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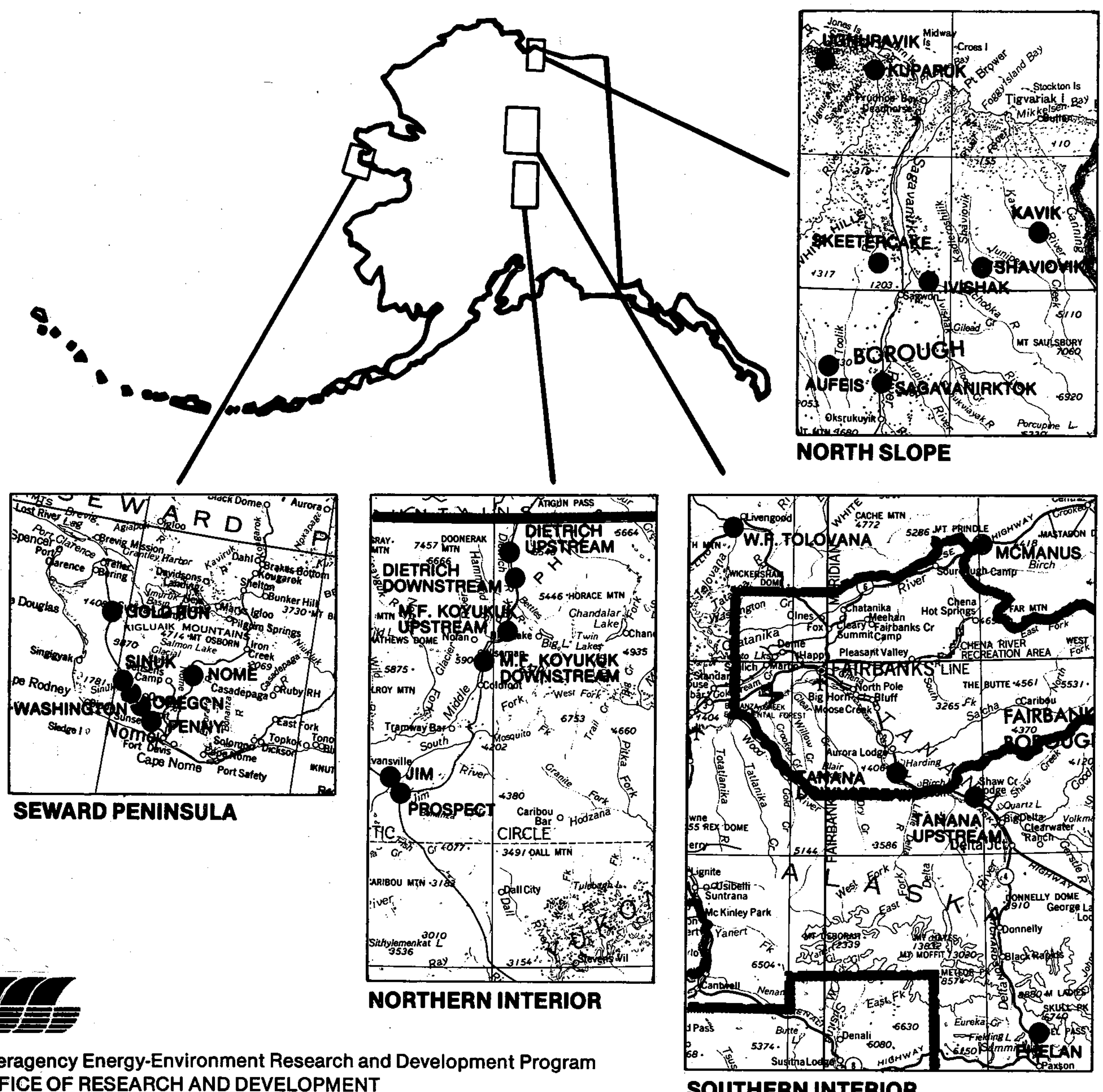
Gravel Removal Studies in Arctic And Subarctic Floodplains in Alaska



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FWS/OBS-80/08
June 1980

GRAVEL REMOVAL STUDIES IN ARCTIC AND SUBARCTIC FLOODPLAINS IN ALASKA

Technical Report

by

Woodward-Clyde Consultants
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EXECUTIVE SUMMARY

A 5-year gravel removal study was initiated in mid-1975 to evaluate the effects of gravel removal from arctic and subarctic floodplains in Alaska. The primary purpose of the project was to provide information that will assist resource managers in minimizing detrimental environmental effects resulting from floodplain gravel mining. To achieve this objective 25 material sites were studied by a team of scientists and engineers. Two major products of the project are a Technical Report which synthesizes and evaluates the data collected at the sites, and a Guidelines Manual that aids the user in developing plans and operating material sites to minimize environmental effects.

Data from the 25 study sites were collected and analyzed by the following six disciplines:

- River Hydrology and Hydraulics
- Aquatic Biology
- Terrestrial Ecology
- Water Quality
- Aesthetics
- Geotechnical Engineering

Data Analysis compared the Physical Site Characteristics (drainage basin size, channel width, channel configuration, channel slope, and stream origin) and the Gravel Removal Area Characteristics (type of gravel removal method, location of gravel removal, and age of the gravel removal site) with the measured effects of mining activities.

The general conclusion reached was that proper site selection and project design facilitate gravel mining with minimal effects on the habitats and fauna of floodplains. The key to the successful mitigation of potential detrimental effects is to carefully match the material site design and operation (site location, configuration, profile, schedule, and rehabilitation) with the Physical Site Characteristics of the selected floodplain.

VARIABLES INFLUENCING MINING EFFECTS

Physical Site Characteristics

Among the Physical Site Characteristics, channel configuration was the most important. Potential floodplain change is least for a braided river and greatest for a straight river. Size of channel is an important factor, with the least change to be expected in a large system and the greatest in a small system (assuming equally-sized material sites). Combining these two variables (channel configuration and size), gravel removal operations can be expected to have the least effect on large braided rivers and the greatest effect on small straight rivers.

Other influencing Physical Site Characteristics, which are related to configuration and size, are the availability and size of unvegetated gravel bars, floodplain width, and the distance that can be maintained between the mining site and the active channel. For example, in a small straight river system the floodplain is narrow and gravel bars are neither plentiful nor large. Thus, to extract gravel, either a significant length of active floodplain or the adjacent inactive floodplain and terrace must be disturbed. In the latter case the narrowness of the floodplain forces the operation to closely encroach upon the active channel. In large river systems these problems can be less significant because gravel bars are larger and, if the inactive floodplain or terrace are used, the wider floodplain allows maintenance of a broader undisturbed buffer zone between the material site and active floodplain.

Gravel Removal Area Characteristics

All of the Gravel Removal Area Characteristics were found to significantly influence the effects of gravel mining. The location of the material site relative to the active channel is considered to be the most important factor. Whether a material site is scraped or pit-excavated is important, but often pits are located away from an active channel, avoiding the types of changes that can be associated with scraping in active floodplains.

The major effects of pit sites located in inactive floodplains and terraces are the loss of vegetated habitat, the possibility for the occurrence of fish entrapment, a change in the appearance of the floodplain, and long-term delay in the re-establishment of predisturbance conditions. Where pit sites are situated close to active channels, particularly on the inside bends in meandering systems, the possibility exists for diversion of the channel through the pit, eventually forming a channel cutoff in the meander. This highlights the importance of providing a buffer between the material site and the active channel. Where pit sites are of suitable size, of sufficient depth, and have contoured perimeters, they can increase local habitat diversity and provide conditions suitable for fish and various species of terrestrial fauna.

Scraped material sites in active floodplains have minimal effects on the floodplain environment when only exposed gravel bars are excavated above the water level, and when slope and contours are maintained (resembling those of natural bars). Removal of vegetated areas or banks, which results in decreased lateral stability of active channels or allows water to spread over a large area, is not desirable. Decreased water depth and velocity increases sedimentation rates, alters water temperature, and alters dissolved oxygen levels. These changes in aquatic habitat usually affect the local distribution and community structure of benthos and fish.

The effects of scraping in vegetated areas of inactive floodplains and terraces can be similar to those described for pits. However, long-term changes typically are minimal because the lack of standing water in the closed site will facilitate re-establishment of pre-mining vegetation conditions.

If material sites are located and operated to prevent or greatly minimize effects on channel hydraulics, and to utilize only exposed gravel bars, the probability of major localized changes to a floodplain generally is greatly reduced. Where exposed gravel bars are not available or are inadequate, a tradeoff decision between sites must be made that weighs the potential effects of aquatic disturbances against terrestrial disturbances. In these cases, minimization of hydraulic change to active channels should be important in the decision -- major hydraulic changes can have a greater long-term effect on terrestrial systems than the controlled disturbances associated with a site located in a vegetated inactive floodplain or terrace.

RECOMMENDED FUTURE STUDIES

During the present study a number of subject areas were identified that should be investigated.

1. Evaluation of gravel mining from coastal and upland sources; and, preparation of guidelines for users of these sources. These alternatives to sources have not been studied.

2. Evaluation of the effects of multiple sites on one river system. Such an investigation should be aimed at determining the critical, spatial, and temporal relationships of multiple sites. Gravel replenishment rate predictions should be an integral part of this investigation.

3. Several floodplain gravel removal sites should be investigated before, during, and after mining to assess the adequacy of the Guidelines Manual.

4. Several topics of the Guidelines Manual should be studied in detail to assess their adequacy, (i.e., buffers, pit design, and active channel dredging).

This report was submitted in fulfillment of Contract Number 14-16-0008-970 by Woodward-Clyde Consultants, Anchorage, Alaska, under sponsorship of the Office of Biological Services, U.S. Fish and Wildlife Service. Work was completed as of June 1980.

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Woodward-Clyde Consultants appreciates the contributions of a number of scientists and engineers.

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INTRODUCTION

E. H. Follmann[a]

This Technical Report and the accompanying Gravel Removal Guidelines Manual for Arctic and Subarctic Floodplains (Guidelines Manual) present data analyses and conclusions resulting from a 5-year study of 25 floodplain material sites in arctic and subarctic Alaska, and provide guidelines to insure minimal environmental degradation when siting, operating, and closing floodplain material sites. This study, its results and conclusions, and these reports directly relate only to floodplains, although several aspects may also be applicable in nonfloodplain locations.

BACKGROUND

A common denominator in all resource and industrial development is the need for granular material; gravel is used worldwide for construction projects and transportation routes. In the arctic and subarctic, however, the presence of permafrost creates special construction problems that place additional demands on the supply of gravel.

Even slight alterations in the permafrost thermal regime caused by surface disturbances can cause thawing, thermokarst formation, subsidence, and erosional problems. Maintenance of the thermal regime is essential when building or operating in permafrost areas, but especially in regions characterized by fine grained soils with high water content. These latter areas are highly susceptible to subsidence when surface disturbance alters

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the thermal regime. In these cases, the thawed ground becomes a morass in which vehicle passage can be impossible and maintenance of structural stability of facilities becomes difficult.

The current major solution for eliminating or greatly reducing permafrost thaw is to use gravel as either pads for structures or as roadways. Although these demands exist elsewhere, the thickness of gravel required in permafrost areas is far greater than in nonpermafrost areas. The gravel pad in permafrost areas replaces the insulative function of the vegetative mat that was removed or compressed by the gravel fill. Since the insulative quality of the vegetative mat is greater than that of an equivalent thickness of gravel, a gravel pad must be considerably thicker to maintain an equivalent thermal regime. Under these circumstances the most important considerations for determining pad or road thickness are: climatic factors, soil surface temperatures, permafrost temperatures, and subgrade soil properties (McPhail et al. 1975). The objective is to establish the freeze front in or slightly below the fill (McPhail et al. 1975). Where this is accomplished, potential thaw problems can be greatly diminished.

Arctic and subarctic regions have been the focus of attention during the past several decades because of the wealth of natural resources known or thought to occur in these regions. The discovery of oil and gas on Naval Petroleum Reserve No. 4 (now the National Petroleum Reserve-Alaska) in the 1940's, at Prudhoe Bay in 1968, and in northern Canada has stimulated this interest and expanded it to include metallic minerals and coal. Expansion of exploration activities can be expected to continue.

As resource development in remote arctic and subarctic areas becomes more economically feasible the region's resources will be utilized to meet society's energy and material needs. These future projects will require increased quantities of gravel to facilitate construction and to provide stable substrates for various permanent and temporary facilities. For example, the gravel requirement for the Trans-Alaska Pipeline System was about 49 million cubic meters (m^3) (Michael Baker, Inc. 1977). Smaller projects requiring gravel, such as exploratory well drill pads and associated camps, typically use up to 75,000 m^3. If, however, airstrips and roads are associated with these sites, quantities can increase to several hundred thousand cubic meters. Based on experience constructing the Yukon River to Prudhoe Bay Haul Road (Haul Road), approximately 31,000 m^3 of gravel are required per kilometer of road construction, and maintenance requirements average about 700 m^3 per kilometer (km) per year for about the first 5 years (Alson personal communication). Alyeska Pipeline Service Company requested about 1.5 million m^3 of gravel for maintenance of their project over a 5 year period. The figures presented above for the large pipeline projects represent gravel needs from both upland and floodplain sites. About half of the gravel used on the oil pipeline was from floodplains.

Alluvial deposits found in broad floodplains offer one of the prime sources of gravel in northern areas. Individual material sites vary considerably in size, as indicated by the range of those considered for study in this project: 7,738 to 631,000 m^3 of material removed. Several different sites may be necessary to supply material meeting the required project specifications because one site may not contain all types of material needed. For example, not all potential sites will have material suitable for topping. Also, since road and pipeline construction projects need materials throughout their lengths, one site or a series of sites in one area will not satisfy the demands of these projects. A haul distance of 6.5 km or less has been estimated to be economically efficient for construction in Alaska, and haul distances of 13 to 16 km or less are planned for maintenance of the Trans-Alaska Pipeline System (Alson personal communication). Therefore, material sites for these types of projects necessarily must be located at regular intervals due to economic considerations.

To protect an environment from unacceptable disturbance, the elements comprising the environment must be known, the various elements of the proposed activity must be known, and the effects of the activity on the environmental elements separately and as a whole must be known. Where this information is available, guidelines to conduct the proposed activity with a minimum of environmental perturbation can be developed. Where information on one or more of these elements is lacking or is only partly understood, any guidelines that are developed are based on estimates and assumptions whose validity is dependent on the experience and predictive powers of those developing the guidelines. The latter condition is the rule in most cases where environmental impacts are concerned. Impacts from resource exploration and development have not been studied as much as is necessary to make intelligent decisions regarding environmental impacts. This lack of research is particularly true in arctic and subarctic regions. The remoteness of the area and the high cost of conducting research have not facilitated an adequate description of the environmental elements. Studies of the environmental effects of development have been similarly hindered.

Extensive literature review revealed that the specific impacts of gravel removal had seldom been studied and, therefore, were poorly understood. Description of impact had been attempted in only a few cases (Bull and Scott 1974, Federal Water Pollution Control Administration 1968, Forshage and Carter 1973, Sheridan 1967); and these studies dealt specifically with only one aspect, e.g., fisheries. LaBelle (1973) reviewed gravel and sand availability in the Barrow area of the National Petroleum Reserve-Alaska and made recommendations on gravel extraction and evaluations of potential environmental impact. Northern Engineering Services Company Limited and Aquatic Environments Limited (1975) evaluated the material sites associated with the Trans-Alaska Pipeline System with reference to aquatic habitat. In addition, several reports identified problems associated with gravel extraction as one of many sources of environmental perturbations that could be expected from new and continued exploration and development in the north (Bliss and Peterson 1973, Klein 1973, Weeden and Klein 1971, West 1976). None of these latter reports presented results of any material site studies.

There have been few studies on the environmental effects resulting from construction of the Trans-Alaska Pipeline System. The Joint State/Federal Fish and Wildlife Advisory Team (JFWAT) prepared a report on surveillance experience with gravel mining recommendations (Burger and Swenson 1977). The JFWAT also produced a series of reports dealing with experiences on the pipeline, including environmental effects studies. However, the major responsibility of the majority of JFWAT staff was environmental surveillance of construction, not research on environmental effects.

Weeden and Klein (1971:481) stated: "As with so many other problems of tundra management, the design of criteria for mining operations in gravel lags far behind present need because detailed knowledge of fish populations -- where they are, when they migrate, where they spawn, their vulnerability to added silt loadings of river waters, etc. -- is lacking". By early 1975, the state of knowledge had not progressed or expanded greatly. This fact, coupled with the dependence on gravel for arctic and subarctic construction, stimulated the U.S. Fish and Wildlife Service to initiate a project to investigate the effects of gravel removal on floodplain systems. The project objective was to provide a comprehensive information review and data synthesis to form the basis for future mining of river and floodplain gravels. The purpose of the project is to provide an information base that will assist resource managers to formulate recommendations concerning operations that will minimize detrimental environmental effects of gravel removal from arctic and subarctic streams.

PHILOSOPHY

Little is known about the natural changes which occur in riverine systems in arctic and subarctic regions. Therefore, determining the effects of resource exploitation in these regions is often difficult because of the interplay of natural changes and man-induced disturbances. The basis for this study was the assumption that gravel removal operations in a floodplain cause change, the magnitude of change depending primarily on the floodplain characteristics, the location of the site, and the method of gravel extraction. Since almost all riverine systems in arctic and subarctic regions have evolved to the present through natural change and without man-induced disturbances, all changes due to gravel removal identified in this study were considered undesirable. To maintain a river system in its natural or near-natural state was considered the essence of guidelines development and provided the best conceptual base from which to minimize environmental degradation. However, it is recognized that there may be situations where resource managers may wish to exercise other options. Any site characteristics or methods that facilitated rapid recovery to predisturbance conditions were considered for implementation as guidelines.

The presupposition that all changes due to gravel removal are undesirable does not, by necessity, cause the data analyses and recommendations to be impractical. It is a foregone conclusion that changes will occur when gravel is removed from a floodplain. To note that changes from the natural state were less at one site than another suggests that the former site was operated more consistently with characteristics of the system than the latter, thereby reducing the magnitude of change. The floodplain and gravel removal characteristics at sites that produced these minor changes formed the primary basis for development of constructive guidelines to minimize change. Conversely, the floodplain and gravel removal characteristics at sites with major changes supported development of guidelines primarily of a precautionary nature.

The analyses in succeeding chapters treat the changes that were measured at individual study sites. There are sites, for example, where species diversity increased as a result of site disturbance. In some contexts, this increased diversity would be considered a beneficial effect of gravel removal. However, in the context of this project, this effect initially was evaluated equal to one which caused an equivalent decrease in species diversity because it reflected a change from the naturally evolved condition.

This project treats all changes consistently and objectively as a change from the natural, and special interest perspectives are neither recommended nor encouraged. However, it is recognized that a resource manager in certain circumstances may be greatly influenced by the need to consider a site from a multiple or optimal use standpoint. For example, subsequent to gravel removal a deeply dug site might be considered as a water source in areas where winter supplies of water are minimal. Several study sites were deep pits that contained water throughout the year. Formation of a pit represents a major change from the natural situation and the site will not revert back to a natural situation for many years, if at all.

In the context of this project, pits represent a major divergence from the natural. However, when considered from the standpoint of multiple use or habitat diversification, a resource manager may elect to recommend or approve a permit for this form of gravel removal. In these situations the resource manager will be able to predict the results of such an operation by review of the following sections in this report.

PROJECT DESCRIPTION

A 5-year gravel removal study was initiated in mid-1975 to evaluate the effects of gravel removal from arctic and subarctic streams in Alaska. The primary purpose of the project was to provide an information base that will assist resource managers in formulating recommendations for minimizing detrimental environmental effects of removing gravel from arctic and subarctic streams. To achieve this the following objectives were met:

- A comprehensive literature review and synthesis was conducted to evaluate known and conjectured effects of gravel removal and other similar disturbances on floodplain environments.

- Physical, chemical, and biological characteristics of seven sites inhabited by fish after gravel removal were evaluated in moderate detail on a short-term basis.

- Physical, chemical, and biological characteristics of 18 sites that reflected various removal methods, stream types, and times since completion of operations were determined in gross detail and on a short-term basis.

- Relationships between parameters related to gravel removal operations, geomorphic characteristics of streams, water quality, and biota were evaluated.

The study of three sites prior to, during, and immediately after gravel removal was an original project objective that was eliminated due to a lack of suitable sites meeting project schedules.

A thorough and broad-spectrum evaluation of the impacts gravel removal can have in floodplains requires assessment from a number of disciplines. To look at only one element could lead to conclusions and recommendations that might cause major changes to a riverine system on a long-term basis. Therefore, the approach taken in this study included analyses in the following six disciplines:

- River Hydrology and Hydraulics
- Aquatic Biology
- Terrestrial Ecology
- Water Quality
- Aesthetics
- Geotechnical Engineering

This approach not only allowed analysis by individual discipline, but permitted consideration of the interdiscipline trade-offs inherent in evaluations of disturbances to natural environments. For example, gravel mining techniques that would avoid effects on aquatic biota could require removal of important floodplain habitat used by terrestrial fauna or be impractical from geotechnical considerations.

These disciplines were selected for the study because they were believed to cover the various impacts that were known or surmized to be associated with gravel removal. Due to a paucity of background information, it was not possible to be assured that all significant impacts were addressed by these disciplines.

Although the main purpose of this gravel removal study was to provide an information base for recommendations to be made by resource managers, another important contribution is to provide a base for subsequent long-term studies. For example, a problem needing extensive study is the effect of removing gravel from many sites in one river system, as occurs along highways and pipelines when they parallel floodplains for routing or geotechnical reasons. This problem is not treated in the present study and, in fact, was consciously avoided when sites were selected.

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APPROACH AND METHODOLOGY

E. H. Follmann[a]

SITE SELECTION

The site selection process began in July 1975 and initial work involved contacting various agencies and groups to locate potential study sites. Among those contacted, the main sources of information were the Bureau of Land Management, the Alaska Pipeline Office, the Alaska Division of Lands, and the State Pipeline Coordinator's Office. In addition, the Alaska Department of Highways (now Alaska Department of Transportation and Public Facilities) provided a considerable amount of information.

A total of 575 potential sites were identified and subdivided into three areas north of Latitude 66° -- the North Slope, the Yukon River Basin, and the Seward Peninsula -- to obtain representative sites throughout arctic and subarctic Alaska. Later in the project the Yukon River Basin sites were separated into Northern Interior and Southern Interior sites. Following identification of these sites, field reconnaissance was initiated to assess the suitability of the sites for the study and to characterize those sites considered potential candidates for the study. Sixty-four sites remained as candidates following field reconnaissance.

To augment the drainage and material site descriptions developed in the field for the 64 sites, additional information on gravel removal activities and watershed characteristics was obtained from various agencies,

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topographic maps, and other data sources. Based on more complete site descriptions, preliminary variables were established with which to compare and select sites.

Site comparisons were restricted to sites within the same region to insure adequate representation of the North Slope, the Northern Interior, Southern Interior, and the Seward Peninsula. Six sites were selected to represent the Seward Peninsula, eight for the North Slope, six for the Northern Interior, and five for the Southern Interior (Figure 1). The sites were categorized by the presence or absence of fish on the basis of field observation and reliable background information. The sites that were known to contain fish after gravel removal were compared to determine which should receive additional study.

All sites were previously mined. As stated earlier, sites could not be identified which would allow studies (within project schedules) before, during, and after gravel removal operations. All sites were named in accordance with the U.S. Board of Geographic Names. However, two sites occurred on unnamed streams and were assigned project names of Skeetercake Creek (unnamed tributary to the Toolik River) and Aufeis Creek (unnamed tributary to the Kuparuk River). When two study sites occurred on the same river, they were designated upstream and downstream respective to their locations.

Major Variable Matrix

Following site selection the preliminary variables used to compare sites were reviewed to determine which should be considered major variables. Initially, nine major variables identified as either site characteristics or mining characteristics were selected to describe each of the 25 sites (Woodward-Clyde Consultants 1976). These parameters were chosen because they were thought to be important from the standpoint of assessing gravel removal effects, they best described the sites, and they allowed selection of sites which exhibited the greatest variety of variables. The variety was especially important because it insured that sites were different, thus

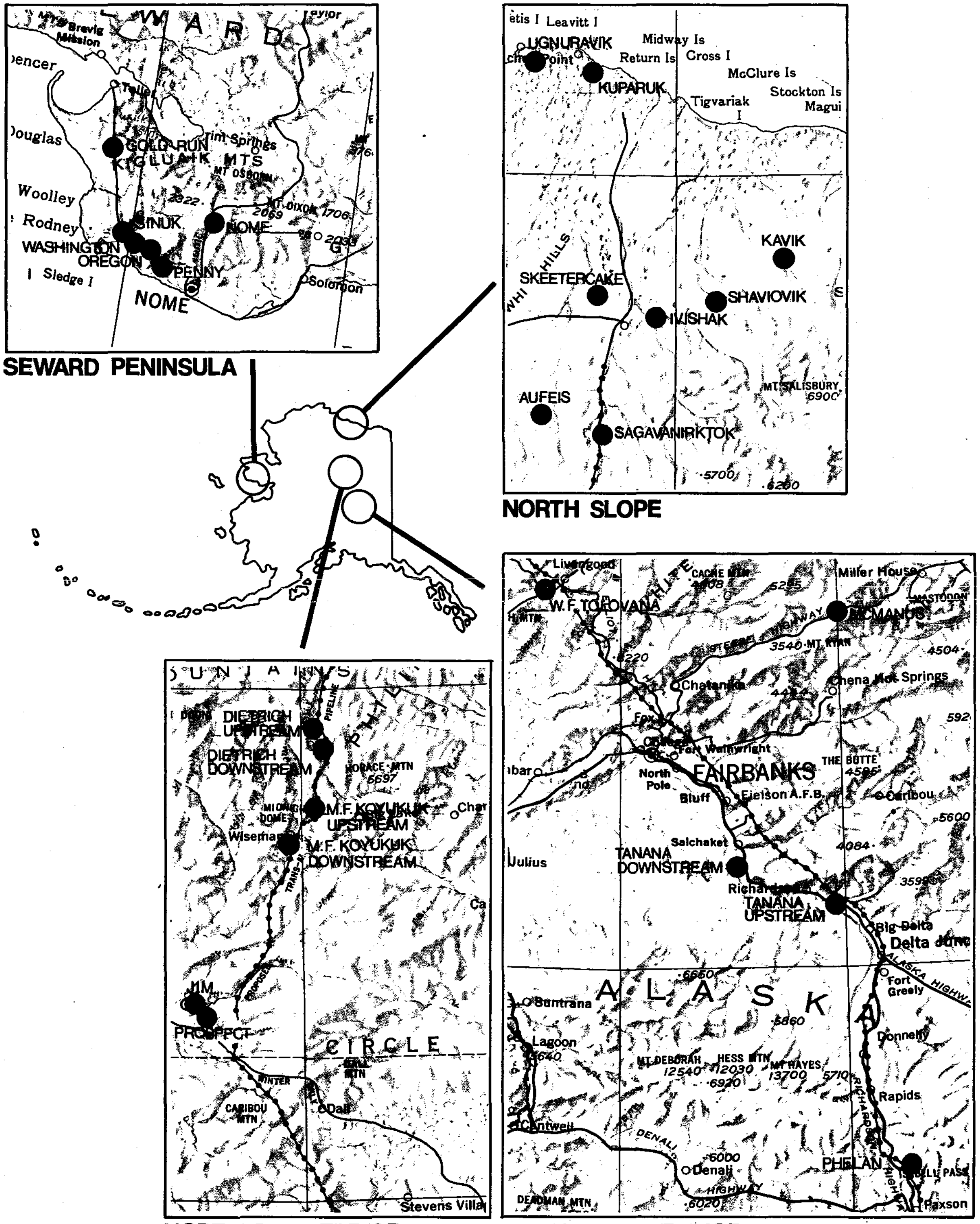

Figure 1. Location of the 25 gravel removal study sites in Alaska.

permitting assessment of the effects of various gravel removal procedures on sites with different physical and biological characteristics.

The major variables were again reviewed following the field investigation, when detailed site characteristics were available to determine which were still suitable for comparing the 25 material sites. The seven variables selected for the final Major Variables Matrix included:

- Drainage basin size,
- Channel width,
- Channel configuration,
- Channel slope,
- Stream origin,
- Type of gravel removal, and
- Location of gravel removal.

These parameters were categorized as either Physical Site Characteristics or Gravel Removal Area Characteristics. Each of the sites was characterized according to these variables (Table 1). Definitions of these variables are included in the Glossary.

Physical Site Characteristics. Drainage basin size and channel width are significant because the impact of gravel removal could differ depending on the amount of disturbance in proportion to the size of stream and floodplain. Also, systems having greater discharge and bed load movement could be expected to regenerate a material site more rapidly than a system with smaller discharge and less bed load movement assuming the amount of mining disturbance is proportionate in the two streams. Categories used were small, medium, and large based on the drainage area above the site and small, medium, and large based on the channel top width within the study reach at mean annual flow. Although from a hydrological standpoint categorization only according to drainage basin area would have been sufficient, we considered it important to include channel width because width is a tangible measurement that can be observed at a site location.

Table 1. Major Variable Matrix

Study Site	Drainage basin size: Small	Drainage basin size: Medium	Drainage basin size: Large	Channel width: Small	Channel width: Medium	Channel width: Large	Channel configuration: Braided	Channel configuration: Split	Channel configuration: Meandering	Channel configuration: Sinuous	Channel configuration: Straight	Channel slope: Mild	Channel slope: Moderate	Channel slope: Steep	Stream origin: Mountain	Stream origin: Foothill	Stream origin: Coastal plain	Stream origin: Glacial	Type of gravel removal: Pit-connected	Type of gravel removal: Pit-not connected	Type of gravel removal: Scrape	Location of gravel removal, In channel: Active channel	Location of gravel removal, In channel: High-water ch.	Location of gravel removal, In channel: Abandoned channel	Location of gravel removal, Adjoining channel: Point bar	Location of gravel removal, Adjoining channel: Lateral bar	Location of gravel removal, Adjoining channel: Mid-channel bar	Location of gravel removal, Adjoining channel: Bank	Location of gravel removal, Separated from active channel: Inside meander	Location of gravel removal, Separated from active channel: Outside meander	Location of gravel removal, Separated from active channel: Island	Location of gravel removal, Separated from active channel: Near channel	Location of gravel removal, Separated from active channel: Distant from ch.	Years since gravel removal
SEWARD PENINSULA																																		
Gold Run Creek	X			X						X				X		X					X				X		X	X			X			11
Sinuk River		X			X			X					X		X						X		X			X	X	X			X			10
Washington Creek	X			X						X				X		X					X	X	X			X		X			X			13
Oregon Creek	X			X							X			X		X					X	X	X			X		X						13
Penny River	X			X						X			X			X			X		X	X	X		X	X	X	X	X	X				11
Nome River		X			X					X			X		X						X	X	X		X	X								20±
NORTH SLOPE																																		
Ugnuravik River		X			X					X		X					X		X		X				X	X		X						7
Aufeis Creek		X			X				X				X			X					X	X	X		X	X	X		X	X		X		5
Kuparuk River			X			X		X				X				X					X					X								9
Skeetercake Creek	X			X					X				X			X					X	X			X	X		X	X					11
Sagavanirktok River			X			X		X					X			X					X		X			X	X				X			3
Ivishak River			X			X	X						X		X						X							X						3
Shaviovik River		X			X					X			X		X						X				X	X								5
Kavik River		X			X			X						X	X				X		X	X	X			X	X	X						7 & 3[a]
NORTHERN INTERIOR																																		
Dietrich River-US		X			X		X						X		X				X		X		X					X				X		2
Dietrich River-DS		X			X		X						X		X						X		X			X							X	3
M.F. Koyukuk River-US			X		X					X			X		X						X		X		X	X		X	X					4
M.F. Koyukuk River-DS			X		X					X			X		X						X		X		X				X					2
Jim River		X			X					X			X		X						X		X			X		X	X				X	2
Prospect Creek		X		X					X				X		X				X					X				X	X			X		2
SOUTHERN INTERIOR																																		
W.F. Tolovana River		X			X				X				X			X			X					X				X				X		3
McManus Creek	X			X						X				X		X					X					X						X		16
Tanana River-DS			X			X	X						X					X		X											X			4
Tanana River-US			X			X	X						X					X	X													X		13
Phelan Creek	X				X		X							X				X			X	X	X			X	X							3

[a]The Kavik River was mined during two separate periods: 1968-1969 and 1973-1974.

Channel configurations vary from straight mountain streams to braided rivers. Factors associated with various types of streams such as bed load movement, bank erosion, and water fluctuation were considered important. Configurations included in this study were braided, split, meandering, sinuous, and straight.

Channel slope, along with other variables, is a major factor governing water velocity, discharge, and sediment transport. Therefore, streams with slopes categorized as mild, moderate, and steep were included.

Stream origin was considered because it governs aspects of stream hydrology. Stream origin also influences the amount of bed load material available for transport, thereby indicating the regenerative capacity of a stream, and the availability of suspended sediment that could deposit in a gravel removal area. Categories used were mountain, foothill, coastal plain, and glacial.

Other factors such as stream bed material, bank vegetation, and watershed characteristics are important, but were not considered as major variables. To a large extent these factors are accounted for by the major variables and the physiographic provinces occurring within the regions.

Gravel Removal Area Characteristics. Two major types of gravel removal operations used in floodplain areas are pits and scrapes, distinguished primarily by depth of excavation and permanent inundation by water after site closure. During site visits it was apparent that pits were either connected or not connected to an active stream channel. Because magnitude of change to a system could be greatly influenced by this factor, pits were characterized as either connected or not connected.

Location of gravel removal sites within a floodplain influences the degree of impact and the regenerative potential of a site. Therefore, distinctions were made between sites located in a channel, adjoining a channel, and separated from a channel.

To determine the impact of gravel removal over time and the regenerative capacity of various types of streams, it was necessary to observe sites that were active during different years. Information was not available for sites associated with construction activity early in this century, but was for sites ranging back to the late 1950's.

Specific descriptions of the regional characteristics, physical site characteristics, and characteristics of the gravel removal operation at the 25 study sites occur in a subsequent section.

DATA REVIEW

Available information regarding the effects of gravel removal and other similar disturbances in floodplains was reviewed. Information was solicited from many Federal and most State agencies, from various Canadian groups, and from literature sources. Due to a minimum of information on the effects of gravel removal, particularly in arctic and subarctic regions, some of the processes involved had to be discussed from a theoretical standpoint.

The results of this work were included in a Preliminary Report prepared in 1976 (Woodward-Clyde Consultants 1976). This report should be referred to if a review of available literature is desired.

FIELD STUDY OF SELECTED MATERIAL SITES

Preparation for the field program began in Spring 1976 and the last site was visited in March 1979. Site visits were split over three summers with 7 sites studied in 1976, 10 sites in 1977, and 8 sites in 1978. In addition, seven sites were visited during the winters of 1977-1978 and 1978-1979 to determine the presence or absence of fish, to record water quality parameters, and to describe the occurrence of icing conditions.

During the 1976 field program field teams representing River Hydrology and Hydraulics, Aquatic Biology, and Terrestrial Ecology worked each site simultaneously. The Aquatic Biology team also collected water quality data. Simultaneous effort of field teams was considered advantageous during the first field season to insure coordination of work where necessary. In addition, simultaneous work permitted on-site discussion of methodology changes by all disciplines, thus further insuring coordination and cooperation. During subsequent field seasons, some of the sites were visited by individual field teams, but all teams visited the sites during the same summer. These individual visits allowed each team to visit sites during peak events for parameters associated with their discipline. Data and sample collection areas were flagged to facilitate collection of data at the same sites during subsequent visits by either the same or different teams. In addition, the hydrology and hydraulics and terrestrial teams placed semi-permanent posts at each site from which to initiate surveys for future studies.

The following section includes a review of the field and laboratory programs conducted during the field effort. Programs are described only for River Hydrology and Hydraulics, Water Quality, Aquatic Biology, and Terrestrial Ecology because these were the only disciplines for which data were specifically collected. Geotechnical Engineering and Aesthetics relied completely on field information collected by other groups.

River Hydrology and Hydraulics

Introduction. Emphasis of the field program was on describing local fluvial geomorphic processes, obtaining evidence of past flood histories, measuring river hydraulic parameters, investigating sediment transport properties of the channels, describing river processes, and investigating specific effects of gravel removal on these factors. Photographs were taken for documentation of significant features. Hydraulic and hydrological data collection were coordinated with the water quality, aquatic biology, and terrestrial ecology studies.

Hydrological and geomorphological literature pertaining to each site and its drainage basin, e.g., hydrological records, surficial geology, and aerial photographic interpretations were also used in the analysis of each site.

Geology and Geomorphology. Using topographic maps, stereo aerial photography, and surficial geology maps, a brief analysis of each drainage basin was made to evaluate the geomorphology of the river valley, the river terraces, and the present and past regime of the river. The morphological features pertaining to the general area around the material site were verified in the field.

Hydrology. The U.S. Geological Survey Water Resources Records were reviewed for flow measurements within a study site's drainage basin. Where flow measurements were representative, various key discharges with the respective stages were estimated and documented. In the field, evidences of floods were investigated. Where sufficient data could be obtained at the study site or near vicinity, a stage-discharge relationship and flood frequency analysis were included in the data package. For the rivers that had no past flow records, the hydrology was synthesized using a regional flow analysis (Lamke 1979).

Hydraulics. Hydraulic parameters for each river channel and floodplain were measured in the field. At each study site cross sections were surveyed upstream from, within, and downstream from the area of gravel removal (in conjunction with the aquatic ecology program) to measure the following hydraulic parameters: width, depth, and area. All cross section locations were documented and elevations referenced to temporary benchmarks. The longitudinal slope of the water surface and, where possible, the bed were surveyed. All surveys used standard surveying techniques. The discharge at the time of the survey was measured using standard techniques (Buchanan and Somers 1969).

Materials and Sediment. Representative samples of the river's floodplain surface material were obtained upstream and downstream from the gravel removal area using the photographic-grid method (Kellerhals 1971). These were considered to be representative of the channel bed material. The size distribution was determined by the frequency-by-number method. In addition, the underlying material was measured using hydraulic sieves and the size distribution determined by percentage-by-weight.

The river bank materials were described at cross section locations based on a subjective evaluation and photographed for documentation. Material gradation samples of river bank materials were not obtained.

Channel Processes. The fluvial morphology at each site was assessed using comparative aerial photography. In the field, fluvial morphological features were verified and documented in more detail, e.g., gravel bar types, bed formations, scour holes, and sediment deposition. Degradation and/or aggradation upstream from, and downstream from the gravel removal site were investigated.

River Ice. In the field, evidences of ice processes (breakup jams, ice scour, gouging, and aufeis) were documented to help evaluate the role of ice on the river morphology.

Water Quality

Water quality parameters measured were temperature (^{o}C), dissolved oxygen (ppm), conductivity (micromhos/cm^2), turbidity (JTU), suspended solids (mg/ℓ), oxidation-reduction potential (MV), and pH (Table 2). Water quality measurements were taken at the aquatic macroinvertebrate sample sites. Usually the measurements were taken along a transect across the river or pit with the number of replicates within a site adjusted to the size of the water body. The measurements were normally within 30 cm of the water surface, although depth profiles were taken in pits.

Aquatic Biology

Introduction. Field emphasis was placed on aquatic invertebrates, changes in fish distribution in relation to the gravel mined area, and potential fish spawning and rearing habitat during the ice-free period.

Table 2. Methods Used for Measuring Water Quality Parameters with the Number of Replicates Taken per Study Area

Parameter	Method of determination	Replicates per study area
Dissolved oxygen	YSI Model 57 DO meter	3 - 15
Temperature	YSI Model 57 DO meter	3 - 15
Conductivity	Hach Model 2510 conductivity meter	3 - 15
Turbidity	Hach Model 2100A turbidimeter	2 - 11
Suspended solids	Millipore filter procedure (5 µm filter)	1 - 3
Oxidation-reduction potential	Delta Scientific 1212-P2 ORP meter	2 - 5
pH	Delta Scientific 1212 pH meter Hach pH kit	1 - 5 1

Additional visits were conducted to specific sites if potential overwintering habitat or suspected spawning areas were present within the mined area.

Study sites were categorized into two groups. Eighteen sites were visited once during the open water season. Seven sites with known fish utilization in the mined area were subject to additional field study. These seven sites were visited on three separate occasions during open water conditions of 1 calendar year. In addition, seven pit sites where winter utilization by fish was suspected were visited to document overwintering.

The 18 sites subject to a less intensive field program were visited only once.

Selection of Sample Areas. Three sample areas were selected at all sites: upstream, within the mined area, and downstream. Selection of upstream and downstream sample areas was based on similarity to the aquatic and terrestrial characteristics exhibited in the mined area prior to gravel removal. Selection of sample areas was made so that substrate, depth, width, velocity, and pool:riffle ratio were similar at the upstream and downstream locations.

The upstream area was typically located at least 400 m above the mined area and the downstream area was between 400 and 800 m below the mined area. Selection of the 400 m criteria was based on the assumption that the hydrological effect of gravel removal would be minimal that far upstream. Selection of a downstream area between 400 and 800 m below the mined area was based on the probability that changes occurred in this area either during or immediately after gravel removal.

At sites with more than one mined area, additional sample areas were selected to assess effects. Similar selection criteria were used.

Selection of Sample Gear. Fish and aquatic macroinvertebrate sampling gear were selected relative to the types of habitat present. Features such as width, depth, stream velocity, shoreline configuration, stream bank vegetation, obstructions, channel substrate, and presence of pits affected the gear selection process. Sample gear used at each study site is listed in Table 3.

Sample Program. Information recorded in the field included stream name, sample location and description, description of the disturbed area, and the date, time, and existing weather conditions. Visual surveys were conducted within sampling areas to describe habitat and to record the presence of fish.

Sample Collection, Disposition, and Analysis. A variety of seines with square mesh (3.2 mm), 6 to 10 m long and 1.8 m deep, were used. Seines were extended across the stream from bank to bank and pulled downstream in narrow streams. In larger streams and pits the quarter-haul technique was used. Experimental, multifilament gill nets 15 x 1.8 m, with panels of 12.7, 25.4, 38.1, 50.8, and 76.2 mm square mesh, were anchor-set in pits, and, in one case, in the deep, slow-moving section of a large river.

A backpack shocker, one of the least selective of all active fishing methods, was used in appropriate watercourses. Stream width permitting, a preselected length of stream was blocked with seines and the enclosed area shocked repeatedly until fish were no longer captured or observed. The area of the shocked section was usually measured to allow for density estimation.

Minnow traps selective for juvenile and small adult fishes were used to sample aquatic habitats. Traps were located in pools, riffles, and pits and were baited with salmon eggs. Traps were usually fished from 12 to 24 hours.

A dip net was used at one site to capture juvenile fishes for identification. Visual surveys were made at each site to record distribution and unusual events or critical habitats, such as spawning areas.

Table 3. Aquatic Biology Sampling Methods Used at Each Study Site

Study site	Macroinvertebrate sampling gear: Surber sampler	Macroinvertebrate sampling gear: Ponar grab	Fish sampling gear: Minnow trap	Fish sampling gear: Seine	Fish sampling gear: Gill net	Fish sampling gear: Electro-shocker	Fish sampling gear: Hook & line	Fish sampling gear: Set line
Seward Peninsula								
Gold Run Creek	+					+		
Sinuk River	+		+	+		+		
Washington Creek	+		+			+		
Oregon Creek	+		+	+		+		
Penny River	+	+	+	+				
Nome River	+		+	+				
North Slope								
Ugnuravik River	+	+	+	+				
Aufeis Creek	+		+	+		+		
Kuparuk River	+		+	+	+			
Skeetercake Creek	+		+	+				
Sagavanirktok River	+		+	+		+	+	
Ivishak River	+		+	+		+		
Shaviovik River	+		+	+		+		
Kavik River	+		+	+		+	+	
Northern Interior								
Dietrich River-US	+	+	+	+	+			
Dietrich River-DS	+		+	+				
M.F. Koyukuk River-US	+		+	+				
M.F. Koyukuk River-DS	+		+	+		+		
Jim River	+	+	+	+		+		
Prospect Creek	+	+	+	+				
Southern Interior								
W.F. Tolovana River	+	+	+	+	+			+
McManus Creek	+		+	+		+		
Tanana River-DS		+	+		+			
Tanana River-US		+	+	+	+			+
Phelan Creek	+		+	+				

Captured fishes were identified, measured (fork length), weighed, and released except when preserved for reference. Data collected were used to determine species composition, size distribution, and relative abundance; estimates of density were made. These evaluations were compared within and between gravel removal sites.

Macroinvertebrates. A 30-cm square Surber sampler was used to collect macroinvertebrates in riffle areas. Sampling areas were stratified by depth, bottom type, current velocity, and other variables that may have been correlated with benthic distribution. At most study areas three sampling sites were selected and five replicate samples were collected at each sampling site. Two sampling sites were selected in a few cases where there were multiple mined areas or where the river was not directly affected by gravel removal, e.g., a pit site away from the stream channel, with five replicates taken per site.

A Ponar grab was used to collect macroinvertebrates in pits. Single grabs were taken at several stations spaced to cover the main depth regions within the pits. Ponar grab samples were cleaned, separated (the slurry passed through a U.S. Standard No. 30 sieve), and placed in labeled containers.

Samples collected with the Surber sampler were placed directly into labeled containers. All sample containers were filled with 70 percent alcohol to preserve specimens for later examination. Samples were picked and sorted in the laboratory. Organisms were sorted into major categories and placed into labeled vials containing 70 percent alcohol. Identification was to the lowest practical taxonomic level.

Data from quantitative samples were used to obtain total and individual taxon density. Data on standing crop and number of taxa were evaluated; comparisons were made within and between sample sites.

Pit Sampling Program. Four pits were visited during March 1978 to assess the potential for fish entrapment and overwintering. During the following summer these pits, plus three additional ones, were visited to assess if fish were present. The pits were then revisited during the 1978-79 winter to assess if fish remained in the pit after freezeup or moved into the river. If fish remained in the pit, subsequent visits were made to determine if fish could survive the winter. Sampling was conducted with a variety of gear types including minnow traps, set lines, gill nets, hook and line, and observation. In addition, an underwater television system was used for surveillance under the ice at two pits. Dissolved oxygen and temperature were measured when water was present. Ice thickness, presence or absence of flowing or open water, or both, and formation of aufeis by overflow were recorded.

Terrestrial Ecology

Introduction. The terrestrial field program identified habitats affected by gravel removal operations and assessed the impact of habitat modification on associated wildlife. Qualitative and quantitative surveys were conducted during a 3-day field effort to characterize the plant communities and seral stages present on disturbed and undisturbed areas. Wildlife utilization of these habitats also was evaluated. The undisturbed sites encompassed seral stages likely to develop with time on the disturbed site, and were believed to be most representative of the disturbed areas prior to gravel removal.

The program was expanded to 5 days at one representative study site (regional representative site) in each of five geographical areas: Arctic Coastal Plain (North Slope), Arctic Foothills (North Slope), Seward Peninsula, Northern Interior, and Southern Interior. The increased time at these study sites allowed for additional sampling efforts using the same sampling procedures.

Soils. Soil sampling was conducted within each habitat on disturbed and undisturbed sites to evaluate the growing conditions and the potential for revegetation. Within each habitat or definable soil unit, the character of the upper horizon, depth of organic layer, surface drainage, and dominant vegetation were recorded. Approximately 15 subsamples were collected with a soil auger-tube sampler from the ground-cover rooting zone (approximately the upper 20 cm). These subsamples were combined to form one composite sample for each soil unit. Composite samples were air dried and analyzed for pH, percent organic matter, and percent nitrogen, phosphorus, and potassium. A particle size distribution analysis was conducted to determine the percent sand, silt, and clay in the composite sample.

<u>Vegetation</u>. Vegetation surveys delineated the major cover types within the study area. Within each habitat, the seral stage of development was noted and the plant species were recorded.

Qualitative site descriptions were augmented by limited use of quantitative sampling methods that employed a systematic, nested plot design (James 1978). Strand or patch habitats required "spot" location of nested plots or qualitative description only.

Description of the overstory vegetation included the following parameters: dominant and subordinate tree species, average height and DBH (diameter at breast height) of the stand and stand components, and representative ages by species and height class. A limited number of circular plots (0.04 ha) were used to quantitatively sample each habitat. Forester's calipers or a diameter tape, or both, were used to determine tree DBH; tree height was estimated and an increment borer or cross-sectioning method was employed to determine the age of woody plants. Increment cores and cross sections were returned to the laboratory for staining and age determination when necessary.

Shrub growth within each habitat was described by identifying species composition and relative density, average height by species, and representative ages by species and height class. Stem and clump density counts were conducted on a limited number of systematically located, 0.004-ha circular plots. Selected shrubs were aged by cross-sectioning above the root collar. Evidence of herbivore browsing was noted.

Ground cover sampling identified species composition within each habitat and provided an estimate of percent surface coverage for each taxon. Percent surface coverage was visually estimated in systematically located, 0.0004-ha plots. Percent surface coverage was estimated as follows: if only one plant of a given taxon was present and its coverage was very sparse, it was rated at 1 percent coverage; if more than one plant of a given taxon was present, but its coverage was less than 10 percent of the plot's surface area it was rated at 5 percent coverage; the percent coverage of all other taxa was estimated in increments of 10.

Wildlife. Evidence of wildlife use of disturbed and undisturbed areas was recorded at each site. Direct observations and evidence of use (tracks, trails, nests, dens, runways, food caches, and scats) were keyed to their presence in specific seral stages. Historical use of a cover type was noted (i.e., hedged growth form of preferred browse species) and seral stages critical to certain life history stages of wildlife were inspected. The disturbed area was examined for the presence of special attractants or deterrents to wildlife use of the site.

An avian census was conducted in disturbed and undisturbed habitats at all study sites; attempts were made to visit the five intensive study sites during the peak avian activity period. The census in homogeneous habitats employed a Modified Strip Plot technique for three consecutive mornings (five mornings at the intensive sites) to obtain data on the species present and habitat utilized. Small, isolated habitats were qualitatively surveyed to ascertain avian species occurrence. Waterfowl, shorebirds, and game birds were inventoried by total counts when areas of concentration were clearly visible.

Small mammals (shrews, voles, and lemmings) were inventoried at all sites in disturbed and undisturbed habitats using a trap and removal technique. A "line" or "spot" trapping configuration was used in all cover types. Trapping was conducted for two nights at nonintensive sites and four nights at regional representative sites with the traps checked, baited, and reset each day. The species, sex, age, and weight of captured specimens were recorded to assess occurrence and characteristics by habitat.

