of the haul road and pump stations.

Considering the slow growth rate of most fish species inhabiting the region, any devastating effect on fish would be expected to remain apparent in the population structure for some time. No evidence of such shifts in population structure was observed. There is no evidence that localized habitat modifications resulting from instream mining or stream training have had any adverse effect on overall population levels of grayling, char, or round whitefish. It appears the primary effect of these modifications has been displacement.

Small losses of fish continue to occur as a result of delayed emigration where heated water is emerging from the pipeline trench. Similarly, entrapment of fish in areas of discontinuous flow or upstream of various forms of disturbance is delaying emigration and causing small losses. Taken in total, the sum of all these losses appears to be relatively low compared to the total population size, and is probably insignificant compared to natural mortality.

## 5.0 SUMMARY OF IMPORTANT FINDINGS

The following is a brief summary of the more important findings of this study:

1. Regional fish population levels do not appear to have been adversely affected by TAPS.

2. There have been some localized changes in the distribution of fish in a few tributary streams. These changes have resulted primarily from habitat modification in materials sites and from blockages to fish passage at haul road culverts.

3. Stream training structures in large streams have caused channel diversion, habitat modification, sedimentation, and channel dewatering which appear to have resulted in localized shifts in fish distribution.

4. Habitat modifications in tributary streams appear to have caused the displacement of fish from previously occupied habitats rather than a reduction in the size of regional populations.

5. Summer feeding habitat for grayling is present in excess in the study area, and does not appear to be a significant factor controlling regional population levels.

6. The pipeline workpad and access roads are causing few problems for migrating fish. Low-water crossings, severely criticized during construction, appear to provide adequate fish passage now that workpad traffic is reduced.

7. Pipeline buried in the floodplains of major streams is causing elevated temperatures in surface flow which are attracting fish and delaying their late summer and fall emigration to overwintering areas. Losses of these fish are, however, probably small in relation to natural mortality.

8. Instream mining of granular materials has caused a wide range of long-term habitat changes in tributary streams, including reduced stream stability. This reduced stability is responsible for seasonal reductions in the benthic invertebrate community in at least one stream.

9. The use of extensive bank armor has caused localized shifts in the scour/deposition pattern in a few locations which have resulted in minor changes in benthic invertebrate communities.

10. Sediments originating from Atigun Pass are increasing the sediment load of both the Atigun and North Fork Chandalar rivers. These sediments, however, are having no effect on the benthic invertebrate community of the Atigun River, and only a localized late-season effect in the North Fork Chandalar River. Neither area is used by spawning fish.

11. The pipeline and associated facilities are well stabilized both at stream crossings and where the pipeline has been buried in floodplains. There is little evidence of slumping, erosion, or stream sedimentation which might affect fish habitats.

12. Entrapment of fish occurs as a result of discontinuous flow in several mined streams in the Northern District. All streams studied which display this problem appear to have some natural tendency toward discontinuous flow. In some locations, however, instream mining may have aggravated the flow problem, and contributed to the incidence of entrapment.

13. The relationship of instream disturbance to the major fish entrapments which occur periodically in the North Fork Chandalar River is unclear. The materials mining operation in the floodplain was small in terms of both its areal extent and the amount of material removed, and there was relatively little disturbance of stream habitats. Dewatering and entrapment now occur both upstream and downstream of the area of disturbance. The area may be naturally subject to dewatering, and entrapment may have occurred before the construction of the pipeline.

## 6.0 LITERATURE CITED


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.

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.

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.

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.

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.

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

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.

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.


Plate 1 Arctic grayling (Thymallus arcticus), is the most abundant and widely distributed fish species in the Northern District.


Plate 2 Trevor Creek (foreground), a tributary of the Atigun River (background), showing the haul road, pipeline and a large instream materials site, MS-112-2 (light green area).


Plate 3 Oksrukuyik Creek, a typical Foothills Stream and a tributary of the Sagavanirktok River, near Pump Station 3.


Plate 4 The Atigun River headwaters near Atigun Bridge No. 1 (MP. 160 in background). Violent freshets are common in Mountain Streams as typified by the Atigun River.

Plate 5 Typical low water crossing with armored banks, widened pool at vehicle ford and constricted outlet which helps prevent blockage at low flow (Polygon Creek, MP. 99).

Plate 6 Sediment laden water entering the North Fork Chandalar River (foreground) from Pipeline Branch (in background) following a freshet.

Plate 7 Undisturbed portion of Trevor Creek showing normal habitat development including winding configuration, boulder controlled pools and overhanging vegetation.

Plate 8 Mined and channelized reach in Airstrip Creek (North Fork Chandalar River tributary) showing straight channel configuration, absence of distinct banks and overhanging vegetation, and complete absence of pools.