Collection of terrestrial invertebrates was conducted at all fish intensive sites and at the regional representative sites. Collections were made adjacent to the watercourse at the disturbed site and near the upstream aquatic sampling station to assess the availability of potential food sources for the aquatic environment. Sweep nets were used to collect invertebrates. Specimens were preserved in 40 percent alcohol and returned to the laboratory for identification.

DATA BASE

The data base, the third end product of the gravel removal study, (the Technical Report and Guidelines Manual are the first two end products) consists essentially of all information collected during site selection and field data collection. Information for each of the 25 study sites includes:

- Case history information including mining plans and permits, if available;
- Biological, hydrological, and water quality field data;
- Geotechnical evaluations;
- Tabulation of data summations;
- Computer printouts for aquatic ecology and hydrology and hydraulics;
- Draft site description reports;
- Site photographs, including both ground and aerial;
- Topographic maps showing site location; and
- Depiction of actual data collection areas within each site.

The information is in a form to allow any professional to evaluate where the data was collected, what data was collected, and the general conclusions of the original investigator.

This data base is on file with the U. S. Fish and Wildlife Service. It will not be distributed routinely with the Technical Report and Guidelines Manual. Due to the mass of information available, a specific need will have to be identified before the data relevant to that need can be provided.

TECHNICAL REPORT

Analyses of field data, beyond the immediate data reduction after site visits, began in winter 1977-78. This initial effort prepared descriptions of each of the study sites visited in previous summers and analyzed data specific to each site. Brief summaries of essential information relevant to each of the 25 material sites studied during this project are included in the subsequent chapter. These are included to orient the reader for the discussions that follow in the individual discipline chapters.

Data syntheses for all sites did not begin until after the 1978 field season. Analyses of combined site data are contained totally in this report. Each of the six disciplines included in the project, (River Hydrology and Hydraulics, Aquatic Biology, Terrestrial Ecology, Water Quality, Aesthetics, and Geotechnical Engineering), is discussed in separate chapters. These chapters include some integration with other disciplines. For example, Aquatic Biology is dependent, for some of its data interpretation, on the Water Quality parameters measured, and on the physical changes that are described in the River Hydrology and Hydraulics section.

An interdisciplinary overview of the effects of gravel removal follows the discipline chapters. This chapter reviews the analyses of the six disciplines in terms of the similarities and differences that are evident. An important aspect of this chapter is discussion of the tradeoffs and comparisons between disciplines that must occur with respect to the siting, operation, and closing of material sites. Where possible, the similarities in approach of the various disciplines to minimize disturbance from gravel removal are emphasized because these conditions maximize protection of floodplain environments.

GUIDELINES MANUAL

The Guidelines Manual (printed separately) is based on the evaluations and recommendations contained in the Technical Report, on the preliminary guidelines developed in an earlier phase of this project (Woodward-Clyde Consultants 1976), and on stipulations and recommendations used by certain resource agencies when reviewing material site applications and projects.

The guidelines are intended to provide guidance to the persons responsible for writing material site permits and for planning resource or industrial development in localized areas. The guidelines also are helpful to potential applicants for material site permits because they will help in planning a project characterized by minimal environmental perturbations.

The guidelines are not designed as stipulations to be attached to each permit granted. If used in this manner contradictions in siting, operational, and rehabilitation procedures could occur, thus negating the value of the guidelines. It is intended that the guidelines user evaluate the proposed project within the context of the guidelines, and the proposed area for the material site, to insure that it will develop in an environmentally acceptable manner.

The guidelines were developed for use by personnel with some background in an environmental science. Ease of use was considered necessary because, at least on large projects such as pipelines and roads, permit agencies can be inundated with applications requiring quick consideration. A set of guidelines that are cumbersome and inefficient to use, under these circumstances, could foster disregard of the guidelines or their misuse e.g., attaching the guidelines as stipulations to a permit.

The guidelines, as mentioned, were developed with the assumption that the potential user has some experience with environmental problems and issues and, thus, appreciates the potential complexities associated with a material removal project. It is strongly recommended that the user read the Technical Report and understand why and how the guidelines were developed. A comprehension of the total project is considered necessary for intelligent, efficient, and expeditious use of the guidelines. Without this understanding, the guidelines could be viewed out of context and used inappropriately.

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DESCRIPTION OF STUDY RIVERS

L. L. Moulton, Ed.

As previously mentioned, 25 sites were selected for study. These sites occurred in four geographical regions of Alaska and include a wide variety of Physical Site Characteristics and Gravel Removal Area Characteristics (Table 1). Site locations are shown on Figure 1. Table 4 summarizes disturbed area size, volume of gravel removal, and period of activity at each site.

SEWARD PENINSULA

General Description of Region

The region of Seward Peninsula containing the six study sites is in the foothills of the Kigluaik Mountains, characterized by broad rounded hills with elevations of 250 to 700 m (Figure 2). The surficial geology at Sinuk River, Washington Creek, and Nome River is dominated by remnants of highly modified moraines and associated drift resulting from Pleistocene glaciation. Gold Run Creek however, is just outside the northern edge of glacial influence and the surficial geology is fine-grained alluvial and colluvial deposits with rare bedrock exposures. At Oregon Creek and Penny River the surficial geology is characterized by coarse and fined-grained deposits of alluvium and colluvium associated with moderate to steep-sloped mountains and hills. Bedrock exposures are common on the upper slopes and crests. The region is generally underlain with permafrost of variable thickness. Normal temperatures range from 3 to 13°C in the summer and -23 to -13°C in the winter. The annual precipitation of the region is about 30-40 cm, including approximately 130 cm as snow.

Table 4. Size and Quantity Values of the 25 Study Sites

	Drainage basin area (km^2)	Area of gravel removal (ha)	Gravel volume removed (1000 m^3)	Volume/Drainage basin index[a]	Average depth (m)	Period of gravel removal
Seward Peninsula						
Gold Run Creek	67	4	8	1.2	0.2	1963-65
Sinuk River	540	88	174	3.2	0.2	1960-66
Washington Creek	29	3	49	17.0	1.6	1960-63
Oregon Creek	31	7	27	8.8	0.4	1960-65
Penny River	62	15	51	8.2	0.3	1960-65
Nome River	130	2	--[b]	--	--	Late 1950's
North Slope						
Ugnuravik River	279	1	<23	<0.8	<2.3	1969
Aufeis Creek	255	46	570	22.0	1.2	1972 and 1974
Kuparuk River	8500	14	41	0.1	0.3	1969
Skeetercake Creek	82	10	38	4.6	0.4	1966
Sagavanirktok River	4700	35	431	0.9	1.2	1974-75
Ivishak River	3600	40	119	0.3	0.3	1972 and 1974
Shaviovik River	410	--	116	2.8	--	1972
Kavik River	891	40	247	2.7	0.6	1968-69 and 1973-74
Northern Interior						
Dietrich River-Upstream	520	35	631	12.0	1.8	1974-77
Dietrich River-Downstream	667	8	129	1.9	1.7	1975
Middle Fork Koyukuk River-Upstream	2400	20	177	0.7	0.9	1974
Middle Fork Koyukuk River-Downstream	4100	28	215	0.5	0.8	1975-76
Jim River	687	11	135	2.0	1.2	1974-76
Prospect Creek	248	6	84	3.4	1.4	1974-75
Southern Interior						
West Fork Tolovana River	754	8	132	1.8	1.7	1975
McManus Creek	14	4	<75	<54.0	<1.9	1961
Tanana River-Downstream	44,600	8	310	1.0	3.9	1971
Tanana River-Upstream	38,700	9	135	1.0	1.5	1962-65
Phelan Creek	83	95	575	70.0	0.6	1975-76

[a]Ratio of volume of gravel removed to size of drainage basin area times 10.
[b]Quantity unknown.

Figure 2. Typical Seward Peninsula terrain.

Vegetation within the floodplains consists of dense mature willow thickets interspersed with less advanced mixed woody-herbaceous communities. The valley walls contain occasional willow and alder thickets in the moist ravines and pockets, and shrub-tussock tundra on the slopes. The river systems contain both anadromous and resident fish species. Typical anadromous species include Arctic char, pink, chum, coho, and sockeye salmon and various whitefish species. Typical resident species include Arctic grayling, resident Arctic char, northern pike, Alaska blackfish, and slimy sculpin.

Description of Study Rivers - Location and Gravel Removal Area Characteristics

Gold Run Creek. Gold Run Creek is a small, sinuous river which originates in the foothills of the Kigluaik Mountains at an elevation of 427 m and flows through rolling hills for 23 km to its confluence with the Bluestone River. The study site is approximately 7 km from the mouth at an elevation of 100 m. Gravel was removed from this site for construction of the Nome-Teller Highway. Gravel removal occurred by shallow scraping over approximately 3.5 ha between 1963 and 1965 with 7,738 m^3 of material extracted. Scraping occurred in the active channel, on mid-channel and lateral bars, and on a vegetated island between the active channel and a high-water channel. Approximately 1 ha of riparian willow thickets and an accompanying 0.5-m layer of overburden were removed prior to gravel removal. This organic overburden was placed in a stockpile on the edge of the scraped area along the right (northern) floodplain bank downstream from the highway bridge. An additional overburden pile, composed primarily of sand, was located at the downstream limit of the scraped area. Both stockpiles still remained during the site visit. A 50-m long gravel access road also was present leading from the highway to the scraped area located upstream from the highway bridge. The floodplain bank at the floodplain end of this access road was incised and approximately 1 m high. Rehabilitative measures were not conducted after completion of gravel mining activities.

Sinuk River. The Sinuk River is a medium, split river which originates in the Kigluaik Mountains at an elevation of 425 m. It flows through a narrow, steep-walled valley before entering a broad valley containing the study reach. The lower section flows across a relatively flat coastal plain for 26 km before discharging into Norton Sound. The study site is approximately 19 km from the mouth at an elevation of 30 m.

Between 1960 and 1966, 174,221 m^3 of gravel were extracted for highway construction by shallow scraping within the active floodplain and adjoining the active channel of the Sinuk River. Access to the floodplain was gained via two short (about 30 m) gravel roads leading from the highway. Scraping extended approximately 1,500 m upstream and downstream from the Sinuk River bridge and encompassed 88 ha.

Material within the Sinuk River floodplain was described from highway department analyses as stream-deposited sandy gravel with less than 25 percent greater than 50 mm in size (coarse gravel) and about 2 percent exceeding 250 mm (boulders). Several (three or four) islands were removed during the mining operation. These islands were heavily vegetated with willow thickets averaging 1.2 m in height. These islands comprised approximately 35 ha of the site. Stripping of 0.15 m of overburden was necessary in these vegetated areas. In addition, approximately 150 m of incised floodplain bank and 1.2 to 1.6 ha of adjacent tundra were removed from the northeast side of the floodplain to expose gravel deposits. Also, within the active floodplain, debris and soil from vegetated islands were pushed into a long narrow overburden pile (approximately 450 m in length) in the middle of the material site to expose underlying gravel deposits. The water table was encountered at about 0.75 m below vegetated sand bars with seasonal frost present in the floodplain and permafrost encountered at depths of 0.9 to 2.4 m in adjacent terraces. It does not appear that this material site was shaped, contoured, or rehabilitated in any way following gravel removal. Various aspects of this site are shown in Figures 2 and 11.

Washington Creek. Washington Creek is a small, sinuous creek which originates in the foothills of the Kigluaik Mountains at an elevation of about 265 m and flows through a wide, V-shaped valley for about 13 km before entering the Sinuk River. The study site is approximately 5 km from the mouth at an elevation of about 105 m.

This study site consists of two gravel removal areas approximately 1,000 m apart on Washington Creek. Both areas were developed between 1960 and 1963 during construction of the Nome-Teller Highway. The lower site was still being used in 1978 to supply gravel for road maintenance.

Gravel at both sites was removed by scraping the Washington Creek floodplain and the alluvial fan deposits formed near the confluences of two unnamed tributaries of Washington Creek. A reported 8,000 m^3 of materials were removed from 1 ha in the upstream site, while 41,000 m^3 had been removed from 2 ha in the downstream site.

Clearing of large amounts of overburden was required for the development of both sites. Overburden was not removed from the material sites but was collected into large mounds which were still present at the time of our visit. Large stockpiles of clean gravel were also seen at both sites. Efforts to rehabilitate the floodplain or to maintain the natural character of the channel were not observed during the field study. Dikes, however, were constructed in the downstream mined area to maintain the course of the main channel in its pre-mining location. Various aspects of this site are shown in Figures 12, 38, 39, 43, 53a, 53b, and 67.

Oregon Creek. Oregon Creek is a small, straight river which originates in the foothills of the Kigluaik Mountains at an elevation of 380 m and flows approximately 7 km through a V-shaped valley to a confluence with Cripple River. The valley walls are steeply sloped over the upper half of its length; the lower half is flanked by moderately sloped hills. The Cripple River headwaters lie at an elevation of about 300 m and the river flows in a broad V-shaped valley for 40 km before discharging into Norton Sound. The Oregon Creek confluence occurs 15 km downstream from the headwaters of Cripple River at an elevation of 80 m.

The material site was developed by scraping gravel bars within and adjoining the active channel near the Oregon Creek-Cripple River confluence. Scraping of angular gravel and cobbles was conducted west of the Nome-Teller Highway in Oregon Creek from 1960 to 1963 when 20,500 m^3 of material were removed from approximately 5.5 ha. Vegetation was removed from 4 ha at the downstream end of this site. Mounds of vegetated overburden along the banks of the broadened channel and stockpiled gravel within the active floodplain were observed during site inspection. Between June and September 1965, 6,000 m^3 of gravel were excavated from 1 ha in the Cripple River immediately downstream from the highway bridge. Various aspects of this site are shown in Figures 13, 40, 41, 53c, 64, and 74.

Penny River. The Penny River is a small, sinuous river which originates in the foothills of the Kigluaik Mountains at an elevation of 230 m and flows approximately 23 km before discharging into Norton Sound. In its upper reaches, the Penny River flows in a narrow V-shaped valley. The valley broadens downstream and the valley floor typically reaches widths of 350 m between moderately sloping hills in the vicinity of the study reach. The study reach is approximately 8 km upstream from the mouth at an elevation of 28 m.

The material site was developed by scraping within the active floodplain and excavation of a pit adjacent to the main channel of the river. Material removed from the 15-ha site was primarily sand and gravel alluvium with some colluvial debris along the southeast edge of the working limits. Rock types were quartz mica schist, limestone, and quartz; rock fragments were subangular to rounded with 3 to 10 percent greater than 50 mm in size and less than 1 percent greater than 250 mm.

Clearing and stripping were necessary to remove the dense willow (that covered approximately 12 ha) and an average 0.6 m of overburden. The water table varied from 0.8 m to more than 1.5 m deep with no permafrost encountered up to a depth of 2.1 m. Scraping was conducted during 1960-63 when 3,646 m^3 were removed and during August and September, 1965 when 47,034 m^3 were extracted. The 1965 operation yielded some select materials, indicating that a processing plant probably operated within the site. A small 0.6-ha pit was excavated in the southeast corner of the material site during the 1965 operation. This pit averaged 1 to 1.5 m in depth during the site visits and was directly connected to the main channel. Small stockpiles were present within the disturbed area during field inspection. The site was not shaped, contoured, or rehabilitated in any way following gravel removal. Thus, many shallow depressions, which are not sloped to drain toward the river, collect standing water. In addition to the 0.6-ha pit, scraping occurred to below the water table in several small isolated pockets, and these areas were covered with standing water during site visits. Four organic overburden piles and the gravel access road remain on the site. Various aspects of this site are shown in Figures 33, 58, 61, 65, 66, and 85.

Nome River. The Nome River is a medium, sinuous river which originates in the Kigluaik Mountains at an elevation of about 230 m and flows through a broad valley for about 57 km to its mouth at Norton Sound. The Nome River drainage basin is long and narrow, with an average width of about 8 km. The study site lies about 37 km from the mouth at an elevation of about 58 m.

This material site was developed by scraping 1.5 ha across the entire floodplain width. Scraping apparently occurred in the active channel and on adjacent mid-channel and lateral bars. Vegetative and overburden clearing was not necessary because the site was sparsely vegetated prior to gravel removal. Mining was conducted at this location in the late 1950's during construction of the Nome-Taylor Highway. Access was via a short 60-m gravel road leading from the highway. A gravel fill ramp protected the 1.5-m incised floodplain bank. There was no evidence of site rehabilitation; the access road remains and its end has been eroded by the river. Material stockpiles and overburden berms were not observed in the floodplain. Various aspects of this site are shown in Figure 25.

NORTH SLOPE

General Description of Region

Eight gravel removal sites from two North Slope physiographic provinces, the Arctic Coastal Plain (ACP) and Arctic Foothills (AFH), were included in this study (Wahrhaftig 1965). Both provinces are underlain by continuous permafrost. The study sites at Ugnuravik River and Kuparuk River are in the Teshekpuk Section of the ACP while the Skeetercake Creek site is in the White Hills Section. Aufeis Creek, Sagavanirktok River, and Kavik River sites are in the Northern Section of the Arctic Foothills Province while the Ivishak River and Shaviovik River sites are near the border between the two provinces. The Teshekpuk Section of the ACP Province is flat and poorly drained, being very marshy in the summer (Figure 3). The poor drainage results in part from a continuous permafrost layer from 0.2 to 1.2 m beneath the surface. Ice wedge polygons, beaded streams, and elongated thaw lakes are common in this area. Pingos and incised river channels provide the only relief to the flat terrain. The study sites in this section are in an area of coastal delta deposits of interstratified alluvial and marine sediments with some local glacial drift deposits.

In the White Hills Section of the ACP Province, the surficial geology contains areas of undifferentiated alluvium and colluvium consisting of

Figure 3. Arctic Coastal Plain wetlands.

fine-grained deposits associated with greatly sloping hills. Bedrock outcrops are rare in this area. The Northern Section of the AFH Province is characterized in its northern area by gently rolling terrain with occasional isolated hills and in its southern area by rolling plateaus and low linear mountains with broad east-trending ridges (Figure 4). The surficial geology of the AFH is more complex than that in the ACP Province. The Aufeis Creek study site is near a geologic contact between eolian silt deposits and undifferentiated alluvial and colluvial deposits while the Kavik River and Sagavanirktok River sites are flanked by remnants of moraines and associated drift. The topography surrounding the Ivishak River site, near the border of the ACP and AFH Provinces, is more typical of that of the White Hills Section (Figure 5) while the Shaviovik River site is right at the interface of the two provinces. The area to the south and west of the Shaviovik River site is flat while that to the north and east is predominated by mildly sloping hills up to 360 m.

Figure 4. Northern portion of the Arctic Foothills.

Figure 5. Typical view of the White Hills Section of the Arctic Foothills.

The climate of the North Slope is characterized by long winters, cold temperatures, and frequent winds. Normal temperature ranges are from 2 to 13°C in the summer and -30 to -22°C in the winter. Annual precipitation along the Arctic Coastal Plain is approximately 13-15 cm, which includes 30-120 cm as snow, while in the Arctic Foothills, the annual precipitation is about 25 cm, including 140 cm as snow.

The Teshekpuk Section of the ACP Province is characterized by flat topography, wet tundra, and numerous lakes and ponds. All plants, including woody forms such as willow and heath, are low growing. In most areas tundra vegetation occurs up to the stream banks and woody thickets are not present. The vegetation of the Northern Section of the AFH Province consists of tundra species with small stands of taller riparian shrub thickets (2-5 m in height) along the river systems.

Small river systems of the North Slope contain primarily resident fish species, such as Arctic grayling, resident Arctic char, round whitefish, burbot, and slimy sculpin, with estuarine species, such as fourhorn sculpin, ninespine stickleback, and possibly whitefish species, entering lower reaches. Larger river systems, such as the Sagavanirktok-Ivishak drainage, also contain anadromous species, including Arctic char, chum and pink salmon, broad whitefish, humpback whitefish, least cisco, and Arctic cisco, as well as the resident species.

Description of Study Rivers - Location and Gravel Removal Area Characteristics

Ugnuravik River. Ugnuravik River is a medium, sinuous river which originates on the Arctic Coastal Plain at an elevation of 100 m and flows across coastal plain tundra for 65 km before emptying into the Beaufort Sea. It is primarily confined to a single channel except for a few short beaded sections in the upper reaches. The study site is approximately 6 km from the mouth at an elevation of 2 m.

The study site was developed by pit excavation and scraping approximately 1 ha within and adjoining the active channel of the Ugnuravik River. Gravel removal was conducted during the winter from 26 March to 1 April 1969 with an unknown quantity of sand and gravel extracted from the site. Twenty-three thousand cubic meters had been approved for removal, but the permittee found that the gravel was only a veneer and not in sufficient quantities for their needs. During this short period of operation, gravel was removed from below the water table. Silt accumulation was noted in the gravel removal area; overburden had been stripped and piled along both banks of the river; and backhoe teeth were observed near the working limits. Various aspects of this site are shown in Figures 26, 36, 83, and 92.

Aufeis Creek. Aufeis Creek is a medium, meandering river originating in the foothills near the Imnavait Mountains at an elevation of 670 m and flows approximately 100 km before joining the Kuparuk River. The study site lies at an elevation of 275 m approximately 60 km upstream from the confluence with the Kuparuk River.

Material removed from this site was used for the construction of facilities associated with oil exploration. Facilities constructed include a 1,341-m airstrip, a camp work and storage pad, and access roads of approximately 7 km in length connecting the stream with the airstrip and camp pad. An estimated 288,000 m^3 of material were removed during the winter of 1972.

There are two large and distinct gravel removal areas separated by approximately 3,130 m of undisturbed stream. The upstream gravel removal area covers 46 ha along a 2,260 m reach of the stream. The entire floodplain was scraped, including the channel bed itself. Clearing and removal of approximately 20 ha of vegetation and overburden were required. There is no evidence of rehabilitation following mining.

Mining at the downstream gravel removal area was less extensive and included scraping the inactive floodplain, and in some areas, the adjacent terraces along a 600 m reach of the stream. Deep and shallow scraping, as well as pit excavation, were utilized to remove gravels. The main channel of the creek was apparently not disturbed at the downstream area. Clearing and removal of vegetation and overburden were required in the downstream area. Dikes were also constructed, possibly to protect the integrity of the main channel and prevent its spreading into the mined area. Various aspects of this site are shown in Figures 14, 39, 54, 68a, 68b, 69, 75, and 81.

Kuparuk River. The Kuparuk River is a large, braided river which originates in the Brooks Range foothills and crosses the Arctic Coastal Plain before discharging into the Beaufort Sea. The study site is located approximately 9 km upstream from the mouth of the Kuparuk River at an elevation of less than 10 m.

The material site was developed by scraping unvegetated mid-channel and lateral bars within the active floodplain of the Kuparuk River. Approximately 41,300 m^3 of gravel was removed from 14 ha between April and August 1969 to provide material for drill site pads, roadways, and airstrips near the site. The site was scraped to within or slightly below the existing water table. The 5-m incised floodplain bank was protected with a gravel fill ramp. Small mounds of stockpiled material were noted within the material site. Various aspects of this site are shown in Figure 51.

Skeetercake Creek. Skeetercake Creek is a small, meandering stream which originates in the northern edge of the foothills of the Brooks Range at an elevation of about 300 m and flows approximately 40 km to its confluence with the Toolik River. The study area lies at an elevation of about 160 m, approximately 15 km upstream from the confluence.

Material removed from Skeetercake Creek was used for oil drilling operations. Gravel extraction at the site was accomplished during December 1965 by scraping 10 ha of floodplain deposits on three consecutive meanders. Approximately 38,000 m^3 of gravel were reportedly removed, much of which apparently was not used; the unused material was pushed into large stockpiles which still remain in the upstream gravel removal area.

Vegetative clearing, overburden removal, and berm construction were conducted at each of the three gravel removal areas. At the upstream area the overburden was formed into an earthen dike, the purpose of which is unclear. The gravel removal areas were not rehabilitated following disturbance. Various aspects of this site are shown in Figures 37, 42, and 48a.

Sagavanirktok River. The Sagavanirktok River is a large, sinuous river (at the study site) which originates in the Philip Smith Mountains of the Brooks Range at an elevation of approximately 1,500 m and flows through mountains, foothills, and coastal plains approximately 300 km before entering the Beaufort Sea. The study site, at an elevation of 335 m, is located about 11 km downstream from Pump Station Number 3 on the Trans-Alaska Pipeline, 16 km downstream from the mouth of Ribdon River, and 21 km upstream from the mouth of Lupine River.

Gravel removal occurred in 1974 and 1975 by scraping vegetated and unvegetated gravel bars totaling approximately 35 ha. About 15 ha had been vegetated with mature riparian willow thickets. The original mining plan called for scraping to an average of 1.5 m in depth with an average of 15 cm of overburden removal required prior to gravel extraction. Approximately 283,000 m^3 and 148,000 m^3 of gravel were removed from the upstream and downstream gravel removal areas, respectively. Access to the floodplain was gained via a gravel ramp which protected the floodplain incised bank.

Prior to site abandonment in 1976, existing stockpiles and berms were leveled and contoured, and the gravel fill ramp protecting the bank was to be removed. Various aspects of this site are shown in Figures 44, 45, 76, and 82.

Ivishak River. The Ivishak River is a large, braided river which originates in the Philip Smith Mountains at an elevation of 1,829 m and flows 80 km through the mountains and 45 km through the foothills before entering the Sagavanirktok River. The study site lies 11 km upstream from the confluence of the Sagavanirktok River.

Material removed from the Ivishak River was used for the construction of facilities associated with oil exploration. Gravel extraction was accomplished by scraping unvegetated, mid-channel gravel bars within the active floodplain of the Ivishak River. Two separate winter gravel removal operations were conducted at this location with 115,000 m^3 extracted during March and April 1972 and 3,800 m^3 extracted during November and December 1974. Information pertaining to the size of the gravel removal area is not available because removal occurred on randomly located gravel bars within the permit area; however, the average depth of excavation planned for the 1972 operation would require approximately 40 ha of exposed material.

Three separate gravel removal areas were observed in the field. The upper area is located upstream from the airstrip in the left quarter of the active floodplain. The middle area lies in the middle of the floodplain covering an area equivalent to the upstream one-third of the airstrip. The lower area lies about one-third of the way across the floodplain from the left bank, just downstream of the downstream end of the airstrip.

Vegetative clearing, overburden removal, or dike construction were not necessary at the site. Gravel ramps were used for access to the floodplain over the river bank at most points of entry, however, at the downstream access point the 2-m incised bank was cut instead of protected by gravel fill. Two gravel haul roads 90 to 150 m long connect the airstrip to the material site. During 1972 and 1974 dozers were used to rip and stockpile material for front-end loader transfer to scrapers and trucks. Maximum excavation depth was to the existing water level at the time of the gravel removal operation.

Rehabilitation measures used in 1972 and 1974 were similar: depressions were filled, stockpiles were leveled and gravel ramps were removed prior to breakup. Various aspects of this site are shown in Figure 71.

Shaviovik River. The Shaviovik River is a medium, sinuous river which originates in the Brooks Range at an elevation of 909 m and flows for 95 km before emptying into the Beaufort Sea. The study area is 95 km from the mouth at an elevation of 230 m.

Gravel was scraped from unvegetated gravel bars within the active floodplain. The gravel was used in construction of oil exploration facilities including a drilling pad, campsite, supply pads, and landing strip. The proposed extraction area encompassed approximately 2.4 km of floodplain. Gravel removal was conducted during the winter of 1972 with 116,000 m^3 extracted between March and spring breakup. Vegetative clearing and overburden removal were not necessary before gravel removal. Material was stockpiled with a dozer and loaded into dump trucks with a front-end loader. Excavation below the water table was not permitted under the provisions of the mining plan. Access over the river bank to the mined area was by gravel ramp.

Upon completion of gravel removal all excavated sites were to be smoothed by back-blading with a dozer and the gravel access ramp over the stream bank was to be removed. At the time of site inspection the gravel ramp was still present and essentially intact. Various aspects of this site are shown in Figures 4, 72, and 91.

Kavik River. The Kavik River is a medium river flowing in split channel configuration. It originates in the Brooks Range at an elevation of 1,200 m and flows 125 km to its confluence with the Shaviovik River. The study site is 60 km from the confluence with the Shaviovik River at an elevation of 180 m. Downstream from the study reach the floodplain widens and takes on a braided configuration.

Approximately 40 ha were mined by scraping mid-channel and lateral gravel bars within the active floodplain of the Kavik River. Gravel was used for construction of an airstrip and road, and for development of four oil well pads. Approximately 196,000 m^3 were removed in 1968-1969 with another 50,000 m^3 extracted in 1973-1974. The initial gravel removal activity at this site was a trespass action and a mining plan is not available. Gravel removal was conducted during the winter with scrapers and belly dumps; gravel removal was completed prior to breakup. Most disturbed gravel bars contained sparse vegetative cover consisting of herbaceous plants and scattered young willows; however, one 2-ha island vegetated with a mature willow thicket was removed. The overburden and slash from this island were piled within the gravel removal area.

Diversion dikes were constructed to direct flow from the gravel removal area, and a 2-ha gravel stockpile was located on the edge of the floodplain. The 2-m incised floodplain bank was cut in five locations to gain access to the floodplain or to reach underlying gravel deposits. Approximately 375 m of bank were disturbed. Rehabilitative measures were not employed following the activity, hence all dikes, stockpiles, overburden piles, and cut banks remained during the site visit. Various aspects of this site are shown in Figures 5 and 77.

NORTHERN INTERIOR

General Description of Region

All six study sites in this region are located in the Koyukuk River watershed. Four sites, Dietrich River-Upstream, Dietrich River-Downstream, Middle Fork Koyukuk River-Upstream, and Middle Fork Koyukuk River-Downstream, are in the Central and Eastern Brooks Range Section of the Arctic Mountains Physiographic Province, while Jim River and Prospect Creek, are in the Kokrine-Hodzana Highlands Section of the Northern Plateau Physiographic Province (Wahrhaftig 1965). The Central and Eastern Brooks Range Section is characterized by flat-floored glacial valleys and east-trending ridges that rise to elevations of approximately 1,800 m (Figure 6). Minor tributaries typically flow east and west, parallel to the structure imposed by the belts of sedimentary and volcanic rocks. Valley walls are dominantly coarse rubble deposits associated with steep sloped mountains which have a high percentage of bedrock exposures. The valley bottom in the vicinity of the Middle Fork Koyukuk River study sites consists of unmodified moraines and associated drift. The area is underlain by continuous permafrost. The Jim River and Prospect Creek sites, in the Kokrine-Hodzana Highlands, are in an area of

Figure 6. M.F. Koyukuk River valley looking upstream.

coarse and fine-grained deposits associated with moderate to steep sloped mountains and hills; bedrock exposures are limited to upper slopes and crestlines (Figure 7). The area is underlain by discontinuous permafrost.

Normal temperature ranges in the Northern Interior are from 2 to 20°C in the summer and -30 to -8°C in the winter. The annual precipitation is about 28-38 cm, which includes 190-210 cm as snow.

The valleys in the Dietrich River-Middle Fork Koyukuk River region are heavily wooded with both steep, timbered slopes and gently sloping terraces adjacent to the river. The slopes are vegetated primarily with stands of white spruce and paper birch. In the Jim River-Prospect Creek area, the valleys are heavily wooded with white spruce and paper birch and a thick understory. Resident fish species found in the Koyukuk River system include burbot, Dolly Varden or Arctic char, Arctic grayling, long-nose sucker, northern pike, slimy sculpin, round whitefish, inconnu, and

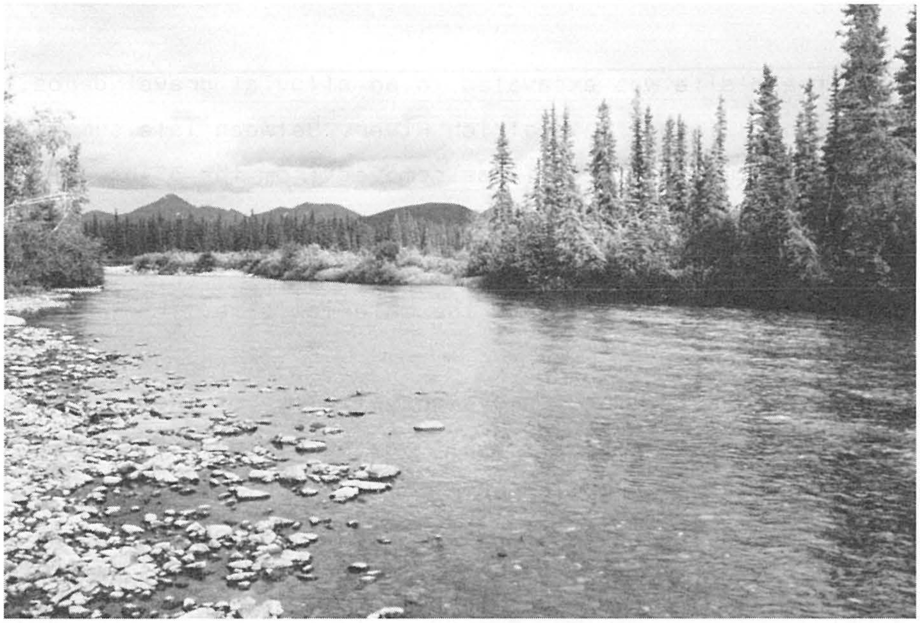

Figure 7. Typical terrain of the Kokrine-Hodzana Highlands.

other whitefish species. Anadromous species include chum and chinook salmon and possibly anadromous whitefish species.

Description of Study Rivers - Locations and Gravel Removal Area Characteristics

Dietrich River - Upstream and Downstream. The Dietrich River is a medium, braided river which originates in the Endicott Mountains of the Brooks Range at an elevation of approximately 1,500 m and flows southward through mountainous terrain for 110 km, joining the Bettles River to form the Middle Fork Koyukuk River.

The upstream study site is located approximately 4 km, 14 km, and 25 km upstream from the confluence with Big Jim Creek, Snowdon Creek, and Bettles River, respectively. The downstream site is located 17 km and 6 km upstream from the confluence with the Bettles River and Snowdon Creek, respectively, and 8 km from the upstream site.

The upstream site was excavated in an alluvial gravel deposit within the active floodplain of the Dietrich River. Between late summer 1974 and early 1977, 631,000 m^3 of gravel was removed from the 35-ha site for construction of the Trans-Alaska Pipeline. A dike was constructed across an intermittent channel north of the gravel removal area to divert active flow or seasonally high water away from the material site.

Two methods were used to remove gravel. Most of the site was scraped to an average depth of 3 m while a pit was excavated by dragline in the southern end of the work area. This pit is approximately 240 x 90 m and was excavated to an average depth of an additional 2 m below the scraped portion of the gravel removal area. Within this pit two deeper holes approximately 9 m deep were excavated. Ground springs were encountered during the scraping operation. The ground springs have been diverted through two channels into the deep pit. Aufeis formation was a natural occurrence in this area before gravel removal and was observed downstream from the pit drainage channel during the first winter following excavation.

A screening-crushing operation was used to produce pipeline padding and bedding material; stockpiled processed material also was stored at this location. The material site was utilized as a concrete fabrication area in August 1975 to produce cement castings of pipeline weights.

In the summer of 1977 the area was sloped and contoured to drain water into the gathering channels leading to the deep pit. The southern and northern portions were then reseeded with annual grasses. The central portion was left open for access to stockpiled maintenance and operation gravel for the Trans-Alaska Pipeline.

The Dietrich River-Downstream site was worked by shallow excavation of a gravel deposit within the active floodplain of the Dietrich River. Gravel was removed from the 7.5-ha site with 128,590 m^3 of material extracted during 1975 for construction of the Trans-Alaska Pipeline. Overburden within the working limits required disposition and stabilization outside the active floodplain. Permit provisions required a 90-m undisturbed buffer between the working limits of the material site and active channels of the Dietrich River. Braided channels that flowed east of the material site were diverted west of the site by an upstream dike to prevent active flow during excavation. Fine to coarse gravel with sand and a trace of silt was excavated to a 0.9 m depth. Rehabilitation measures conducted after mining included sloping of all aliquots to the southwest. Various aspects of this site are shown in Figures 47a and 73.

Middle Fork Koyukuk River - Upstream and Downstream. The Middle Fork Koyukuk River is a large, sinuous river which originates in the Brooks Range at the confluence of the Dietrich and Bettles Rivers and flows 116 km before joining the North Fork Koyukuk to form the Koyukuk River. The Middle Fork Koyukuk River flows in inconsistently spaced reaches of braided and single channel patterns.

The upstream study site is located about 92 km from the confluence of the Middle Fork Koyukuk and North Fork Koyukuk Rivers at an elevation of 365 m. The downstream study site is 45 km from the confluence with the North Fork Koyukuk River and 47 km downstream from the upstream study site at an elevation of 282 m.

At the upstream study site gravel extraction was accomplished by shallow excavation of sparsely vegetated gravel bars associated with the active channel and excavation to the same elevation in the contiguous, vegetated alluvial terrace. From August to November 1974, 135,000 m^3 of gravel was removed from about 20 ha.

The material site is comprised of two parcels; the upper area encompasses a high-water channel while the lower area is situated on the inside bend of the next meander downstream. The upper area was unvegetated prior to gravel removal. Scattered stands of shrub thickets occurred within the active floodplain portion of the lower area and the adjacent alluvial terrace had to be cleared of mature white spruce and balsam poplar prior to gravel removal. Overburden was not present on the active floodplain area, however, 15 cm of organic silt were stripped from the alluvial terrace and disposed of southeast of the lower area.

An undisturbed 30-m buffer was maintained between the active channel and the working limits of the lower area; natural depressions and minor channels through the buffer were augmented by construction of perimeter dikes not exceeding 0.3 m above the natural buffer elevation. Caterpillar tractors with rippers and self-loading bottom dump scrapers were used to excavate to depths of 0.9 m in the active floodplain and 3.0 m in the adjacent alluvial terrace area. The upper area was scraped to a depth of 0.9 m.

Material extracted from the active floodplain was seasonally frozen, sandy, fine to coarse rounded gravel. The alluvial terrace provided frozen, interlayered silty and sandy gravel to the water table. Screening and stockpiling of select material was conducted on the floodplain. Permit provisions required that unused material of silt size and finer be disposed of outside the active floodplain; unused coarse material from the screening process could be evenly spread in the gravel removal area.

During site rehabilitation the disturbed area was graded to an even bottom with cut faces no steeper than 2:1, stockpiles were removed, and outlet channels were constructed at the downstream end to allow high-water drainage. Revegetation within the active floodplain was not attempted due to the likelihood of periodic flooding. Various aspects of this site are shown in Figures 15, 47b, 49, 52, and 88.

The Middle Fork Koyukuk River-Downstream site was developed by shallow scraping of a sparsely vegetated lateral gravel bar within the active floodplain. The gravel removal operation was conducted during the winters of 1975 and 1976 with 215,000 m^3 of material removed from 28 ha. Permit provisions required overburden encountered within the working limits to be disposed of and stabilized outside the active floodplain.

A material site investigation conducted prior to removing gravel reported well-rounded gravel with some seams of fine sand and an absence of permafrost in test pits. Approximately 38,000 m^3 of select material was produced from a screening operation and stockpiled outside the material site working limits. Rehabilitation of the site following completion of the gravel removal activity did not include seeding or revegetation of the leveled gravel due to the likelihood of periodic flooding. Various aspects of this site are shown in Figure 6.

Jim River. The Jim River is a medium, sinuous river which originates at an elevation of 880 m and flows about 96 km before emptying into the South Fork of the Koyukuk River. The study area is located 37 km from the mouth at an elevation of 275 m.

Material removed from this site was used for the construction of facilities associated with the Trans-Alaska Pipeline. An access road (90 m in length) was constructed connecting the site to the Haul Road. Vegetative cover and underlying organics were removed. Gravel extraction was accomplished by scraping about 11 ha, yielding an estimated 200,000 m^3 of gravel. The site was worked during winter to a level below the water table. As a result, the site was inundated during summer, leaving, at the time of the survey, a shallow pit consisting of two ponded segments, approximately 5 and 1 ha in size with a maximum water depth of 1.2 m. The former high-water channel now flows continuously through the site thus connecting the pit area with the main Jim River.

Restoration began during the fall of 1976. The site was contoured, including sloping the banks on the south, north, and west sides of the site, and revegetated. The excavated depression was filled in restricting water to the east side of the gravel removal area and reducing the inundated pit area to 1 ha by 1978. Various aspects of this site are shown in Figures 7, 48b, and 78.

Prospect Creek. Prospect Creek is a medium, meandering stream which originates at an elevation of about 600 m and flows 40 km to its confluence with the Jim River. The study site lies at an elevation of 270 m approximately 5 km from the mouth of Prospect Creek. The site was worked by scraping surface gravel deposits over 6 ha of gently sloping terrain adjacent to Prospect Creek. In addition, a 1-ha pit was excavated on the northern edge (lowest point) of the gravel removal area to act as a sediment catch basin. Gravel removal was conducted intermittently from April 1974 through April 1975 with 63,636 m^3 of gravel removed for construction of the Trans-Alaska Pipeline System. A 45-m wide buffer was maintained between Prospect Creek and the gravel removal area, however, a 90-m wide swath was cleared through this buffer zone on 22 May 1974.

Gravel removal was accomplished by ripping frozen material prior to conventional loading and hauling methods. Material varied from clean to silty fine to coarse gravel. An average working depth of 2.7 m was planned for the catch basin pit with additional excavation permitted if suitable material was present below this level. A screening operation to produce select material was conducted in the pit.

The pit has filled with water as a result of intergravel flow during the summer months. During the site visit, this ponded water averaged approximately 1 m in depth. The pit does not have an inlet, however, an outlet leading to Prospect Creek from the northwest corner was constructed during site rehabilitation activities to allow unimpeded fish passage into and out of the pit.

Additional rehabilitation measures included grading the material site to 1 percent downslope, ensuring that all cut slope faces were no steeper than 2:1, and leveling of temporary stockpiles to blend with the natural terrain. Various aspects of this site are shown in Figures 28 and 55.

SOUTHERN INTERIOR

General Description of Region

All five study sites in the Southern Interior were located in the Tanana River drainage, which empties into the Yukon River. The study sites are located in three physiographic provinces - the Yukon-Tanana Upland Section of the Northern Plateaus Province (West Fork Tolovana River and McManus Creek), the Tanana-Kuskokwim Lowland Section of the Western Alaska Province (two Tanana River sites), and the eastern portion of the Alaska Range Section of the Alaska-Aleutian Province (Phelan Creek) (Wahrhaftig 1965).

The Yukon-Tanana Upland Section is characterized by rounded ridges and flat, alluvium floored valleys (Figure 8). Surface deposits tend to

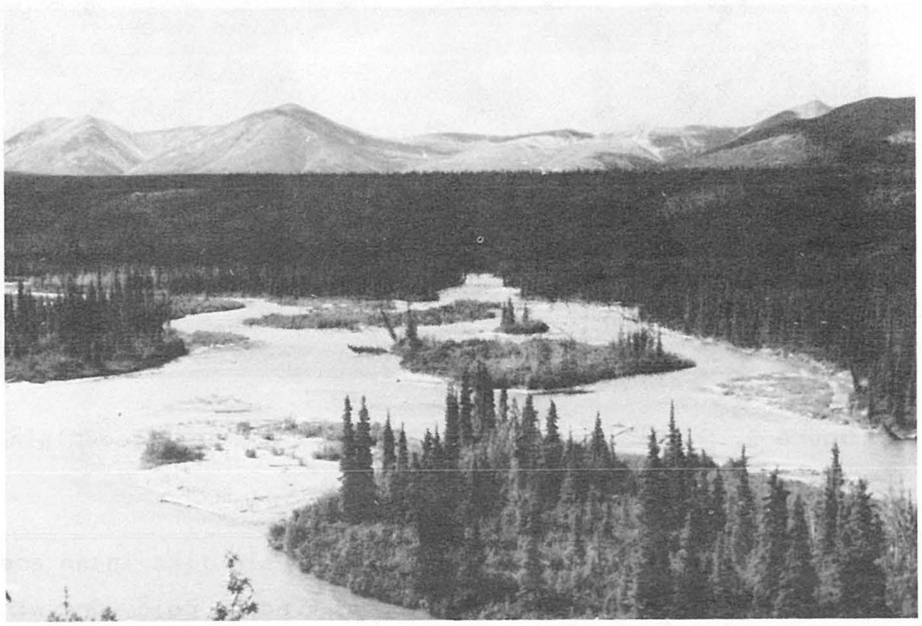

Figure 8. Typical terrain in the Yukon-Tanana Upland Section.

coarse and fine-grained alluvium and colluvium. Bedrock exposures are generally limited to upper slopes and ridges. The area is underlain by discontinuous permafrost and is subject to extreme temperature ranges, from -45°C in the winter to 32°C in the summer. The average annual precipitation is 33-35 cm, which includes 130-150 cm as snow.

The Tanana-Kuskokwim Lowland Section in the vicinity of the Tanana River study sites is characterized by extensive glaciofluvial deposits and large alluvial fans (Figure 9). The area is immediately south of the

Figure 9. Glaciofluvial deposits in Dry Creek floodplain.

Yukon-Tanana Upland section. The Tanana River basin lies in an area of discontinuous permafrost. The climate is typified by cold, dry winters and warm, relatively moist summers with an annual precipitation of around 32 cm, including about 90 cm as snow.

The Alaska Range Section is characterzed by glaciated ridges between mountains to 2,900 m (Figure 10). Unmodified moraines and associated drifts dominate the surficial geology. The area is underlain by discontinuous permafrost. Normal temperatures range from 2 to 17°C in the summer and -33 to 1°C in the winter. An annual precipitation of 43 cm includes 275 cm as snow.

Figure 10. Typical view of Alaska Range Section.

The vegetation at the Southern Interior study sites varied because of differences in climate, elevation, and geology of the three physiographic provinces. The West Fork Tolovana River site is in a valley heavily wooded with white spruce and paper birch with a thick understory, particularly along the river. At McManus Creek, the surrounding hillsides have thin stands of white spruce with dense underbrush. The floodplain areas devoid of white spruce are covered with willow thickets with woody and herbaceous groundcover. At the two Tanana River sites the adjoining hillsides are covered with dense stands of aspen and paper birch with scattered white spruce while islands in the floodplain are covered by 10 to 20 m tall stands of white spruce with scattered paper birch. The vegetation surrounding the Phelan Creek site consists of subalpine tundra, upland thickets associated with the drainages, and scattered, open stands of white spruce.

Resident fish species found in the Tanana River system include Arctic grayling, northern pike, burbot, longnose sucker, slimy sculpin, various whitefish species, and scattered Dolly Varden populations. Anadromous species include coho, chum and chinook salmon, and various whitefish species. Species of whitefish found in the drainage include Bering cisco, broad whitefish, humpback whitefish, least cisco, round whitefish, and inconnu. Most of these species show substantial movements within the Yukon River drainage and distribution and anadromy has not been well documented for many of the species.

Description of Study Rivers - Location and Gravel Removal Area Characteristics

West Fork Tolovana River. The West Fork Tolovana River is a medium, meandering river originating in the foothills of the White Mountains in the Yukon-Tanana Upland Section at an elevation of 915 m. The confluence of the West Fork Tolovana River and Tolovana River, a tributary to the Tanana River, lies 6 km downstream from the study site. The material site is located on the east side of the river with an undisturbed 60-m buffer strip between the site and the river. The mining occurred in an abandoned channel with the upstream end of the channel plugged to prevent water flow through the site. The outlet, however, is open to a backwater area of the river. The 8-ha site was worked in 1975 by a dragline with 101,500 m^3 of material removed, stockpiled, and screened to produce the required quantities of select materials. The pit filled with groundwater and has depths in excess of 6 m. The unflooded portions of the gravel removal area were contoured and sloped to drain toward the pit in 1976. Most of these areas were also reseeded by Alyeska Pipeline Service Company with annual grasses. Various aspects of this site are shown in Figures 48c, 56, 59, 62, 63, and 84.

McManus Creek. McManus Creek is a small, sinuous stream which originates in foothills at an elevation of 1,000 m and flows 25 km to its confluence with Smith Creek, forming the Chatanika River. The study site lies at an elevation of 675 m, approximately 20 km from its confluence with Smith Creek. During the course of its development, McManus Creek has tended to migrate laterally southward, causing a slightly steeper valley wall on the left than on the right.

The material site was developed during construction of the Steese Highway by scraping gravel deposits within and adjoining the main channel of McManus Creek. A small gravel pit was also dug along the northwest boundary of the site, in an area where the floodplain meets the valley wall. During gravel removal operations, it was necessary to clear and remove the dense vegetation at the 3-ha site. An estimated 75,000 m^3 of gravel were made available for use by these efforts, although a considerably smaller amount is thought to have actually been removed. Large mounds of removed overburden and unused gravels were left within the site. Site rehabilitation was not performed following mining activities. The revegetation that has occurred is attributed to natural reinvasion. Various aspects of this site are shown in Figure 89.

Tanana River - Downstream and Upstream. The Tanana River is a large, braided river fed by many glaciers in the Alaska Range. The Tanana River-Downstream study site is adjacent to the Richardson Highway approximately 57 km downstream from the Tanana River and Delta River confluence at an elevation of 260 m. The site was developed by pit excavation of the central portion of a vegetated island located within the active floodplain of the Tanana River. Excavation was conducted after March 1971 with approximately 310,000 m^3 of material removed from within the 8-ha working limits. Cleared and stripped surface materials were disposed of in waste areas along the borders of the pit. Permit stipulations required a minimum 91 m buffer along the highway and a minimum 30-m undisturbed buffer along adjacent side-channels of the Tanana River. Maximum depth of excavation in this unconnected, water-filled pit was approximately 9.4 m. The site was not rehabilitated.

The Tanana River-Upstream study site is adjacent to the Richardson Highway approximately 9 km downstream from the Tanana River and Delta River confluence at an elevation of 290 m. The gravel removal area was developed by pit excavation of a vegetated gravel deposit adjacent to an active side channel of the Tanana River. The pit was excavated in two parcels herein called the upper and lower pits, which are segregated from the river by a 30 to 40-m wide vegetated buffer. A single channel at the downstream end of the lower pit connects the excavated area to the Tanana River. Mining operations were conducted between 1962 and 1965 during reconstruction of the Richardson Highway between Shaw Creek and Delta Junction. The actual amount of gravel removed is unknown but 133,600 m^3 were approved for removal at this location. The upper and lower pits total about 7.5 ha. Access to the site was via a 100-m gravel road from the Richardson Highway.

Clearing of dense willow and alder and scattered white spruce and paper birch was necessary before stripping of 0.6 to 0.9 m of brown silt, fine sand, and organic material. Coarse gravel was present below the overburden with 10 to 15 percent oversized material. Small stockpiles of gravel were noted along the south edge of the pit. In the upper pit the excavation occurred in an irregular pattern over about 3.5 ha, creating numerous islands and spits. The lower pit on the other hand was mined contiguously over 4 ha, is of greater average depth, and contains no major elevated land forms within its main boundaries. It did not appear that the site was rehabilitated following gravel removal. Various aspects of this site are shown in Figures 27, 57, 70, and 80.

Phelan Creek. Phelan Creek is a small, braided river which originates at an elevation above 1,200 m at the Gulkana Glacier and flows 19 km through the mountainous terrain of the Alaska Range before joining the Delta River. The study site is located approximately 3 km upstream from the Richardson Highway crossing of Phelan Creek and 9 km downstream from the terminous of the Gulkana Glacier.

The material site was worked by scraping unvegetated exposed deposits in the active floodplain of Phelan Creek during construction of the Trans-Alaska Pipeline System. Approximately 152,000 m^3 were removed from the 25-ha original work area between July and October 1975; a 70-ha upstream expansion was approved in late October and yielded an additional 423,000 m^3.

Several high-water channels traversed both the original work limits and the area encompassed by planned expansion to the east. The major active channels of Phelan Creek flowed through the original working area at the time of the survey.

Vegetative clearing and overburden removal were not necessary for the removal of the sandy gravel with some cobbles and boulders. A 15-m buffer was maintained between the work area and main channel of Phelan Creek; this natural buffer was augmented by dikes across depressions and minor channels. A dike was constructed at the upstream end of the site to divert intermittent channel flow and an outlet channel was provided at the downstream end of the gravel removal area to facilitate drainage. Material was removed to a 0.9-m working depth with conventional loading and hauling methods; permafrost was not present but ripping with dozers was necessary for excavation of seasonally frozen ground. Similar working depths, excavation methods, and diversion/buffer procedures were used during development of the upstream expansion.

The site apparently was not rehabilitated, because several dikes and one stockpile remained during the time of the site visit in 1978. Various aspects of this site are shown in Figure 90.

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EFFECTS OF GRAVEL REMOVAL ON RIVER HYDROLOGY AND HYDRAULICS

L. A. Rundquist

INTRODUCTION

The purpose of the hydrology and hydraulics study was to evaluate the effects of floodplain gravel removal on the river configuration, hydraulics, sedimentation, ice characteristics, and hydrology at the 25 study sites. The locations of these sites are shown in Figure 1. The characteristics describing the physical aspects of the site and the gravel removal methods are listed in Table 1. General descriptions of the sites are provided in DESCRIPTION OF STUDY RIVERS.

Previous studies of gravel removal from river floodplains are limited in number. A preliminary report for this project (Woodward-Clyde Consultants 1976a) reviewed literature on gravel removal up to that time. Significant results of that review are included and expanded upon in this section. Other pertinent literature identified since 1976 are included in this section.

A few general statements (from Woodward-Clyde Consultants 1976a) concerning the behavior of rivers are given in the following paragraphs to provide a basis for the information presented in subsequent sections.

A river continually changes its position and shape as a consequence of hydraulic forces acting on its bed and banks. These changes reflect the dynamic condition of the natural environment; they may be slow, gradual processes or sudden morphological changes resulting from an extreme flood event. A river system always strives toward a state of equilibrium in order to convey the water and sediment delivered to it.

Similarly, when a stream is altered locally, the change often causes modification of the channel characteristics for considerable distances both upstream and downstream. The river response to changes is quite complex, but all rivers are governed by the same basic forces. From a review of available literature on river response to alterations, some general statements can be made on the basis of past research results (Karaki et al. 1974).

- Depth is directly proportional to water discharge and inversely proportional to sediment discharge.

- Channel width is directly proportional to water discharge and to sediment discharge.

- Channel shape (width:depth ratio) is directly related to sediment discharge.

- Meander wave length is directly proportional to water discharge and to sediment discharge.

- River slope is inversely proportional to water discharge and directly proportional to sediment discharge and grain size.

- Sinuosity is proportional to valley slope and inversely proportional to sediment discharge.

Although these relationships cannot be used to predict the exact response of a river to alterations, they do reveal the interdependency of the river parameters.

Local modifications to a river can induce short-term and long-term responses. During excavation, channel morphology and sedimentation characteristics may be changed. After the operation has ceased, the river will tend to readjust to the geometry and pattern that it had previously; if the magnitude of the modification is large enough, the readjustment may take many decades to complete. The short-term responses are usually observable and may be measurable; however, the long-term response may be so gradual that the changes will not be noticeable for decades.

In addition to these general statements pertaining to all rivers, a few characteristics of arctic and subarctic rivers are introduced below. Flow stops in many rivers for much of the winter. Those rivers that continue to flow in the channel beneath the ice or in the gravel beneath the channel have the potential to develop aufeis, which is ice that forms upon itself by a series of overflows. The remaining flow is considered vital to fish over-wintering areas.

At breakup, the water levels of large snowmelt floods are often increased by ice jamming or aufeis in the channel. After the snowmelt flood, flow may decrease significantly for the rest of the summer except for a few short duration events in response to summer storms. Very low summer flow is especially common on the North Slope, which is semiarid, receiving only 150 mm of precipitation annually.

In subarctic Alaska, glaciers feed many rivers, resulting in generally more uniform flows through the summer. Diurnal fluctuations are evident in these rivers near their headwaters. Associated with glaciers are glacier dammed lakes that can empty rapidly causing extensive flooding downstream.

METHODS OF DATA COLLECTION

The hydrology and hydraulics field program was conducted to provide information for the evaluation of gravel removal impacts on the physical characteristics of the river within the study reach. Three consecutive days were available at each of the 25 study sites for collection of these data. The site visit was during the summer when the water level was relatively low so that the channels could be more easily crossed. Details on the procedures used can be found in APPROACH AND METHODOLOGY.

METHODS OF DATA ANALYSIS

The evaluation of changes resulting from gravel removal operations at the 25 study sites was based primarily on subjective judgement. A few hydrologic and hydraulic analyses were performed to enhance the data base for making further evaluations and biological analyses. A table was prepared that listed quantitative values for the subjective evaluation of changes, and was used to compare sites and, thereby, to evaluate the relative change. The following subsections describe briefly the methods used in the analyses.

HYDROLOGY

Mean annual flows and flood frequency curves were developed for the 25 study sites. There were no U. S. Geological Survey gaging stations at the study sites. Nine sites were near enough to gaging stations to use the gaging station data, although none of the station records exceeded 12 years in length. Standard regional regression techniques were difficult to use because of the sparse gaging station network in arctic and subarctic Alaska. The hydrologic analyses thus include a significant amount of judgement; thus, the results should be considered as rough estimates.

Mean Annual Flow

The mean annual flows at six U. S. Geological Survey gaging stations were used as a basis for the analysis. The unit mean annual flow (mean annual flow per square kilometer of drainage basin) was computed for these stations. Nine of the study sites were near enough to the stations to use the station's unit mean annual flow. At the remaining 16 sites, the unit mean annual flow from the nearest gaging station was modified after considering the difference in mean annual precipitation of the drainage basins for the gaged river and the study site.

Flood Frequency Analysis

Flood frequency curves for each of the study sites were generated by applying a regional analysis technique described by Lamke (1979). Discharges for the 1.25-, 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals were computed. In order to improve these estimates, flood frequency data based on the application of the Log Pearson Type III distribution were requested from the U.S. Geological Survey for 17 gaging stations on or in the general area of the study sites. The regression equations presented by Lamke were also used on these gaged rivers and the ratio of the Log Pearson Type III discharges to the discharges calculated from the regression equations were computed. These ratios were then applied to the study sites if the sites were (1) on the same river but upstream or downstream from the gaging site, (2) a similar size to that of the gaged river, and (3) if the drainage basin characteristics such as headwaters location, aspect, and drainage basin shape were similar. The resulting discharges were used to develop flood frequency curves for each of the study sites.

HYDRAULICS

Three analyses were included in the hydraulic investigation: backwater analysis, uniform flow analysis, and hydraulic geometry analysis. Each of these are discussed in the following separate subsections.

Backwater Analysis

A backwater analysis was performed for most of the rivers included in the study using the standard step method (Chow 1959). Input data to the program included a selected discharge, a corresponding water surface elevation at the control section, cross-sectional geometry of each cross section in the study reach, distances between cross sections, and roughness coefficients for each subsection of each cross section.

Uniform Flow Analysis

In addition to the flood flow computations performed in the backwater analysis, values of some geometric and hydraulic parameters at low flows were computed in order to relate these parameters to the corresponding discharge and to provide data for the aquatic habitat evaluation. Use of the backwater program was not appropriate for low flows because of the small number and wide spacing of cross sections in the study reaches. The flows at the surveyed cross sections were assumed to be uniform and computations were made using the Manning equation (Chow 1959).

The input data to the uniform flow program included the cross-sectional coordinates, roughness coefficients, energy slopes, selected discharges, and initial estimates of stage. The surveyed water surface slope was used as an estimate of the energy slope because most surveys took place when rivers were carrying flow similar in magnitude to the mean annual flow. Similarly, the roughness coefficient was calculated from the measured discharge and geometry rather than from estimates used in the backwater analysis. This calculation technique was used because roughness would likely be greater at low flows than that at flood flows due to the greater influence of the bed roughness at small depths.

Hydraulic Geometry Analysis

Values of the coefficients and exponents in the power relations for the hydraulic geometry (including mean velocity) at a cross section were computed for disturbed and undisturbed cross sections at five selected study sites. Power curve fitting was completed for the geometric and corresponding discharge data which were determined by the hydraulic analyses discussed in the previous subsections. The resulting coefficients and exponents were compared with the values obtained for other rivers in Alaska and other parts of the United States. In addition to this quantitative comparison, a qualitative comparison of power relation coefficients and exponents for disturbed and undisturbed cross sections was made based on plots of the power curves for each cross section of other sites having insufficient data range for a quantitative analysis.

QUANTIFICATION OF CHANGES

At each of the 25 study sites an attempt was made to quantitatively rate the degree of change of selected river characteristics due to the gravel removal operations. When quantifying changes, the selected characteristic should be compared before and after the gravel removal operation under similar flow conditions. Whenever possible, this was done using aerial photographs. Aerial photographs often did not provide the necessary detail, or the lack of information concerning flow conditions in the photographs made such comparisons less meaningful. Thus, the upstream sample area was assumed to represent the undisturbed condition for many of the comparisons. After comparisons were made, a rating scale was applied to establish the relative degree of change occurring in physical characteristics at the various sites.

A scale was selected ranging in value from 0 to 10, with 0 being a very large decrease in the quantity of a characteristic, 5 indicating no change, and 10 being a very large increase in the quantity of a characteristic. Intermediate values reflect various degrees of change between the extreme values. More specific meanings of the degree of change for each characteristic are given in the following RESULTS AND DISCUSSION section.

All sites were rated using the rating scales. Sites with more than one physical response to the gravel removal activity were given more than one rating. These sites included Sinuk River, Washington Creek, Oregon Creek, Aufeis Creek, and Middle Fork Koyukuk River-Upstream. At all other sites, the physical changes resulting from the gravel removal operation were similar throughout the site. The gravel removal areas for all sites are discussed in general in the previous section (DESCRIPTION OF STUDY RIVERS). The separation of the gravel removal areas for the hydrologic and hydraulic analyses at selected sites is described in the following paragraphs.

At Sinuk River, different responses to gravel removal were observed for two gravel removal locations. These locations are shown in Figure 11. An island that split the channel upstream of the highway bridge was completely

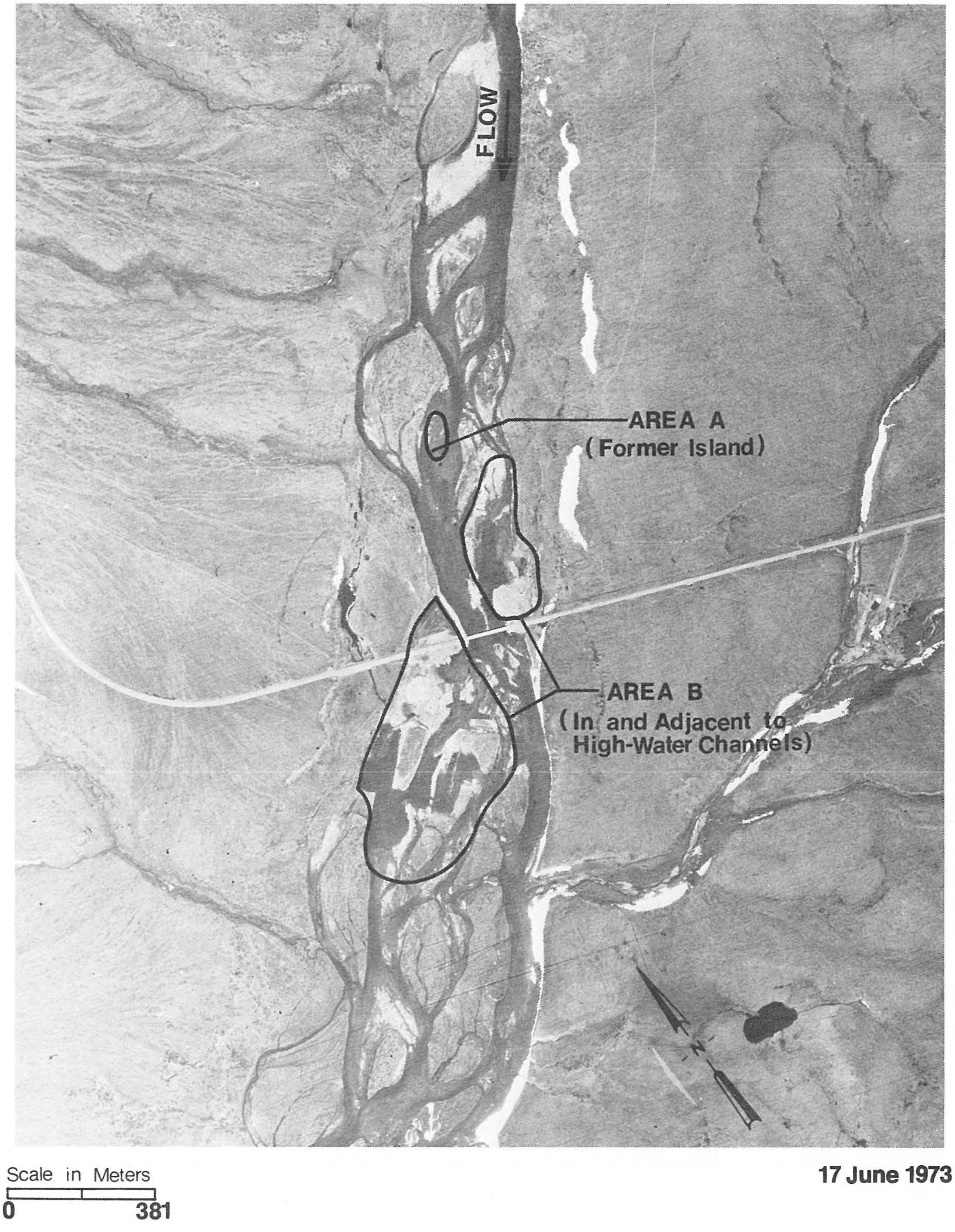


Figure 11. Aerial photograph showing the two gravel removal locations at Sinuk River considered separately in the hydrology/hydraulics analysis.

removed (this area is designated Area A). The other location (Area B), in and adjacent to high-water channels upstream and downstream from the highway bridge, was separated from the main channel.

At Washington Creek, two gravel removal areas were separated by approximately 1 km of undisturbed river (Figure 12). The upper (upstream) and lower (downstream) gravel removal areas are designated A and B, respectively.

At Oregon Creek the major area of disturbance was immediately upstream of its confluence with Cripple River (Figure 13, Area A). The unvegetated gravel bar (Area B) immediately downstream from the highway bridge was also used for gravel extraction.

At the Aufeis Creek site, the two major gravel removal areas were separated by over 3 km of river channel (Figure 14). The upper and lower sites are designated A and B, respectively.

Gravel removal at the Middle Fork Koyukuk River-Upstream site was located in a high-water channel and on a point bar (Figure 15). The upper and lower sites are designated areas A and B, respectively.

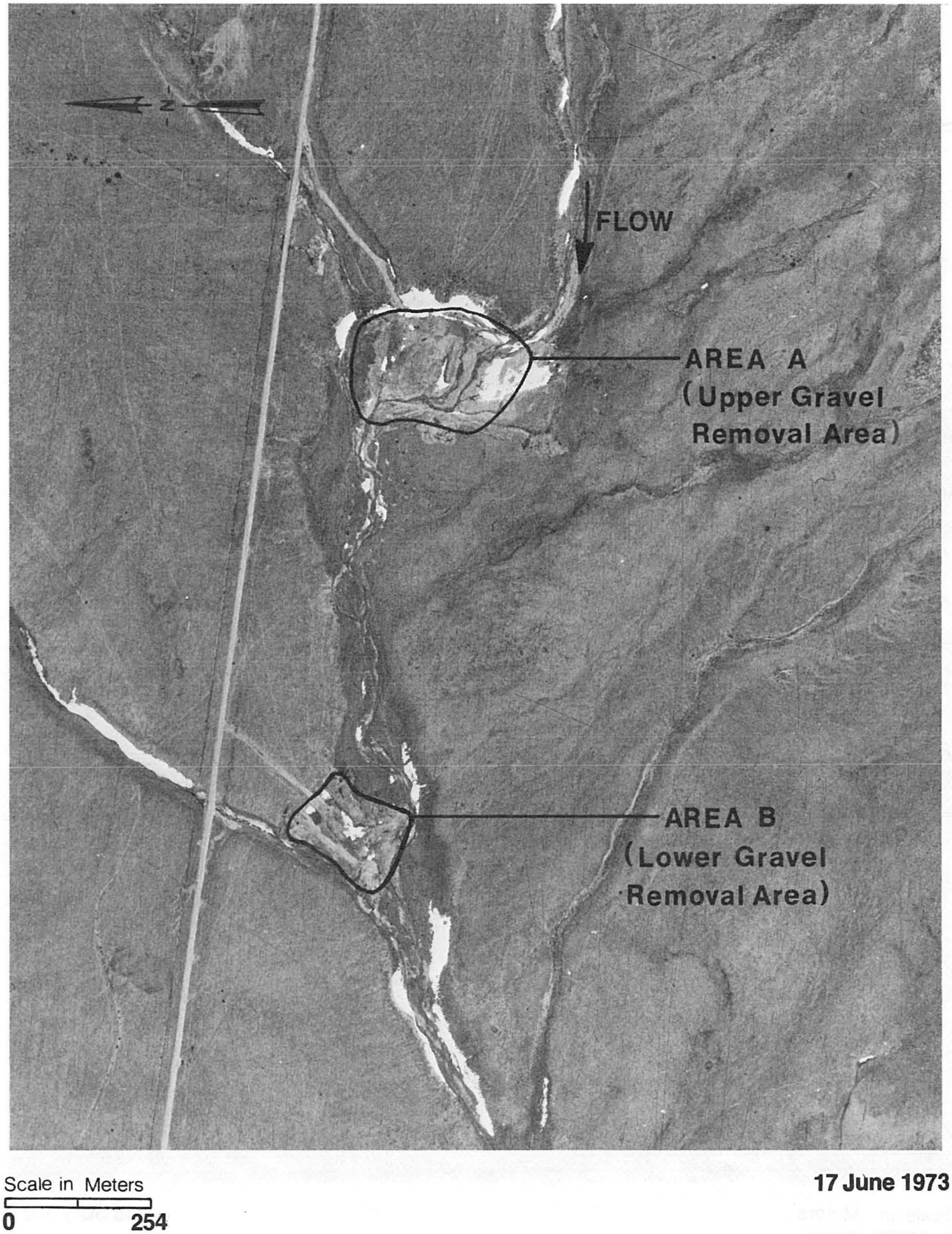


Figure 12. Aerial photograph of Washington Creek showing the upper and lower gravel removel areas.

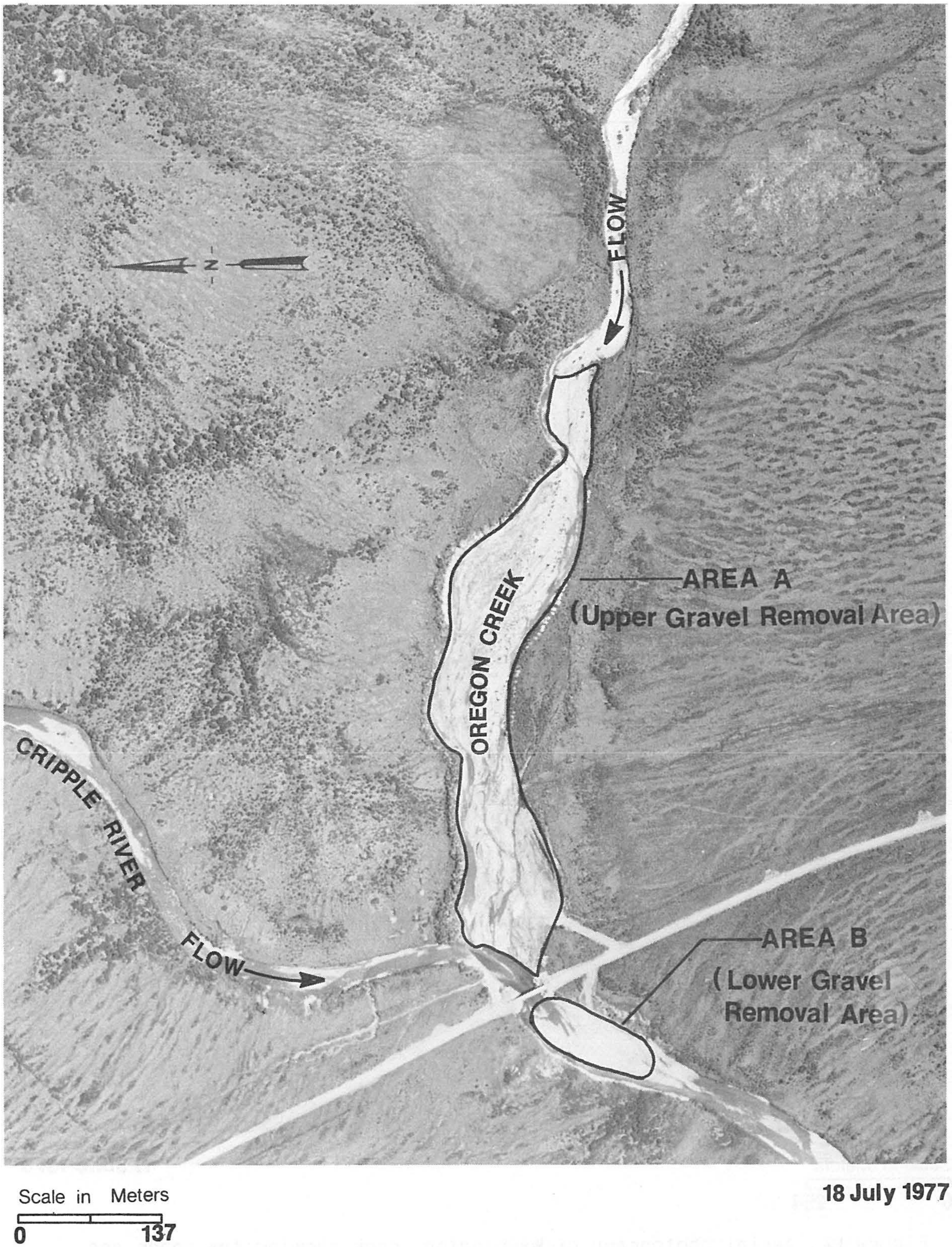


Figure 13. Aerial photograph of Oregon Creek showing the upper and lower gravel removal areas.

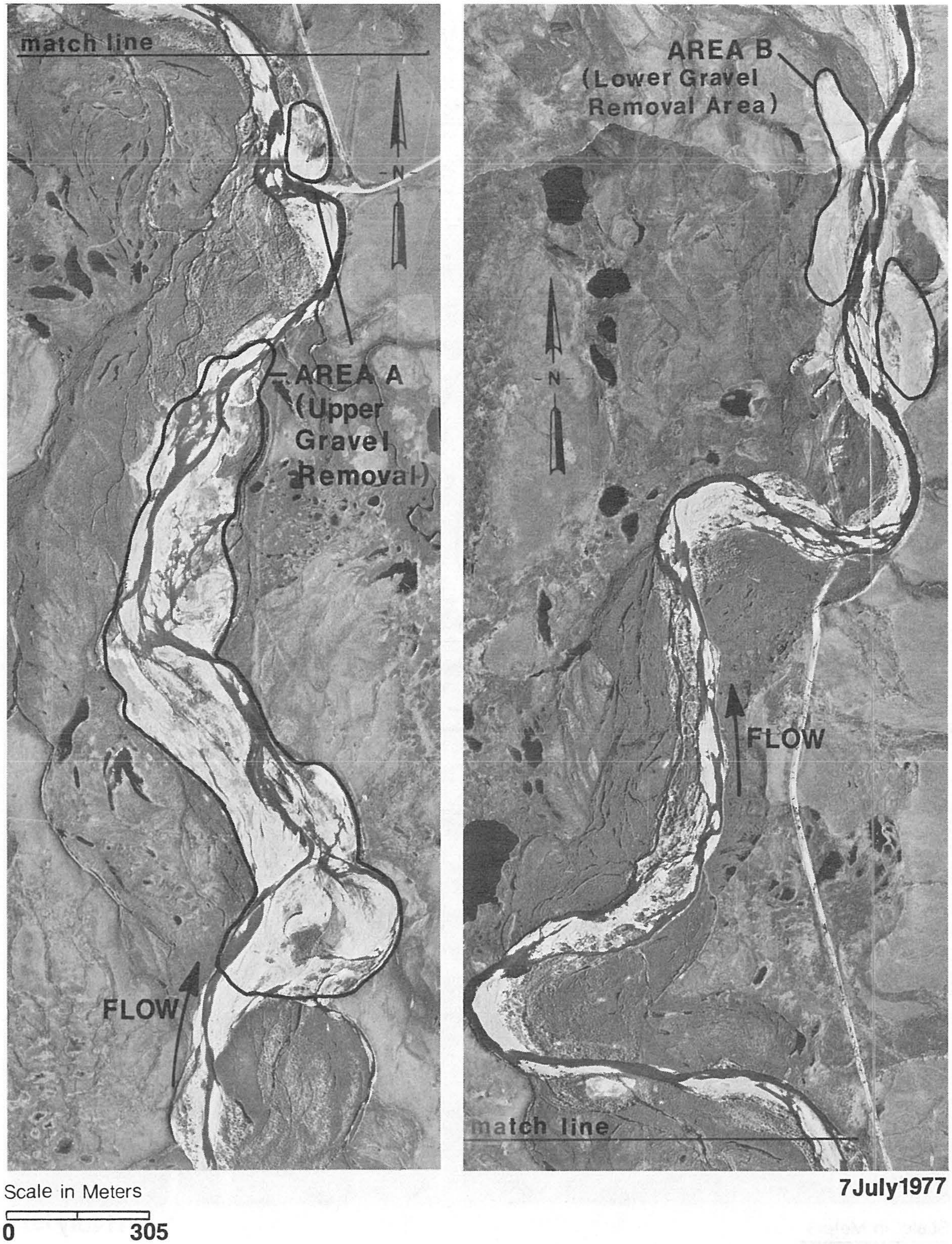


Figure 14. Aerial photograph of Aufeis Creek showing upper and lower gravel removal areas.

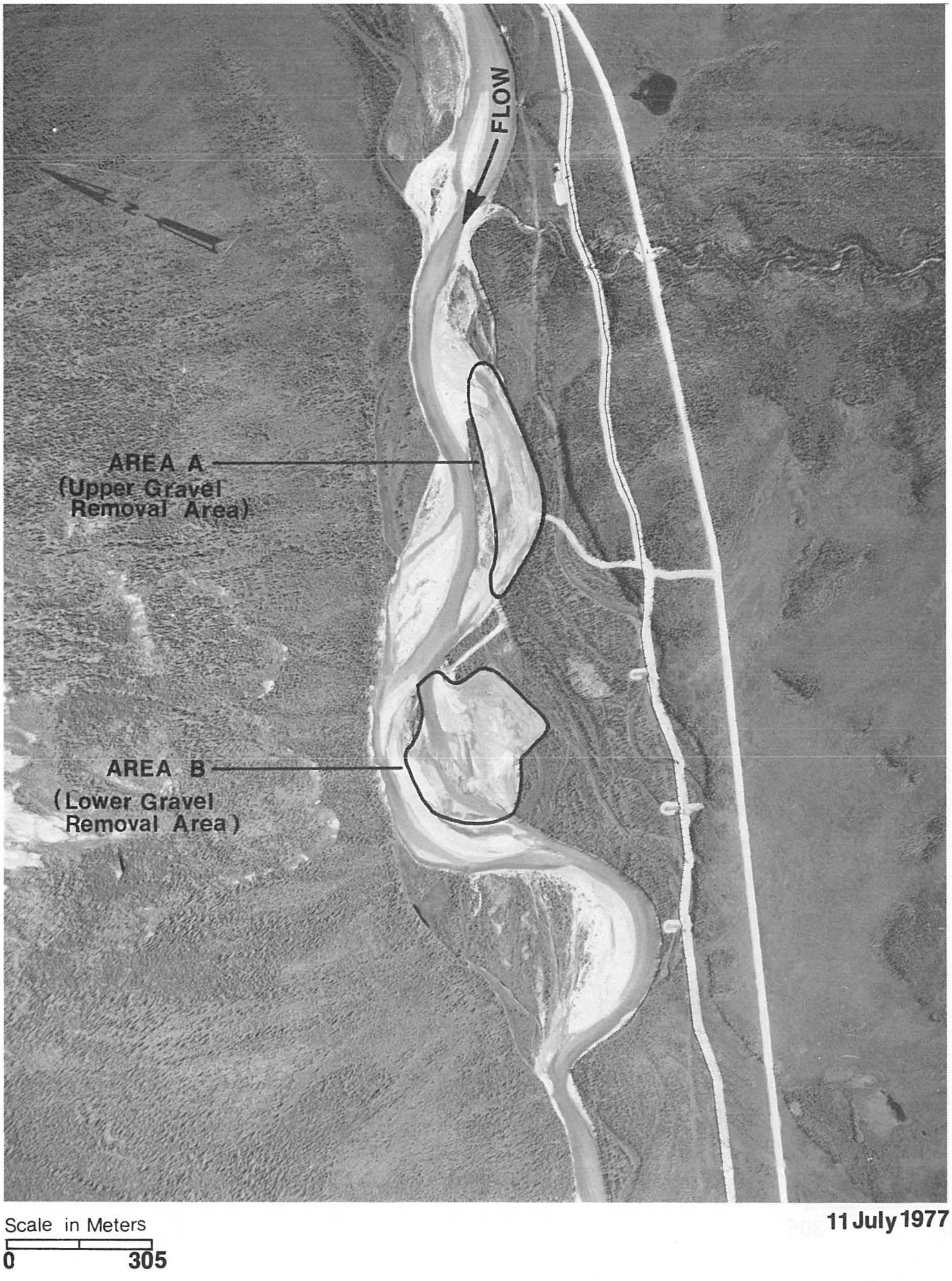


Figure 15. Aerial photograph of Middle Fork Koyukuk River-Upstream showing upper and lower gravel removal areas.

RESULTS AND DISCUSSION

The following subsections present and discuss the results of the data analysis for the 25 study sites. The five subsections represent five categories of river characteristics which exhibited changes resulting from gravel removal operations. These include:

- Channel configuration and process,
- Hydraulics,
- Sedimentation,
- Ice characteristics, and
- Hydrology.

Each subsection includes background information that provides the reader with a knowledge of selected characteristics of undisturbed rivers and a description of changes which occurred in these river characteristics as a result of gravel removal operations.

CHANNEL CONFIGURATION AND PROCESS

The channel configuration of a river is the shape of the river channel(s) when looking vertically down at the river. Configurations represented by the 25 study sites include braided, split, meandering, sinuous, and straight. A sixth configuration, beaded, is unique to northern environments, but was not investigated during this study; beaded systems are typically very small and are not likely to contain much gravel. Associated with the channel configurations are processes of sediment erosion and deposition which form features characteristic of the configuration. The five channel configurations that were used to describe the studied sites are described in subsequent paragraphs.

The channel configuration is a function of river stage (water level); the optimum stage for defining the channel configuration is at low flow. The channel configuration is also a function of location along the river; a river could conceivably exhibit all channel configurations between its headwaters and its mouth. The channel configurations describing the 25 study sites are those only through the reach studied. Configuration combinations, local spatial variations, and variations over time complicate channel configuration selection.

Undisturbed Condition

Braided Configuration. A braided river typically contains two or more interconnecting channels separated by unvegetated or sparsely vegetated gravel bars (Figure 16). Its active floodplain is typically wide and sparsely vegetated, and contains numerous high-water channels and occasional vegetated islands. Active channels are typically wide and shallow and carry large quantities of sediment at high flows. Bars separating the channels are usually low, gravel surfaced, and easily erodible. The lateral stability of the channels is quite low; channels shift by bank erosion and/or by channel diversion into what was previously a high-water channel. The lateral activity of channels within the active floodplain of a braided river that carries large quantities of bed load, is expected to be high because gravel deposits may partially or fully block channels, thereby forcing flow out of the channel. Maximum depths and corresponding top widths of undisturbed major, side, and high-water channels, at four braided study sites, are plotted in Figure 17.

Split Configuration. A split channel river has numerous stable islands which divide the flow into two channels (Figure 18). The banks of the channels are typically vegetated and stable. The split river floodplain is typically narrow relative to the channel width. There are usually no more than two channels in a given reach and other reaches are single channel. One of the two channels in a split reach may be dry during periods of low flow. The channel cross section is narrower and deeper than a braided river with similar flow characteristics. Maximum depths and corresponding top widths of

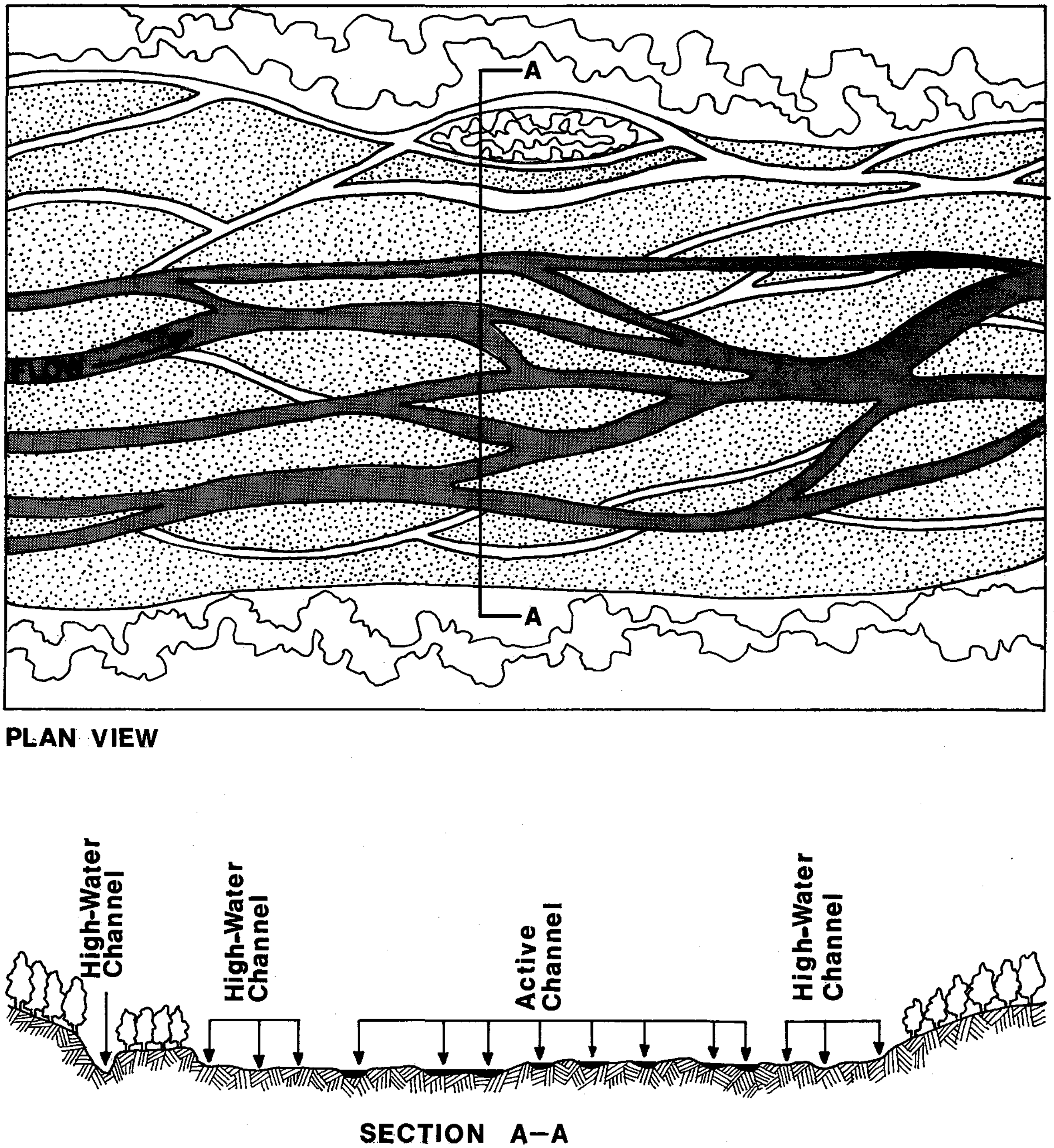


Figure 16. Schematic diagram of the plan view and cross section of a typical braided river.

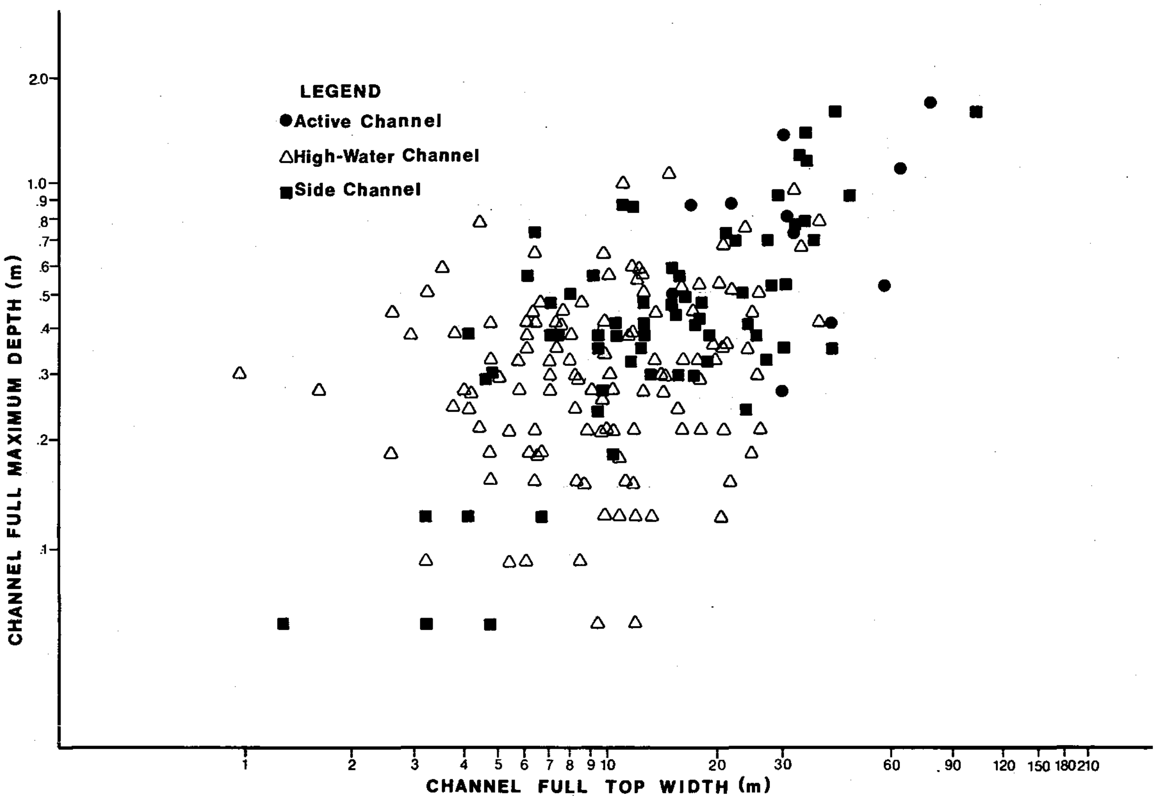


Figure 17. Maximum depths and corresponding top widths of undisturbed major, side, and high-water channels at four braided study sites.

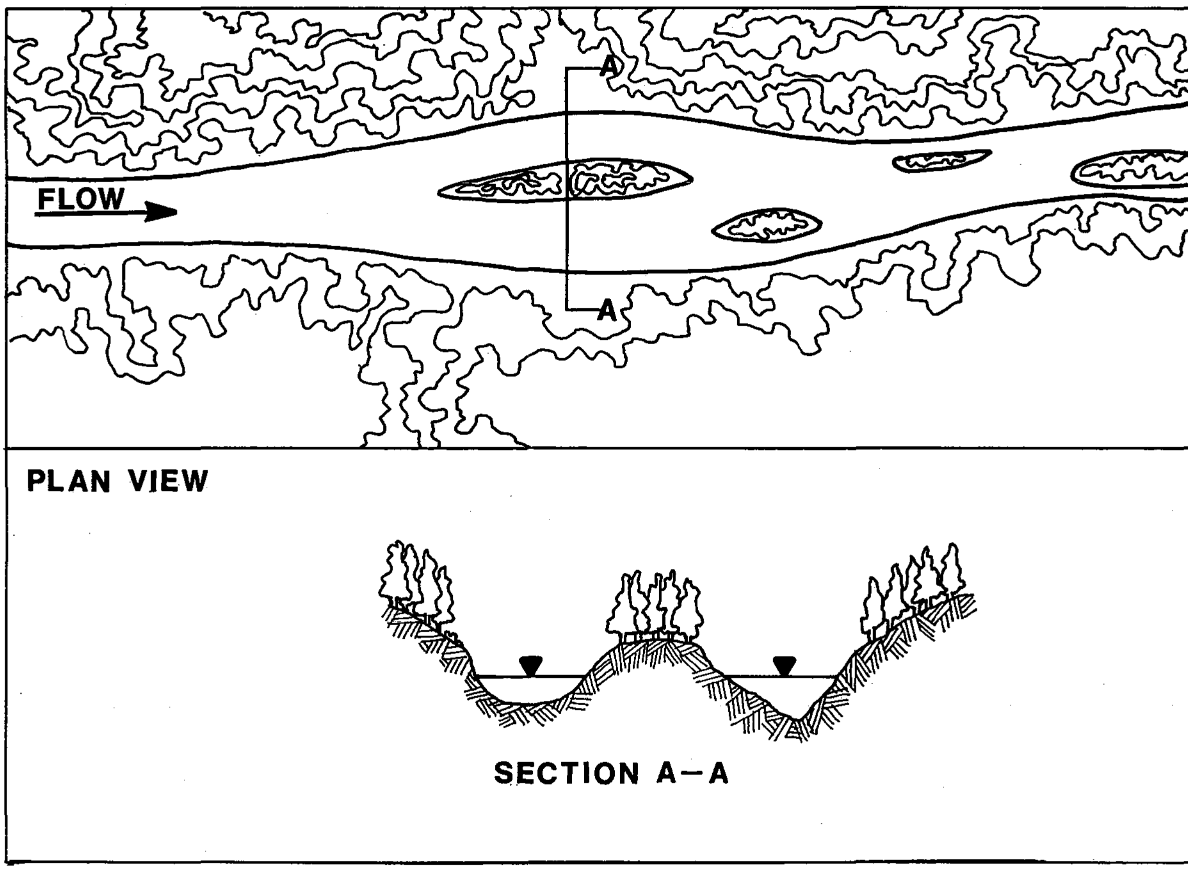


Figure 18. Schematic diagram of the plan view and cross section of a typical split channel river.

undisturbed major, side, and high-water channels, at four split channel study sites, are plotted in Figure 19. Sediment discharge is typically less than that of a braided river. Bed load is deposited at low flow to form gravel bars along the sides or in the middle of the channels. These bars are typically more erodible than the banks. The bars, rather than the banks, are eroded during subsequent floods, resulting in a laterally stable channel.

Meandering Configuration. A meandering river winds back and forth within the floodplain (Figure 20). The ratio of the channel length to the downvalley distance is called the sinuosity ratio, or sinuosity. Meandering rivers have a sinuosity greater than 1.5. Flow is contained in a single

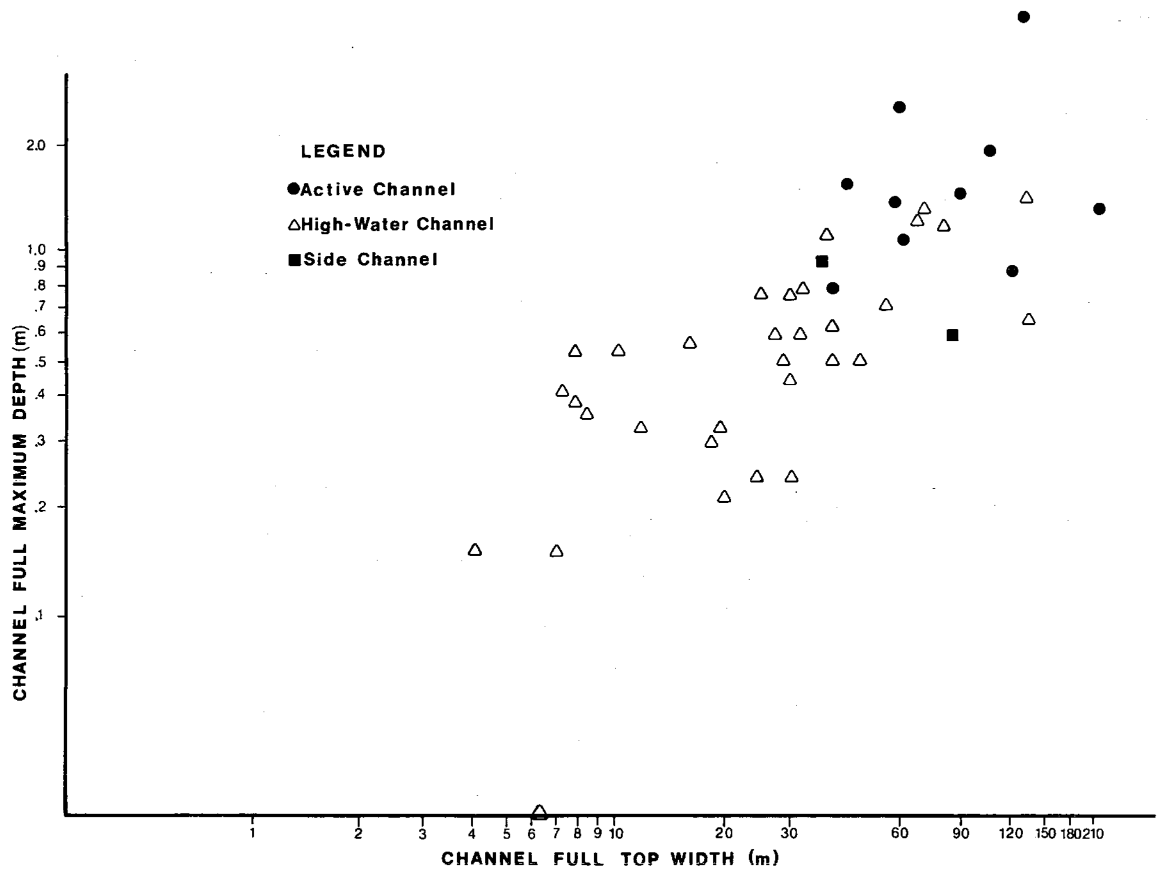


Figure 19. Maximum depths and corresponding top widths of undisturbed major, side, and high-water channels at four split channel study sites.

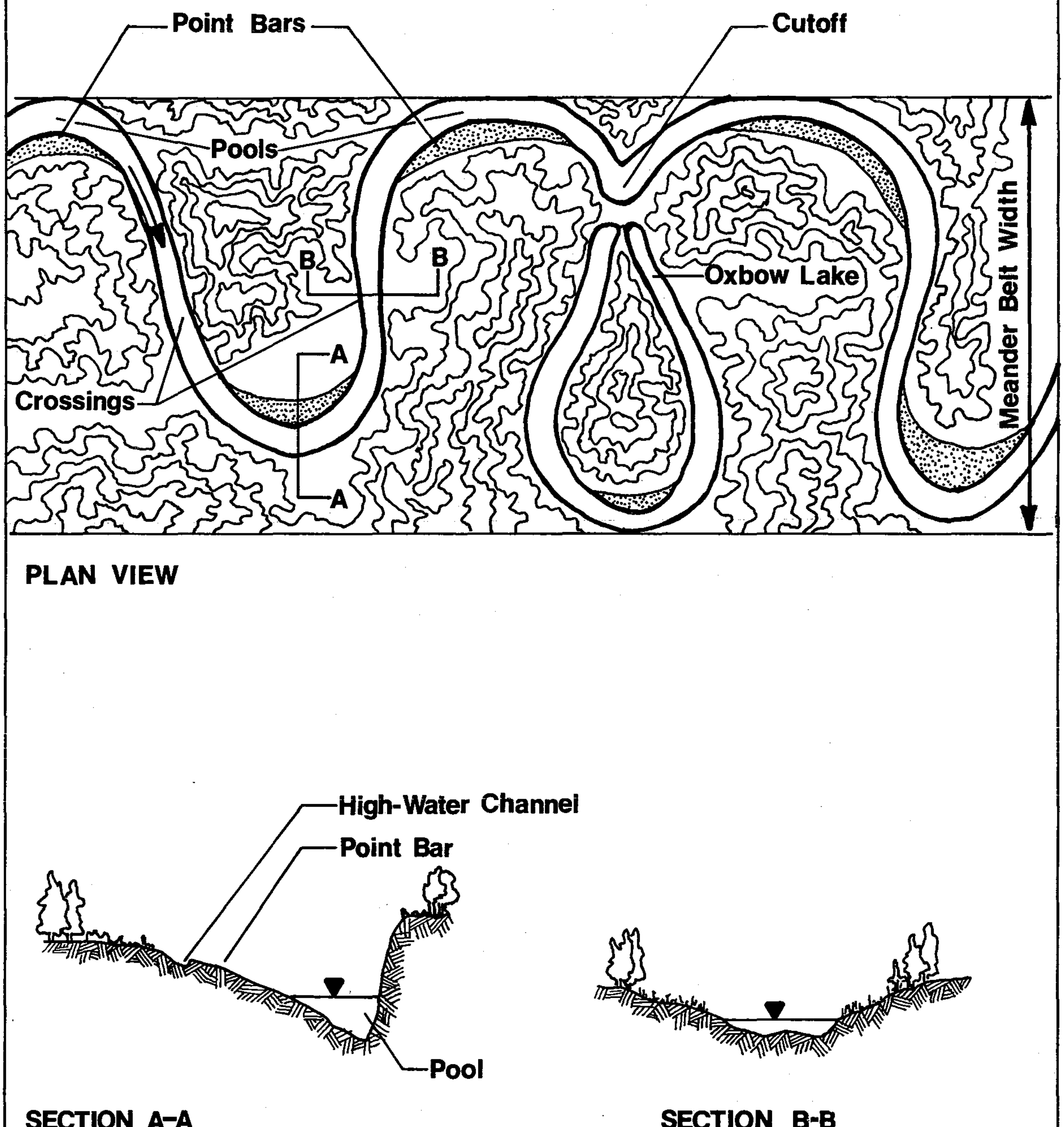


Figure 20. Schematic diagram of the plan view and two cross sections of a typical meandering river.

channel, with very few islands. At each bend, the typical cross section contains a point bar on the inside of the bend and a pool on the outside of the bend, resulting in a triangular shaped cross section. Point bars are the primary area of sediment deposition in a meandering river. Between the bends is a crossing, which typically has a wide and shallow cross section similar to that of a single braided channel. Since the width of the channel in the crossing is similar to that in the bend, the average velocity is often greater through the crossing. Maximum depths and corresponding top widths of undisturbed major, side, and high-water channels at 15 study sites with meandering, sinuous, and straight configurations are plotted in Figure 21. A meandering river shifts in the downvalley direction by

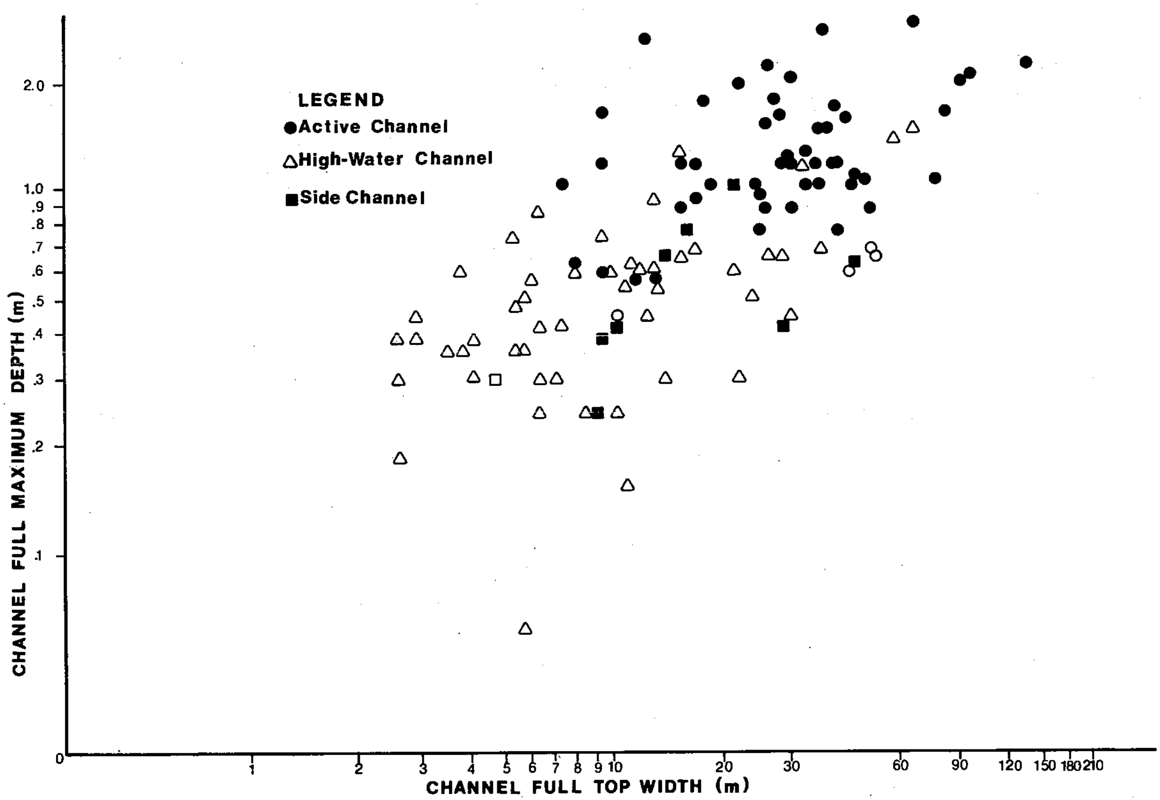


Figure 21. Maximum depths and corresponding top widths of undisturbed major, side, and high-water channels at 15 study sites with meandering, sinuous, and straight configurations.

a continuous process of erosion and deposition; erosion takes place on the outside bank, downstream from the midpoint of the meander bend and deposition occurs on the downstream end of the next point bar downstream. The rate of downvalley shifting varies from one river to another. The rate and direction of shifting is much more predictable than the lateral shifting of braided channels. A result of nonuniform shifting is channel cutoffs.

The floodplain width of a meandering river is often roughly equal to the meander belt width, which is the average width from the outside of one meander bend to the outside of the next opposite meander bend (Figure 20). High-water channels on the inside of point bars are typical on meandering rivers. Sediment transport in meandering rivers is typically moderate.

Sinuous Configuration. A sinuous river is similar in plan view to a meandering river except that its sinuosity is between 1.1 and 1.5 (Figure 22). In sinuous rivers, point bars are smaller and downvalley shifting is generally less than that of a comparable-size meandering river. Other than the greater stability, sinuous rivers are quite similar in form and hydraulic characteristics to meandering rivers.

Straight Configuration. A straight river flows in a single channel with a sinuosity less than 1.1 (Figure 23). The thalweg, or deepest part of the channel, typically wanders back and forth within the channel with alternate ground bars formed by sediment deposition opposite those locations where the thalweg approaches the side of the channel. The alternate bars may or may not be exposed at low flows. Rivers with a long reach of straight channel pattern are much less common than rivers with other configurations. Banks of straight channels are expected to be relatively stable. Sediment transport is likely to be light to moderate in these systems.

Other Processes. Rivers with any configuration may be found in narrow mountain valleys and on alluvial fans. Rivers in these locations have different processes of erosion and deposition than those described for the typical river with the same configuration. Channel configurations of mountainous rivers are typically not controlled by alluvial processes, but

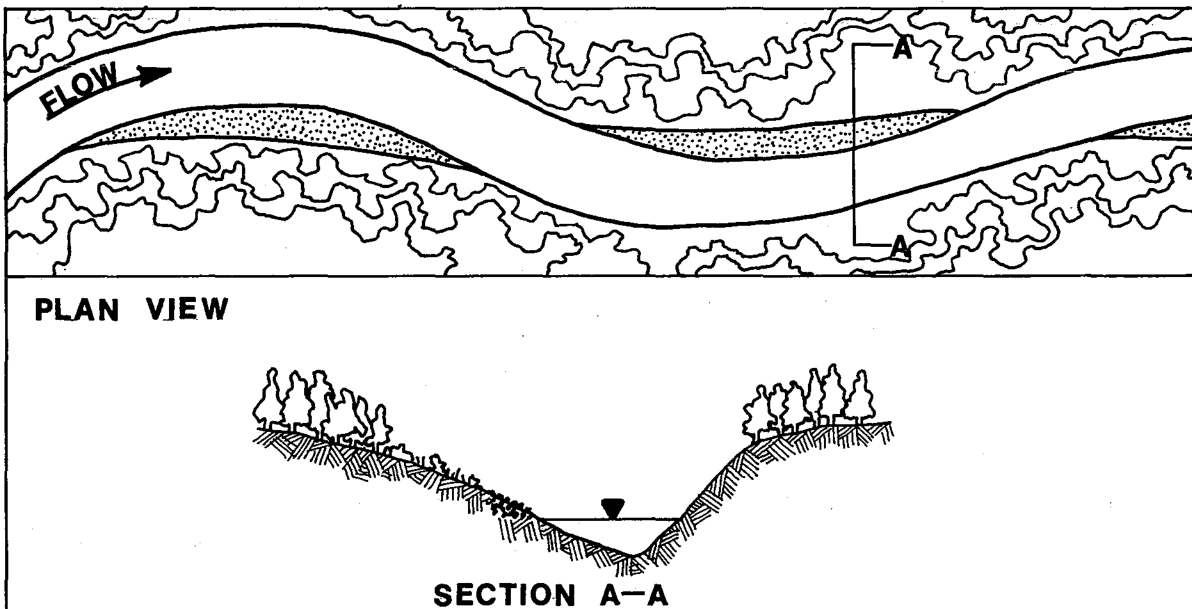


Figure 22. Schematic diagram of the plan view and cross section of a typical sinuous river.

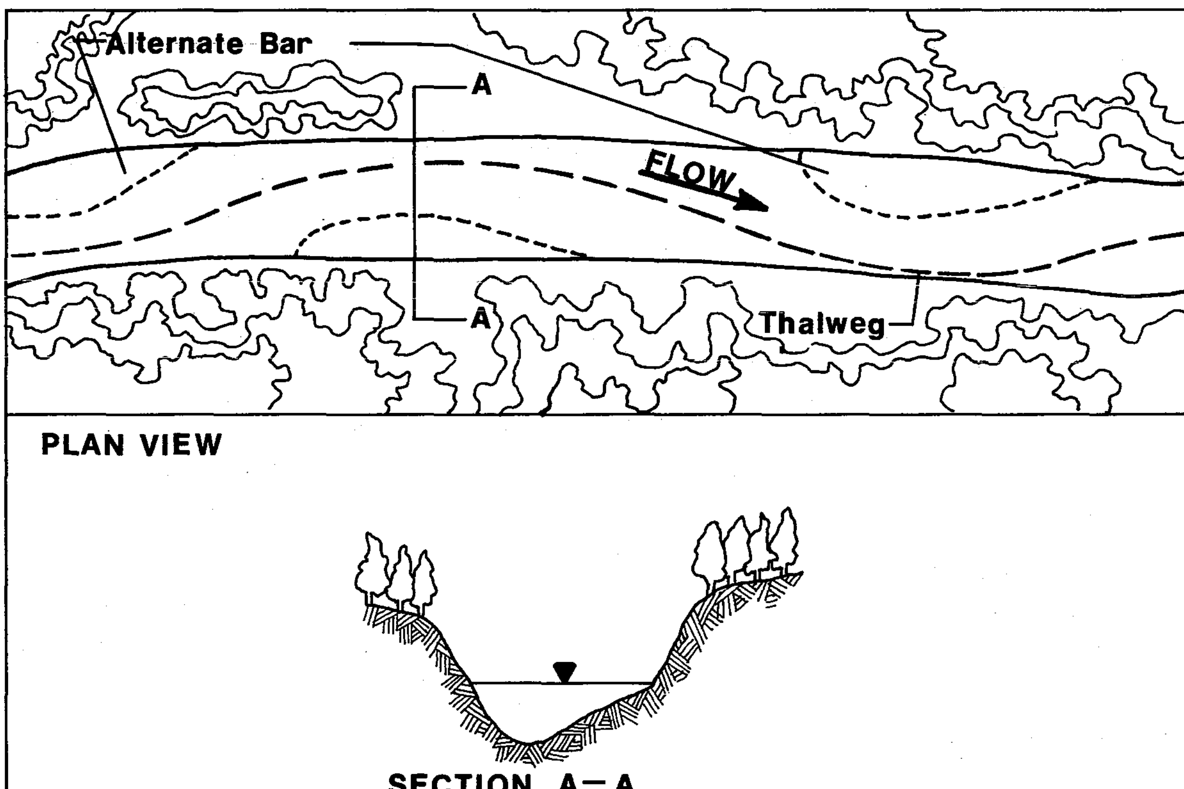


Figure 23. Schematic diagram of the plan view and cross section of a typical straight river.

rather are controlled by geological and morphological features of the valley. Mountainous rivers commonly have very little or no floodplain and consequently, have small quantities of gravel. Alluvial fans develop when a steep gradient stream flows onto a substantially less steep terrain; its sediment transport capacity is significantly reduced causing sediments to be deposited. This deposition fills the channel, thus forcing the flow to develop a new channel. This may occur by a gradual migration process or by a rapid abandonment of one channel to develop a new channel. Such processes develop a partial cone-shaped deposit of gravels with the apex being near the end of the steep gradient river valley (Figure 24). The fan may or may not be vegetated; denser vegetation implies greater stability.

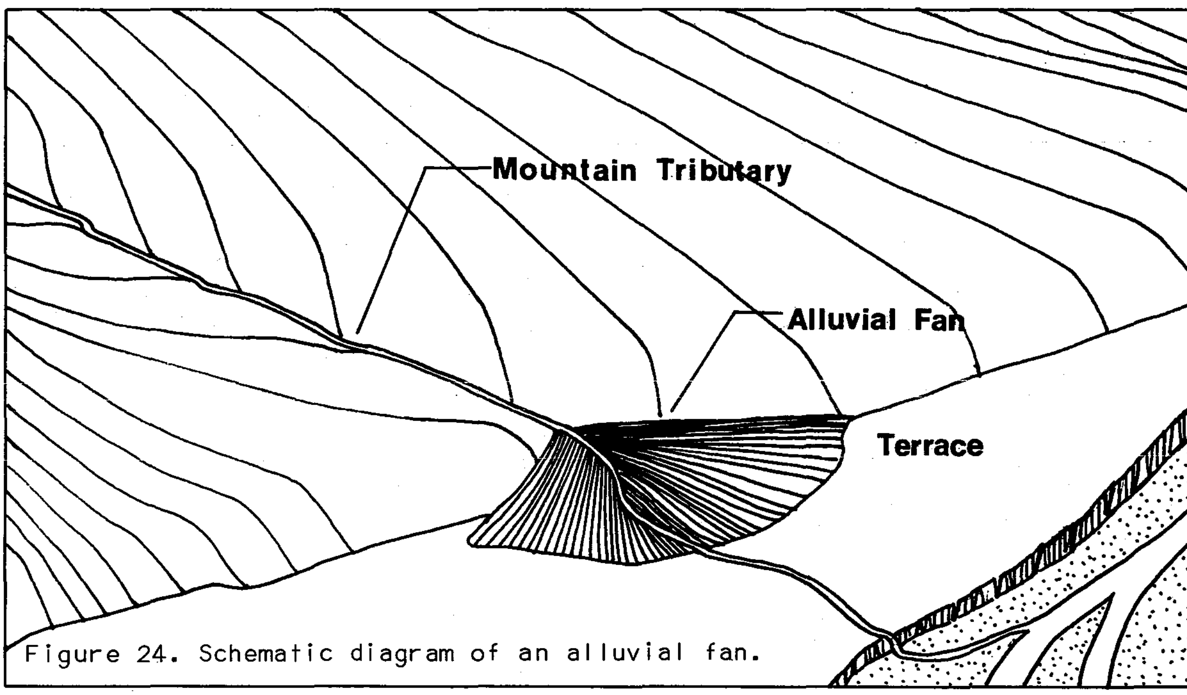


Figure 24. Schematic diagram of an alluvial fan.

Changes Due to Gravel Removal

The most common change to the channel configuration resulting from gravel removal was a shift towards a more braided configuration as indicated, in part, by an increase in the number of channels. A decrease in lateral stability of the channels was often associated with changes to more numerous channels. These changes were most prevalent in scraped sites and most prominent in single channel sites. Gravel removal at many scraped and pit excavated sites caused a diversion or a high potential for diversion of flow through the gravel removal site. These observed channel configuration changes were given quantitative ratings for comparative purposes (Table 5). These changes in channel configuration are discussed in more detail in the following sections.

Braiding Characteristics. The two braiding characteristics considered were the number and stability of the channels. The most significant changes in these characteristics resulted from scraping operations in straight, sinuous, split, and meandering rivers with lesser changes observed in scraped braided rivers. This difference was expected, because braided rivers had such characteristics prior to gravel removal, thus, any change was comparatively less significant. The locations of the gravel removal operations that caused the most significant change in the braiding characteristics were those which disturbed the bars adjacent to active channels or those which caused diversion of flow into the material site.

Disturbance of the bars adjacent to active channels can hypothetically reduce the flow within the channel during floods because flow spreads out through the mined area. The reduced flow within the channel would reduce the ability to transport sediments; sediment deposition within the channel may result. This deposition would potentially aggravate the problem by further reducing the cross-sectional area available to the flow. This process can result in widening the channel and the development of mid-channel bars. Although the potential for this hypothetical process exists, it was not observed at the study sites.

Braiding characteristics increased at many sites due to the diversion of flow through the site and the lack of a well-defined channel to confine the flow. The flow thus spread through the material site and likely did not have sufficient scour potential to develop a new channel. Thus, numerous poorly-defined channels flowed through the site.

Table 5. Quantification Ratings of Change in Channel Configuration Characteristics Resulting from the Gravel Removal Operation at Each of the 25 Sites

River	Gravel removal area	No. of channels[a]	Channel stability[b]	Diversion through pit[c]	Diversion through scrape[c]
Gold Run Creek		5	5	–	6
Sinuk River	A	4	3	–	9
	B	–	–	–	7
Washington Creek	A	10	0	–	10
	B	5	4	–	6
Oregon Creek	A	9	0	–	9
	B	7	5	–	6
Penny River		9	0	7	10
Nome River		10	0	–	10
Ugnuravik River		6	3	10	9
Aufeis Creek	A	9	0	–	10
	B	5	4	–	6
Kuparuk River		7	3	–	7
Skeetercake Creek		5	1	–	10
Sagavanirktok River		10	4	–	9
Ivishak River		8	4	–	7
Shaviovik River		6	5	–	6
Kavik River		8	2	–	9
Dietrich River–Upstream		5	5	7	7
Dietrich River–Downstream		6	5	–	7
Middle Fork Koyukuk River–Upstream	A	5	5	–	6
	B	10	0	–	10
Middle Fork Koyukuk River–Downstream		8	4	–	7
Jim River		5	5	–	7
Prospect Creek		5	5	8	–
West Fork Tolovana River		5	5	8	–
McManus Creek		5	5	–	6
Tanana River–Downstream		5	5	7	–
Tanana River–Upstream		5	5	7	–
Phelan Creek		4	5	–	10

(Footnotes on following page)

Table 5. Footnotes

[a]Number of channels ratings:

$$B_R = \frac{\text{Number of active channels in the mined area}}{\text{Number of active channels upstream from the mined area}}$$

10 $3 < B_R$

9 $2.5 < B_R \leq 3$

8 $2 < B_R \leq 2.5$

7 $1.5 < B_R \leq 2$

6 $1 < B_R \leq 1.5$ or other B_R values if they are within normal variation ranges of the river

5 $B_R \doteq 1$ of if other data indicate no change

4 $0.67 \leq B_R < 1$ or other B_R values if they are within normal variation ranges of the river

0–3 Not used

[b]Channel stability ratings:

6–10 Not used

5 No change in channel stability

4 Slight decrease in stability, but within natural stability variation of the river

3 Moderate decrease in channel stability due to gravel removal

2 Large decrease in channel stability due to gravel removal

1 Substantial decrease in channel stability due to gravel removal

0 Very substantial decrease in channel stability due to gravel removal

[c]Flow diversion ratings:

10 High potential for river to divert all its flow permanently through the site

9 Diversion of a significant quantity of flow through the site occurred within several years

8 Moderate potential for river to divert all of its flow permanently through the site

7 Moderate to high potential for some of the river flow to divert permanently through the site or for flow diversion through the site during flood events

6 Low potential for river diversion through the site

0–5 Not used

Ten sites had more than twice as many channels in the material site as were upstream. At four of these sites, Washington Creek, Nome River, Sagavanirktok River, and Middle Fork Koyukuk River-Upstream, the numbers of channels increased more than three times due to gravel removal operations. Most sites (7 of 10) with large increases in numbers of channels also had a very substantial apparent decrease in the lateral stability of those channels. Lateral stability evaluations were based on subjective judgements of stability indicators. Lateral stability indicators included the height and erodibility of the gravel bars at the edge of the active channels, the bed load transport characteristics evident at the time of the site visit, and the channel configuration.

The Nome River is an example of a material site with increased braided characteristics (Figure 25). In this sinuous river, single channel flow was prevalent prior to the gravel removal operation; exceptions to this are the split in the channel immediately downstream from the material site location and two high-water or small active side channels adjacent to the material site location. Approximately 20 years after the gravel was removed, the river was flowing in numerous, poorly-defined channels through the material site. The river apparently diverted into the scraped area soon after the operation was completed and has attempted to develop a well-defined channel since it diverted. The state of equilibrium between erosion and deposition in the Nome River was disturbed by the gravel removal operation. To restore equilibrium it will probably take several decades from the time of the initial disturbance.

Flow Diversion Through Site. Gravel removal operations caused flow diversion or a high potential for flow diversion at 12 of the 25 study sites. Sites with a high potential for the diversion of all of the flow permanently through the site included upper Washington Creek, Penny River, Nome River, upper Aufeis Creek, Skeetercake Creek, lower Middle Fork Koyukuk River-Upstream, and Phelan Creek. At most of these sites, all of the flow had already diverted when the site was visited. All of these sites were scraped and the lower Middle Fork Koyukuk River-Upstream site was the only site where a buffer was known to have been used to separate the site from

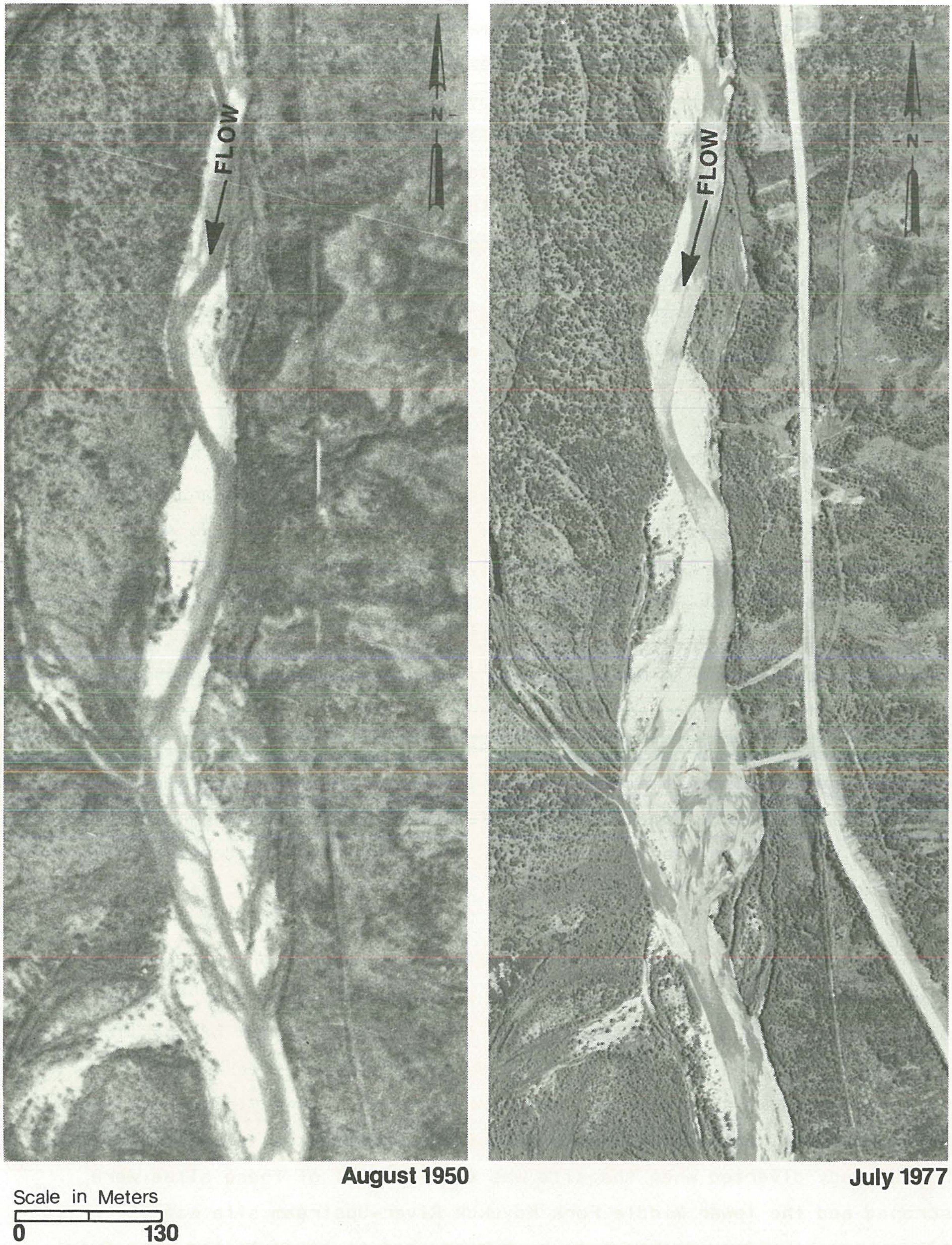


Figure 25. Comparative aerial photography of the Nome River showing change in channel configuration resulting from gravel removal activities.

the active channel. The vegetated buffer was approximately 30 m wide and roughly 1 m in height; vegetation was missing in and adjacent to a high-water channel which crossed the buffer. Low (0.3 m) dikes were used to block off this high-water channel. Flow began to divert through the material site during the first breakup following the removal of gravel. The buffer breached, apparently caused by overtopping and subsequent erosion of the top and downstream face during the flood. At the time of the site visit in 1978, 3½ years after the mining took place, 85 percent of the flow was going through the material site. Scraped sites with a large amount, but not all, of the flow diverted through the material site by the time the site was visited included Sinuk River (in-channel site), upper Oregon Creek, Ugnuravik River, Sagavanirktok River, and Kavik River. None of these sites had a vegetated buffer.

A major consequence of flow diversion through scraped sites was the development of braiding characteristics, as was discussed in the previous section. Another consequence was that flow in the former main channel(s) was eliminated or significantly reduced, thus affecting their hydraulics and their regime. Flow through scraped sites that had the potential to aid the replenishment of gravel within the site occurred at Sinuk River (in-channel site), Washington Creek, Oregon Creek, Ugnuravik River, Aufeis Creek, Kavik River, and Phelan Creek. At other sites, such as Penny River and Middle Fork Koyukuk River-Upstream, flow through the site was probably eroding more sediments than it was depositing.

Most (6 of 7) pit excavated sites had vegetated buffers separating the material site from the active channel(s). The exception is Ugnuravik River (Figure 26), which had only a 5- to 10-m wide gravel bar separating the material site from the active channel. Therefore, the potential for flow diversion through this pit is high; flow has diverted through the site during floods, but the diversion has not yet been permanent.

The two pit excavated sites on the Tanana River were judged to have moderate to high potential for some of the flow diverted permanently through the site within several decades following site closure. Both sites had

Figure 26. Aerial photograph of the Ugnuravik River pit site showing the insufficient buffer zone.

approximately 30 m to 40 m wide vegetated buffers. The main channel of the Tanana River has the capability to erode through such a buffer in less than a year. The side channel at the Tanana River-Upstream site (Figure 27) eroded 3 m of the widest part of the buffer between early June and mid-September of 1978. At either of the Tanana River sites, it could take several years or several decades for the river to breach the buffer and flow through the pit, the length of time depending on the lateral direction of travel of the main channels.

The Prospect Creek and West Fork Tolovana River sites were judged to have a moderate potential for all of the flow to divert through the pits. Both sites had vegetated buffers that included portions of abandoned channels. The upstream end of the abandoned channel, in both cases, causes a zone of weakness in the buffer. Even though, at both sites, the width and height of the buffers were likely sufficient to prevent breaching for several decades, zones of weakness in the buffers at the abandoned channels and channel aufeis development in the active channel may cause earlier flow diversion and buffer breaching. At the West Fork Tolovana River site, the upstream end was diked off and heavily riprapped; however, in spring of 1979, flow apparently overtopped the dike and scoured the channel leading into the pit, leaving a large delta gravel deposit in the pit. Flood stage was probably high because of aufeis development in the channel. Channel aufeis development also influenced the Prospect Creek site (Figure 28). Aufeis developed in the channel reach upstream from the material site, reducing the channel capacity during the snowmelt runoff period. The runoff thus flowed directly down the valley, rather than following the ice-filled channel. The water flowed through the pit causing headcutting of the upstream edge. The edge was subsequently riprapped to prevent further headcutting. Doyle and Childers (1976) documented this April 1976 occurrence.

HYDRAULICS

Hydraulics, as used in this investigation, is the study of those parameters which influence the mechanics of water flow through the study reach. The hydraulic parameters which were considered include hydraulic geometry,

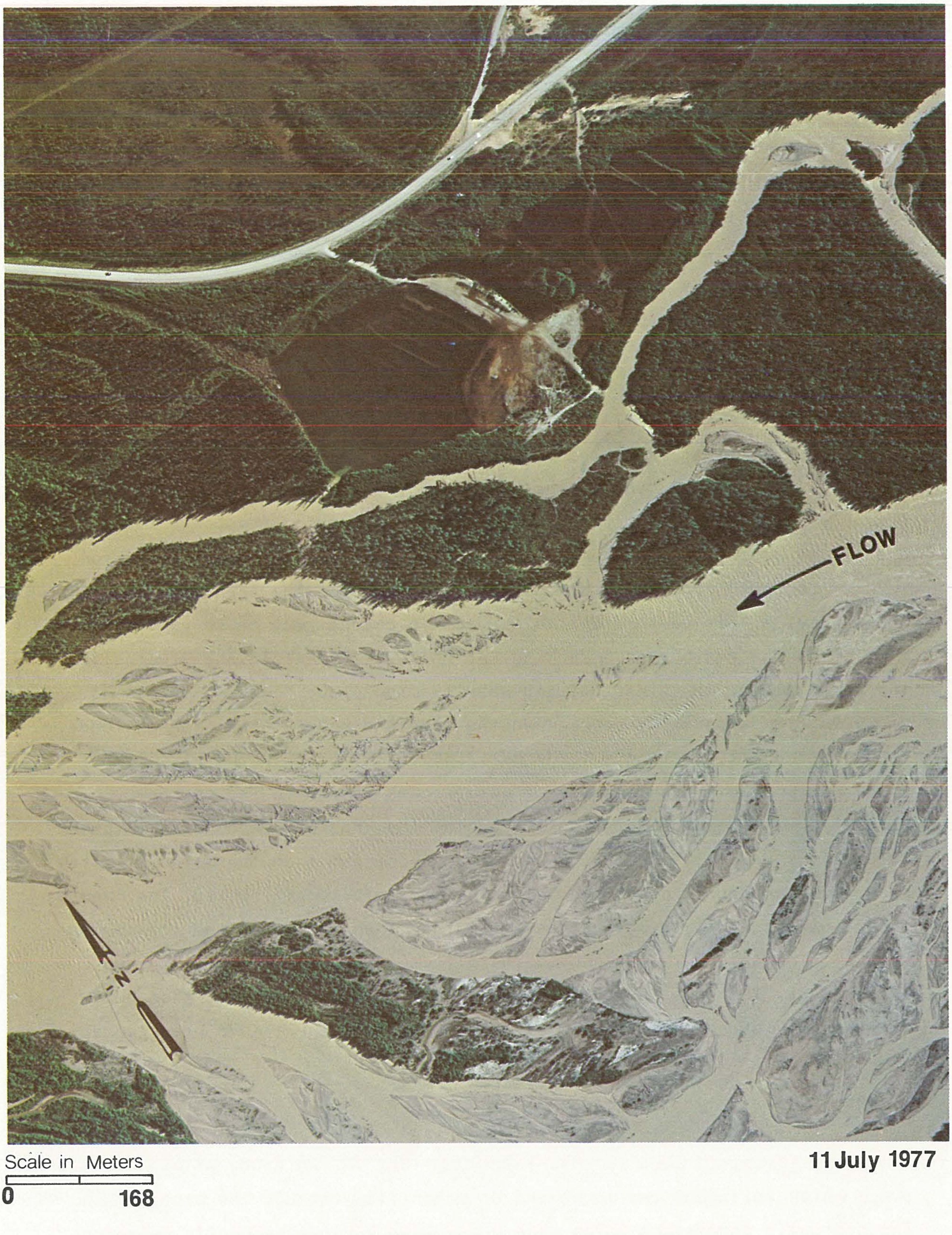


Figure 27. Aerial photograph of the Tanana River-Upstream site with substantial buffer zone separating the pit from the active side channel.

Scale in Meters
0 145

11 July 1977

Figure 28. Aerial photograph of the Prospect Creek pit showing wide buffer zone separating the pit from the active channel.

channel slope, and local flow characteristics at flow obstructions. Hydraulic geometry is defined as the geometric and hydraulic variables at a cross section that vary with changes in discharge. The hydraulic geometry variables discussed are top width, hydraulic depth, and mean velocity. Channel slope (gradient) is the reduction of the water surface elevation in the downstream direction. A general discussion of these hydraulic parameters is presented in the following subsection, followed by a description of the effects on these parameters due to gravel removal.

Undisturbed Condition

The hydraulic geometry parameters considered herein are top width, hydraulic depth, and mean velocity. The top width is the width of the water surface at a given cross section and a given discharge (Figure 29). The

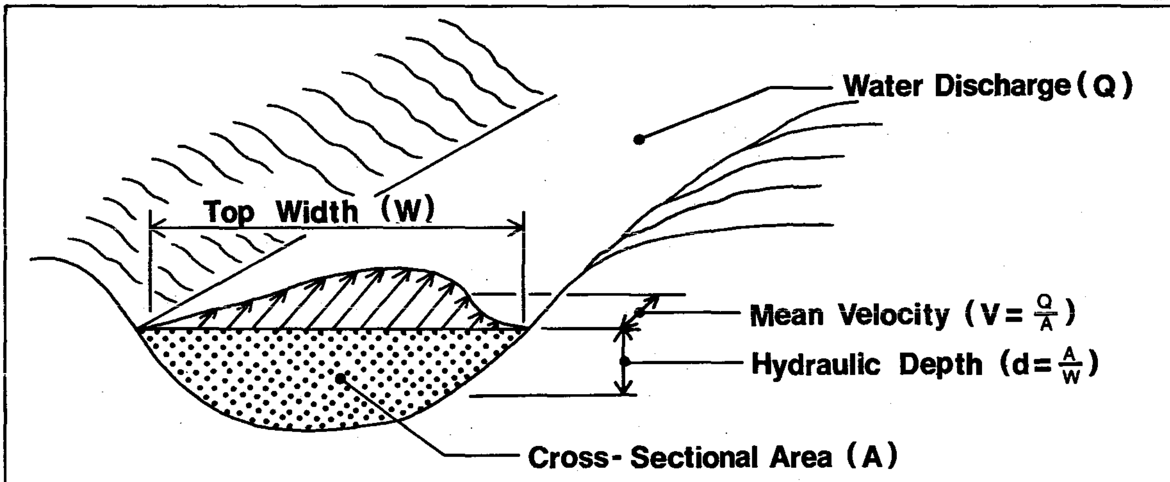


Figure 29. Schematic diagram illustrating definitions of channel geometric and hydraulic variables.

hydraulic depth is defined as the cross-sectional area of flow divided by the top width. The mean velocity is defined as the ratio of discharge to cross-sectional area of flow. An estimate of the carrying capacity of the channel is the conveyance, which is defined by:

$$K = CAR^{x} \qquad (1)$$

where K = conveyance

C = a coefficient related to the roughness of the channel

A = cross sectional area of flow

R = hydraulic radius

x = a fractional exponent

The discharge is directly proportional to the conveyance with the proportionality constant being the energy slope to a fractional power, usually $\frac{1}{2}$.

The variation in the hydraulic geometry as a function of discharge at a river cross section is an indicator of the shape of the channel cross section. The shape primarily reflects the magnitude of the bank-full discharge which typically has sufficient sediment carrying capacity to shape a channel and occurs frequently enough to maintain the resulting shape. The top width, hydraulic depth, and mean velocity at a cross section are often expressed as a function of discharge in the form of power relations:

$$W = a\ Q^{b} \qquad (2)$$

$$D = c\ Q^{f} \qquad (3)$$

$$V = k\ Q^{m} \qquad (4)$$

where W = top width

D = hydraulic depth

V = mean velocity

Q = discharge

a, c, k = coefficients

b, f, m = exponents

Typical relations for a hypothetical river are shown in Figure 30. Substituting the power relations for the hydraulic geometry variables into the flow continuity equation illustrates the interdependence of the variables:

$$Q = A\ V = W\ D\ V \qquad (5)$$

$$= (a\ Q^{b})(c\ Q^{f})(k\ Q^{m})$$

$$= (a\ c\ k)\ Q^{(b + f + m)} \qquad (6)$$

Thus, for continuity,

$$a \times c \times k = 1 \quad (7)$$

and

$$b + f + m = 1 \quad (8)$$

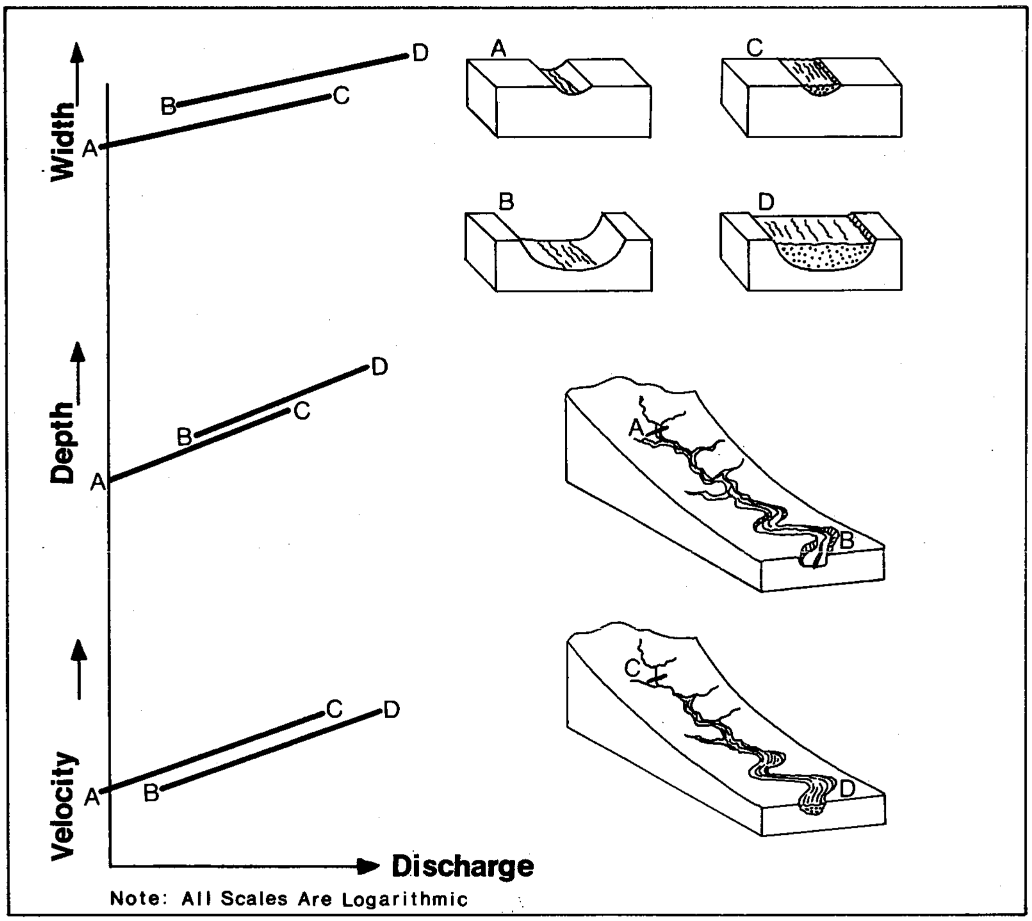


Figure 30. Average hydraulic geometry of river channels expressed by relations of width, depth, and velocity to discharge at two locations along a river (modified from Leopold, Wolman, and Miller 1964).

If a coefficient or exponent for one hydraulic geometry variable changes due to the gravel removal operation, at least one of the other variables must also change to maintain continuity of flow. Generally speaking, if a channel is widened, it often satisfies continuity by becoming shallower. Similarly, if a channel slope, or gradient, is increased, thus increasing velocity, continuity is commonly satisfied by a reduction in depth. Exponent values for selected study sites and other rivers are given in Table 6. The exponents exhibit a wide range of variability for different rivers; Rundquist (1975) found that the exponents and the coefficients can be expressed as functions of the bank-full discharge. The coefficient c and exponent f in the power relation for hydraulic depth were found in addition to be a function of the median bed material size. The exponents in the power relations may change at a given site for discharges above bank-full because of the typically abrupt change in bank slope at bank-full conditions.

The slope of the water surface profile for a typical river generally will parallel the bed slope at low flow, often producing a sequence of riffles and pools. At flood flows, the pool-riffle sequence is not apparent in the water surface profile (Figure 31).

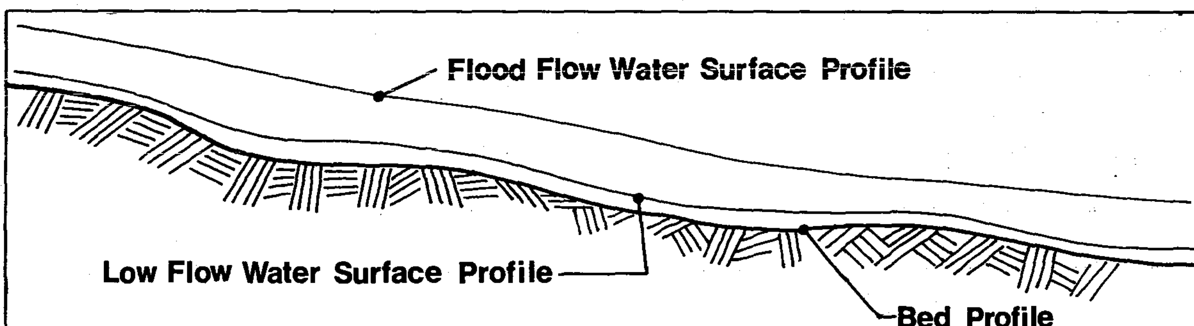


Figure 31. Schematic diagram showing change in water surface slope in response to a change in water discharge.

Naturally occurring flow obstructions in rivers can include vegetation, rock or snow avalanches, aufeis, and boulders. The effect of an obstruction on the hydraulics is to cause a local increase in velocity which often

Table 6. Values of Exponents for Hydraulic Geometry Power Relations[a]

River	Undisturbed areas b	Undisturbed areas f	Undisturbed areas m	Disturbed areas b	Disturbed areas f	Disturbed areas m
Kuparuk River	0.43	0.28	0.29	0.48	0.28	0.24
Sagavanirktok River	0.25	0.40	0.35	0.32	0.42	0.26
Shaviovik River	0.40	0.33	0.27	0.52	0.29	0.19
Middle Fork Koyukuk River-Upstream	0.29	0.44	0.27	0.44	0.33	0.23
Middle Fork Koyukuk River-Downstream	0.54	0.28	0.18	0.37	0.29	0.34
Average values, midwestern United States[b]	0.26	0.40	0.34			
Brandywine Creek, Pennsylvania[b]	0.04	0.41	0.55			
Ephemeral streams in semiarid United States[b]	0.29	0.36	0.34			
Average of 158 gaging stations in United States[b]	0.12	0.45	0.43			
10 gaging stations on Rhine River[b]	0.13	0.41	0.43			
Average of 17 stations in Southcentral Alaska[c]	0.19	0.39	0.42			
Average of 30 stations in Upper Salmon River area, Idaho[d]	0.14	0.40	0.46			

[a] $W = a\,Q^b$
$D = c\,Q^f$
$V = k\,Q^m$

[b] Compiled by Leopold, et al. (1964)

[c] Emmett (1972)

[d] Emmett (1975)

results in erosion of the obstruction or bed scour adjacent to the obstruction (Figure 32). Complete channel relocation is also a potential response to flow obstructions blocking a high percentage of the channel's cross-sectional area.

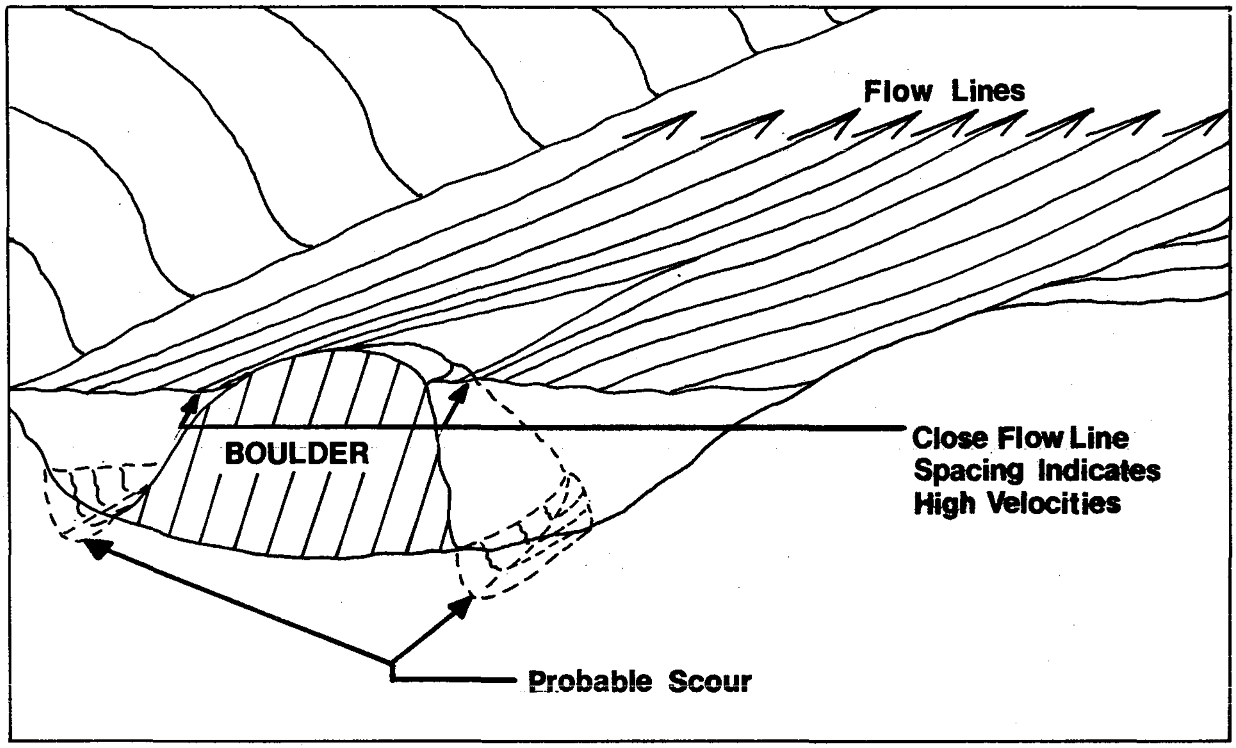


Figure 32. Schematic diagram illustrating the effects of a flow obstruction on the local hydraulics.

Changes Due to Gravel Removal

Substantial changes in hydraulic geometry, slope, and flow obstructions resulted from gravel removal operations at roughly 60 percent of the sites. Typical hydraulic geometry changes in the mined area included increased channel top width, reduced hydraulic depth, reduced mean velocity, and increased conveyance. Changes in slope due to gravel removal operations took the form of increases through the mined reach resulting from channel cutoffs and local slope redistributions affecting the pool-riffle sequence. Flow obstructions in the forms of material stockpiles, diversion dikes, and overburden piles have the potential for causing local scour, ice jam formation, and siltation.

Hydraulic Geometry. Gravel removal operations caused changes in the natural cross-sectional shape of the active channels of approximately half of the rivers included in the study. The backwater analysis was not complete enough at some sites to confirm the hydraulic geometry change evaluation. A comparison of power equation exponents for cross sections in disturbed and undisturbed areas (Table 6) indicated a varied response to gravel removal. The coefficients in the power equations must also be considered to understand the effects of gravel removal. For example, at the Middle Fork Koyukuk River-Downstream site, the top width increased at a slower rate within the gravel removal area than outside of it. However, the coefficients in the power relations were greater for the disturbed than the undisturbed cross sections indicating that the top widths were larger at low flows in the disturbed areas than the undisturbed areas and were similar in both locations at higher flows. A qualitative evaluation of this effect can be made by comparing the relative channel widths in the material site at low flow and flood flow (Channel width and Flooded area, Table 7).

The coefficient in the power equation for the top width was greater for the disturbed cross section than the undisturbed cross sections at eight of the sites; this difference resulted from a consistently greater top width at all discharges considered in the hydraulic analysis. The sites at which this occurred were Gold Run Creek, Washington Creek, Nome River, Aufeis Creek, Skeetercake Creek, Sagavanirktok River, and both sites on the Middle Fork Koyukuk River. At Sinuk River the exponent of the power relation for the top width was observed to be greater at the disturbed cross section than at the undisturbed cross section. This difference indicates that the gravel removal area had smaller top widths at low flows, but larger top width at high flows, than the undisturbed cross section.

Table 7. Quantification of Change in Hydraulic Variables Resulting from the Gravel Removal Operation at Each of the 25 Sites

River	Gravel removal area	Channel width[a]	Flooded area[a]	Ponded area[a]	Overall slope[b]	Local slope redistribution[c]	Flow obstruction[d]
Gold Run Creek		7	6	5	6	5	8
Sinuk River	A	6	7	6	5	7	8
	B	–	9	8	–	–	8
Washington Creek	A	8	10	10	8	7	9
	B	6	8	10	5	5	8
Oregon Creek	A	10	9	8	6	7	8
	B	5	6	5	5	5	5
Penny River		10	10	10	10	5	9
Nome River		10	10	7	7	5	7
Ugnuravik River		7	10	8	7	5	7
Aufeis Creek	A	8	10	10	7	7	7
	B	6	6	6	5	5	5
Kuparuk River		6	7	6	5	5	7
Skeetercake Creek		5	8	10	10	5	10
Sagavanirktok River		8	10	6	6	5	5
Ivishak River		6	6	6	5	5	5
Shaviovik River		5	6	5	6	5	7
Kavik River		6	7	6	6	7	10
Dietrich River-Upstream		5	5	5	5	5	7
Dietrich River-Downstream		6	7	7	5	10	5
Middle Fork Koyukuk R-US	A	5	6	9	5	5	5
	B	7	9	8	10	5	5
Middle Fork Koyukuk R-DS		9	10	7	7	5	5
Jim River		10	10	8	5	7	5
Prospect Creek		5	5	5	5	5	5
West Fork Tolovana River		5	5	5	5	5	5
McManus Creek		5	10	6	7	5	8
Tanana River-Downstream		5	5	5	5	5	5
Tanana River-Upstream		5	5	5	5	5	5
Phelan Creek		4	2	6	5	5	9

(Footnotes on following page)

Table 7. Footnotes

[a]Width and area ratings:

$$W_R = \frac{\text{Parameter in the mined area}}{\text{Parameter upstream from the mined area}}$$

where the parameter is:

- top width of the channel(s) during the survey period for Channel Width
- top width of the channel(s) during floods of approximately bank-full flood magnitude for Flooded Area
- area of ponded water, excluding pits, for Ponded Area.

10 $3 < W_R$

9 $2.5 < W_R \leq 3$

8 $2 < W_R \leq 2.5$

7 $1.5 < W_R \leq 2$

6 $1 < W_R \leq 1.5$ or other W_R values if they are within the natural range of variation of the river

5 $W_R \doteq 1$ or if other data indicates no change

4 $0.67 \leq W_R < 1$ or other W_R values if they are within the natural range of variation of the river

3 $0.50 < W_R < 0.67$

0-2 Not used

[b]Overall slope ratings:

$$L_R = \frac{\text{Length of disturbed reach after gravel removal}}{\text{Length of disturbed reach before gravel removal}}$$

$$S_R = {}^{1}/L_R$$

10 $1.4 < S_R$ $L_R < 0.71$

9 $1.3 < S_R \leq 1.4$ or $0.71 \leq L_R$ 0.77

8 $1.2 < S_R \leq 1.3$ or $0.77 \leq L_R < 0.83$

7 $1.1 < S_R \leq 1.2$ or $0.83 \leq L_R < 0.91$

6 $1.0 < S_R \leq 1.1$ or $0.91 \leq L_R < 1.0$

5 $S_R \doteq L_R \doteq 1$ or if other data indicate no change

0-4 Not used

[c]Local slope redistribution ratings:

10 Very steep slope followed by a very long pool

9 Steep slope followed by a long pool

8 Moderate slope followed by slightly longer than average pool

7 Slope and pool length slightly more than that in the undisturbed areas

6 Some local slope redistribution detected or likely to have occurred but not likely that of the natural river

5 No local slope redistribution

0-4 Not used

[d]Flow obstruction ratings:

10 Obstructions in an active low-water channel such that flow is diverted

9 Obstructions adjacent to an active low-water channel

8 Obstructions in or adjacent to high-water channels

7 Obstructions in the floodplain but away from any developed channels

6 Small obstructions not much different in size from those occurring naturally in the floodplain

5 No obstructions

0-4 Not used

Associated with the trend towards larger top widths in the gravel removal areas, the hydraulic depth in seven of these areas decreased. Sites with smaller hydraulic depths, in the mined area, for all discharges included Washington Creek, Nome River, Aufeis Creek, Skeetercake Creek, Sagavanirktok River, and both sites on the Middle Fork Koyukuk River.

The mean velocity was consistently less at the disturbed cross section than at the undisturbed cross section at nine of the sites for the range of discharges included in the backwater analysis. These sites included Gold Run Creek, Washington Creek, Ugnuravik River, Aufeis Creek, Skeetercake Creek, Sagavanirktok River, Dietrich River-Downstream, and both of the Middle Fork Koyukuk River sites. At two sites, the rate of increase of velocity with discharge was different in the disturbed area than in the undisturbed area. At Sinuk River, the velocity increased at a lesser rate at the disturbed cross section than at the undisturbed cross section. At Middle Fork Koyukuk River-Downstream, the reverse was found.

The conveyance, or carrying capacity of the channel, was consistently greater in the gravel removal area of eight sites compared with conveyances at undisturbed cross sections. These sites were Gold Run Creek, Sinuk River, Washington Creek, Aufeis Creek, Sagavanirktok River, Kavik River, Dietrich River-Downstream, and Middle Fork Koyukuk River-Upstream. The Sinuk River had a larger exponent or, equivalently, a more rapid increase in conveyance with discharge than cross sections which were not disturbed by the gravel removal operation. Conversely, the conveyance at the downstream site on the Middle Fork Koyukuk River increased with discharge at a slower rate than did the conveyance of the undisturbed cross sections.

Significant changes in hydraulic geometry were observed primarily at sites which were scraped, although not all scraped sites showed a significant increase. Most of the significant changes were observed at meandering, sinuous, and straight rivers. Although no single gravel removal location caused a significantly greater change in hydraulic geometry than others, most of the sites that had significant change were those sites that were excavated by scraping in-channel and immediately adjacent-to-channel locations.

The area of ponded water, which includes those low-lying areas which accumulate water but are not effective in the conveyance of flow, was increased at roughly half of the study sites. This ponding indicated that the site was not smoothed during restoration, was excavated too deeply, or was not properly drained. Table 7 lists the relative effect of this parameter at the 25 study sites. The impact of the ponding to the hydraulics of the systems was not great. However, it was a concern to aesthetics and fish entrapment evaluations.

Channel Slope. Channel slope changes took the form of an overall increase in slope or a local redistribution of slope. An overall increase in slope was commonly due to the formation of a meander cutoff. A redistribution of slope without changing the overall slope occurred when the slope was increased leading into the gravel removal area and decreased through the gravel removal area. Table 7 indicates those sites which had slope changes.

Study sites exhibiting an overall increase in slope due to gravel removal were generally in small, nonbraided river systems that were excavated by scraping techniques. The location of gravel removal was an important factor affecting the overall slope of the system. Sites such as upper Washington Creek, Penny River, Skeetercake Creek, and lower Middle Fork Koyukuk River-Upstream, that were excavated on the inside of bends, meanders, and islands most significantly affected the overall slope of the river system. This influence was expected because significant increases in slope are most likely to result from the development of a meander cutoff (reducing channel length and increasing slope).

The Penny River gravel removal operation caused a significant increase in overall slope (Figure 33). The photograph of the site after the gravel was removed shows that the main channel flows in a relatively straight course along the inside of two broad meanders that were cut off in the excavation process. The channel length was reduced by a factor of two in the process, equivalent to doubling the overall slope through that reach. Doubling the slope has the effect of increasing the mean velocity by roughly 40 percent.

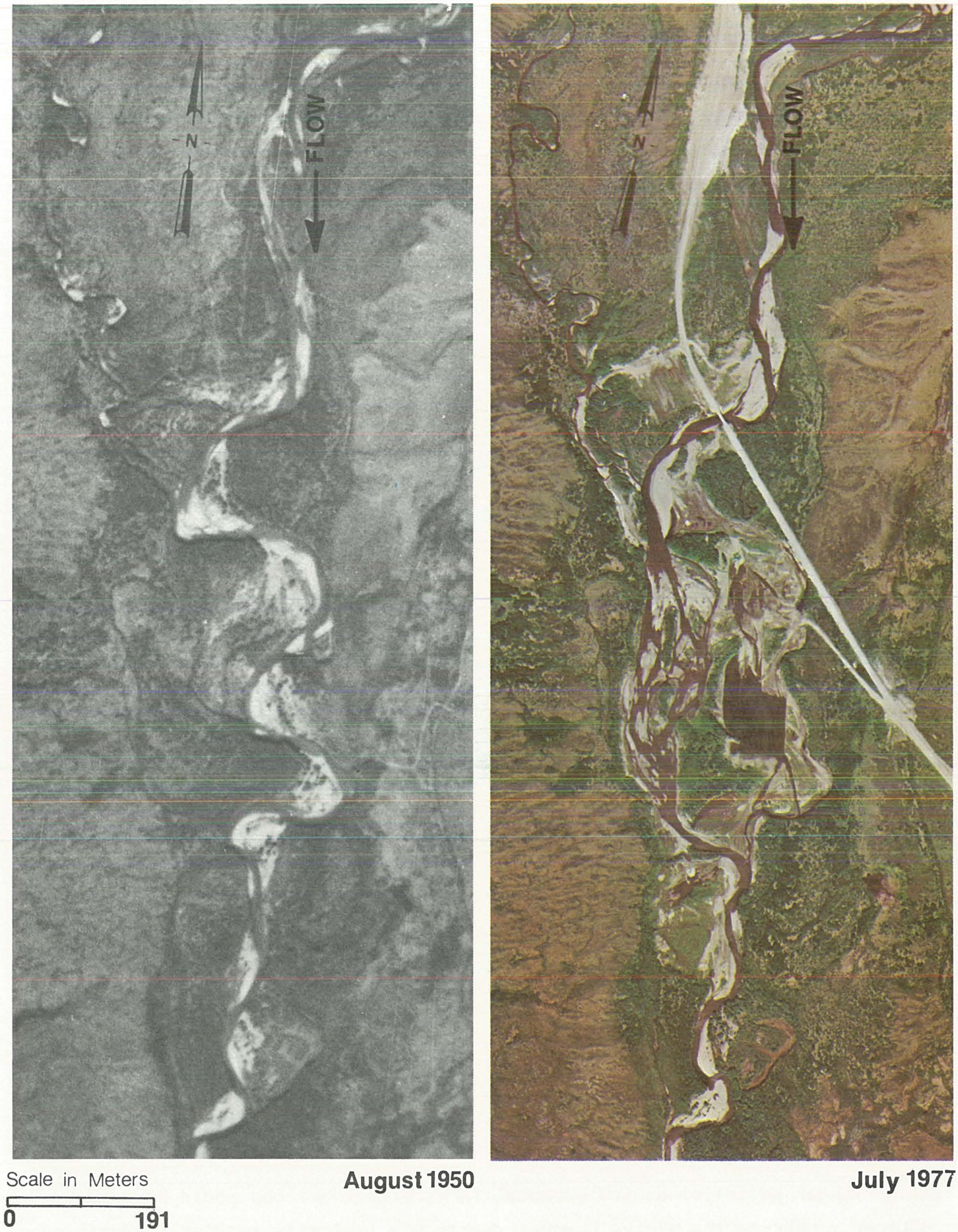


Figure 33. Comparative aerial photography of the Penny River showing change in hydraulic characteristics resulting from gravel removal activities.

Gravel removal from active and high-water channels generally caused local slope redistribution. Removing gravel from bars and banks immediately adjacent to channels also appeared to cause a local redistribution of the water surface slope. An example of a local slope redistribution, which is similar to the situation at the Dietrich River-Downstream site, is schematically illustrated in Figure 34.

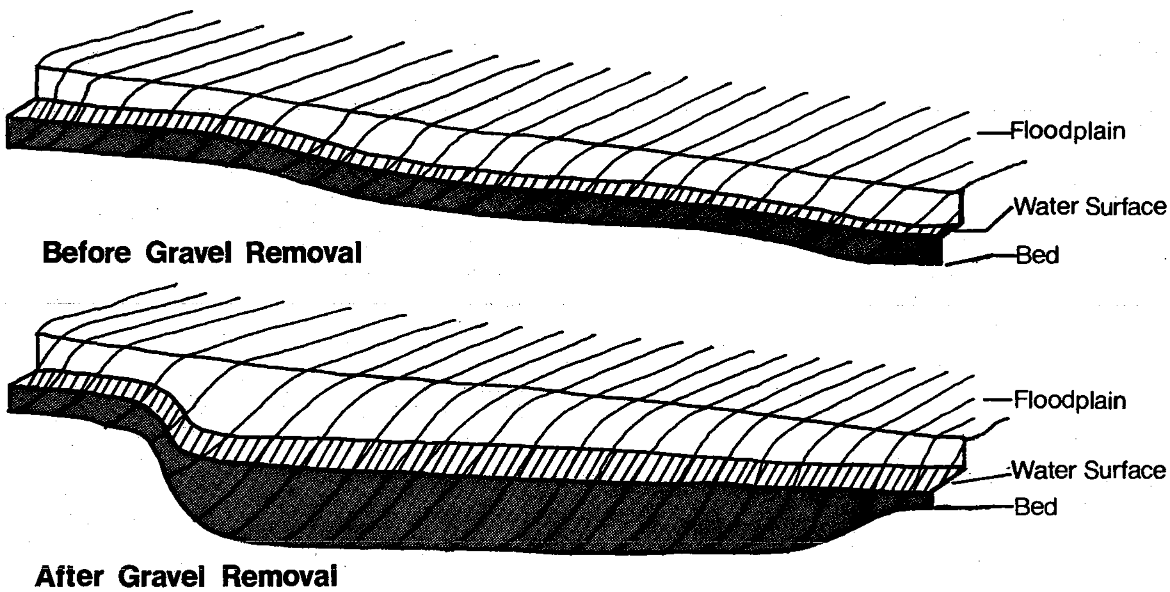


Figure 34. Schematic diagram illustrating an example of a change in local water surface slope that resulted from an in-channel gravel removal operation.

Flow Obstructions. Flow obstructions in the form of material stockpiles, diversion dikes, and overburden piles had a larger potential for hydraulic disturbance on small rivers than those on medium and large rivers. This larger potential exists because the flow obstructions would have to be placed closer to the active channel due to the typically smaller floodplain width. There were no significant hydraulic impacts observed due to flow obstructions, but the potential exists for bed scour at the base of the obstruction, erosion of the obstruction, and ice jamming at the obstruction. Erosion of a dike at Skeetercake Creek increased siltation as discussed in the following section.

SEDIMENTATION

Sedimentation includes the processes of erosion, transportation, and deposition of sediment. These are complex processes related to sediment and water flow properties. Attempts to quantify these processes provide, at best, estimates of the quantity. A very brief discussion of sediment size distribution, channel erosion, and sediment transport are given in the following section. Changes to these sedimentation characteristics due to gravel removal are then briefly discussed.

Undisturbed Condition

Sediment Size Distribution. An important factor influencing most sedimentation problems is the size distribution of the sediments. The typical descriptors of the size distribution of sediment are the median diameter and graduation coefficient of the material. Natural sediment distribution tends to be log-normal, which is a two parameter distribution. The median diameter of a distribution has 50 percent of the material smaller by weight and 50 percent of the material larger by weight. The second parameter, the gradation coefficient, gives the slope of the straight line resulting from plotting the distribution on log-probability paper. It is defined as

$$\sigma = \frac{1}{2}\left[\frac{D_{50}}{D_{16}} + \frac{D_{84}}{D_{50}}\right] \qquad (9)$$

where σ is the gradation coefficient and D_x is the particle diameter for which x percent of the material is finer. The gradation coefficient is related to the standard deviation of the material. The material can be described as uniform if its gradation is less than 1.3 or graded if its gradation is greater than 1.3.

The median sediment size in the floodplain generally decreases in the downstream direction along a river. Thus, the median size may be cobbles in the headwaters and fine gravel near the mouth. However, the median size can significantly vary around this general average within a small area at a specified point along the river. This variation is a consequence of the variation in hydraulic forces from one point in the floodplain to another.

Channel Erosion. Channel erosion in rivers is generally considered to be either local erosion (scour) or degradation. Both result from an increase in the sediment transport capacity, or a decrease in the sediment load entering the area, or both.

Local scour is most commonly a result of local increases in velocity due to flow obstructions or contractions. The increased velocity increases sediment transport capacity. Degradation can result if the channel bed is steepened in a short reach by, for example, a meander cutoff. The sediment transport capacity would be increased through this reach causing erosion and a general upstream progression of the steepened slope (Figure 35).

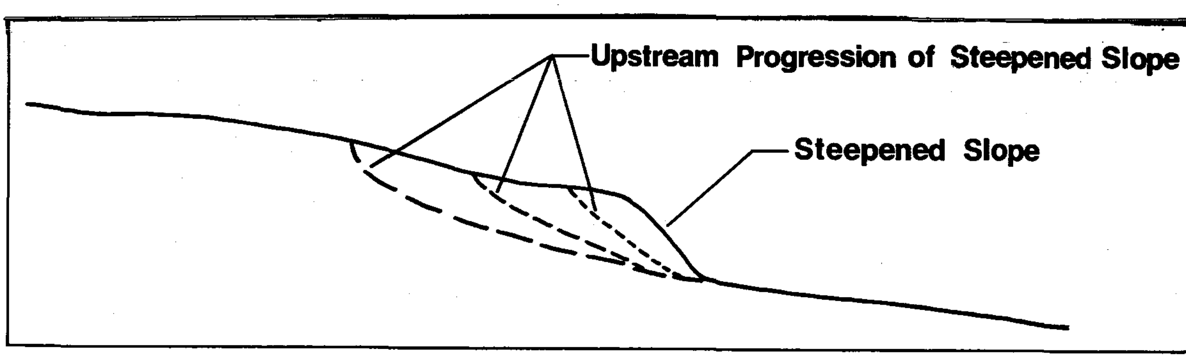


Figure 35. Schematic diagram showing degradation process.

The progressive erosion continues upstream until equilibrium is reached. In theory, equilibrium is reached when the slope is equal to the slope prior to the occurrence of the cutoff, which would require the steepened slope to migrate to the headwaters. In practice, the steepened slope is reduced during its upstream migration and gradually reaches an equilibrium condition. However, the degradation may extend over a long reach before equilibrium is achieved.

Sediment Transport. Sediment transport is the movement of sediments past a specific cross section of a river. The sediment may be transported as suspended load or bed load. Suspended load is sediment that is transported long distances suspended in the water column. Bed load is sediment that is transported by saltation (bouncing), or by rolling or sliding along the river bed. The sediment size distinction between bed load and suspended load varies with variations in discharge. At low flows, assuming the sediments were available, silts and clays may be transported in suspension and sands and gravels transported as bed load. During floods, suspended load may include clays, silts, sands, and gravels, with cobbles and boulders transported as bed load. Often, the suspended load is assumed to include clays, silts, and sands and the bed load includes gravels, cobbles, and boulders.

Changes Due to Gravel Removal

Very little sediment data were collected at the study sites. Direct measurements or observations of bed or suspended transport were not made because site visits were scheduled during periods of low flow when the sites would be most workable. Because the sedimentation characteristics prior to gravel removal were also unknown, the upstream cross section was usually used as the undisturbed cross section. The effects of gravel removal were evaluated by comparing sedimentation features in the gravel removal area to those in the undisturbed upstream area.

At six sites, a decrease in the median size of the surface layer, or armor layer, was observed in the mined area as compared with the undisturbed area. Similarly, an increase or decrease was observed in the median diameter of the material underlying the armor layer at eight sites. In many cases it was difficult to evaluate whether the variation in median diameter was a result of the gravel removal operation or simply a result of the natural variation of the median diameter at a site. Degradation was also observed at a few sites although at other sites only causative evidence was available to indicate that this process can occur. Sediment transport changes were suggested at several sites where there were observations of bedforms in or downstream from the gravel removal area, observations of changes in the bed material size, computations of changes in shear stress, or observations of sediment sources which remained from the gravel removal operation. The effects of gravel removal activity on these sedimentation characteristics were evaluated and given quantitative ratings for comparative purposes (Table 8).

Sediment Size Distribution. The most common significant change in sediment size distribution resulting from gravel removal was a decrease in the size caused by fine material deposition in the material site. This change was reflected in the surface material at six sites and the subsurface material at six sites. Oregon Creek, Penny River, and Ugnuravik River had significant changes in both surface and subsurface material sizes. At Sinuk River, fine and medium sized gravels were nearly missing from the subsurface samples in the material site, causing an increase in the median size. The explanation for this is unknown. At Washington Creek, the subsurface material size was larger in the material site even though fine material deposition in the site reduced the median size of the armor layer.

A pattern of correlation was not evident between increases or decreases in armor layer median diameter resulting from gravel removal and physical site or gravel removal area characteristics. One reason for this lack of correlation is that armor layer development is a complex function of several interrelated factors including degree of development of undisturbed armor layer, flooding history since gravel was removed, and flow characteristics in the gravel removal area. If the undisturbed size distribution of the armor layer was not significantly different from that of the material underlying it, the relative change due to gravel removal would have been less and the time required for recovery to the undisturbed condition would also be less. The time for recovery is also a function of the floods during the recovery period; one large recurrence interval flood may be sufficient to

Table 8. Quantification Ratings of Change in Sedimentation Characteristics Resulting from the Gravel Removal Operation at Each of the 25 Sites

River	Gravel removal area	Armor coat size[a]	Subsurface material size[a]	Channel degradation[b]	Bed load[c]	Suspended load[d]
Gold Run Creek		4	1	6	8	8
Sinuk River	A	4	9	5	3	6
	B	–	–	–	–	–
Washington Creek	A	2	8	10	3	3
	B	3	–	5	5	5
Oregon Creek	A	2	1	5	3	8
	B	–	–	5	4	5
Penny River		2	2	5	3	8
Nome River		2	7	5	4	4
Ugnuravik River		2	0	5	5	8
Aufeis Creek	A	6	1	5	5	5
	B	–	–	5	5	5
Kuparuk River		4	7	5	8	6
Skeetercake Creek		5	2	5	9	8
Sagavanirktok River		7	4	5	5	5
Ivishak River		6	4	5	5	6
Shaviovik River		7	5	5	8	5
Kavik River		7	4	5	10	3
Dietrich River–Upstream		5	5	9	5	5
Dietrich River–Downstream		5	5	8	4	3
Middle Fork Koyukuk River–Upstream	A	5	5	5	5	5
	B	1	7	6	9	5
Middle Fork Koyukuk River–Downstream		5	5	5	4	3
Jim River		–	–	5	5	6
Prospect Creek		3	3	5	5	5
West Fork Tolovana River		–	–	5	5	5
McManus Creek		4	–	8	5	5
Tanana River–Downstream		–	–	5	5	5
Tanana River–Upstream		–	–	5	5	5
Phelan Creek		7	5	6	5	5

(Footnotes on following page)

Table 8. Footnotes

[a]Sediment size distribution ratings:

$$D_R = \frac{\text{Median size in the gravel removal area}}{\text{Median size upstream from the gravel removal area}}$$

10 $10 \le D_R$ (due to gravel removal activity)

9 $2 \le D_R < 10$ (due to gravel removal activity)

8 $1.2 \le D_R < 2$ (due to gravel removal activity)

7 $1.2 \le D_R$ (cause uncertain)

6 $1 \le D_R < 1.2$

5 $D_R \simeq 1$

4 $0.8 < D_R \le 1$

3 $D_R \le 0.8$ (cause uncertain)

2 $0.5 < D_R \le 0.8$ (due to gravel removal activity)

1 $0.2 < D_R \le 0.5$ (due to gravel removal activity)

0 $D_R \le 0.2$ (due to gravel removal activity

[b]Channel degradation ratings:

10 Very substantial degradation upstream of the disturbed area

9 Substantial degradation upstream of the disturbed area

8 Large amount of degradation upstream of the disturbed area

7 A noticeable amount of degradation upstream of the disturbed area, but not unlike degradation which could occur naturally

6 Slight degradation upstream of disturbed area observed or implied; may not be a result of gravel removal

5 No degradation observed or implied by the data

0–4 Not used

[c]Bed load ratings:

10 Substantial increase in bed load by erosion in the gravel removal area

9 Large increase in bed load by erosion in the gravel removal area

8 Increase in bed load by erosion in the gravel removal area

7 Bed load increase due to gravel removal activity expected but not verified by direct evidence

6 Slight bed load increase potentially due to gravel removal activity

5 No bed load change evident

4 Slight bed load decrease by deposition in the gravel removal area

3 Moderate bed load decrease by deposition in the gravel removal area

0–2 Not used

[d]Suspended load ratings:

9–10 Not used

8 Large temporary and/or moderate long term increase in suspended load

7 Temporary increase in suspended load as a result of disturbance of armor coat

6 Potential slight increase in suspended load resulting from gravel removal activity

5 No apparent change in suspended load

4 Potential slight decrease in suspended load resulting from deposition

3 Moderate amount of deposition of suspended material

0–2 Not used

develop an armor layer comparable to that in the undisturbed area. The development of an armor layer in the gravel removal area is also greatly dependent on the location of the area relative to the active channel and the resulting flow characteristics through the site. The location and extent of gravel removal may be such that an armor layer may not develop until the area fills in sufficiently to have appropriate hydraulic characteristics for armor layer development.

Channel Erosion. Channel erosion in the form of local scour was not observed at any of the study sites. The potential exists for local scour to develop as a result of flow obstructions in the form of material stockpiles, overburden piles, and diversion dikes. This potential was discussed in the previous section discussing hydraulics.

Channel degradation was observed at four sites and may have been developing at three other sites. At Washington and McManus Creeks, obvious degradation had occurred upstream from the site in the main channel. At the two Dietrich River sites, degradation was occurring in high-water channels; at the downstream site, one of the high-water channels developed into an active side channel after work completion. Channel degradation resulting from gravel removal activity has been documented elsewhere (Woodward-Clyde Consultants 1976b, Li and Simons 1979). Li and Simons (1979) suggest that the installation of check dams can restrict upstream degradation. Sheridan (1976) discusses in-channel gravel removal, noting that the pits filled in with sediment; a similar situation occurred on Sinuk River with no apparent degradation.

Sediment Transport. Changes in sediment transport due to gravel removal were difficult to evaluate. The ratings given in Table 8 are thus highly subjective. A few possible changes which were suggested by the sedimentary features in and around the material sites are discussed below. It is likely that most scraped sites exhibited an increase in suspended load during the first flood event and possibly during one or two subsequent events as the material in the gravel removal area was washed clean of the fine grain sizes. This increase was thus likely a temporary increase common at most scraped sites. Long-term increases in suspended load were implied at sites with disturbed areas which contributed fine materials to the flow. Examples of such long-term increases were the access road degradation at Ugnuravik River (Figure 36), the diversion dam at Skeetercake Creek (Figure 37), and several sites with overburden piles or berms containing fine-grained materials. Similar increases in suspended load could occur from accelerated bank erosion at the site. Deposition of fine-grained sediments in several of the gravel removal areas was also observed. Sites with changes in suspended load showed no pattern with the physical site or gravel removal area characteristics.

Apparent changes in bed load were observed at some sites in the form of gravel dunes or loose gravel deposits in and downstream from the gravel removal area. When these deposits occur in the gravel removal area, they could indicate the inability of the flow through the area to carry the sediment load delivered to it or generated within it. Deposition occurring downstream from the gravel removal area would imply that the flow through the area is sufficient to erode the loose gravel from the gravel removal area. It is possible that when these gravels reach the main channel they are transported in the form of another bed form or possibly in suspension. Bed load changes occurred most often at scraped sites in active and high-water channels, and in locations immediately adjacent to such channels.

ICE CHARACTERISTICS

Undisturbed Condition

Ice jamming can occur during breakup when ice floes moving down the river are blocked, thereby blocking subsequent ice floes and eventually creating a surface dam to the flow of ice. Ice jams can cause scour due to increased velocity beneath the ice dam; they can also cause the water level to rise, resulting in increased flooding. Ice jams are normally caused by a constriction in the channel width or depth, a reduction in flow velocity, or manmade structures in the floodplain.

Figure 36. Upstream view of thermal and fluvial erosion in the access road at Ugnuravik River, acting as a long-term sediment source to the river.

Figure 37. View of erosion of a diversion dam which acts as a long-term sediment source to Skeetercake Creek. Dunes in foreground are atypical of the undisturbed river.

Aufeis is defined as areas of ice which have developed by a sequence of events of overflowing water on top of the previous ice surface. The general mechanism for the growth of *aufeis* involves an increase in the hydrostatic pressure due to a reduced flow area; when the pressure exceeds the elevation of the ice surface, overflow onto this surface results and subsequently freezes. The overflow causes the pressure to decrease and ice surface elevation to increase. This sequence continues to repeat until the source water cannot produce sufficient pressure to exceed the elevation of the ice surface. Three requirements for the formation of *aufeis* are given by Carey (1973); (1) significant ground water or under-ice flow, (2) growth of ice to the channel bed or near the bed, and (3) subsurface constriction such as bedrock, less pervious soil, or permafrost.

Changes Due to Gravel Removal

An organized program of winter and spring observations of *aufeis* and breakup were not included in this study. Therefore, much of the following discussion is based on observations of *aufeis* and ice jamming potential, rather than of actual *aufeis* and ice jams. However, at two sites, Washington Creek (Figure 38) and Oregon Creek, large areas of *aufeis* were observed in early June. Incidental winter observations at a few other sites documented the existence of *aufeis*.

Ice jams could be caused by several aspects of floodplain gravel removal. In rivers which are increased in width and depth by the gravel removal, such as by in-channel mining, the velocity would decrease causing the ice floes to gather. At the downstream end of the gravel removal area these floes could jam where the channels constrict back to the natural width. This ice jam could cause flooding in and upstream from the gravel removal area and possible bed scour beneath the ice jam. River channels which are widened causing shallower depths, such as by removing bars adjacent to the channel, could cause ice jamming by grounding the ice floes. Another potential mechanism for ice jam formation resulting from a gravel removal operation is the blocking of ice floes by flow obstructions in the form of overburden piles, stockpiles, or dikes.

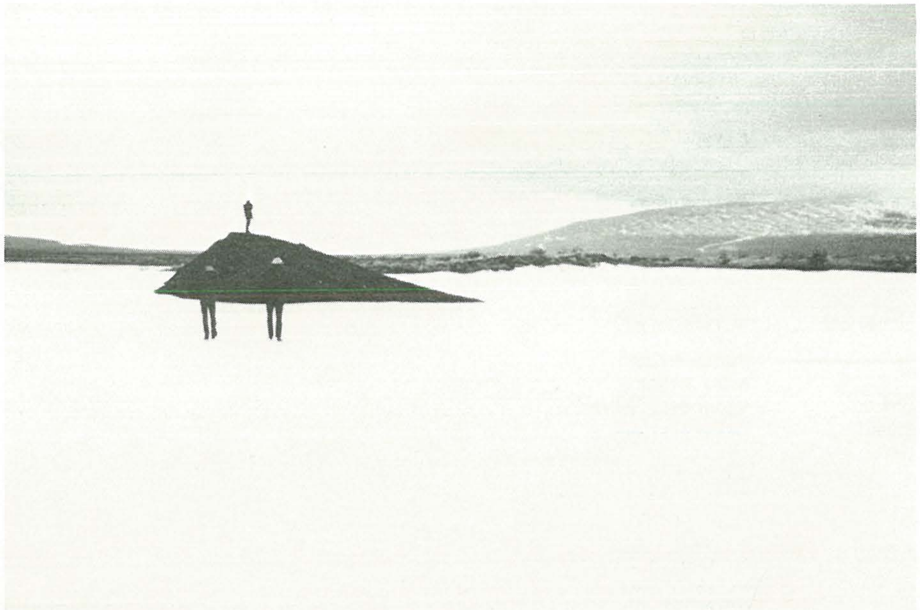


Figure 38. Large area of aufeis at the upper gravel removal area at Washington Creek as it appeared in early June.

In evaluating the potential for aufeis development at each of the study sites, it was assumed that wide, shallow channels were more likely to develop aufeis than narrow, deep channels. This assumption is probably valid because shallow channels are more likely to freeze to their bed and to have a shallow talik (unfrozen zone) than deep channels carrying equivalent flow. The results of this evaluation of aufeis potential are listed in Table 9, along with the identification of those rivers with aufeis activity or potential aufeis activity prior to the gravel removal operation.

Most of the observations of increases or potential increases in aufeis activity were associated with mining activities in straight and sinuous rivers, although some activities in braided, split, and meandering rivers also caused potential increases. Increases in aufeis activity were associated with scraping operations. Increased aufeis activity or potential aufeis activity often occurred at those sites where the gravel removal operation was located in active or high-water channels and in locations immediately

Table 9. Quantification Ratings of Change in *Aufeis* Potential that Resulted from the Gravel Removal Operation at Each of the 25 Sites

River	Gravel removal area	*Aufeis* potential[a]
Gold Run Creek		6
Sinuk River	A	5
	B	6
Washington Creek	A	10
	B	6
Oregon Creek	A	10
	B	5
Penny River		6
Nome River		6
Ugnuravik River		6
Aufeis Creek	A	6[b]
	B	5[b]
Kuparuk River		6[b]
Skeetercake Creek		5
Sagavanirktok River		6
Ivishak River		6[b]
Shaviovik River		5
Kavik River		6[b]
Dietrich River-Upstream		7[b]
Dietrich River-Downstream		5[b]
Middle Fork Koyukuk River-Upstream	A	5
	B	6
Middle Fork Koyukuk River-Downstream		8[b]
Jim River		8
Prospect Creek		5[b]
West Fork Tolovana River		5
McManus Creek		6
Tanana River-Downstream		5
Tanana River-Upstream		5
Phelan Creek		5

[a]*Aufeis* potential ratings:

10 Large *aufeis* development observed in the disturbed area where no *aufeis* was previously recorded
9 Moderate sized *aufeis* development observed in the disturbed area where no *aufeis* was previously recorded
8 Small *aufeis* development observed or a strong potential for *aufeis* occurrence is inferred
7 Relocation of an existing *aufeis* area by gravel removal activity
6 Potential increase in *aufeis* activity resulting from gravel removal activity
5 No change in *aufeis* characteristics
0-4 Not used

[b]Rivers with a high potential for icing activity prior to the gravel removal operation.

adjacent to the channels. Such locations, when excavated for gravel, tend to increase channel width, decrease depth, and allow for freezing down to the channel bed.

As noted earlier, large areas of aufeis were observed in the Washington Creek and Oregon Creek study sites. Both of these sites had been extensively scraped and that caused numerous channels to form and loss of surface flow to intergravel flow because of loosely compacted gravels. The aufeis may be retarding the recovery of the surface flow by protecting the loose gravels from the flood flows during the snowmelt runoff period. At both sites, the channels flowing during the survey were not flowing where the channel had previously been; it is thus likely that the talik was not as deep beneath the newly formed channels, thereby providing the aufeis requirement of a subsurface constriction. The shallow channels would likely freeze to the bed, thereby satisfying another requirement for aufeis formation. The third requirement, a water source, was already available. Thus, at these two sites the gravel removal operation changed the channel location and cross section sufficiently to provide two of the three requirements for aufeis formation.

HYDROLOGY

Hydrology is the study of the origin, distribution, and properties of water during the time it is at or near the earth's surface. Of concern in this section is the distribution of the water. More specifically, this section discusses briefly the quantity of water that can be expected at the 25 material sites during low flow and flood flow conditions and potential effects on the quantity due to the removal of gravel.

Undisturbed Condition

The mean annual flow of a river at a specific point is, as the term implies, the mean flow during any 12 month period. It is an indication of total annual runoff and may also be used as an approximation of the typical low summer flow. Estimates of mean annual flow for the 25 study sites are listed in Table 10. They range from 0.09 m^3/s at McManus Creek to 540 m^3/s at Tanana River–Downstream.

Flood frequency curves show the expected frequency of occurrence of different magnitude floods at a specific point on a river. The frequency of occurrence is commonly referred to by the recurrence interval of the flood, which is the average number of years between floods of that magnitude. The reciprocal of the recurrence interval is the probability of occurrence of a given magnitude flood in any year. Flood frequency curves were developed for each of the study sites. Discharge values corresponding to selected frequencies of occurrence are shown in Table 11.

Changes Due to Gravel Mining

Hydrologic characteristics are, to a large extent, governed by basin-wide parameters such as climate and geology. Gravel removal operations did not have a significant effect on these characteristics. However, local changes in the ratio between surface flow and subsurface flow occurred at several sites. The local changes were not measured; quantitative ratings shown in Table 12 were assigned based on a subjective evaluation. A local reduction in mean annual flow occurred at the upper Washington Creek and upper Aufeis Creek sites as a result of a loss of surface flow to intergravel flow. At Washington Creek, the flow entered the gravel removal area and spread out through loose, uncompacted gravel; a large percentage reduction in surface flow resulted at low flows. This intergravel flow component was still evident in the site 13 years after the site was worked. The relative effect of the loss of surface flow during flood events was likely minimal. At Aufeis Creek, surface flow appeared to cease entirely for a period of 2 years, although continuous surveillance was not available to verify this. Thus, the mean annual flow of Aufeis Creek in this local region was reduced to near zero for 2 years. The effect on flood flows was unknown.

Two other sites, the upper Oregon Creek and Penny River sites, had a potential for a similar, but not as extensive, decrease of surface flow lost to intergravel flow. No observations or measurements were available

Table 10. Mean Annual Flow Estimates at Each of the 25 Study Sites

River	Unit mean annual flow ($m^3/s/km^2$)	Mean annual flow (m^3/s)
Gold Run Creek	0.013	0.9
Sinuk River	0.033	18.0
Washington Creek	0.018	0.5
Oregon Creek	0.023	0.7
Penny River	0.023	1.4
Nome River	0.033	4.3
Ugnuravik River	0.0023	0.6
Aufeis Creek	0.0044	1.1
Kuparuk River	0.0045	38
Skeetercake Creek	0.0035	0.3
Sagavanirktok River	0.0083	39
Ivishak River	0.0066	24
Shaviovik River	0.0040	1.6
Kavik River	0.0062	5.5
Dietrich River-Upstream	0.006	3.1
Dietrich River-Downstream	0.006	4.0
Middle Fork Koyukuk River-Upstream	0.0054	13
Middle Fork Koyukuk River-Downstream	0.0054	22
Jim River	0.010	7.1
Prospect Creek	0.010	2.6
West Fork Tolovana River	0.0062	4.7
McManus Creek	0.0062	0.09
Tanana River-Downstream	0.012	539
Tanana River-Upstream	0.012	468
Phelan Creek	0.063	5.2

Table II. Calculated Discharges in m^3/s Corresponding to Selected Recurrence Intervals for Each of the 25 Study Sites

River	Recurrence interval (years)						
	1.25	2	5	10	25	50	100
Gold Run Creek	11.2	19.2	32.1	42.8	53.6	70.2	91.0
Sinuk River	113	171	256	323	391	481	589
Washington Creek	2.58	5.63	10.7	16.6	28.1	39.5	54.9
Oregon Creek	6.21	11.1	19.4	26.3	33.5	44.8	59.3
Penny River	18.2	23.7	31.7	37.0	43.7	50.2	57.0
Nome River	32.4	53.3	86.3	114	142	182	232
Ugnuravik River	31.4	46.1	71.5	92.1	121	149	180
Aufeis Creek	39.2	56.8	89.3	116	160	196	235
Kuparuk River	905	1355	2165	2848	3906	4840	5912
Skeetercake Creek	10.6	16.7	28.4	38.4	54.6	69.8	87.0
Sagavanirktok River	376	462	592	665	785	863	970
Ivishak River	267	333	432	489	579	641	726
Shaviovik River	35.8	59.6	98.1	130	164	212	272
Kavik River	108	171	271	353	444	559	701
Dietrich River-Upstream	35.6	58.6	102	140	195	253	322
Dietrich River-Downstream	46.9	75.9	131	178	247	318	402
Middle Fork Koyukuk R-US	126	189	302	396	534	661	808
Middle Fork Koyukuk R-DS	190	276	428	552	736	896	1079
Jim River	101	125	156	178	204	228	251
Prospect Creek	33.3	43.6	57.6	67.3	78.5	90.4	102
West Fork Tolovana River	63.9	89.2	130	159	203	242	282
McManus Creek	1.65	3.32	7.48	12.0	20.6	29.8	42.1
Tanana River-Downstream	1562	1752	1992	2120	2356	2460	2619
Tanana River-Upstream	1341	1518	1738	1857	2069	2169	2318
Phelan Creek	49.3	65.3	92.8	114	146	171	197

Table 12. Quantification Ratings of Change in Quantity of Intergravel Flow Resulting from the Gravel Removal Operation at Each of the 25 Sites

River	Gravel removal area	Intergravel flow[a]
Gold Run Creek		5
Sinuk River	A	5
	B	5
Washington Creek	A	9
	B	5
Oregon Creek	A	7
	B	5
Penny River		7
Nome River		5
Ugnuravik River		5
Aufeis Creek	A	10
	B	5
Kuparuk River		5
Skeetercake Creek		5
Sagavanirktok River		5
Ivishak River		5
Shaviovik River		5
Kavik River		5
Dietrich River-Upstream		3
Dietrich River-Downstream		5
Middle Fork Koyukuk River-Upstream	A	5
	B	5
Middle Fork Koyukuk River-Downstream		5
Jim River		5
Prospect Creek		5
West Fork Tolovana River		5
McManus Creek		5
Tanana River-Downstream		4
Tanana River-Upstream		4
Phelan Creek		5

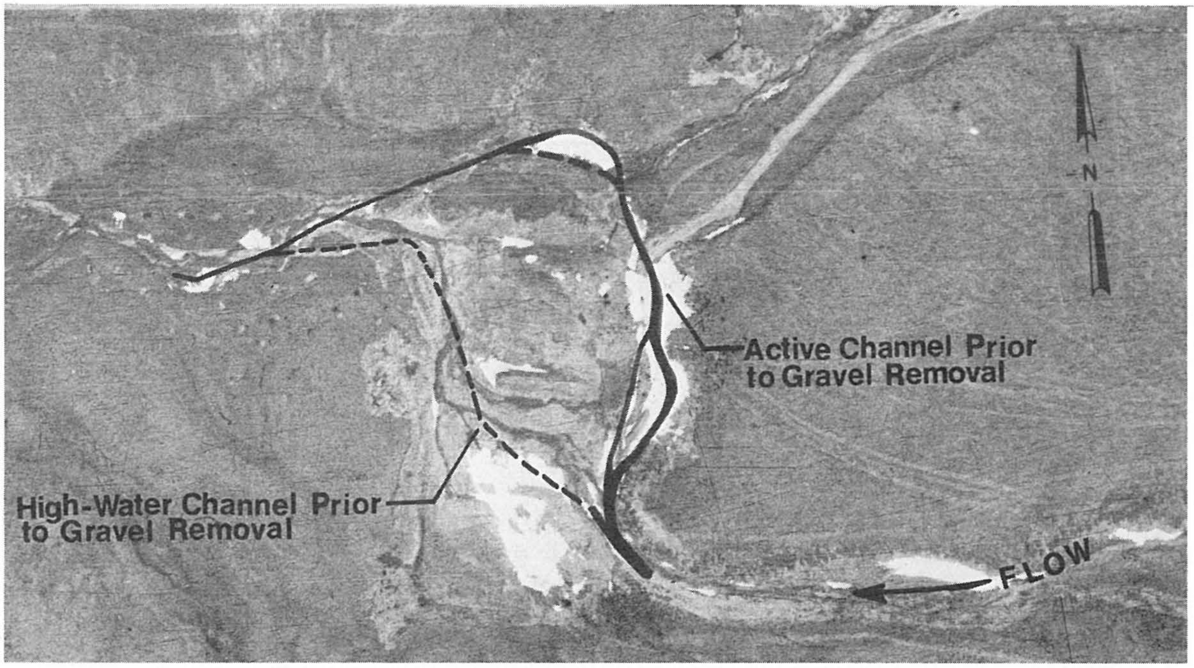
[a] Intergravel flow ratings:

10 All surface flow converted to intergravel flow for one summer or more
9 Substantial long-term loss of surface flow to intergravel flow
8 Moderate long-term loss of surface flow to intergravel flow
7 Implied long-term loss of surface flow to intergravel flow
6 Small quantities of surface flow lost to intergravel flow
5 No apparent change
4 Implied increase of surface flow and decrease of intergravel flow
3 Known increase of surface flow and decrease of intergravel flow
0-2 Not used

to estimate the magnitude of the decrease. The location of the gravel removal area may provide an explanation for the significant intergravel flow at Washington Creek and Aufeis Creek. At these two sites the scraping occurred near the downstream end of a sharp meander bend (Figure 39). It appeared that the scraping in this location caused most of the flow to leave the confinement of the channel. The lack of a well defined channel caused the flow to spread over the gravels in the material site and deposit the sediment load that it was carrying. These deposits were quite loose and unstable, and thus were very conducive to intergravel flow. Other sites having a similar specific location of scraping were slightly different in configuration from that shown in Figure 39; either the bend upstream from the scraped area at these sites was not as sharp or the scraping occurred further downstream on the bend, thus allowing some of the flow and likely much of the bed load to be retained in the original channel.

Three possible explanations for the continued loss of surface flow at Washington Creek are (1) that the suspended load is not sufficient to fill the openings in the gravel, (2) the presence of aufeis in the site protects the gravels from the significant snowmelt floods, and (3) water freezes in the gravel, expanding and separating the gravels in the process.

Pit sites, such as Dietrich River-Upstream and the two Tanana River sites, had a potential to locally increase the mean annual flow as a result of intercepting intergravel flow and allowing it to surface at the pit. However, the percentage increase in the mean annual flow at these sites is probably quite small.



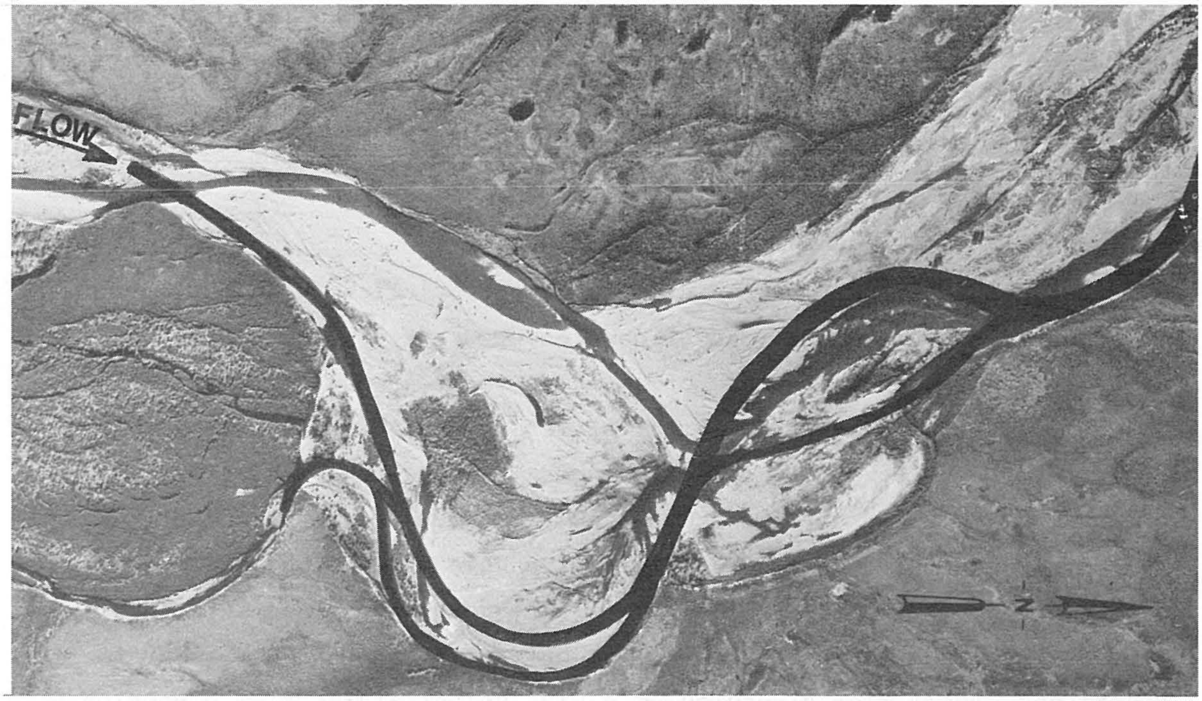


Figure 39. Aerial photographs of Washington Creek (top) and Aufeis Creek (bottom) showing material site locations and approximate channel locations before the disturbance.

SUMMARY AND CONCLUSIONS

Various physical characteristics of arctic and subarctic rivers were affected by gravel removal operations. These characteristics were divided into five categories:

1. Channel configuration and process,
2. Hydraulics,
3. Sedimentation,
4. Ice characteristics, and
5. Hydrology.

One or more characteristics from these categories were observed to have changed as a result of removing gravel from the 25 floodplain study sites.

CHANNEL CONFIGURATION AND PROCESS

Channel configuration and process characteristics that changed as a result of gravel removal operations included braiding characteristics, such as increase in the number of channels and decrease in lateral stability of the channels, and the potential for diversion of flow through the gravel removal area. The greatest changes in braiding characteristics occurred at 10 study sites and resulted from gravel removal operations that disturbed the bars adjacent to active channels or that diverted flow through the material site. Flow diversion through the mined site resulted from having insufficient buffers or no buffers at all. Gravel removal operations caused flow diversion or a high potential for flow diversion at 12 of the 25 study sites.

HYDRAULICS

Hydraulic characteristics exhibiting changes as a result of gravel removal operations included the hydraulic geometry (including width, depth, velocity, and conveyance), overall channel slope, local slope redistribution, flow obstructions, and area of ponded water. Increases in channel width, conveyance, overall slope, flow obstructions, and ponded water were typical responses to gravel removal, as were decreases in channel depth and velocity. One or more of these effects from gravel removal were observed at all of the sites except those pit excavated sites that were separated from the active channels by a buffer. Small river systems typically had smaller floodplains which forced the gravel removal operation closer to active or high-water channels, causing hydraulic changes.

SEDIMENTATION

Sedimentation characteristics which appeared to have changed as a result of gravel removal operations included armor layer and subsurface material site distributions, channel degradation, and suspended and bed loads. The most common significant change in sediment size distribution resulting from gravel removal was a decrease in the size caused by fine material deposition in the material site. This change was reflected in the surface material at six sites and the subsurface material at six sites, three of which were different from those with surface material changes. Channel degradation was observed at four sites and may have been developing at three other sites. Changes in sediment transport due to gravel removal apparently took the form of increases as well as decreases, with apparent changes occurring at 11 sites. Most changes in the sediment characteristics resulting from gravel removal operations occurred at scraped sites in or immediately adjacent to active and high-water channels and at those sites where fine sediment sources were left in the floodplain near the channel.

ICE CHARACTERISTICS

Two ice characteristics were identified as potentially being increased as a result of gravel removal activity. They are ice jamming and aufeis formation. These can be affected by a widening of the channel followed by a rapid reduction in width, a reduction in depth, obstructions in the floodplain, and relocating the channel through an area which was previously dry. Aufeis formation was observed at four study sites.

HYDROLOGY

The only characteristic related to the hydrology of the river which was identified as potentially changing as a result of gravel removal operations was a change from surface flow to groundwater flow or vice versa. This change, although relatively minor at most sites, can have a local effect on the mean annual flow, flow duration curve, and potentially, on the flood frequency curve. Significant reduction of surface flow occurred at two study sites.

RECOMMENDATIONS

Listed below are several recommendations concerning gravel removal operations, the purpose of which is to reduce the number or magnitude of changes to the physical characteristics of rivers:

1. Small rivers should not be considered as gravel sources.

2. Braided rivers should be considered as primary gravel sources; other river configurations, listed in order or likelihood of causing the least physical change, are split, meandering, sinuous, and straight.

3. Pit excavations should be located on terraces or possibly inactive floodplains and should be separated from the active floodplain by a buffer designed to maintain this separation for two or more decades.

4. Material sites within the active floodplain should:

- Not disturb the edge of the active channel(s);

- Maintain a high-water channel shape, within the material site, similar to that which enters and leaves the site;

- Not increase the bed slope of active or high-water channels locally to more than that of naturally occurring slopes;

- Form new high-water channels through the site if flow is expected through the site;

- Be shaped and contoured to provide proper drainage;

- Have material stockpiles, overburden piles, and dikes removed from near active channels unless they have a specific purpose for being there and are designed to withstand the hydraulic forces; and

- Be protected from low flow channels until the occurrence of the first flood after the site is completed.

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EFFECTS OF GRAVEL REMOVAL ON AQUATIC BIOTA

L. L. Moulton

INTRODUCTION

Populations of organisms are controlled by physical and chemical factors, often termed their environment, and by biological factors, including predation and competition. Environmental constraints on a particular species determine the usable habitat available to that population and the size of the population is often restricted by the amount of usable habitat. After the maximum number of individuals a particular habitat can support (termed the carrying capacity) has been reached, the population cannot increase without an increase in usable habitat. Predation and competition can act on a population to limit numbers below the carrying capacity, thus undisturbed populations are not necessarily fully utilizing the available habitat.

Alterations to the habitat can alter the quality of the habitat, leading to direct changes in the carrying capacity, and consequently, to reductions in the affected populations. Decreases in habitat diversity may reduce the carrying capacity for one species while leaving that for another unchanged. If the two species were in competition, the reduction or removal of one may allow the other species to increase. Generally, decreases in habitat diversity will result in an increased carrying capacity of one species which is able to efficiently utilize the more uniform habitat. Conversely, increases in habitat diversity generally cause increases in the number of species or life history stages present as new habitat types are added. These species increases are often accompanied by decreases in the populations which had formerly been utilizing the more uniform, less diverse, habitat.

The decreases may be due either to less available habitat or to competition from species which more efficiently utilize the newly created habitats.

The types of habitats present in a river are determined by the location, size, configuration, and water quality characteristics of the river. Features which define specific habitats include depth, velocity, substrate, and cover. Alterations to a river which affect any of these features will also affect the habitat available in the river and may impact habitats downstream from the alterations. Habitat alterations may affect the quality or diversity of the habitat, or both. Reduced habitat quality makes the area less desirable to the species present prior to alteration, while altered habitat diversity may favor one species or life history stage over another. Reduced habitat quality implies alteration of a single habitat type whereas reduced habitat diversity implies reduction in the number of available habitats but the two responses are not independent.

Several types of habitats may be used in the life cycle or even seasonal cycle of an organism, and there is often a critical habitat which controls the size of the population. In the arctic and subarctic environment, the critical habitat for fish populations is often the amount of overwintering habitat. Other critical habitats often controlling fish populations are spawning and rearing areas. Critical habitats vary from stream to stream and species to species depending on the characteristics of the streams and the life cycle requirements of the species.

Recent studies have been aimed at quantifying the effects of habitat alteration on stream populations (Stalnaker and Arnette 1976, Bovee and Cochnauer 1977, Binns and Eiserman 1979). Two of the basic requirements of these efforts are detailed measurements of appropriate habitat parameters and an intimate knowledge of the habitat requirements of the species in question. The emphasis of the present study was on a multiple-disciplinary survey of the effects of floodplain gravel removal on a broad geographical scale. Because of the limited data on many species and complete lack of data on many of the river systems studied, a detailed habitat analysis was not possible. The 3 to 4 day surveys at each site allowed for gathering of basic physical and biological data but not the type of detail required for sophisticated correlation analysis. For these reasons the present analysis was confined to analysis of trends and subjective evaluations of habitat alterations and their effects on aquatic organisms.

The material sites were visited 2 to 20 years after mining was complete, thus the immediate effects of gravel removal operations were not studied. The changes evaluated during the present study were those which persist over a number of years rather than those affecting the biota during the year of disturbance. A literature review of impacts at the time of actual gravel removal was presented by Woodward-Clyde Consultants (1976).

METHODS OF DATA COLLECTION

As detailed in APPROACH AND METHODOLOGY a variety of standard sampling methods were utilized at each study site with the specific methods used dependent on the type of river system and habitat being studied.

METHODS OF DATA ANALYSIS

The data from each of the 25 sites were first analyzed on a site-by-site basis to determine the effect of gravel removal operations on the aquatic environment at each study site. These individual site evaluations provided the basis for further analysis to identify trends and correlations relating to major site variables (Table I, Major Variable Matrix). These individual site evaluations are not included because of space limitations but are part of the permanent data base maintained by the U. S. Fish and Wildlife Service.

The various physical and biological parameters measured at the different sites varied greatly in magnitude and the variation made the direct comparison of data among sites impractical. The various parameters recorded at the study sites were standardized on a scale of 0 to 10 to obtain a relative measure of the degree of change. A rating of 5 indicates that a parameter measured in the mined area had not changed from the same parameter in the upstream area; ratings of 0-4 and 6-10 indicate decreased and increased parameter values in the mined area relative to the upstream area. The rating was determined by calculating the percentage change in the mined area relative to the upstream area for each site and subjectively assigning rating values to various percentage intervals such that all or most of the 0-10 scale was utilized for those sites at which the parameter was evaluated. Data from study sites with similar ratings were examined for similar alterations that might lead to a similar parameter response.

The analysis of habitat alteration was based on field notes from the site surveys, ground and aerial photographs, direct measurement of habitat parameters, results of hydraulic analysis, and visual observations. Habitat parameters considered in the analysis included changes in substrate type, substrate porosity, configuration of adjoining banks, bank and instream cover, number of channels, pool-riffle frequency, depth, velocity, and wetted perimeters at different flow levels. Additional habitat alterations were noted where appropriate, such as excessive siltation, aufeis formation and creation of new aquatic habitats. Much of the analysis was subjective because many habitat parameters were difficult to quantify, consequently, the analysis was kept conservative. The results of hydraulic analysis, as described in the EFFECTS OF GRAVEL REMOVAL ON RIVER HYDROLOGY AND HYDRAULICS, allowed for a certain amount of habitat parameter quantification and these results supported the subjective evaluations whenever comparisons were available, indicating that subjectivity was not a major source of error.

Analysis of changes in fish populations was accomplished by evaluating the types of habitat alterations occurring in the mined area relative to the upstream area. Then the measured parameters that appeared to be most important at the particular site were examined to determine if there had been a change in fish distribution, as indicated by a difference in catch rate between the upstream and mined areas. In this manner the combinations of habitat alteration could be evaluated for their cumulative effect on the population of fish present during the site visit. Additional effects were postulated based on known life history requirements of the various species.

The large number of benthic sample replicates obtained at each study site during the field surveys allowed for an analysis of variance to determine if significant differences existed in the densities among sample areas within a study reach. All Surber sample data were computer coded and the densities were subjected to an analysis of variance and multiple classification analysis (Nie et al. 1975). A nonparameteric procedure, the Mann-Whitney U-test (Zar 1974), was also used to evaluate differences in density. The results of the two tests were compared and, where the results of the two tests differed, the more conservative nonparametric test was used. Additional computer analysis included the calculation of various indices of diversity and similarity, such as the Bray-Curtis and Raabe similarity indices, and Shannon-Weaver and Simpson density indices. The indices respond differently to changes in density and diversity and were used primarily to search for changes in the aquatic macroinvertebrate assemblages vulnerable to Surber samplers.

Because the level of identification was to the generic level at best and often only to family or order, the indices were applicable only to the present study. Comparison with results of other studies and extensive analysis of the data are not justified. Often multiple species within a genus were recognizable but the absence of suitable taxonomic aids for arctic aquatic macroinvertebrates inhibited identification. A list of collected taxonomic groups by phyletic classification, with associated common names, is included in Appendix A.

RESULTS AND DISCUSSION

MAJOR GRAVEL REMOVAL HABITAT ALTERATIONS

Habitat Quality

Alterations of habitat quality observed at many of the sites consisted primarily of substrate alteration and removal of both instream and bank cover. Siltation, commonly associated with instream disturbances, was observed at a few sites, but was not a major factor because most of the sites were visited several years after mining had been completed. At three sites where siltation was observed it was caused by eroding berms (Kavik River) or melting aufeis fields (Washington Creek, Oregon Creek) (Figure 40).

Two types of substrate alteration were observed: (1) a shift from a moderately compacted gravel substrate to a very loose, unconsolidated sand-gravel substrate, usually with considerable intergravel flow and (2) a shift from a smooth, paved substrate which produced near laminar flow to a more porous, irregular substrate producing turbulent flow. Most of the substrate alterations recorded were Type 1 alterations with only two Type 2 alterations observed. Type 1 alterations occurred at four of the eight sites where scraping was conducted in an active channel (Washington Creek, Oregon Creek, Penny River, McManus Creek) and at four where flow subsequently increased or diverted to inundate a scraped area (Sinuk River, Kuparuk River, Sagavanirktok River, Ivishak River) (Table 13). The effects of this type of alteration appear to be long-term, because this alteration was noticeable at McManus Creek 16 years after mining. The effect on the substrate was caused by removal of the armor layer, loosening of the gravels, and subsequent washing out of fine materials. Formation of ice in the mined areas appeared to prolong the recovery time of this type of alteration.

a) Sediment being released by melting aufeis.

b) Silt deposited in substrate downstream from aufeis field.

Figure 40. Siltation resulting from extensive aufeis field at Oregon Creek mined study area, 20 June 1977.

Table 13. Major Habitat Alterations Observed at Sites Mined by Scraping (5 = No Change, 6–10 = Trend Towards Parameter, 0–4 = Trend Away From Parameter)

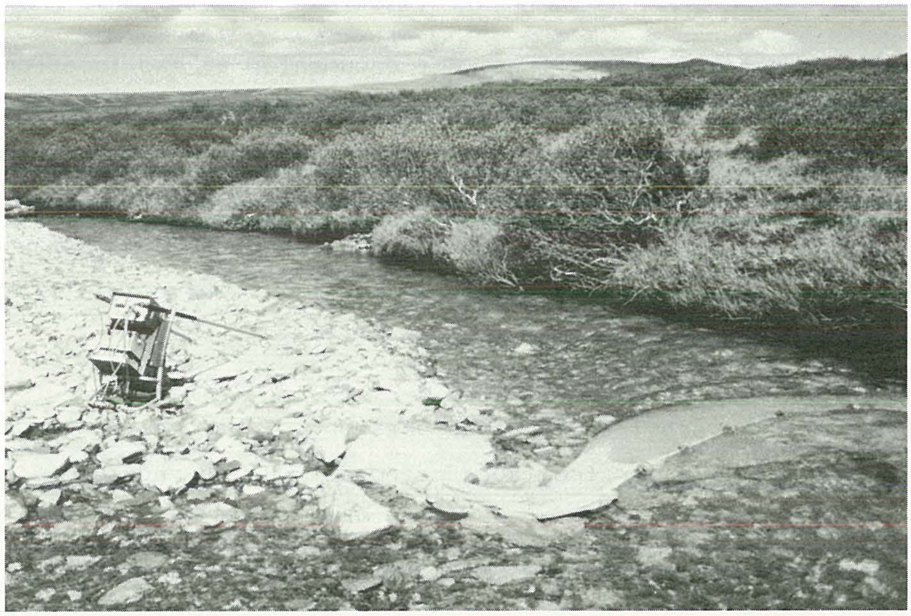
Site	Substrate alteration Type 1	Substrate alteration Type 2	Bank cover reduced	Instream cover reduced	Braiding increased	Backwater increased	Ponded water increased
Seward Peninsula							
Gold Run Creek	–[a]	5	5	8	5	6	5
Sinuk River	7	5	8	–	6	9	8
Washington Creek	10	5	10	10	10	10	10
Oregon Creek	10	5	10	10	9	9	8
Penny River	9	5	10	8	9	10	10
Nome River	–	5	5	–	10	10	7
North Slope							
Ugnuravik River	5	8	5	5	6	10	8
Aufeis Creek	–	5	5	8	9	10	10
Kuparuk River	8	5	5	5	8	7	6
Skeetercake Creek	–	5	9	8	5	8	10
Sagavanirktok River	9	5	5	9	10	10	6
Ivishak River	6	5	5	5	8	6	5
Shaviovik River	5	3	5	5	6	6	5
Kavik River	–	5	5	9	8	7	5
Northern Interior							
Dietrich River-Upstream	5	5	5	5	5	5	5
Dietrich River-Downstream	5	5	5	5	6	7	7
M.F. Koyukuk River-US	5	5	10	5	10	9	9
M.F. Koyukuk River-DS	5	5	5	5	8	10	7
Southern Interior							
McManus Creek	7	5	5	5	5	10	5
Phelan Creek	5	5	5	5	4	2	5

[a]Dash means parameter not evaluated at this site.

Type 2 substrate alterations were documented at two locations, both on medium size North Slope rivers (Table 13). In one case, Ugnuravik River, the upstream area showed near laminar flow that was changed to turbulent flow while in the other case, Shaviovik River, the reverse occurred – the upstream flow was turbulent whereas the flow through the mined area was laminar. Such changes would be expected naturally where localized substrate or slope differences alter flow characteristics.

Bank cover is provided by structures on or features of the stream bank that provide shelter from surface predation and reduce visibility. Examples of bank cover include overhanging vegetation and incised or undercut banks, thus bank cover was eliminated when mining removed these features (Figures 41 and 42). These types of bank cover were typically present in straight, sinuous, meandering or split channel rivers, but were less common in braided rivers. Significant bank cover loss was observed at 6 of the 21 scraped sites, Sinuk River, Washington Creek, Oregon Creek, and Penny River sites on the Seward Peninsula, at the Skeetercake Creek site on the North Slope, and at the Middle Fork Koyukuk River–Upstream in the Northern Interior (Table 13).

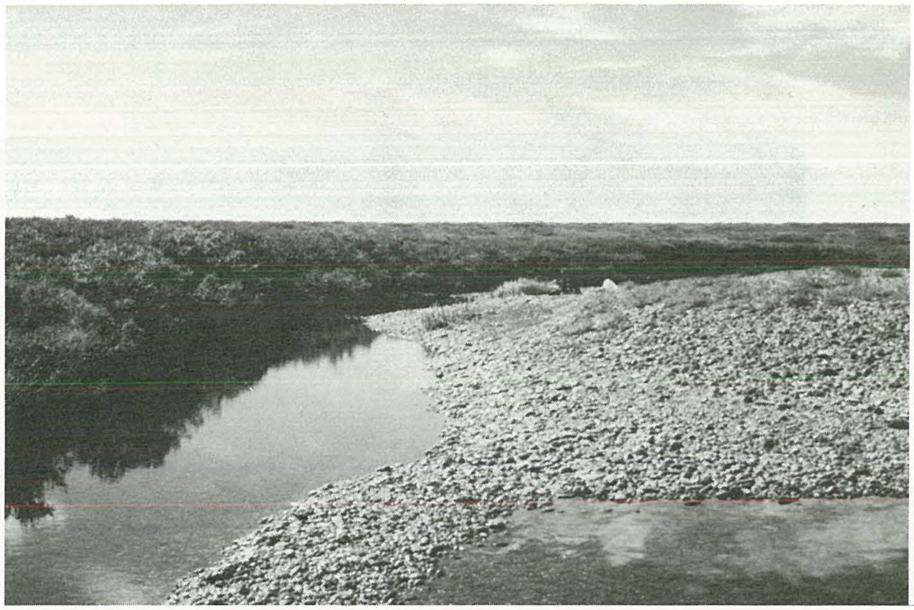
Instream cover is created by obstructions, such as boulders or logs, that provide slack water where fish can hold position with minimal energy expenditure and reduce predation from above by being less visible. Water depth can also function as cover, because deep pools and runs offer more overhead protection and often lower velocities than shallow riffles. Certain species, such as Arctic char and Arctic grayling, are often associated with instream cover. Instream cover was reduced at five sites, Washington Creek, Oregon Creek, Penny River, Kavik River, and Sagavanirktok River, as a result of directly removing boulders and large cobbles or altering flow such that new channels did not possess this habitat (Figures 43 and 44). At six sites, Gold Run Creek, Washington Creek, Oregon Creek, Aufeis Creek, Skeetercake Creek, and Sagavanirktok River, the channel configuration was altered so that the channel was wider and shallower in the mined areas, thus the instream cover provided by depth was reduced by lowering the ratio of pools to riffles.



a) Undercut vegetated bank typical of Oregon Creek upstream study area.

b) Oregon Creek mined study area - notice lack of bank cover, multiple channels.

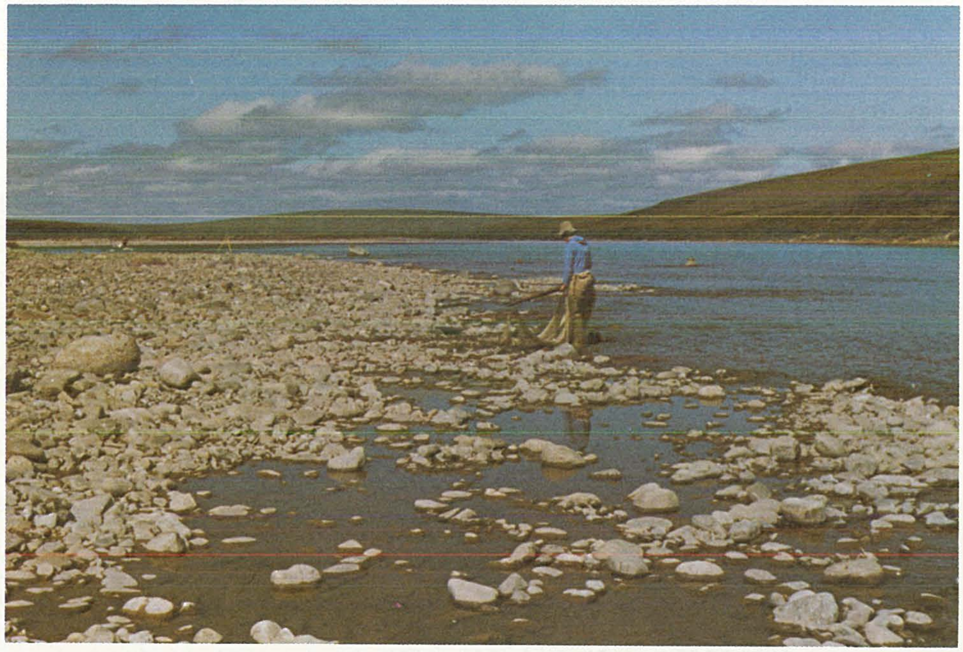
Figure 41. Removal of bank cover at Oregon Creek as observed on 24 June 1977.



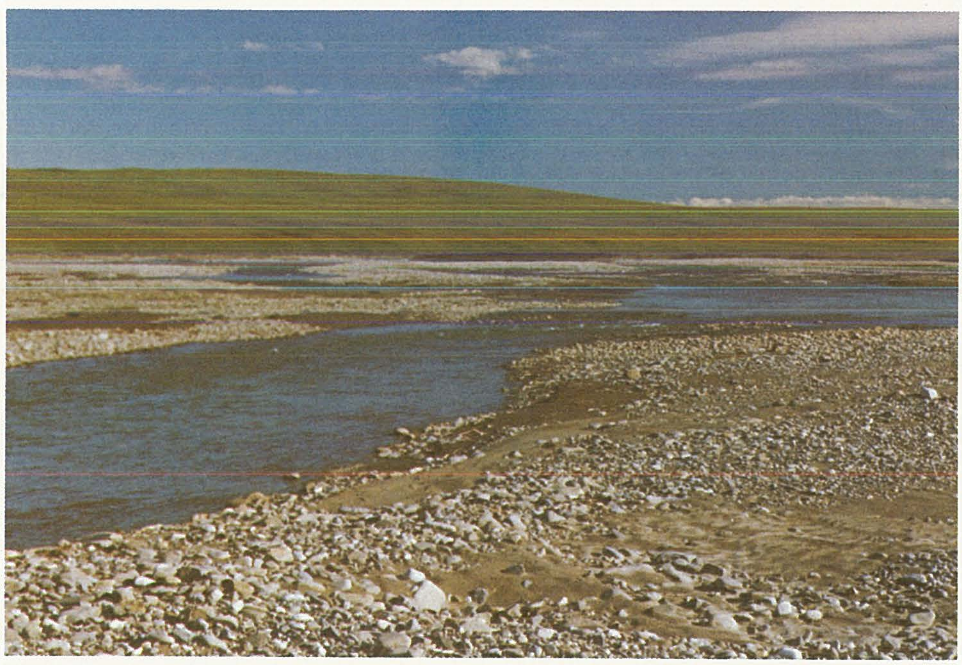
a) Skeetercake Creek upstream study area - note undercut vegetated bank.

b) Skeetercake Creek mined study area - bank cover absent, flow spread over wide, shallow area.

Figure 42. Removal of bank cover at Skeetercake Creek as observed on 18 June 1977.



a) Sagavanirktok River upstream study area, note predominance of boulders.



b) Sagavanirktok River mined study area showing extensive sedimentation and backwaters.

Figure 44. Reduction of instream cover as provided by boulders at Sagavanirktok River, 3 August 1978 (flow level, 60 m^3/sec, = 155% of estimated mean annual flow).

Habitat Diversity

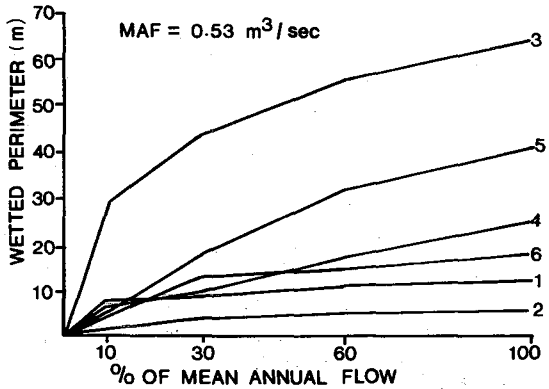
The result of decreasing habitat diversity, that is, creating uniform habitats by gravel removal operations, was to favor certain species or life history stages over others. One of the main indicators of reduced habitat diversity was increased braiding in the mined area caused where gravel deposits were scraped to below the water line or where flow subsequently increased to inundate the mined area. This type of habitat alteration occurred at 10 study sites (Washington Creek, Oregon Creek, Penny River, Nome River, Aufeis Creek, Kuparuk River, Sagavanirktok River, Ivishak River, Kavik River, and Middle Fork Koyukuk River–Downstream) (Figures 43 and 45, Table 13). The channels in a braided area usually have a uniform depth, velocity, and substrate with minimal bank cover. The areas were generally characterized by increased wetted perimeter, reduction in channel depth, and reduced mean velocities (Figure 46). At Washington Creek (Figure 46a), for example, the cross section in the upper mined area (Cross Section 3) had the greatest wetted perimeter at all flow levels, but most of this was in shallow open channels with little cover. Similarly, at Oregon Creek (Figure 46b) the wetted perimeter at cross sections in the mined area (Cross Section 2 and 3) was considerably greater than that in the upstream area and approached or exceeded that of the Cripple River cross sections, a river with greater than three times the estimated mean annual flow of Oregon Creek. Again, the Oregon Creek mined area channels were wide and shallow, providing low quality and low diversity habitat. The final example, Sagavanirktok River (Figure 46c), showed a similar pattern with the mined area cross sections having a greater wetted perimeter, but a shallower depth profile than cross sections in undisturbed areas.

Habitat diversity was increased in some other mined areas by the creation of new habitats. Three types of new habitats were usually found: (1) low velocity backwater areas, (2) a side channel off the main river, and (3) a flooded pit forming a pond habitat (Figures 47 and 48). Low velocity backwater areas were found at five sites (Sinuk River, Skeetercake Creek, Sagavanirktok River, Dietrich River–Downstream, and Middle Fork Koyukuk River–Upstream); side channel formation occurred at three sites (Skeetercake

a) 27 July 1973 - pre-mining

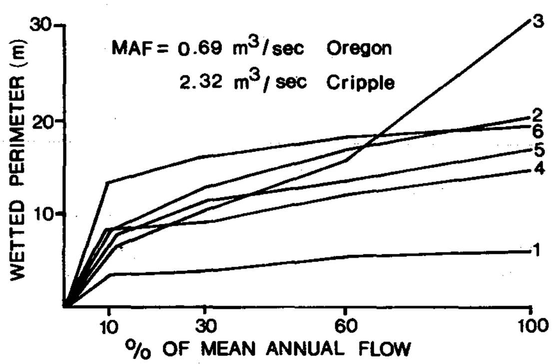
b) 2 August 1976 - post mining

Figure 45. Increased braiding at Sagavanirktok River study site caused by mining mid-channel gravel bars and a vegetated island in the active channel (mining operation conducted during the winter of 1974-1975).



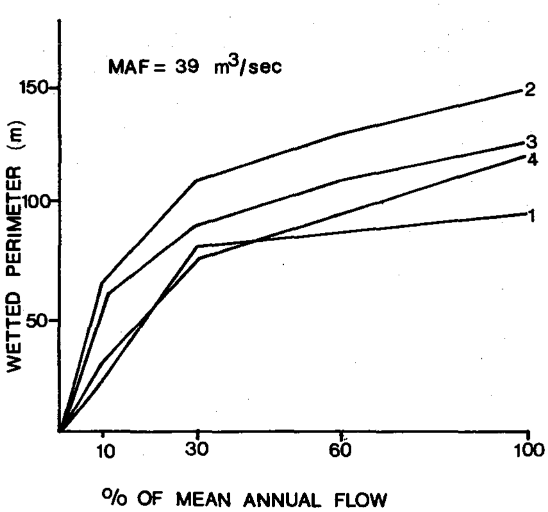
a. Washington Creek

CENTIMETERS Depth Interval	Cross Section 1 US	2 US	3 UM	4 BM	5 LM	6 DS
0-10	42%	26%	88%	42%	53%	39%
10-20	35	22	12	26	26	28
20-30	24	19		18	10	14
30-40		15		11	7	10
40-50		11		3	4	6
50-60		6			0.4	2
60-70		0.7				



b. Oregon Creek — Cripple River

CENTIMETERS Depth Interval	Cross Section 1 O-US	2 O-UM	3 O-LM	4 C-Bridge	5 C-LM	6 C-DS
0-10	39%	66%	64%	24%	29%	31%
10-20	29	32	29	21	24	28
20-30	24	4	9	16	19	24
30-40	9		0.2	15	15	15
40-50	0.3			15	11	2
50-60				8	2	
60-70				0.4		



c. Sagavanirktok River

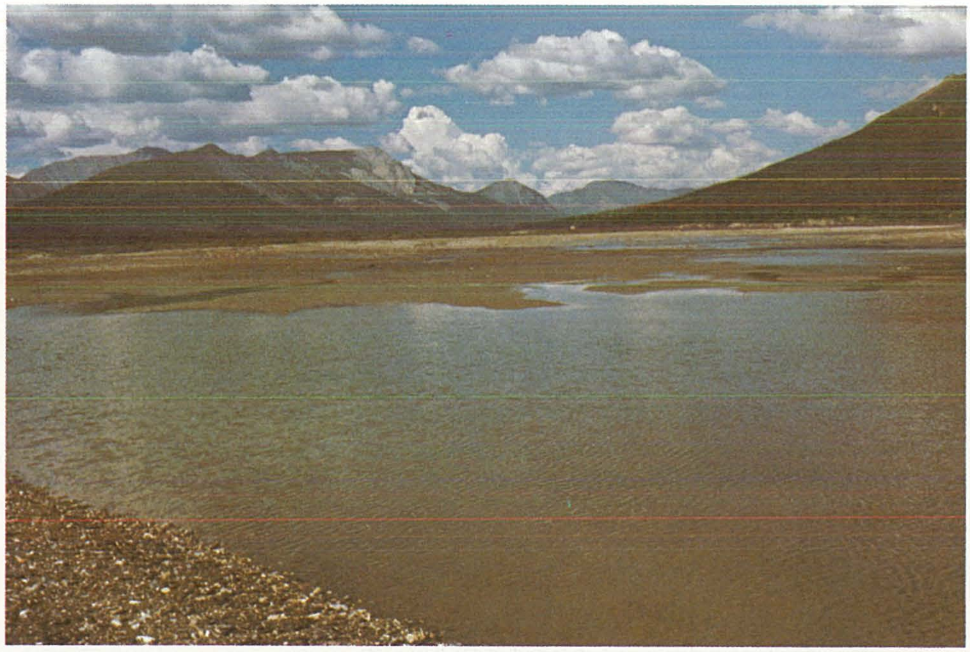
CENTIMETERS Depth Interval	Cross Section 1 US	2 UM	3 LM	4 DS
0-10	14%	23%	21%	21%
10-20	13	21	19	19
20-30	13	19	17	17
30-40	12	16	14	14
40-50	11	10	11	11
50-60	7	6	10	7
60-70	5	3	6	5
70-80	4	1	2	3
80-90	4	0.2	0.4	2
90-100	3			1
100-110	3			1
110-120	3			3
120-130	3			0.2
130-140	2			0.07
140-150	2			
150-160	1			
160-170	1			
170-180	0.4			
180-190	0.4			
190-200				

KEY

US	Upstream
UM	Uppermined
BM	Between Mined
LM	Lower Mined
DS	Downstream
O	Oregon Creek
C	Cripple River

*MAF - Mean Annual Flow

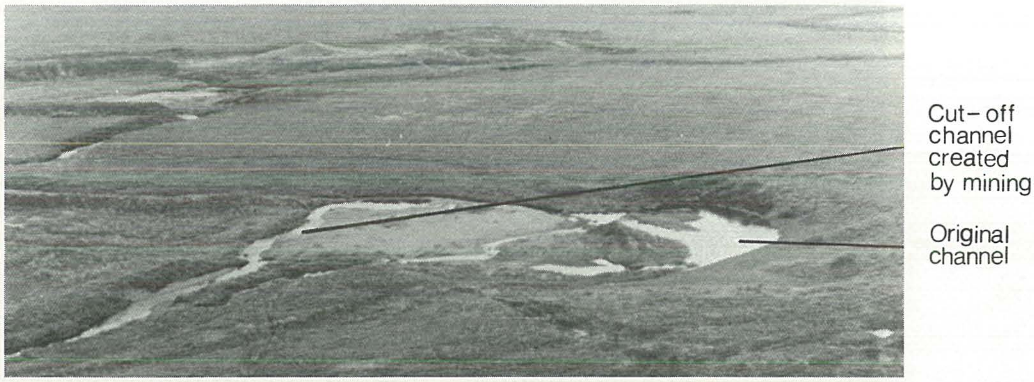
Figure 46. Response of cross-sectional wetted perimeters to percentage of mean annual flow and percentage of cross sections comprised of selected depth intervals at mean annual flow at three gravel removal study sites.



a) Dietrich River-Downstream - inundated mined study area.

b) Middle Fork Koyukuk River-Upstream - backwater in lower mined area.

Figure 47. Low velocity backwaters formed by gravel removal at Dietrich River-Downstream (13 July 1978) and Middle Fork Koyukuk River-Upstream (18 July 1978), note extensive silt deposition in both cases.



a) Skeetercake Creek showing cut-off channel, 4 September 1975.

b) Jim River showing side channel created by mining in a high-water channel, 12 August 1978.

c) West Fork Tolovana River pit created by deep excavating in an abandoned channel, 29 July 1978.

Figure 48. Creation of low velocity side channels and inundated pit following gravel extraction.

Creek, Middle Fork Koyukuk River-Upstream and Jim River); and flooded pits were created at seven sites (Penny River, Ugnuravik River, Dietrich River-Upstream, Prospect Creek, West Fork Tolovana River, Tanana River-Downstream, and Tanana River-Upstream).

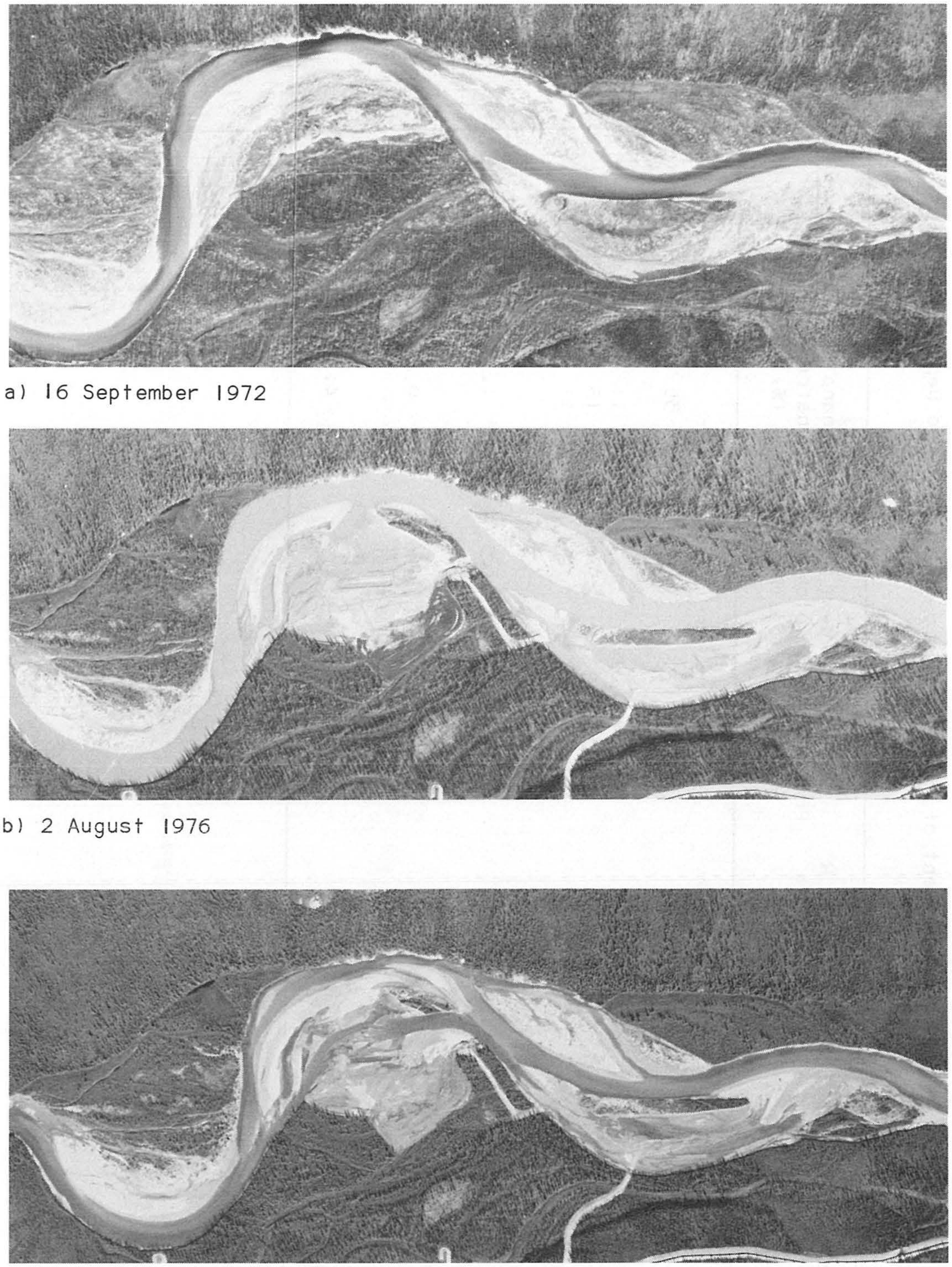
The changes in habitat diversity were determined by the location of mining and, to some extent, the type of mining. Braiding (decreasing habitat diversity) occurred where the majority of flow went through a mined area, such as where a meander was eliminated (two sites: Penny River, Middle Fork Koyukuk River-Downstream), an inchannel island or gravel bar was removed (five sites: Washington Creek, Kuparuk River, Sagavanirktok River, Ivishak River, Kavik River) or where excavation occurred in an active channel (five sites: Washington Creek, Oregon Creek, Penny River, Nome River, Aufeis Creek). Removal of gravel in active channels created braided areas in what had previously been pool-riffle habitats, thus, in these cases there was often a loss of instream and bank cover, substrate alteration, depth alteration, spreading of flow combined with decreased velocity, and loss of pools and riffles. Habitat diversity increased at two sites with incomplete meander cutoffs forming backwater and ponded areas or side channels (Skeetercake Creek, Middle Fork Koyukuk River-Upstream) and with gravel removal in a high-water channel to below the water table such that it contained ponded water (Sinuk River) or annual flowing water (Jim River).

Habitat diversity also increased at three sites where recent gravel extraction or channel changes created low velocity backwater areas and braided characteristics were not well established (Sagavanirktok River, Dietrich River-Downstream, Middle Fork Koyukuk River-Upstream). Ponded areas or low velocity backwaters were characterized by a sand to silt substrate. The low velocity with associated clear water often allowed increased growth of filamentous algae. Water temperatures were usually increased over those in the active channel because of the dark substrate and poor circulation. Similar effects, although not as great in magnitude, were observed where side channels were formed at Jim River and Middle Fork Koyukuk River-Upstream. Water velocities were reduced and increased silt deposition was observed in the main channel.

The three sites with increased habitat diversity due to recent flow were 3 to 4 years old and, in two cases (Dietrich River-Downstream and Middle Fork Koyukuk River-Upstream), flow had only entered the site within a year or two of the site study (Figure 49). The habitat diversity in these areas will probably decrease within a few years as meander cutoffs are completed and braiding characteristics are established.

Inundated pits were formed when gravel removal was conducted away from the active channel and the depression, usually deeper than 1 m, filled with water either by direct connection to the river or through intergravel flow. These areas developed characteristics typical of pond habitats, i.e., mud bottom, rooted aquatic vegetation around shorelines, high density plankton communities, and macroinvertebrates typically associated with a lentic environment. Two types of pits were included in the study: shallow (< 2 m) and deep (> 2 m) pits (Table 14). Shallow pits (Penny River, Ugnuravik River, Prospect Creek) normally froze to the bottom in the winter while deep pits (Dietrich River-Upstream, West Fork Tolovana River, Tanana River-Downstream, Tanana River-Upstream) contained water year-round.

Two of the deep pits (West Fork Tolovana River, Tanana River-Upstream) showed dissolved oxygen and temperature stratification in the summer of study while the other two (Dietrich River-Upstream, Tanana River-Downstream) did not (Figure 50). The time at which stratification would be most pronounced was missed at Dietrich River-Upstream and Tanana River-Downstream and it is possible that there was some stratification mid-summer; however, the Tanana River-Upstream and West Fork Tolovana River were thermally stratified from early June to mid-September. All pits except the Tanana River-Downstream pit were connected to the associated rivers. The Tanana River-Downstream pit was on a vegetated island and connection to the river was inundated only during annual high water events. This pit had clear water (bottom visible to deeper than 5 m), very little mud or silt even in the deepest area, and virtually no thermal stratification. Aquatic vegetation was absent except along the shoreline, despite the extreme water clarity. Four of the five deep pits had extensive shallow areas, with over 25 percent of the area less than 1 m deep. Only at the Tanana River-Downstream was a majority of the area deeper than 2 m (Table 14).



a) 16 September 1972

b) 2 August 1976

c) 11 July 1977

Figure 49. Sequence of aerial photographs showing effects of overmining the inside of a meander bend at Middle Fork Koyukuk River-Upstream. Immediately following mining (b) there was an increase in backwater areas. The next year (c) the meander was partially cut off, creating a variety of low velocity habitats.

Table 14. Percent of Pit Area Composed of Selected Depth Intervals

Depth interval (m)	Penny R (%)	Dietrich R Upstream (%)	Prospect Ck (%)	West Fork Tolovana R (%)	Tanana R Downstream (%)	Tanana R-Upstream Upper (%)	Tanana R-Upstream Lower (%)
0-1	90[a]	70.0	90[a]	54.0		28	23
1-2	10[a]	21.0	10[a]	32.0	35	38	31
2-3	0	4.4	0	6.2		34	45
3-4	0	1.3	0	4.2	11	0	0
4-5	0	0.6	0	3.0	13	0	0
> 5	0	2.2	0	0.7	41	0	0
Mean depth (m)	0.6	1.0	0.6	1.5	4.5	1.6	1.7
Maximum depth (m)	1.5	7.5	1.5	6.4	9.4	2.7	2.9
Total area (ha)	0.6	1.8	1.0	4.5	4.25	7.5	

[a]Estimated.

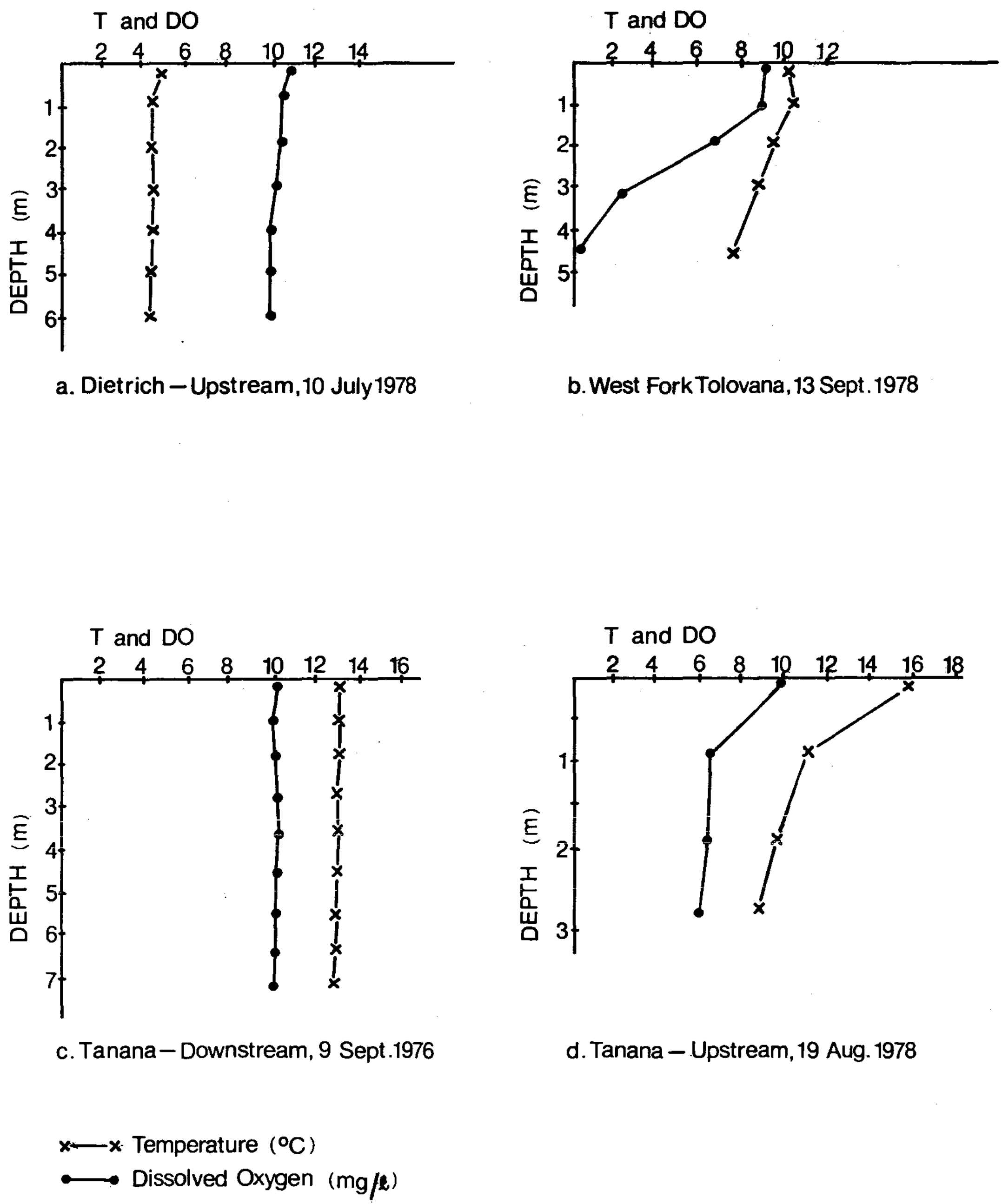


Figure 50. Temperature and dissolved oxygen profiles at four deep gravel pit study sites.

Water Quality

Water quality measurements reflected habitat alterations in several ways. First, dissolved oxygen and temperature responded in a predictable fashion to increased braiding. The spreading and shallowing of flow and loss of cover led to an increased rate of heat exhange, with the temperature, and therefore dissolved oxygen, responding more quickly to ambient air temperatures in the mined area than in the upstream area. Similarly, areas with ponded water showed increased temperatures and reduced dissolved oxygen (Skeetercake Creek, Dietrich River-Downstream). An increase in dissolved oxygen and decrease in temperature which was not caused by flow alteration was recorded at Dietrich River-Upstream where a spring was uncovered during gravel removal operations. As mentioned, inundated pits functioned as pond habitats with corresponding water quality characteristics. These included higher temperature and lower dissolved oxygen than the associated rivers and in some cases, thermal and oxygen stratifications.

A second type of water quality change was a change in conductivity between the upstream and mined areas. A change in conductivity may indicate the existence of a spring water source near or exposed by the gravel removal operation. Such changes were recorded at Aufeis Creek, Skeetercake Creek, Dietrich River-Upstream and Penny River. As already mentioned, the Dietrich River-Upstream was an identified spring exposure. The Penny River had a spring-fed tributary entering the floodplain in the mined area. Springs were not recorded at Aufeis Creek or Skeetercake Creek, but the conductivity changes may indicate their existence.

A third type of water quality change was alteration in turbidity or suspended solids, or both, in the mined area compared to the upstream area. These changes probably indicate erosional or depositional characteristics of the mined area, but the sampling was insufficient to reach definite conclusions on an individual site basis.

EFFECTS OF HABITAT ALTERATION ON FISH POPULATIONS

Observed Alteration of Summer Distributions or Densities

Several types of changes in summer fish distribution were observed in the mined areas; specific types of distributional changes were related to certain types of habitat alterations caused by gravel removal. These changes included: (1) reduction in the numbers of all fishes in a disturbed area, (2) replacement of one species by another species, (3) replacement of one age group by another age group, and (4) increase in the number of fish or species, or both (Table 15). A list of all species caught during the study and their scientific names is included in Appendix A.

Density Reductions. Reductions in numbers of all fish populations occurred at Washington Creek, Aufeis Creek, and Kavik River sites. The habitat in the upper mined area of Washington Creek was altered in several ways, reducing habitat quality and diversity to an extent that few organisms could utilize the newly created habitat. The density and biomass of Arctic char was significantly reduced downstream of the upstream sample area (Table 16). The slimy sculpin density and biomass was also reduced in the upper mined area, but increased in the lower sample areas to densities exceeding those in the upstream area. The sculpin biomass remained low, indicating the slimy sculpin captured below the mined area were smaller than those captured above. Thus, there was a replacement of Arctic char habitat by a habitat more suitable for slimy sculpin in the lower three sample areas. The specific habitat alterations that led to a loss of Arctic char habitat were removal of bank and instream cover and possibly reduced water quality (i.e., increased turbidity) caused by siltation from the melting aufeis field.

At the Aufeis Creek site, there was only one life history stage of Arctic grayling present during each sampling trip, thus any changes would have to be density reductions rather than species or age-group shifts. Density reductions were recorded in the upper mined area during the first trip and all disturbed areas in the second trip. Specific habitat alterations that led to reductions in Arctic grayling habitat were: (1) the reduc-

Table 15. Effects of Cumulative Habitat Alterations on Fish Populations in the Mined Area of Study Sites Mined by Scraping

Study site	Habitat alterations caused by mining	Effects of total alteration to fish populations in mined area
Seward Peninsula		
Gold Run Creek	Scraped bars; decreased instream cover; increased ponded water	No measurable response (Arctic char, Arctic grayling)
Sinuk River	Scraped high-water channel, island, and bank; increased unstable substrate, slight braiding, backwaters, ponded water; decreased bank cover	Arctic char, Arctic grayling, chum salmon fry reduced, slimy sculpin unaffected; potential for stranding
Washington Creek	Scraped active channel; increased siltation, unstable substrate, braiding, backwaters, ponded water, aufeis; decreased bank and instream cover	Arctic char eliminated, shift to slimy sculpin below mined area, potential for temporary blockage and stranding
Oregon Creek	Scraped active channel; increased unstable substrate, braiding, backwaters, ponded water, aufeis; decreased bank and instream cover	Arctic char habitat eliminated, potential temporary migration blockage, stranding
Penny River	Multiple meander cutoff; increased unstable substrate, braiding, backwaters, ponded water; decreased bank and instream cover	Loss of overwintering and spawning areas; species alteration by creation of coho salmon rearing habitat
Nome River	Scraped bars; increased braiding, backwaters, ponded water	Potential for stranding and temporary migration blockage

Continued

Table 15. (Continued)

Study site	Habitat alterations caused by mining	Effects of total alteration to fish populations in mined area
North Slope		
Ugnuravik River	Scraped bars; increased braiding, backwaters, ponded water; change from laminar to turbulent flow	No effect - only a few fourhorn sculpin caught
Aufeis Creek	Scraped active channel; increased braiding, backwaters, ponded water; decreased instream cover	Reduction of Arctic grayling, documented blockage due to lack of surface flow
Kuparuk River	Scraped bar; increased unstable substrate, braiding, backwaters, ponded water, possibly aufeis	Reduction in number of species and life history stages; age-I Arctic grayling dominant, documented stranding
Skeetercake Creek	Meander cutoff; increased backwaters and ponded water; decreased bank and instream cover	Arctic grayling usage reduced where cover was lost, increased in area of partial meander cutoff
Sagavanirktok River	Removal of island; increased unstable substrate, braiding, backwaters, ponded waters, possibly aufeis; decreased instream cover	Increased Arctic grayling, reduced round whitefish, loss of Arctic char habitat; potential for stranding
Ivishak River	Scraped mid-channel bars; increased unstable substrate, braiding, backwaters, ponded water, possibly aufeis	Slight increase in Arctic grayling, no significant changes

Continued

Table 15. (Continued)

Study site	Habitat alterations caused by mining	Effects of total alteration to fish populations in mined area
Shaviovik River	Scraped point bars; increased laminar flow, slight braiding, and backwater increase	No measurable changes
Kavik River	Scraped floodplain; increased siltation, braiding, backwaters, ponded water; decreased instream cover	Arctic char and Arctic grayling both decreased
<u>Northern Interior</u>		
Dietrich River-US	Scraping in high-water channel, exposed spring water	Creation of overwintering area
Dietrich River-DS	Scraping in high-water channel; increased backwaters and ponded water - newly flooded depression	Some use by Arctic grayling, potential for stranding
M.F. Koyukuk River-US	Partial meander cutoff; increased braiding, backwaters, ponded water; decreased bank cover	Altered species composition, round whitefish and longnose sucker increased, documented stranding, overall habitat diversity increased
M.F. Koyukuk River-DS	Scraping in high-water channel; increased braiding, backwaters, ponded water	Altered species composition - round whitefish, slimy sculpin increased, Arctic grayling decreased, potential for stranding

Continued

Table 15. (Concluded)

Study site	Habitat alterations caused by mining	Effects of total alteration to fish populations in mined area
Southern Interior		
McManus Creek	Scraping bars; increased backwaters, ponded water, unstable substrate, *aufeis*	No measurable change (Arctic grayling, slimy sculpin)
Phelan Creek	Scraping channels and bars; increased ponded water; decreased braiding, backwaters	No fish captured at this site

Table 16. Estimated Densities and Biomass of Arctic Char and Slimy Sculpin at Washington Creek Study Site Based on Repeated Electroshocking of Blocked Sections of Stream, 21-23 June 1977

				Arctic char		Slimy sculpin	
Study area	No. of sections sampled	Area sampled (m^2)	No. of passes/w shocker[a]	Avg density (fish/100m^2)[b]	Avg biomass (gm/100m^2)	Avg density (fish/100m^2)	Avg biomass (gm/100m^2)
Upstream	3	254	12	14 (6-21)	77 (37-119)	12 (6-21)	57 (32-107)
Upper mined	3	209	8	1 (0-2)	6 (0-13)	2 (0-3)	8 (0-16)
Between mined	3	221	10	2 (1-2)	13 (8-18)	11 (6-15)	26 (18-40)
Lower mined	2	125	6	2 (0-3)	23 (0-46)	20 (15-25)	41 (32-50)
Downstream	2	249	7	2 (2)	10 (5-14)	24 (10-37)	44 (21-67)

[a]Number of times blocked section of stream was sampled with electroshocker.

[b]Value in parentheses is range of estimated values.

tion of the pool-riffle frequency, and (2) increased braiding characteristics with the associated loss of bank cover and altered flow regime.

At the Kavik River site, habitat quality was altered by the erosion of berms left in and along active channels, channelizing one section of the river, and creation of a more braided configuration. The densities of Arctic char and Arctic grayling for each study area were estimated by repeated shocking of blocked channels (Table 17). Total fish densities in the mined area were reduced by a factor of three or greater when compared to the undisturbed areas (Table 18). The catch of adult Arctic grayling, as determined by angling, was also lower in the mined area (Table 19). The density reductions occurred in both Arctic grayling and Arctic char with neither species apparently favored by the habitat alteration. Removal of instream cover appeared to be a major habitat alteration affecting reduction of fish densities because a channel that contained boulders adjacent to the mined area supported densities of both species comparable to those in undisturbed areas.

Species and Age Group Alteration. Species shifts were observed at nine sites (Washington Creek, Oregon Creek, Penny River, Kuparuk River, Sagavanirktok River, Ivishak River, Dietrich River-Downstream, Middle Fork Koyukuk River-Upstream, and Middle Fork Koyukuk River-Downstream) because alterations in the type of habitat allowed other species to populate an area (Table 20). A similar response is a change in the age structure of fish inhabiting a reach of river, as was observed at Kuparuk River, Skeetercake Creek, and Middle Fork Koyukuk River-Upstream. In these areas newly created habitats favored or excluded certain age groups in the areas affected by gravel removal operations. On Kuparuk River, the mined area had a more uniform habitat than the upstream area and numerous small channels of similar velocity. Age-0 and age-I Arctic grayling and several age groups of slimy sculpin were present in the upstream area while only age-I Arctic grayling were captured in the mined area. At the Sagavanirktok River, Arctic grayling juveniles were confined almost exclusively to the mined area, while the upstream area catch was dominated by round whitefish and an unmined channel adjacent to the mined area contained adult (~300 mm) Arctic grayling. Again, the mined area was changed from a large single channel to an

Table 17. Estimated Densities and Biomass of Arctic Char and Arctic Grayling at Kavik River Study Site Based on Repeated Electroshocking of Blocked Sections of Stream, 1976

Study area	No. of sections sampled	Area sampled (m^2)	No. of passes/w shocker[a]	Arctic char: Avg density (fish/$100m^2$)	Arctic char: Avg biomass[b] (gm/$100m^2$)	Arctic grayling: Avg density[b] (fish/$100m^2$)	Arctic grayling: Avg Biomass[b] (gm/$100m^2$)
<u>22 - 25 July</u>							
Upstream	--	--	--	--	--	--	--
Mined	2	366	4	0.5 (0.5)	8.4 (7.7-8.7)	0	0
Downstream	2	228	6	3.0 (2.6-3.5)	111 (80-142)	4.0 (0.9-7.0)	110 (25-195)
<u>4 - 8 August</u>							
Upstream	1	285	6	0.7	12	0	0
Mined	6	2,190	20	0.3 (0-0.7)	17 (0-68)	0	0
Downstream	9	2,344	24	0.3 (0-1.0)	4 (0-17)	0.8 (0-4.2)	3 (0-20)
<u>28 August - 4 September</u>							
Upstream	2	822	8	1.7 (1.1-2.2)	30 (24-36)	0.9 (0.7-1.1)	35 (18-51)
Mined	9	2,452	32	0.7 (0-2.2)	19 (0-79)	0.5 (0-2.2)	5 (0-30)
Downstream	6	1,548	30	0.9 (0-3.9)	63 (0-281)	3.5 (0-10.9)	9.5 (0-95)

[a] Number of times blocked section of stream was sampled with electroshocker.

[b] Value in parentheses represents range of estimated values.

Table 18. Comparison of Fish Densities in Mined and Undisturbed Areas as Determined by Electroshocking Blocked Sections of Stream at Kavik River Study Site, 1976

Date	No. of sections sampled	Total area sampled (m^2)	Average fish density: Mined area (fish/100 m^2)	Average fish density: Undisturbed areas (fish/100 m^2)	Undisturbed ÷ Mined area
22-25 July	4	594	0.5	7.0	14.0
4-8 August	16	4,819	0.3	0.9	3.0
28 August - 4 September	17	4,822	1.2	3.6	3.0

Table 19. Catch of Arctic Grayling per Angler Hour at Kavik River Study Areas During Summer 1976 Sampling Trips

Area	Periods of fishing	Total hours of effort	Average number of fish per angler hour[a]
22 - 24 July			
Upstream	3	4.7	3.4 (1.8-4.5)
Mined	3	7.9	2.6 (1.3-3.6)
Downstream	4	5.6	4.8 (2.2-6.0)
4 - 8 August			
Upstream	2	4.5	3.6 (2.25-4.9)
Mined	1	2.2	2.3
Downstream	1	2.6	3.1
28 - 31 August			
Upstream	1	6.0	1.7
Mined	1	3.0	0
Downstream	0	0	--

[a]Value in parentheses is range of estimated values.

Table 20. Change in Catch per Effort and Percent Composition of Indicator Species at Selected Study Sites (Selected on Basis of Suitable Sample Size)

River	Sample area[a]	Observed catch per effort: Minnow trap (fish/trap)	Seine (fish/haul)	Electroshock (fish/100m^2)	Species composition: % Char Minnow trap	% Char Electroshock	% Grayling All gear types	Major species lost/gained[b]
Washington Ck	U	1.3	-	26	100	55	-	
	UM	0.2	-	3	100	47	-	+SS
	BM	0.0	-	12	-	14	-	+SS
	LM	0.2	-	22	0	9	-	+SS
	D	2.2	-	26	0	11	-	+SS
Oregon Ck - June	U	-	-	22	-	58	-	
	M	-	-	11	-	93	-	-SS
- August	U	4.6	-	137	93	68	-	
	M	2.7	-	164	78	65	-	+SS
- September	U	1.7	-	14	100	36	-	
	M	2.9	-	30	85	45	-	+SS(MT) -SS(ES)
Penny R - June	U	0.06	-	-	0	-	-	
	M	0.20	-	-	33	-	-	+SS
	P	0.50	-	-	3	-	-	+CS, +SS
	D	-	-	-	-	-	-	
- August	U	15.2	-	-	71	-	-	
	M	40.5	-	-	64	-	-	+CS
	P	7.4	-	-	4	-	-	+CS
	D	24.8	-	-	85	-	-	-CS
- September	U	18.2	-	-	42	-	-	
	M	9.8	-	-	34	-	-	+CS
	P	12.6	-	-	0	-	-	+CS
	D	1.3	-	-	67	-	-	-CS
Kuparuk R	U	-	6.5	-	-	-	43	
	M	-	12.8	-	-	-	94	-SS
	D	-	1.0	-	-	-	75	-SS
Sagavanirktok R	U	-	0.56	-	-	-	10	
	M	-	1.12	-	-	-	61	-RWF
	D	-	0.14	-	-	-	0	
Ivishak R	U	-	-	3.1	-	80	17	
	M	-	-	3.3	-	87	8	+AC
	D	-	-	1.9	-	87	5	+AC
Dietrich R-Downstream	U	-	1.65	-	-	-	54	
	M	-	0.65	-	-	-	79	-SS
	D	-	1.50	-	-	-	48	+RWF
Middle Fork Koyukuk River-Upstream	U	-	4.2	-	-	-	64	
	UM	-	1.9	-	-	-	44	+RWF
	LM	-	4.4	-	-	-	59	+RWF, +LNS
	OC	-	1.8	-	-	-	55	+RWF
	D	-	3.1	-	-	-	25	+SS, +RWF
Middle Fork Koyukuk River-Downstream	U	-	1.2	-			[illegible]	
	M	-	1.3	-	-	-	25	+SS, +RWF
	D	-	2.7	-	-	-	38	+SS, +RWF

[a] U = upstream UM = upper mined BM = between mined D = downstream
LM = lower mined P = pit OC = original channel

[b] + = increased relative to upstream - = decreased relative to upstream SS = slimy sculpin
CS = coho salmon RWF = round whitefish AC = Arctic char LNS = longnose sucker

area criss-crossed with numerous shallow small channels. At Skeetercake Creek, gravel removal in the upper mined area created an extensive backwater which was utilized by adult Arctic grayling; at the middle mined area, bank cover and pools were removed and this led to a reduction in the population density of Arctic grayling. At the lower mined area of the Middle Fork Koyukuk River-Upstream site, the single-channel sinuous configuration of the river was changed to a split channel with extensive backwater areas. The catch and species present were similar between mined and undisturbed areas, but the age structure was more complex in the areas affected by gravel removal. Age-0, age-1, and age-2+ Arctic grayling, age-0 round whitefish, and age-1 and adult longnose sucker were captured in the mined areas while the species caught in undisturbed areas were primarily represented by a single age group. Only round whitefish exhibited a more diverse age structure in the undisturbed areas. Similarly, at the Middle Fork Koyukuk River-Downstream site the river was changed from a single channel to a multiple channel braided system with numerous backwater areas. Arctic grayling dominated the catch at the upstream area, but were replaced in the mined area by round whitefish and slimy sculpin.

Potential for Entrapment. Gravel removal in active floodplains created areas of ponded water which were isolated from the active channel. Typically these ponded areas were inundated during high water and became isolated as the water level receded (Figures 51 and 52). Fish often entered these ponded areas during high water and became stranded as the water level dropped. The mortality rate of these fish was assumed to be high because they were subjected to increased temperature, decreased dissolved oxygen, greater vulnerability to surface predation, desiccation if the area dried completely, and freezing. There were 13 scraped areas at which ponded areas were observed: Sinuk River, Washington Creek, Oregon Creek, Penny River, Nome River, Ugnuravik River, Aufeis Creek, Kuparuk River, Skeetercake Creek, Sagavanirktok River, Dietrich River-Downstream, Middle Fork Koyukuk River-Upstream, and Middle Fork Koyukuk River-Downstream (Table 13). Sampling in these ponded areas revealed significant entrapment at some sites. At Sinuk River the mined area was not heavily utilized by fish. Pink and chum salmon spawn in the river and considerable numbers of chum salmon fry were captured

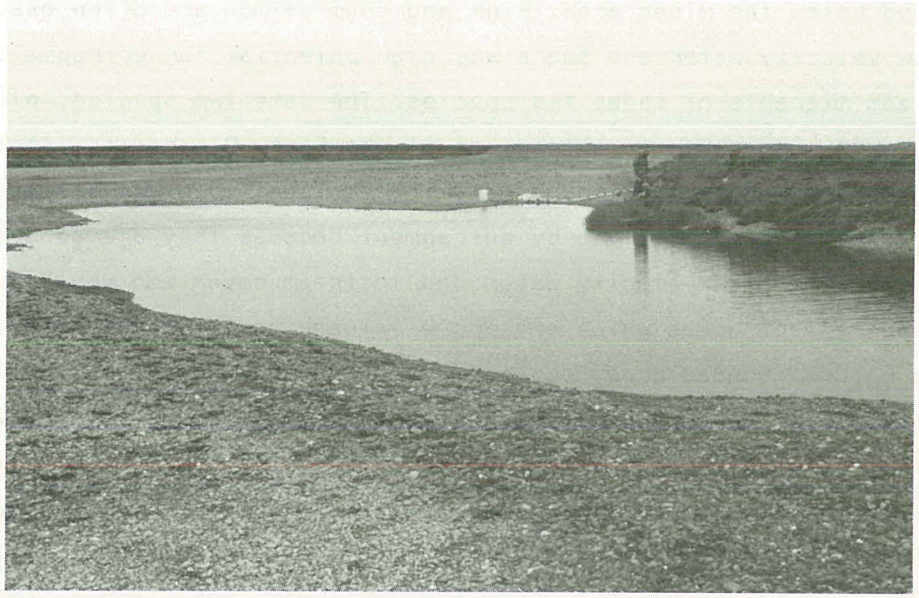


Figure 51. Ponded area at Kuparuk River study site where three seine hauls captured 61 Arctic grayling and 2 slimy sculpin, 9 August 1978 (pool 1 in Table 21).

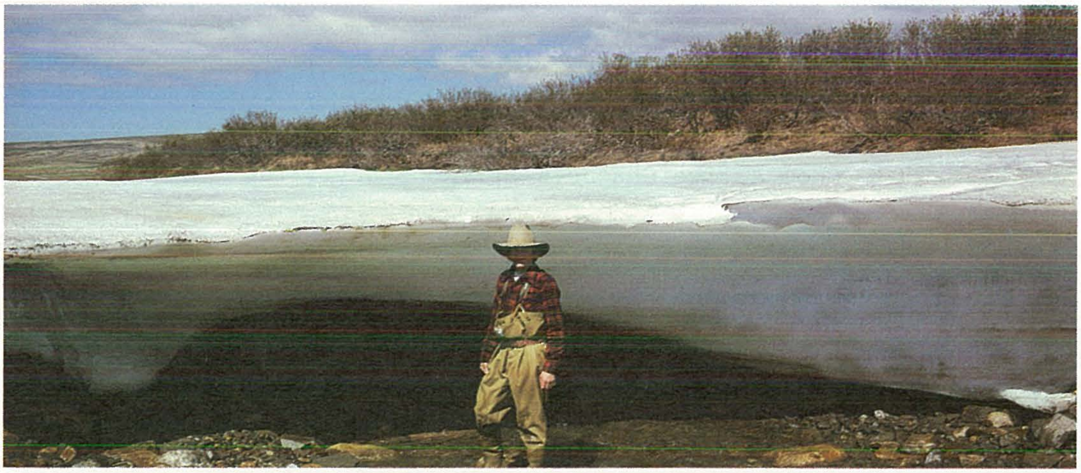
Figure 52. Ponded area at Middle Fork Koyukuk-Upstream study site where one seine haul captured 28 Arctic grayling, 3 round whitefish and 3 slimy sculpin, 18 July 1978 (pool 2 in Table 21).

above and below the mined area. Pink and chum salmon are often associated with low velocity water and there was high potential for entrapment of downstream migrants of these two species. The same two species, plus coho salmon, were vulnerable to entrapment at the Penny River site. At Washington Creek, Oregon Creek, and Penny River, the dominant species, Arctic char, are probably not greatly affected by entrapment because they are generally associated with high velocity water and instream cover and would tend to avoid the type of areas which are prone to ponding. At the Kuparuk River site, a natural ponded area, apparently enlarged by gravel excavation, contained a high density of age-I Arctic grayling (Table 21, Figure 51). At the latter site both natural and ponded areas created by gravel removal were present in the study reach. At the Middle Fork Koyukuk River-Upstream, considerable stranding was documented when several isolated pools were sampled (Table 21, Figure 52). The primary species subjected to entrapment in the Middle Fork Koyukuk River system was Arctic grayling.

Migration Blockage. Two types of potential mining-induced migration blockages were observed during the study: (1) blockage due to aufeis formation, and (2) blockage due to lack of surface flow. Possible temporary migration blockage due to aufeis formation may have occurred at the Washington Creek and Oregon Creek sites (Figure 53). The principal migrations that could be affected in these particular systems would be upstream and downstream movements of juvenile Arctic char and juvenile coho salmon moving from overwintering areas to feeding areas and downstream migrations of adult Arctic char returning to the sea from upstream overwintering areas, if present. A short-term delay in these migrations may not have a critical effect on these particular species, but a similar blockage for another species, such as an upstream spawning migration of Arctic grayling, may have a great effect on the population in the river. A blockage due to lack of surface flow can occur where flow is spread over a wide area and there is considerable intergravel flow. Under such conditions, all surface flow may cease. Such a condition occurred at the Aufeis Creek site (Woodward-Clyde Consultants 1976) (Figure 54) and possibly could occur at the Nome River site (K. Tarbox, personal communication). The potential for such a blockage

Table 21. Summary of Catch from Ponded Water Areas Isolated From Active Channels at Two Study Sites

Location	Pool	No. of seine hauls	Catch per haul			
			Arctic grayling	Slimy sculpin	Round whitefish	Longnose sucker
Kuparuk River	1	3	20.3	0.7	0	0
Middle Fork	2	1	28	3	3	0
Koyukuk River-	3	1	20	1	0	1
Upstream	4	1	0	0	0	0
	5	1	0	0	0	0
	6	1	2	0	0	0
	7	2	9	0.5	0	5



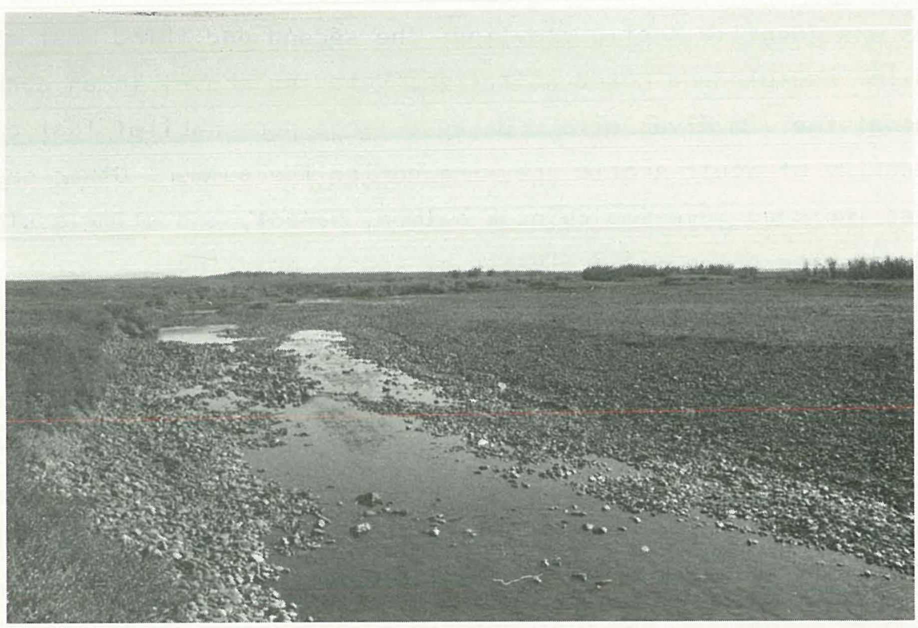
a) Washington Creek aufeis field, 21 June 1977.

b) Washington Creek aufeis field, 21 June 1977. Note sediment layer on ice inside cavern.

c) Oregon Creek aufeis field, 7 June 1977. Note sediment layer on melting ice in foreground.

Figure 53. Potential migration blockages, aufeis fields at Washington Creek and Oregon Creek, June 1977.

a) Aerial view of Aufeis Creek middle mined study area, 21 July 1977.



b) Aufeis Creek upper study area where surface flow disappeared for three years, 22 July 1977.

Figure 54. Region where Aufeis Creek went subsurface creating migration blockage due to lack of surface flow.

existed at several additional sites, such as Washington Creek, Oregon Creek, Penny River, and Skeetercake Creek, but a specific blockage was not observed.

Creation of New Habitats

New aquatic habitat was created at eight sites where mined areas separated from the active channel were flooded subsequent to site closure. These include the Dietrich River-Downstream and Jim River sites as well as the pit sites at Penny River, Dietrich River-Upstream, Prospect Creek, West Fork Tolovana River, Tanana River-Downstream, and Tanana River-Upstream. At the Dietrich River-Downstream site, a wide shallow backwater was created in the spring immediately prior to the site survey, 3 years after mining, and was quickly utilized by round whitefish and Arctic grayling. Less mobile species, such as slimy sculpin, had not moved into the area by the time of the survey (12-13 July) but would probably immigrate into the mined area over the summer period. In the river, the most abundant species was juvenile Arctic grayling; the second and third most abundant were slimy sculpin and round whitefish. Removing gravel in an abandoned channel at the Jim River site created a large pool habitat that contained a high density of adult Arctic grayling during the summer. Other species captured included juvenile chinook salmon, burbot, and slimy sculpin. In the main river, the catch was dominated by Arctic grayling.

The present configuration of the Penny River apparently resulted from two separate periods of mining. Originally, the floodplain was scraped adjacent to the channel. The channel subsequently diverted through the scraped site and gravel was removed from the original channel, leaving a shallow pit. During the site visit the present Penny River channel, formed by flow diversion through the original scraped area, was heavily utilized by Arctic char juveniles. The pit, created by excavating in the original channel, provided rearing area for coho salmon juveniles and spawning and rearing areas for Alaska blackfish and ninespine stickleback. The catch in undisturbed areas was dominated by Arctic char and coho salmon with Arctic char dominant in the spring and coho salmon dominant in the fall. The occurrence of both species in undisturbed areas, compared to the single species dominance in the mined areas, again reflects the reduced habitat diversity in areas disturbed by gravel removal.

The Penny River pit provided coho salmon rearing habitat, which was limited in the river. Arctic char appeared to be more suited to the river environment than coho salmon, and avoided the pit. The pit thus provided ideal rearing conditions for coho with little competition from Arctic char. There was a significant difference in size of coho using the pit as compared to those using the river possibly indicating increased growth rate by those in the pit (Tables 22 and 23). During the winter the coho left the pit and moved to other areas where they possibly would be in direct competition with char for space. If overwintering space is limiting in this river system, the increased number of larger coho could lead to displacement and subsequent reduction in the numbers of char. The Prospect Creek pit, a shallow pond habitat previously not present in the immediate area, was used as a rearing area by Arctic grayling, round whitefish, chinook salmon, burbot, and slimy sculpin, and also provided a feeding area for adult northern pike (Figure 55). In the upstream area of Prospect Creek the catch in 1977 was dominated by round whitefish, Arctic grayling, and slimy sculpin listed in diminishing order of abundance. In 1978 juvenile chinook salmon appeared to dominate the fish populations in the creek.

The Dietrich River-Upstream pit and associated channels provided a deep-water, spring-fed system utilized principally by adult Arctic grayling and Arctic char while the main river contained juvenile Arctic grayling, slimy sculpin, and round whitefish.

The West Fork Tolovana River pit contained extensive vegetated shallow water areas which sloped off rapidly to deep water areas up to 6 m deep, thus creating excellent spawning, rearing, and feeding areas for northern pike and feeding areas for adult Arctic grayling (Figure 56). Arctic grayling were the only species captured in the river during three sampling trips, while northern pike were abundant in the pit. The only Arctic grayling captured in the pit were adults longer than 225 mm; smaller Arctic

Table 22. Mean Fork Lengths of Coho Salmon Caught by Minnow Trap at the Penny River Study Site During 1977

Area	Age-0 Mean length (mm)	Age-0 Standard deviation	Age-0 Sample size	Age-I Mean length (mm)	Age-I Standard deviation	Age-I Sample size
<u>4 - 10 August</u>						
Upstream	46.3	2.85	21	76.7	7.59	27
Pit	49.9	3.56	96	85.4	9.29	35
Mined (scraped)	47.8	2.86	50	80.1	6.78	38
Downstream	46.4	2.03	18	79.7	5.70	20
<u>9 - 13 September</u>						
Upstream	51.0	5.45	90	85.6	7.33	5
Pit	57.3	5.02	387	89.6	7.55	65
Downstream	52.8	4.47	19	83.3	3.51	3

Table 23. Differences of Coho Salmon Mean Fork Length Between Sample Areas and Associated Significance Levels, Penny River Study Site During 1977 (Using Student's T-Test of Differences Among Lengths in Table 22)

Areas	Age-0		Age-1	
	Length difference (mm)	Significance level	Length difference (mm)	Significance level
<u>4 - 10 August</u>				
Pit-upstream	3.6	$p < 0.01$	8.7	$p < 0.01$
Pit-mined	2.1	$p < 0.01$	5.3	$p < 0.01$
Pit-downstream	3.5	$p < 0.01$	5.7	$p < 0.05$
Mined-upstream	1.5	$p < 0.05$	3.4	NS
Mined-downstream	1.4	NS	0.4	NS
Upstream-downstream	0.1	NS	3.0	NS
<u>9 - 13 September</u>				
Pit-upstream	6.6	$p < 0.01$	4.0	NS
Pit-downstream	4.5	$p < 0.01$	6.3	NS
Upstream-downstream	1.8	NS	2.3	NS

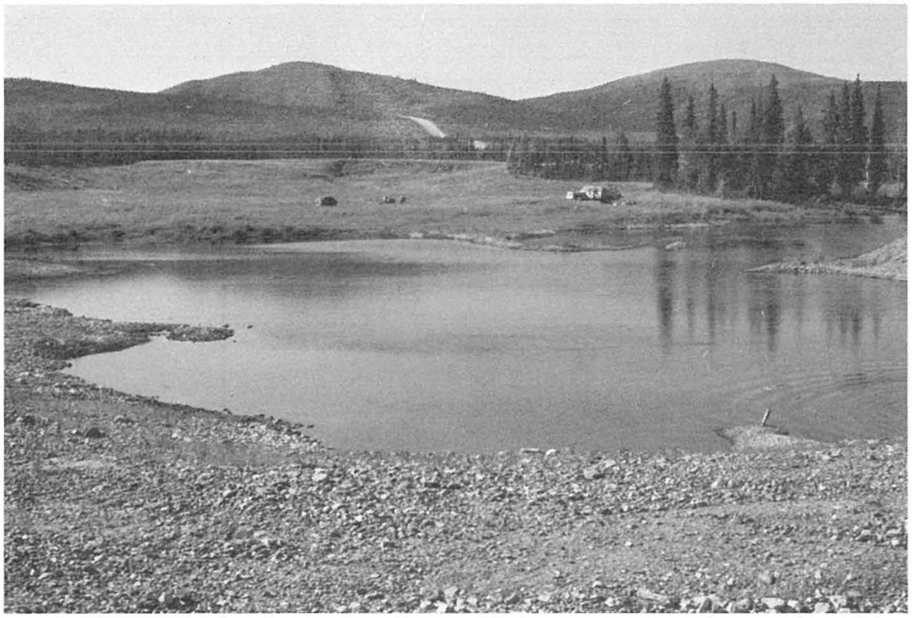


Figure 55. Prospect Creek study site - shallow pond habitat supporting Arctic grayling, chinook salmon juveniles, round whitefish, northern pike, burbot, slimy sculpin, 12 August 1978.

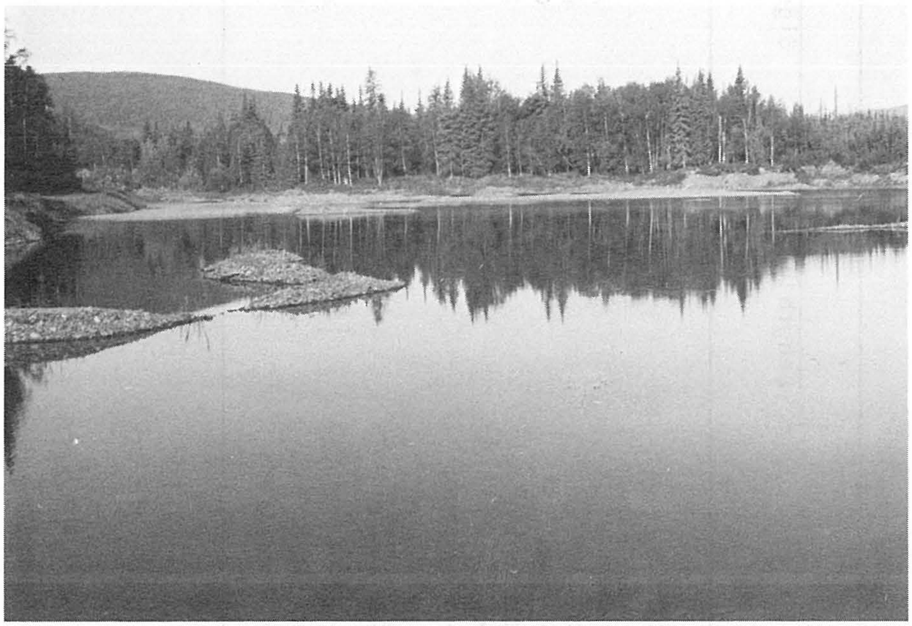


Figure 56. West Fork Tolovana River study site - deep pond with extensive shallows providing northern pike and Arctic grayling habitat, 29 July 1978.

grayling either were not entering the pit or were consumed by pike soon after entering. Northern pike were apparently spawning in the pit because many age-0 pike were caught or observed in the shallows throughout the summer. During September, age-0 pike were observed in the river in a large pool opposite the pit outlet, apparently moving from the pit to the river. Thus, the pit may be increasing the number of pike in the river system in general and, given the high density of age-0 and age-I Arctic grayling observed in the river near the pit, may lead to a localized increase in the density of river-dwelling northern pike near the pit. Studies by Alt (1970) and Cheney (1972) indicate that movements of northern pike in the rivers of the nearby Minto Flats region may not be extensive. On a small river, such as the West Fork Tolovana River, a local increase in the northern pike population may lead to local reductions in the Arctic grayling population.

The upper pit at the Tanana River-Upstream site had a similar habitat and also provided a spawning, rearing, and feeding area for northern pike as well as a feeding area for least cisco and humpback whitefish (Figure 57). On a large river, as at the Tanana River-Upstream pit, the effects of the increased numbers of northern pike must be minimal when compared to the river population. The main effect of a deep pit on this type of river system is providing a clear water feeding area that increases the availability of desirable species to sport fishing. The lower pit was a more uniform depth with minimal littoral area and was used as a spawning and feeding area by longnose sucker. The connection between the two pits, a shallow (8 cm deep) stream, was used by longnose sucker fry, lake chub, and juvenile chum salmon as a rearing area. The lower pit was also utilized as a feeding area by humpback whitefish, least cisco, northern pike, and burbot.

The Tanana River-Downstream pit was a deep (maximum depth = 9.4 m) clearwater pit with apparently very low productivity. Fish species captured in the pit were longnose sucker, Bering cisco, and chinook salmon. There was no connection to the river, thus, the fish apparently immigrated during high water and became trapped after the water level dropped.

a) Upper Tanana River–Upstream Pit, note extensive shallow areas.

b) Upper Tanana River–Upstream Pit – area of high northern pike density.

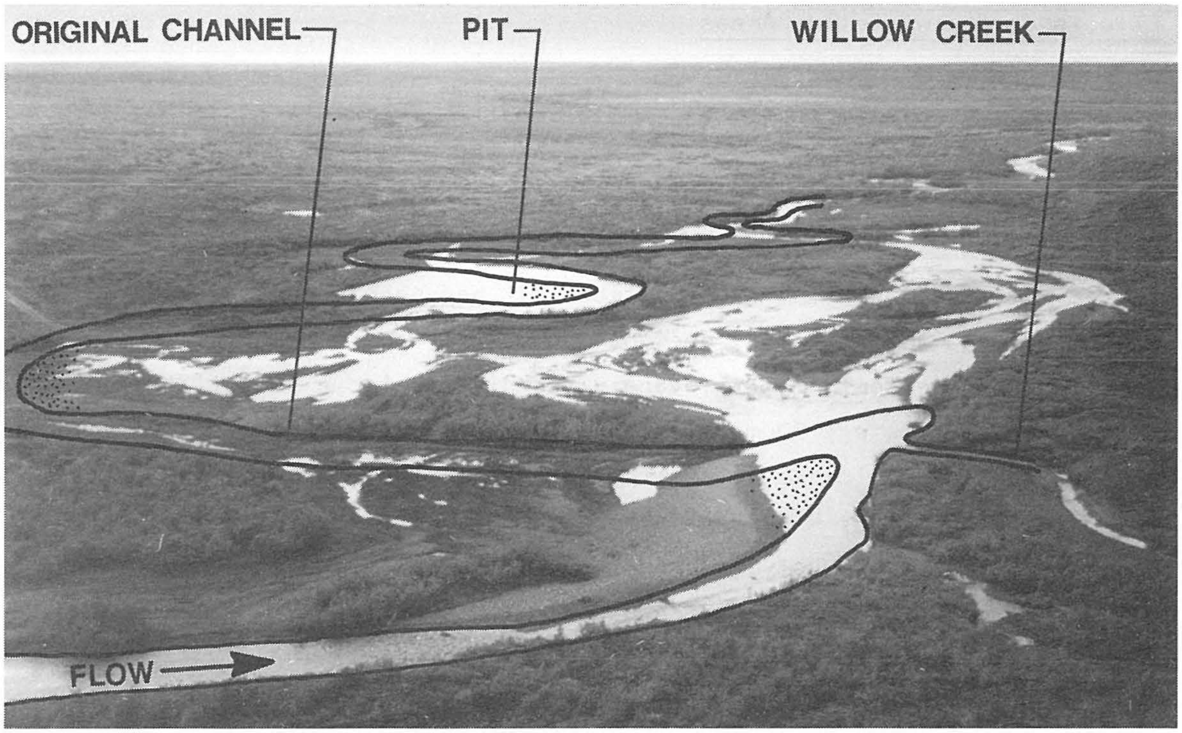
Figure 57. Tanana River–Upstream upper pit showing extensive vegetation beds, 18 August 1978. Note difference in the extent of vegetative development in this 13-year old pit as compared to the 2 and 3-year old pits in Figures 55 and 56.

Effects on Overwintering Areas

Possible effects of gravel removal on fish overwintering areas were observed at several of the study areas. Potential overwintering areas were created at the deep pit sites -- Dietrich River-Upstream, West Fork Tolovana River, Tanana River-Downstream, and Tanana River-Upstream -- by the pits themselves. The Dietrich River-Upstream pit has been reported as an overwintering area (W. Anderson, personal communication to A. Ott). In addition, outflow from the West Fork Tolovana River pit created a potential overwintering area approximately 50 m downstream from the outlet where a deep natural pool with a 1-2 cm ice cover existed into March 1979. A possible overwintering area on the Penny River was altered as a spring-fed tributary; Willow Creek, that had previously entered the main channel at a deep pool, now entered the river through the scraped area in a series of shallow braided channels (Figure 58).

The pattern of freezing observed during winter studies on six of the pit sites indicated that fish entrapment was not a problem during the 1978-1979 winter (Table 24). In those pits studied, the outlet remained open well into winter with outlet flow velocities increasing as the still water at the edges of the pit froze, reducing the volume of the pit. Fish appeared to move to the open water found at the outlet areas and the increased velocities may have induced the fish to move downstream to areas of reduced velocity. If fish were holding at an outlet pool and the outlet closed downstream from the holding fish, entrapment could occur. The outlet area in the pits examined was generally quite small. However, the number of fish affected compared to the numbers using the pit in the summer would be minimal.

The outlets of the Prospect Creek and Jim River sites remained open at least until late January and possibly into early February, thus fish had ample opportunity to emigrate as flow decreased during freeze-up. Fish were present (caught and observed) at both sites in early November but were not evident in late January. Both sites were frozen to the bottom in March. At the Penny River pit site, fish were caught in the pit in late December and



a) Willow Creek, a tributary of Penny River, showing flow diversion following gravel removal operations, September 1975.

b) Willow Creek as it entered Penny River on 20 March 1979.

Figure 58. Potential overwintering area at Willow Creek. This spring-fed tributary, open throughout the winter, had previously entered Penny River at a deep pool.

Table 24. Physical Conditions at Pits Visited During Winter

Date	Penny River			Jim River			Prospect Creek			West Fork Tolovana River		
	Ice thickness/ Water depth (cm)[a]	Water temperature (°C)[b]	Dissolved oxygen (ppm)[b]	Ice thickness/ Water depth (cm)	Water temperature (°C)	Dissolved oxygen (ppm)	Ice thickness/ Water depth (cm)	Water temperature (°C)	Dissolved oxygen (ppm)	Ice thickness/ Water depth (cm)	Water temperature (°C)	Dissolved oxygen (ppm)
16-20 March 1978				76/0	–	–	155/23	0.0	3.5	80/530	0.0	0.7
6 November 1978				2/80	–	–	20/100	–	–			
27-29 November 1978										20/590	–	–
18 December 1978	76/15	-0.6	12.4									
24 January 1979				33/36	-1.0	18.2	107/30	0.0	10.6			
6-8 March 1979										75/535	0.0/3.5	5.8/5.8
13-14 March 1979				90/10	-0.5	5.8	110/0	–	–			
20 March 79	80/0	–	–									
State of outlet	open through December closed in March			open through January closed in March			open through January closed in March			closed by late November flow through dam into March		

[a]First number = maximum ice thickness, second number = maximum water depth from bottom of ice to bottom of pit.
[b]First or one number = surface measurement, second number = bottom measurement.

Continued

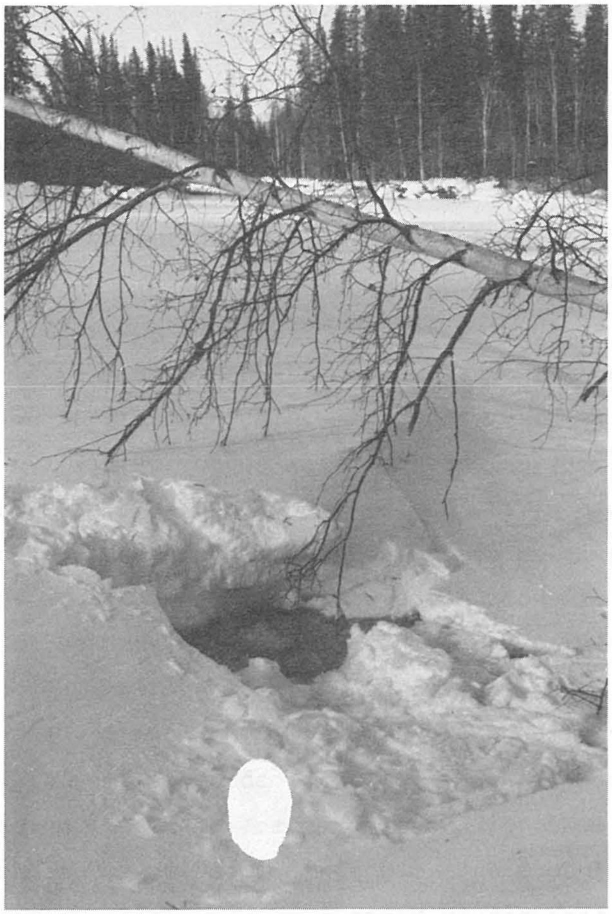
Table 24. (Concluded)

Date	Tanana River-Downstream			Upper Tanana River-Upstream			Lower Tanana River-Upstream		
	Ice thickness/ Water depth (cm)	Water temperature (°C)	Dissolved oxygen (ppm)	Ice thickness/ Water depth (cm)	Water temperature (°C)	Dissolved oxygen (ppm)	Ice thickness/ Water depth (cm)	Water temperature (°C)	Dissolved oxygen (ppm)
16-20 March 1978				33/122	0.0	3.2	100/290	0.0/0.0	8.0/6.6
6 November 1978									
27-29 November 1978				20/100	0.0/0.0	3.4/2.9	20/163	2.1/3.5	6.2/5.1
18 December 1978									
24 January 1979									
6-8 March 1979	75/900	-1.0/3.0	6.2/6.0	105/100	0.0	6.0	90/163	0.5	11.4
13-14 March 1979									
20 March 1979									
State of outlet	no outlet			closed in November open in March			open through November closed in March		

the outlet was flowing at that time. By March all flow in the pit had ceased and the pit and outlet were frozen to the bottom. The spring-fed tributary, Willow Creek, however, remained open and flowing into March, but fish were not detected either in the tributary or in the Penny River downstream from where the tributary entered the mined area. At West Fork Tolovana River, the outlet was blocked at the time of the first winter visit, 29 November 1979, because the deep, low velocity arm connecting the pit to the river was frozen and the other arm flowed through a beaver dam. Flow out of the pit through the beaver dam persisted through March (Figure 59). Fish were not detected during any of the winter visits. There was sufficient water and dissolved oxygen to support overwintering fish in mid-March 1979 and the persisting outflow through the beaver dam indicates the pit may be receiving some intergravel flow from the river.

The Tanana River-Downstream pit was visited only on 6-7 March 1979; fish were not captured but as emigration after the previous September visit was not possible, fish were probably present. The dissolved oxygen should not have been depleted because of the depth, limited phytoplankton production, and absence of littoral vegetation, and, in fact, was 6.0 mg/ℓ in March (Table 24). At the two Tanana River-Upstream pits, a more dynamic pattern of freezing was observed. On 27-28 November 1978, the connection between the two pits was frozen solid, thus isolating the upper pit. The surface of the ice in the upper pit was approximately 1.5 m higher than the surface of the lower pit. A burbot and possible lamprey were observed with an underwater television system. The outlet of the lower pit was open to the Tanana River with a school of juvenile salmon and two species of whitefish holding in the outlet current. Burbot were captured by setline in the lower pit. On 6-7 March 1979, the ice surface of the lower pit had risen to the level of the upper pit and the connection between the two pits was open, approximately 30 cm deep and flowing at about 0.1 m/sec into the lower pit. The outlet to the lower pit was frozen solid. Dissolved oxygen at the upper pit had increased from 3.4 to 6.0 ppm between November and March. Fish were not detected in either pit in March.

a) Flow out of beaver dam at pit outlet, 29 November 1978.



b) Deep pool (>1 m) with thin ice cover approximately 50 m downstream from beaver dam, 15 March 1979.

Figure 59. Creation of a potential overwintering area at West Fork Tolovana River downstream from pit.

The above observations indicate that after November the outlet froze, then the side channel of the Tanana River adjacent to the pit started flowing through gravel into the upper pit, opened the connection between the two pits and flowed back into the side channel through an intergravel pathway. The raising of the surface of the lower pit appeared to have been caused by overflow on top of the existing ice and snow. Oxygen depletion was a potential problem at the upper pit because of the dense stands of aquatic vegetation (the March 1978 dissolved oxygen was 3.2 ppm) but these were absent in the lower pit and the dissolved oxygen was consistently higher than that of the upper pit. The net effect was the creation of one and possibly two overwintering areas, depending on the minimum winter oxygen levels at the upper pit.

Assuming an adequate water depth, the main factor determining the suitability of a pit as an overwintering area is an adequate level of dissolved oxygen through the winter. A pit with sufficient depth for overwintering but with an extensive, heavily-vegetated littoral area may experience an anoxic period following the initial snow cover. Barcia and Mathias (1979) found that winterkill in eutrophic prairie lakes was closely correlated to the mean depth of a lake and developed a method to estimate the potential for winterkill based on the initial oxygen storage, rate of oxygen depletion and the mean depth. The critical mean depth for the lakes studied was approximately 2.0-2.5 m. Lakes with an average depth less than 2.0 m experienced regular winterkill, lakes 2.0-2.5 m experienced occasional winterkill, and lakes with an average depth greater than 2.5 m generally did not experience winterkill. The indications were that a productive pit with an average depth of less than 2.5 m may have marginal utility as an overwintering area, especially during years of early heavy snowfall.

The upper Tanana River-Upstream and West Fork Tolovana River pits had the characteristics to fit this type of pit (Table 14). The 6 m deep area in the latter pit may have provided sufficient volume to maintain a suitable dissolved oxygen level, but both of these pits should be considered marginal overwintering areas. Intergravel flow from the adjoining river, however, adding a continual supply of oxygenated water, could maintain sufficient oxygen levels throughout the winter. The lower Tanana River-Upstream pit did not contain a great average depth, 1.7 m, but the lack of littoral vegetation reduced the probability of oxygen depletion. The water in the pit was turbid during the summer, limiting production of aquatic vegetation. The lower pit maintained higher dissolved oxygen than the upper pit during the winter (Table 24). The Dietrich River-Upstream and Tanana River-Downstream pits both contained deep, clear water regions and did not have well-developed littoral vegetation. Oxygen levels probably remained high throughout the year. The depth and lack of productivity combined to make these two pits excellent overwintering areas; the same features limited their value as rearing areas.

There are other possible effects of gravel removal on overwintering areas, but they are difficult to assess because of the absence of data on the study sites before gravel removal. A primary effect is the loss of overwintering areas due to diversion of flow from an original channel, as occurred at four sites (Penny River, Dietrich River-Downstream, Middle Fork Koyukuk River-Upstream, and Middle Fork Koyukuk River-Downstream). In these cases, complete or partial diversion of flow could lead to loss or reduction of overwintering habitat. Another effect is the loss of overwintering habitat due to increased braiding and the associated changes -- loss of pool-riffle sequence and reductions in depth and velocity which promote rapid freezing. In some areas, gravel removal created or aggravated the formation of <u>aufeis</u> fields, thus leading to a reduction in water available for overwintering downstream (Washington Creek, Oregon Creek, McManus Creek, possibly some of the North Slope sites).

EFFECTS OF HABITAT ALTERATION ON AQUATIC MACROINVERTEBRATES

<u>Observed Effects on Density and Species Assemblage</u>

Habitat alterations expected to affect assemblages of riffle macroinvertebrates would be changes in velocity, substrate, depth, and water quality. During the present study, habitat alterations resulting in a change of each of these parameters were accompanied by changes in the riffle community (Table 25).

Table 25. Response of Aquatic Riffle Macroinvertebrate Taxa to Habitat Alterations Observed at Selected Study Sites[a]

Study site	Habitat alteration caused by mining	Taxa showing density decreases in area of major alteration	Taxa showing density increases in area of major alteration
Washington Creek	Increased *aufeis*, unstable substrate, braiding	*Cinygmula*, *Brachycentrus*, Chironomidae, Empididae	Tipulidae
Oregon Creek - June	Increased *aufeis*, unstable substrate, silt, braiding	Oligochaeta, *Nemoura*, Baetinae, *Centroptilum*, *Cinygmula*, Chironomidae, Hydracarina	None
- August	Increased unstable substrate, braiding	*Nemoura*, *Cinygmula*, *Epeorus*, Chironomidae	*Capnia*, Baetinae
- September	Increased unstable substrate	*Nemoura*, *Cinygmula*	*Capnia*, *Ephemerella*
Penny R - June	Increased unstable, substrate, braiding, *aufeis*	Oligochaeta, *Isoperla*, *Nemoura*, *Paraperla*, Baetinae, *Cinygmula*, *Glossosoma*, Chironomidae, Simuliidae	Tipulidae
- August	Increased unstable substrate, braiding	Oligochaeta, *Nemoura*, *Paraperla*, *Cinygmula*, *Epeorus*, Chironomidae	Baetinae, Athericidae, Tipulidae
- September	Increased unstable substrate, braiding	Oligochaeta, *Nemoura*, *Ecclisomyia*, *Glossosoma*, *Apatania*, Chironomidae	*Capnia*, *Ephemerella*, Tipulidae
Nome River	Increased braiding	*Glossosoma*	*Alloperla*, *Epeorus*, *Ephemerella*, Athericidae

Continued

Table 25. (Continued)

Study site	Habitat alteration caused by mining	Taxa showing density decreases in area of major alteration	Taxa showing density increases in area of major alteration
Aufeis Ck - July	Increased braiding	None	Baetinae, *Ephemerella*, *Cinygmula*
- August	Increased braiding	Baetinae, *Ephemerella*, Simuliidae	Tipulidae
Kuparuk River	Increased unstable substrate, braiding	Oligochaeta, Baetinae, Chironomidae	None
Skeetercake Creek	New channel	Chironomidae, Simuliidae	*Limnephilus*
Sagavanirktok River	Increased unstable substrate, increased braiding	None	Baetinae, *Cinygmula*, *Ephemerella*, *Rithrogena*, *Brachycentrus*, Chironomidae, Empididae, Simuliidae, Hydracarina
Ivishak River	Increased braiding	Oligochaeta	*Diura*, Baetinae, Chironomidae, Simuliidae, Tipulidae
Shaviovik River	Increased substrate alteration	*Capnia*	*Nemoura*, *Cinygmula*, Chironomidae, Simuliidae
Kavik R - July	Increased siltation, braiding	*Nemoura*, *Cinygmula*, Simuliidae	None
- early August	Increased siltation, braiding	Simuliidae	None
- late August	Increased siltation, braiding	Simuliidae	None

Continued

Table 25. (Concluded)

Study site	Habitat alteration caused by mining	Taxa showing density decreases in area of major alteration	Taxa showing density increases in area of major alteration
McManus Ck – June	Increased *aufeis*, unstable substrate	Oligochaeta, *Alloperla*, *Cinygmula*, *Rhyacophila*, Chironomidae	None
– July	Increased unstable substrate	Oligochaeta, *Rhyacophila*	*Alloperla*, *Nemoura*, Baetinae, *Apatania*, Chironomidae, Tipulidae
– September	Increased unstable substrate	Oligochaeta, *Paraperla*, *Rhyacophila*	*Alloperla*, *Centroptilum*, *Cinygmula*, Chironomidae, Psychodidae, Tipulidae

[a] Sites omitted had very low macroinvertebrate densities or involved pit mining rather than river mining.

Response to Substrate Alteration. The two types of substrate alterations observed during the study (a shift to unstable substrate and change from laminar to turbulent flow) significantly affected the total numerical densities of aquatic macroinvertebrates in the mined area as compared to undisturbed areas (Table 26). At Washington Creek, Oregon Creek (June and August), all Penny River, Kuparuk River, and McManus Creek (May) site visits, macroinvertebrate densities in mined areas were significantly less than those in the upstream area. At all five sites there was a shift from a moderately compacted gravel substrate to a very loose, unconsolidated sand-gravel substrate (Table 25). A similar habitat change at the Sagavanirktok River and Ivishak River sites resulted in a significant increase in the density of aquatic macroinvertebrates. In five of the eight cases in which there were total density decreases, there were density reductions in the ephemeropteran genus Cinygmula while in seven of the eight cases, there were reductions in the dipteran family Chironomidae. The density increases at the Sagavanirktok River and Ivishak River sites both contained density increases in the ephemeropteran subfamily Baetinae and dipteran family Chironomidae, as well as some other taxa.

At two sites there was a change from laminar flow to turbulent flow caused by substrate alteration. At both Ugnuravik River and Shaviovik River sites, there was a significant decrease in total macroinvertebrate density, primarily because of a decrease in Simuliidae densities. At Ugnuravik River, the laminar flow was in the upstream (control) area, while at Shaviovik River, laminar flow occurred in the mined area.

At three of the five sites where there were decreased densities in the mined area (Washington Creek, Oregon Creek, McManus Creek) there were also aufeis fields associated with the mined area (Table 25). All three sites were visited early in the summer so that any aufeis effects would have been measured at their greatest magnitude. Later visits at two of the sites (Oregon Creek, McManus Creek) indicated that densities in the mined area increased to levels similar to those in the upstream areas. At Oregon Creek, the summer recovery from aufeis effects was not complete for population densities of Nemoura and Cinygmula, which remained below the densities

Table 26. Changes in Aquatic Macroinvertebrate Densities at Sites Exhibiting Type 1 and 2 Substrate Alterations

	Mean density (organisms/m²)			Significance level		
	Upstream[a]	Mined or upper mined	Down-stream	ANOVA[b]	Mann-Whitney[c]	Major taxonomic groups experiencing change[d]
Type 1 alteration						
Density decreases						
Washington Ck	112(10)	56(9)	79(10)	0.018	**	6, 9, 11, 12
Oregon Ck - June	509(15)	151(15)	--	0.000	**	4, 5, 6, 11
- August	1221(15)	815(14)	--	0.030	**	6, 7, 11
Penny R - June	1002(15)	278(15)	--	0.000	**	4, 6, 11
- August	1702(15)	1168(15)	599(15)	0.000	NS	6, 7, 11
- September	650(15)	498(15)	333(15)	0.004	NS	1, 3, 11
Kuparuk R	443(15)	77(15)	175(15)	0.000	**	1, 4, 11
McManus Ck - May	152(15)	46(14)	274(15)	0.000	**	1, 2, 10
Density increases						
Sagavanirktok R	153(15)	301(15)	195(15)	0.016	**	4, 6, 8, 11
Ivishak R	295(15)	501(10)	208(14)	0.003	**	4, 11, 13
Type 2 alteration						
Ugnuravik R	5046(10)	756(10)	68(10)	0.000	**	13
Shaviovik R	669(15)	1332(15)	922(15)	0.010	NS	13

[a] Number in parenthesis is sample size.

[b] Significance level from ANOVA test, rounded to three decimal places.

[c] Significance level from Mann-Whitney U-Test between upstream and mined areas, ** = $p < 0.01$, NS = not significant.

[d] Code to taxonomic groups: 1 = Oligochaeta, 2 = Alloperla, 3 = Nemoura, 4 = Baetinae, 5 = Centroptilum, 6 = Cinygmula, 7 = Epeorus, 8 = Ephemerella, 9 = Brachycentrus, 10 = Rhyacophila, 11 = Chironomidae, 12 = Empididae, 13 = Simuliidae.

reached by the same genera in the upstream area. The August and September population densities of *Capnia* and Baetinae, however, exceeded those recorded in the upstream area.

At McManus Creek, the mined area densities of Oligochaeta and *Rhyacophila* did not reach those recorded in the upstream area; the mined area densities of *Alloperla*, Chironomidae, and Tipulidae exceeded the upstream area densities on each of the two succeeding trips. The failure of the mined area densities of some taxa to reach upstream densities, while those of other species exceeded the upstream densities, indicated that there was a long-term habitat alteration which has led to an alteration in species composition of the mined area. Another site which showed a similar response, but where an *aufeis* field was not identified, was the Penny River site, where mined area densities of Oligochaeta, *Nemoura*, *Cinygmula*, Chironomidae, and others were generally lower than upstream densities. In the Penny River mined area, population densities of Tipulidae and, at times *Capnia*, Baetinae, *Ephemerella*, and Athericidae were higher than those in the upstream area. The shift in taxa at the above sites appeared to be related to the occurrence of unstable substrate possibly aggravated by an *aufeis* field.

Other sites with a similar substrate alteration (Washington Creek, Kuparuk River) also showed density reductions of most organisms but the site was only visited once and this precluded any analysis of recovery or seasonal patterns. At Kuparuk River, densities of all species were lower in the mined area than in the upstream area while at the Washington Creek upper mined area, only Tipulidae densities exceeded those in the upstream area. In summary, certain taxa, primarily Oligochaeta, *Nemoura*, *Cinygmula*, and Chironomidae were reduced in areas of unstable substrate while others, primarily Tipulidae, but also *Capnia* and Baetinae, showed increased densities.

Response to Increased Braiding. Aquatic macroinvertebrate responses to these alterations were colonization by taxa which are more suited to lower velocity waters with higher organics. Clinging ephemeropterans, as found in the family Heptageniidae (*Cinygmula*, *Epeorus*), were replaced by sprawlers and climbers, e.g., Baetidae. Trichopterans often increased in these areas and the dipteran family Tipuliidae was often associated with the finer sediments found in mined areas. At two sites on large rivers showing increased braiding as well as altered substrate (Sagavanirktok River and Ivishak River) there was an increase in the density of virtually all taxa in the mined area as compared to the upstream area (Table 24). The riffles in the mined area in these two cases were in small shallow channels with extensive riffle area while the riffles in the upstream area were in large channels, were less extensive, and composed of a more coarse material. The riffles in the mined area had greater detrital accumulation, and the decreased depth and velocity associated with the braided areas may have allowed greater periphyton production. Such a situation would increase the quality of the habitat for most of the species unless a critical parameter, such as velocity, had been lost or altered. The increased braiding at other sites, such as Oregon Creek and Penny River, may have contributed in a similar manner to the altered species composition.

The increased braiding at many of the sites led to changes in the water temperature and dissolved oxygen in the mined area. An examination of the seasonal variation in the riffle macroinvertebrates at Aufeis Creek revealed a pattern of density changes which indicated a possible effect of the altered temperature and dissolved oxygen regime on the apparent densities of certain macroinvertebrates (Figure 60). In the ephemeropteran taxa, Baetinae and Cinygmula, the densities in the upstream area increased from the July to August trip while those in and below the mined area decreased. Simuliidae densities decreased between the two trips in the upstream area with simuliids absent in and below the mined area in August. The temperature at the area between the two mined areas was 2.8°C (July) and 1.2°C (August) higher than that in the upstream area. The immature stages of the three taxa apparently emerged earlier in the areas affected by gravel removal than in the unaffected upstream area. The altered water quality parameters may have altered the emergence times of these three taxa because temperature and dissolved oxygen can affect developmental rates (Hynes 1972).

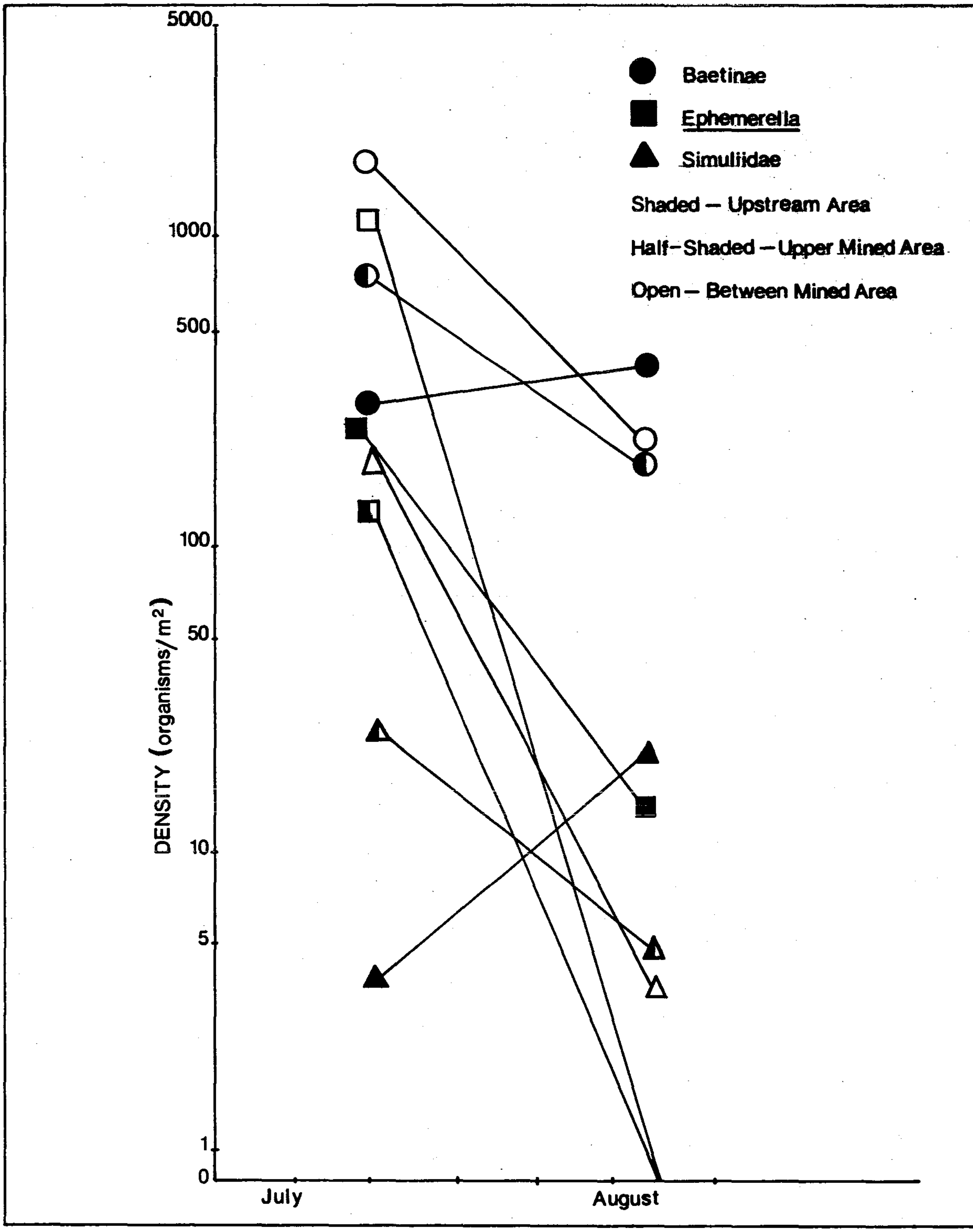


Figure 60. Densities of selected aquatic macroinvertebrates at Aufeis Creek study areas during 1977 sampling trips.

An indication of a similar effect was seen at McManus Creek where Alloperla nymphs were present in the upstream area in densities exceeding those in the mined and downstream areas. An emergence of adult plecopterans was occurring in the mined area during the site visit, however, and this probably caused the reduced densities of nymphs. Thus, the low nymphal densities of Alloperla in the mined and downstream areas may have resulted from an earlier emergence time rather than a lack of suitable habitat. The observed density differences between upstream and mined areas, at sites which were only sampled once, must be viewed with caution because of the possibility that emergence periods were altered due to an altered thermal regime. A major period of emergence may have occurred in one area just prior to the site visit, thus leaving the area with low densities relative to an area with a later emergence period. At present there is not enough information on the natural emergence patterns, and the effects of temperature and dissolved oxygen on those patterns, to predict how the arctic macroinvertebrate species would respond to changes in these habitat parameters.

Creation of Pond Habitat. The creation of pond habitats allowed aquatic macroinvertebrates typically found in a lentic habitat to colonize these areas (Table 27). In these cases the change was from terrestrial to aquatic habitat so there was not a direct effect on river communities. Indirect effects could be enrichment of downstream communities by phytoplankton and nutrients being carried out of the pit. The Southern Interior deep pits (West Fork Tolovana River, Tanana River-Downstream, Tanana River-Upstream) had a higher diversity of organisms than the pits in other regions, probably reflecting a more stable habitat. The age of the pit did not seem to exert much effect because the West Fork Tolovana River and upper Tanana River-Upstream pit both had similar configuration and similar fauna and density but the former was 10 years newer than the latter. The low productivity of the Tanana River-Downstream pit was evident; the density of chironomids at the Tanana River-Upstream pits, about 50 km upstream, was 5 to 20 times greater than those at the downstream pit at a similar time of year.

Table 27. Densities of Aquatic Macroinvertebrates Collected at Inundated Pit Sites, 1976-1978 (Densities in Organisms/m^2, from Ponar Sampler)

	Penny R	Ugnuravik R	Dietrich R Upstream	Jim R	Prospect Ck	West Fork Tolovana R			Tanana R Downstream	Tanana R-Upstream Upper pit			Tanana R-Upstream Lower pit		
	10 Aug. (n=4)	26-28 Aug. (n=5)	8-11 July (n=4)	2-5 July (n=5)	24 July (n=5)	10 June (n=5)	30 July (n=5)	13 Sept. (n=5)	10 Sept. (n=6)	4 June (n=5)	17 Aug. (n=5)	19 Sept. (n=5)	4 June (n=5)	17 Aug. (n=5)	19 Sept. (n=5)
Nematoda	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	1871	-	19	-	-	23	-	-	-	15	4	4	191	268	119
Ephemeroptera															
Ameletus	-	-	-	-	-	-	-	4	-	4	-	-	-	-	-
Baetis	-	-	-	-	-	-	-	4	6	-	-	-	-	-	8
Caenis	-	-	-	-	-	-	-	11	3	-	-	-	-	-	-
Callibaetis	-	-	-	-	-	-	-	8	-	8	19	27	-	-	-
Centroptilum	-	-	-	-	-	-	-	-	3	-	-	8	-	-	-
Ephemerella	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-
Siphlonurus	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-
Odonata															
Enallagma	-	-	-	-	-	-	-	-	-	-	-	27	-	-	-
Ischnura	-	-	-	-	-	-	-	-	3	11	-	27	-	-	-
Libellulidae		-	-	-	-	-	-	-	-	-	-	4	-	-	-
Hemiptera															
Corixidae	-	-	-	-	-	-	42	4	3	-	-	-	-	-	4
Coleoptera															
Dytiscidae	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-
Haliplidae	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-
Trichoptera						4					4				
Leptocella	-	-	-	-	-	-	-	-	80	-	-	-	-	-	-
Oecetis	-	-	-	-	-	4	-	4	89	-	-	-	-	-	27
Phryganea	-	-	-	-	-	-	-	11	16	-	-	-	4	-	-
Polycentropus	-	-	-	-	-	4	4	4	19	-	-	8	-	-	-
Diptera															
Ceratopogonidae	-	-	-	-	19	4	19	19	73	4	-	4	38	8	23
Chironomidae	445	983	859	7025	8060	555	3670	16,472	487	4789	7220	9681	1983	1623	2438
Empididae	-	-	-	-	19	-	4	4	-	4	-	-	46	4	8
Simuliidae	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Mollusca										4					
Lymnaea	-	-	-	-	-	-	-	4	6	-	-	119	-	-	-
Physidae	10	-	-	-	-	-	-	-	-	-	-	4	-	-	-
Planorbidae	-	-	-	-	-	-	4	42	-	-	-	69	-	8	-
Valvata	-	-	-	-	-	-	-	-	-	-	-	-	4	4	8
Pisidium	-	-	-	-	-	4	-	-	-	-	-	8	-	-	-
Gammaridae	-	-	-	-	-	-	-	-	-	4	8	100	4	4	-
Hydracarina	43	11	-	-	38	4	4	11	-	-	-	-	-	-	-
Total	2374	998	883	7025	8136	606	3747	16,602	788	4843	7259	10,090	2274	1919	2635
No. of taxa	5	3	3	1	4	9	7	14	12	9	6	14	8	7	8

SUMMARY AND CONCLUSIONS

EFFECTS OF GRAVEL SCRAPING ON RIVERINE HABITATS

Gravel removal by scraping in floodplains resulted in a number of alterations to aquatic habitats with the biota showing a variety of responses to these habitat alterations. Important habitat alterations included: (1) the creation of braided channel areas with associated changes in various habitat parameters, (2) removal of bank and instream cover, (3) increased habitat diversity, (4) creation of potential migration blockages, and (5) creation of potential entrapment areas.

Increased Braiding Characteristics

This habitat alteration occurred at 15 study sites where active channel deposits were scraped to below the water line or where flow subsequently increased to inundate the mined area. The main effect of braiding on specific habitat parameters was to reduce velocity and depth by spreading flow over a wider area. The populations of both aquatic macroinvertebrates and fish utilizing these areas were altered with shifts in species and life history stages. The reduction in velocity led to increased detrital accumulation, deposition of fine materials, and often altered the temperature and dissolved oxygen regime. The altered temperature regime led to altered emergence periods of aquatic insects; the effect of this alteration on reproductive success and overall population stability is unknown.

Fish populations responded to increased braiding in a number of ways, but the general pattern was a reduction in the diversity of the fish community. The number of species and age groups usually decreased in the braided areas.

The increased braiding also increased the probability of aufeis formation in the mined areas. This effect was documented at Washington Creek and Oregon Creek and was indicated at McManus Creek and Penny River. There may have been additional ice formation at some of the North Slope sites, such as Kuparuk River, Sagavanirktok River, and Ivishak River. The formation of aufeis fields seemed to prolong the recovery of the site as the channels and substrate remained unstable and siltation persisted during the melting process. In addition, the water needed to create the aufeis field became unavailable downstream, thus reducing water available for overwintering, often the factor limiting fish populations in arctic rivers.

Removal of Bank and Instream Cover

Reduction of bank cover occurred whenever a portion of incised or undercut bank was removed. At sites with this habitat alteration, the bank was scraped to remove overburden in order to access underlying gravel deposits. The former bank with cover was changed to a gravel bar following removal operations. Certain species, such as Arctic char and Arctic grayling were strongly associated with bank cover and the loss of this cover led to reduced population densities in the mined areas. Similarly, loss of instream cover led to reduced densities in mined areas.

Increased Habitat Diversity

Habitat diversity increases were documented at three scraped sites, but these were viewed as temporary increases at newly inundated sites. The habitat diversity will decrease as braiding characteristics are established, the channel cutoffs are completed, and the habitats become more uniform.

Migration Blockages

The combination of increased wetted perimeter and decreased depth in mined areas created a situation that could lead to migration blockages during periods of low flow. Such a situation occurred at the Aufeis Creek site and possibly could occur at the Nome River site. The potential for migration blockage was present at sites, including Oregon Creek and Washington Creek, where the entire active channel was scraped. Because of the known complexity of fish movements throughout arctic watersheds, migration blockages can have a significant, but as yet unstudied, effect on populations.

Potential Entrapment Areas

The potential for fish entrapment was high at areas with extensive backwater, as was found at newly inundated areas (Dietrich River-Downstream, Middle Fork Koyukuk River-Upstream) and areas with increased braiding (many sites, including Sinuk River, Kuparuk River, Sagavanirktok River, Ivishak River, and Middle Fork Koyukuk River-Downstream). At these sites, areas of ponded water became isolated from the active channel as the water level dropped, trapping fish and invertebrates that had moved or been carried into these depressions during the high water. Mortality of stranded fish and invertebrates is assumed to be high because they are subjected to high summer water temperatures, low dissolved oxygen, increased predation from terrestrial predators, winter freezing, and total loss of aquatic habitat as the isolated pools often dry up if the river continues to drop.

EFFECTS OF INUNDATED PIT FORMATION ON THE ASSOCIATED RIVER BIOTA

The direct effects of pit excavation on the river biota were difficult to assess because the river habitat was not directly affected; inundated pits were created from previously terrestrial habitat. Because of this, the pits represented a new habitat and the fauna inhabiting the pits was considerably different from that inhabiting the associated river.

Summer Utilization by Fish

Two of the pits, Dietrich River-Upstream and Tanana River-Downstream, were deep clear water pits with low productivity and fish utilization. At Tanana River-Downstream this low utilization was easily explained because there was no connection to the river and immigration into the pit occurred only at infrequent high water levels. The Dietrich River-Upstream pit, however, was connected to the active channels but fish were apparently not utilizing the pit for feeding. Benthic macroinvertebrate densities in both these pits were low when compared to those of other pits. The spring-fed channels upstream from the Dietrich River pit were utilized by adult Arctic grayling and the pit itself was reported to be an overwintering area. All other pits were highly productive and heavily utilized by fish as summer rearing areas. The shallow pits, Penny River, Prospect Creek, and Jim River side channel (this site had some characteristics of a pit) supported high densities of juvenile salmon (coho in the Penny River, chinook in the latter two) as well as some species associated with both a lacustrine environment (Alaska blackfish, burbot, northern pike) and stream environment (round whitefish, Arctic grayling, slimy sculpin). The productive Southern Interior deep pits, West Fork Tolovana River and two Tanana River-Upstream, contained a more lacustrine fish fauna with northern pike dominating the fauna and humpback whitefish, least cisco, and burbot also present in the Tanana River-Upstream complex.

Potential for Winter Mortality and Winter Survival Areas

The creation of shallow pits and subsequent heavy summer usage by fish created the possibility for entrapment during freezeup and subsequent winter mortality when the pit freezes solid or decay of vegetation consumes the dissolved oxygen. The pattern of freezing observed during winter studies indicated that during the year of observation, entrapment was minimal and probably not a significant problem.

The creation of deep pits connected to the river could create over-wintering areas; this was documented or suggested at several study sites. All pits studied, with the exception of Tanana River-Downstream, however, had a mean depth insufficient to preclude winter mortality. Intergravel flow appeared to maintain the ability of some pits to support winter fish survival, but this is an unpredictable factor in the design of pits.

RECOMMENDATIONS

1. It is recommended that mining practices leading to an increased braided configuration be avoided. This is best achieved by avoiding active channels and by mining above the water table.

2. Undercut and incised vegetated banks should not be altered.

3. Critical habitats, such as spawning and overwintering areas should be avoided.

4. Formation of isolated ponded areas that cause entrapment should be avoided by contouring and sloping to provide drainage.

5. Pits should be excavated to a sufficient depth to preclude winter mortality. Generally, a mean depth of at least 2.5 m should ensure winter survival.

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EFFECTS OF GRAVEL REMOVAL ON TERRESTRIAL BIOTA

M. R. Joyce

INTRODUCTION

The ecological importance of floodplain and riparian terrestrial habitats in temperate regions has been well documented in the ecological literature. These habitats, particularly the riparian zones, have high primary and secondary biological productivity and typically support a diverse and abundant flora and fauna. These biotic zones frequently provide temporary and permanent refuge for many of our rare and endangered species. The significance of these floodplain and riparian habitats has recently been recognized and incorporated into the management plans of several Federal agencies (Johnson and Jones 1977; U.S. Army Corps of Engineers 1979).

Arctic and subarctic floodplain and riparian habitats are no less significant in their importance and ecological value. The riparian zones develop dense shrub thickets dominated by willows and alder in all four study regions. Overstory forest dominated by white spruce and paper birch also frequently inhabit the riparian zones of the Northern and Southern Interior regions. (Scientific nommenclature for terrestrial flora and fauna is presented in Appendix A.) High primary productivity in these zones provides optimum feeding, nesting, and cover habitat for a diverse fauna usually dominated by small mammals and passerines. These riparian habitats in interior Alaska frequently support over 100 birds per 40 ha during the nesting season (Spindler and Kessel 1979). Some birds, such as the yellow warbler and northern waterthrush, very seldom nest in habitats other than riparian shrub thickets. These zones also are preferred habitats for tundra voles and singing voles. The more dense riparian shrub thickets provide critical feeding and cover habitats for moose and ptarmigan during winter.

The unvegetated and sparsely vegetated areas within arctic and subarctic floodplains provide equally valuable habitat for a different segment of fauna. Many of the major floodplains provide key migratory corridors for large numbers of waterfowl, shorebirds, and caribou moving to and from wintering zones and summer nesting and calving territories. Unvegetated areas of larger floodplains are used as prime nesting and feeding habitat by numerous shorebirds, gulls, terns, and waterfowl. The delta areas of larger rivers also are prime juvenal rearing habitats for shorebirds and waterfowl. Along coastal regions, these river deltas also are key nesting sanctuaries for geese, brant, swans, gulls, terns, and shorebirds, and during late summer and early fall they provide protected habitat for large concentrations of molting waterfowl. Due to the high secondary productivity of these areas, predators including bears, wolves, eagles and jaegers also frequently concentrate their feeding activities along floodplains.

Unfortunately, from a biological viewpoint, floodplains also provide easily accessible gravels that are available in large quantities and frequently close to development sites. As previously noted, arctic and subarctic conditions, primarily associated with the presence of permafrost, place large demands upon gravel resources by all development projects.

During the construction of the Trans-Alaska Pipeline System, over 3,300 ha of unvegetated floodplain habitat and approximately 1,000 ha of riparian habitat were affected by gravel removal operations (Pamplin 1979). The proposed construction of a gas pipeline through Alaska, depending upon final route selection and the degree of use of existing construction facilities, could require similar gravel supplies. Other development projects are expected to increase the future demand upon gravel resources.

Previous to this study, natural resource managers had little indepth knowledge, relative to arctic and subarctic terrestrial floodplain ecosystems, of how to best mitigate the use of floodplains as gravel removal sites. The short-term effects of gravel removal operations were believed to be associated with reduction of habitat, probable decrease in local fauna population sizes, and potential indirect effects through reduced habitat quality in adjacent and downstream habitats. However, the variations in the levels of influence and the durations of influence between differing gravel removal sites and methods of operation were not completely known. Also, there were no data on long-term effects in the arctic or subarctic. Factors such as the size and location of the site, and the characteristics of the stream and floodplain were believed to be influencing parameters, but their relationships to short-term and long-term detrimental effects were not understood.

To help answer these questions, a terrestrial study was incorporated into this project. The study was designed to be compatible with the hydrology and aquatic biology programs and organized to provide answers on: (1) the degree of flora and fauna change resulting from gravel removal operations; (2) the rate of habitat recovery at disturbed sites respective to the characteristics of the gravel removal operation and the characteristics of the river and floodplain system; and (3) how the detrimental affects of gravel removal operations could best be mitigated.

METHODS OF DATA COLLECTION

As previously described in APPROACH AND METHODOLOGY, terrestrial data were collected at all 25 study sites, with individual site visits occurring either during the summer of 1976, 1977, or 1978. Standard procedures were used to collect field data on flora, soils, birds, and mammals.

Site locations are identified on Figure 1. Sites occurred on the Seward Peninsula, North Slope (in both the coastal plain and Arctic foothills), Northern Interior (between the Brooks Mountain Range and Yukon River), and Southern Interior (between the Alaska Mountain Range and the Yukon River). One study site, selected as being most representative with respect to river type and biological conditions in each regional study area, was sampled during a 5-day visit. We attempted to coincide this visit with the peak of the avian nesting season. All other sites were surveyed during a 3-day visit. Within each region, the 3-day visits were spaced throughout the spring, summer, and fall to measure seasonal fluctuations in species composition and abundance.

The selected approach to meet the objectives of this project was to document the presence and establish the habitat relationships of the flora and fauna of the disturbed area and compare these to predisturbance flora and fauna populations and habitat affinities. A control area which was most representative with respect to physical site characteristics (i.e., inside or outside meander) and habitat characteristics (i.e., dense riparian shrub thickets, or unvegetated floodplain) was selected to establish pre-gravel removal biological conditions and flora-fauna relationships. In addition, surveys were conducted in floristic seral stages representative of the disturbed area during the time of the field visit, and in seral stages representative of anticipated future disturbed-area vegetative development.

These areas were surveyed to identify flora-fauna relationships during various site recovery stages.

The Major Variable Matrix Table (Table I) identifies the variety of sites studied. Study sites varied from large braided rivers to small, single-channel streams located in four major geographical regions of Alaska. Selected sites were studied from 2 to 20 years after disturbance, allowing data gathering on short-term and long-term response and recovery by the terrestrial biota. Characteristics of gravel removal areas included: scraping operations of surface gravels within and adjacent to active channels; scraping in areas separated from the active channels; and pit excavations separated from active channels. This range of sites allowed comparison of the effects of different techniques and site locations on terrestrial biota.

METHODS OF DATA ANALYSIS

Data analysis initially resulted in the identification of the degree of change in measured parameters at each study site. A numerical rating ranging from 0 to 10 was assigned to indicate an increase (ratings 10 through 6), no change (rating of 5) or a decrease (ratings 4 through 0). These ratings indicate the degree of change at the time of the site visit between the pre-gravel removal conditions (i.e., extent of shrub thicket cover, or number of passerines present) and the post-gravel removal conditions. Each numerical unit increase (6 through 10) or decrease (4 through 0) approximates an alteration similar to a 20 percent level of change in that parameter.

Each site was analyzed to determine how measured parameters (vegetation, soils, birds, and mammals) interacted, and how they responded as a whole to the Physical Site Characteristics (such as river size and configuration) and Gravel Removal Area Characteristics (such as type and location of gravel removal). After individual site analysis, all sites were compared to evaluate similarities and differences in the degrees of change in biological parameters.

Fauna directly respond to the presence (and type) or absence of vegetative development, consequently, the degree of change and the rate of recovery at the gravel removal sites received major emphasis in the vegetative data analysis. Factors that influence vegetative recovery (e.g., soil conditions and aufeis development), also were thoroughly reviewed.

Selected biological data were subjected to a computerized hierarchical clustering routine to identify similar responses in a measured biological parameter between rivers. This analysis grouped similar sites and similar responses (increase or decrease) by biological parameters.

All data were thoroughly reviewed to identify any correlations between Physical Site Characteristics, Gravel Removal Area Characteristics, degree of change by the terrestrial biota, and short-term and long-term recovery rates. The following sections include the results of data collection and analysis.

RESULTS AND DISCUSSION

Changes in selected terrestrial parameters that were induced by gravel removal are identified in Table 28. These changes were based upon measured levels of variation in each parameter at each site. In general, the degree of both short-term and long-term changes in local faunal communities strongly reflected the extent of disturbance to floodplain and riparian vegetative communities.

VEGETATIVE COMMUNITIES OF STUDY AREA FLOODPLAINS

Vegetative communities of floodplain and riparian zones at the study sites were typical of those occurring throughout arctic and subarctic regions. In general, the Seward Peninsula rivers and the smaller North Slope rivers usually were meandering or sinuous in configuration with well-defined (incised) outside meander banks (Figure 61). This configuration and profile created a relatively narrow floodplain (30 to 60 m) and allowed extensive development of mature shrub thickets adjacent to single channel rivers. These shrub thickets usually were dominated by Salix alaxensis. On inside meanders (point bars) and in more active portions of floodplains (lateral and mid-channel bars) herbaceous, woody pioneer and early willow communities occurred adjacent to unvegetated gravels bordering the river.

Meandering and sinuous rivers of the Northern and Southern Interior were similar in pattern and were characterized by extensive shrub thickets with dense stands of advanced and mature successional stage boreal forest communities at the edges of active floodplains (Figure 62). White spruce usually dominated these stands, but paper birch and balsam poplar also were common. Similar pioneer and early shrub successional stage communities occupied point bars and edges of lateral and mid-channel gravel bars.

Table 28. Quantitative Changes in Selected Terrestrial Biological Parameters at Gravel Removal Study Sites[a]

Seward Peninsula

	Gold Run Creek	Sinuk River	Washington Creek	Oregon Creek	Penny River	Nome River
Site age (years)	11	10	13	13	11	20±
Hectares of removed vegetation	1	35	2.5	4	12	0.5
Percent of disturbed area	30	40	85	65	80	35
Vegetation						
Overstory forest	–	–	–	–	–	–
Shrub thickets	3	1	1	1	1	4
Early mixed shrub-herbaceous	9	6	7	3	7	4
Soils						
Texture	7	7	9	7	7	6
Nutrients	5	5	4	5	6	3
Birds						
Passerines	3	1	1	1	1	3
Water birds	5	3	6	6	9	5
Ptarmigan habitat	3	1	3	3	1	5
Mammals						
Small mammals	1	5	3	3	7	3
Ground squirrels	5	7	7	5	7	5
Moose habitat	3	1	3	3	1	5

North Slope

	Ugnuravik River	Aufeis Creek	Kuparuk River	Skeetercake Creek	Sagavanirktok River	Ivishak River	Shaviovik River	Kavik River
Site age (years)	7	5	9	11	3	3	5	7+3
Hectares of removed vegetation	0.3	20	0	7	15	0	0	4
Percent of disturbed area	25	45	0	70	45	0	0	10
Vegetation								
Overstory forest	–	–	–	–	–	–	–	–
Shrub thickets	4	1	5	1	1	5	5	4
Early mixed shrub-herbaceous	5	4	5	7	3	5	5	4
Soils								
Texture	5	4	5	5	7	5	5	6
Nutrients	5	5	6	5	3	5	5	5
Birds								
Passerines	5	1	5	3	1	5	5	3
Water birds	5	8	5	6	6	5	5	4
Ptarmigan habitat	5	3	5	3	1	5	5	4
Mammals								
Small mammals	5	7	5	5	1	5	5	7
Ground squirrels	6	5	5	9	5	5	5	6
Moose habitat	5	3	5	3	1	5	5	4

Northern Interior

	Dietrich River-US	Dietrich River-DS	M.F. Koyukuk R.-US	M.F. Koyukuk R.-DS	Jim River	Prospect Creek
Site age (years)	2	3	4	2	2	2
Hectares of removed vegetation	35	7.5	10	7	11	6
Percent of disturbed area	100	100	50	25	100	100
Vegetation						
Overstory forest	5	5	1	5	1	4
Shrub thickets	1	3	3	3	1	3
Early mixed shrub-herbaceous	3	3	7	4	3	3
Soils						
Texture	7	5	7	5	8	7
Nutrients	5	5	5	5	5	5
Birds						
Passerines	1	3	1	4	1	1
Water birds	6	7	6	5	9	5
Ptarmigan habitat	1	4	4	5	1	3
Mammals						
Small mammals	3	5	7	5	0	0
Ground squirrels	6	5	5	5	5	5
Moose habitat	1	4	4	5	1	3

Southern Interior

	W.F. Tolovana River	McManus Creek	Tanana River-DS	Tanana River-US	Phelan Creek
Site age (years)	3	16	4	13	3
Hectares of removed vegetation	8	3	8	9	0
Percent of disturbed area	100	80	100	100	0
Vegetation					
Overstory forest	1	4	0	3	5
Shrub thickets	1	4	7	1	5
Early mixed shrub-herbaceous	3	6	7	3	5
Soils					
Texture	7	6	7	7	5
Nutrients	5	5	5	5	5
Birds					
Passerines	1	5	1	3	5
Water birds	9	5	5	9	5
Ptarmigan habitat	1	4	6	3	5
Mammals					
Small mammals	4	7	5	7	5
Ground squirrels	5	5	5	5	5
Moose habitat	1	4	6	3	4

[a]Degree of change from original conditions was measured as an increase (6 through 10), no change (5), or a decrease (4 through 0). Each numerical unit corresponds to an approximate 20 percent degree of change. A dash indicates no applicability.

Figure 61. Penny River undisturbed floodplain showing typical North Slope and Seward Peninsula floodplain characteristics of sinuous channel bordered with dense shrub thickets with incised outside meander bank, and narrow gravel point bar on inside meander.

Figure 62. West Fork Tolovana River showing typical Southern and Northern Interior medium river floodplain characteristics with shrub thickets and white spruce-paper birch stands along the riparian zone.

The larger rivers within all four regions typically flowed in braided or split channel configurations. These floodplains were more hydraulically dynamic, with much wider active areas, and contained advanced seral stage vegetative communities only along floodplain borders and on isolated mid-channel islands. Much of the floodplain in these large, braided rivers contained expansive areas of unvegetated gravels or were sparsely vegetated with herbaceous and woody pioneer or early shrub thicket communities.

This very briefly describes in general terms the normal vegetative patterns of floodplains in the area of study. For a more detailed description of normal patterns, refer to the "Preliminary Report Gravel Removal Studies in Selected Arctic and Sub-Arctic Streams in Alaska" (Woodward-Clyde Consultants 1976) and for a detailed description of the vegetative structure which occurred at each study site refer to the Project Data Base.

VEGETATIVE COMMUNITY CHANGES AT GRAVEL REMOVAL SITES

The observed changes in vegetative communities of the study sites varied from no significant change to long-term loss of habitat. Habitat loss and alteration (both short-term and long-term) repeatedly resulted in significant secondary changes within the bird and mammal populations that inhabited study area floodplains. These faunal responses are discussed in a following section.

Significant areas of existing floodplain vegetative cover were removed at 18 of the 25 sites (Table 28). Lost vegetative habitats usually consisted of mature shrub thickets on the Seward Peninsula and North Slope sites, and a mixture of shrub thickets and advanced successional stages of boreal forest floodplain communities in Northern and Southern Interior regions. At all sites these habitats supported a diverse and abundant fauna dominated by passerines and small mammals prior to clearing and gravel removal activities. Refer to the Project Data Base for a complete listing of recorded flora and fauna at each study site.

Vegetative habitat removed at these 18 sites averaged 10 ha and ranged from approximately 1 ha at Gold Run Creek to 35 ha at Dietrich River-Upstream (Table 28).

In general, sites separated from the active floodplain frequently disturbed the most vegetative habitat as a percentage of the total disturbed area. For example, Table 28 identifies seven sites that were entirely (100%) vegetated prior to gravel removal and all were separated from the active floodplain. At all seven sites vegetative cover and associated organic overburden were completely cleared prior to gravel removal.

Long-Term Loss of Vegetative Habitats

Long-term loss of terrestrial habitat occurred at those sites where: (1) the gravel extraction method (either pit excavation or deep scraping) removed gravel to depths that resulted in permanent flooding; or (2) the specific site location and material site characteristics resulted in river hydraulic changes which annually affected the site.

Permanently Flooded Material Sites. Eight of the study sites were excavated pits, either totally or in part (Figure 63). Pits varied from an

Figure 63. West Fork Tolovana River showing permanently flooded pit excavated adjacent to the active floodplain with a downstream connection.

average of 1.5-m in depth at the Penny River to over 7 m deep at the Dietrich River-Upstream, West Fork Tolovana River, and Tanana River-Downstream sites. The pits were either connected or unconnected to adjacent active river channels, however, in all cases they were permanently filled with ponded water (Figure 63). Surface areas ranged from 7.5 ha at Tanana River-Upstream to 0.1 ha at Ugnuravik River. Six of the eight sites were separated from the active floodplain and were completely vegetated with mature white spruce-paper birch and/or willow and alder shrub thickets prior to excavation. At these sites the depth and subsequent flooding created aquatic habitats that led to long-term loss of terrestrial habitats. At the two other pit sites, the excavations occurred in unvegetated point bars (Ugnuravik River) and unvegetated lateral bars (Kavik River). Thus, no vegetated habitat disturbance occurred.

Excavation of deep pits, however, was not the only gravel removal method that led to development of permanently ponded water and consequently the long-term loss of terrestrial habitats. The combined gravel removal and site location characteristics at the Jim River and Dietrich River-Downstream sites also led to permanent ponding.

At the Jim River, gravel was scraped from within and immediately adjacent to a high-water channel. The resulting profile at the completion of the scraping operation resulted in an almost circular depression in the middle of the worked area. The high-water channel traversed this depression. Since this channel carries summer flow, it consequently had formed an annually ponded area of approximately 4.5 ha over this centrally depressed portion of the 11 ha site. Before clearing and gravel removal, with the exception of the approximately 10-m wide high-water channel, this site contained a diverse complex of mature and intermediate-aged white spruce-paper birch stands with scattered willow and alder thickets.

The Dietrich River-Downstream site was scraped to an average depth of 1 to 1.5 m in a rectangular shaped 7.5 ha. The area was separated from the active floodplain by approximately 150 m prior to the activity. However, the depth of excavation was the probable cause of a permanent channel change by a major side channel of the Dietrich River. This channel entered the previously dry site during the second spring breakup following the activity. This channel change caused flooding of approximately 90 percent of the material site. This condition will remain as long as this side channel flows through the site.

Thus, at both the Jim River and Dietrich River-Downstream sites, mining depth and site location characteristics also created permanently ponded aquatic habitats which will lead to long-term loss of terrestrial habitats.

Annual Hydraulic Stress. In addition to the creation of permanently ponded sites, long-term loss and alteration of habitat occurred at sites where the gravel removal operation resulted in significant changes in river hydraulics. Examples of such changes include shifted channels, annually flooded sites, and aufeis development within the material site.

On the Seward Peninsula, the Penny River and Oregon and Washington Creeks are small rivers with relatively narrow, densely vegetated floodplains. Penny River and Washington Creek flowed in a sinuous configuration, while Oregon Creek flowed in a straight configuration. The portion of the total disturbed area which was vegetated by dense, mature shrub thickets prior to disturbance at each site was extensive (Oregon Creek 65 percent; Penny River 80 percent; and Washington Creek 85 percent) (Table 28). At all three sites, the working area (which was scraped to a level equal to or slightly below normal water levels) extended across the entire floodplain and at Washington and Oregon Creeks the disturbed area extended approximately 9 to 15 m beyond the floodplain banks and into the adjacent shrub-tussock tundra. The resulting effect of these scraping operations created: an unvegetated, flat floodplain which was 2 to 3 times wider than upstream or downstream reaches; a floodplain that was equal to, or only slightly higher in elevation (10 to 20 cm on the average) than normal summer flows; and a wider channel with increased braiding, straighter configuration and shallower flow (Figure 64).

The effects of these induced hydraulic changes created direct impediments to vegetative recovery and thus they also resulted in long-term alteration of the habitat structure of the disturbed reach in these floodplains.

Figure 64. A view of Oregon Creek looking downstream through the mined area showing site conditions that remain 13 years after gravel removal.

The specific changes that retarded vegetative recovery and development at these sites were related to induced aufeis development and increased annual high-water stresses.

At Washington and Oregon Creeks, extensive aufeis fields annually developed within the material sites. This ice, which is known to last until late June throughout the disturbed areas, severely impeded vegetative recovery at these sites. No significant vegetative communities had developed within the disturbed areas of either site during the 13 years following the gravel removal operations.

There is no evidence of aufeis development at the Penny River site. However, the area was scraped in an irregular surface pattern over 15 ha to a depth equal to or slightly below normal summer flow levels (Figure 65). The site was visited 11 years after gravel was removed. As a result of the depth of scraping, much of the site contained either small pools of ponded

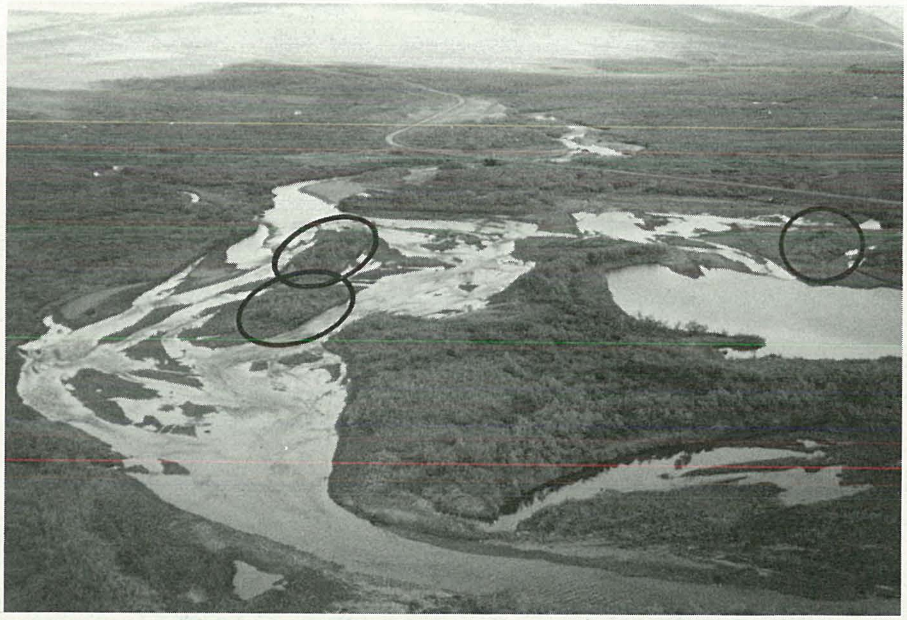


Figure 65. Penny River mined area looking upstream. Note the flooded conditions within the disturbed area, and the overburden piles in the center of the site (circled on photograph).

water or water saturated soils. A small 0.6 ha, 1.5 m deep pit was dug in the southeast corner of the site. The hydraulic analysis shows that the Penny River site is flooded for short durations during higher flows on an annual and possibly semiannual basis. Flows of only approximately 150 percent of mean annual flow begin to flood the material site.

During the 11 growing seasons following the disturbance, only sparse, scattered pioneer and early willow floodplain communities had developed within the scraped portions of the Penny River site. These early successional habitats were not present in the undisturbed floodplain reach which, as previously stated, consisted almost entirely of mature shrub thickets. Thus, the structure of the vegetative community within the mined site changed for the long-term from one dominated by dense mature shrub thicket habitats to one dominated by scattered and low-density immature herbaceous and woody species that are adapted to wet soil conditions. Repeated stress from annual or semiannual high water, combined with the continuously water-saturated soils over much of the Penny River site, were probably the key factors impeding vegetative recovery (especially by woody species).

Another example of gravel removal and site location characteristics which resulted in known short-term (the site was visited 3 years after disturbance), and probably long-term annual hydraulic stress occurred at the Sagavanirktok River study site. At this site 20 ha of a complex mixture of mature and advanced, seral-stage shrub thickets was removed and the underlying gravels excavated to an average depth of 1.5 m. This area was located between a high-water channel and the main river channel. The Sagavanirktok River was a large river with moderate channel slope that flowed in a sinuous configuration.

This gravel removal operation resulted in a permanent shift of much of the main channel through the material site. Hydraulic analysis at this site shows that extensive flooding is expected to occur on an annual basis with water potentially influencing the site for up to 70 days each year.

The site was visited during the third growing season after disturbance, and no vegetative recovery had occurred. As long as the river continues to flow through and annually flood the material site, it is not expected that significant vegetative recovery will occur in the long-term.

Short-Term Alteration of Vegetative Habitat Structure

Short-term alterations, in the types of vegetative habitats present within disturbed areas, occurred at those sites where vegetation was removed, but where some natural vegetative recovery began within 1 or 2 years post-mining and continued thereafter unimpeded. At no instance did an entire disturbed area naturally revegetate over the short-term. However, in portions of 13 sites pioneering communities became well established within 1 or 2 years (Table 29). This development most frequently occurred in those portions of the disturbed areas which: were not influenced by normal or high water flows; had a plentiful seed source or contained root stocks and other woody slash; and/or consisted of well drained but moist soils with high silt

Table 29. Location, Response Time, and Community Characteristics of Vegetative Recovery at Selected Study Sites

Site	Location of first vegetative recovery	Community characteristics	Site age at initiation of vegetative recovery (years)
Gold Run Creek	Overburden piles	Herbaceous (few shrubs)	Unknown
Sinuk River	Overburden piles	Herbaceous with woody shrubs	Unknown
Washington Creek	Overburden piles	Herbaceous with woody shrubs	1
Penny River	Overburden piles	Herbaceous with woody shrubs	1
Aufeis Creek	Broadcast slash and debris at edge of floodplain	Herbaceous with woody shrubs	1
Skeetercake Creek	Inside meander of abandoned channel	Herbaceous (few shrubs)	2
MF Koyukuk River-Downstream	Broadcast slash and debris at edge of floodplain	Herbaceous with woody shrubs	1
Jim River	Sloping banks above ponded water	Herbaceous with woody shrubs and trees	1
Prospect Creek	Sloping banks above ponded water	Herbaceous with woody shrubs and trees	1
West Fork Tolovana River	Sloping banks above ponded water	Herbaceous with woody shrubs and trees	1
McManus Creek	Overburden piles	Herbaceous with woody shrubs	1
Tanana River-Downstream	Overburden piles surrounding ponded water	Woody shrubs	1
Tanana River-Upstream	Overburden piles surrounding ponded water	Herbaceous with woody shrubs	2

and sand content. The results of soil sample analysis indicated soil nutrients were not limiting factors influencing vegetative recovery at any of the 25 study sites.

The initial recolonization of these disturbed areas most frequently occurred by seed development; at several locations, however, willows had reinvaded through development of adventitious stems and roots from old woody slash and root stocks. Adventitious stem development occurred most often in overburden piles where woody slash was placed. All overburden piles occurred in sites developed before 1971. More recent regulation of gravel removal activities require overburden and woody cover to be removed completely from floodplain sites.

In general, herbaceous species dominated in those pioneer communities which were developing from seed. However, *Salix alaxensis* was a frequent member of these communities in all four geographic regions, and seedling *Betula papyrifera* and *Populus balsamifera* commonly occurred in pioneer communities at several Northern Interior sites. Taxa that most often were dominant in these invading communities included *Epilobium latifolium*, *Salix alaxensis*, *Salix* spp., *Equisetum variegatum*, *Stellaria* spp., *Hedysarum Mackenzii*, *Astragalus* spp., *Oxytropis* spp., *Juncus* spp., *Carex* spp., *Eriophorum* spp., *Calamagrostis* spp., and *Poa* spp. In soils that were less moist and more coarse, *Artemisia* spp., *Crepis nana*, *Aster sibiricus*, and *Erigeron* spp. frequently occurred as initial invaders.

Overburden was piled either within the disturbed area or at its edge at many of the older sites. At the Penny River and Washington and McManus Creeks these overburden piles contained many organics and woody slash, root stocks, and debris. At Penny River, three piles of material were located within the 15-ha site (Figure 65). At Washington Creek, one pile was placed in the middle of the 3-ha site and one on its edge, and at McManus Creek the organic overburden was all piled on the edge of the 4-ha disturbed area. These piles averaged 1 to 2 m in height, however, a few were 5 to 7 m (Figure 66).

At all three sites, herbaceous and woody vegetation were well established on the overburden piles within 1 year after disturbance. Development

Figure 66. Close-up view of an overburden pile in the Penny River mined area. Note the development of herbaceous and woody vegetation during the 11 years following gravel removal.

on these piles preceded other disturbed area revegetation at Penny River and McManus Creek by approximately 6 to 7 years. At Washington Creek, which was visited 13 years after disturbance, the only significant revegetation of the site occurred on overburden piles (Figure 67). At all sites, the initial

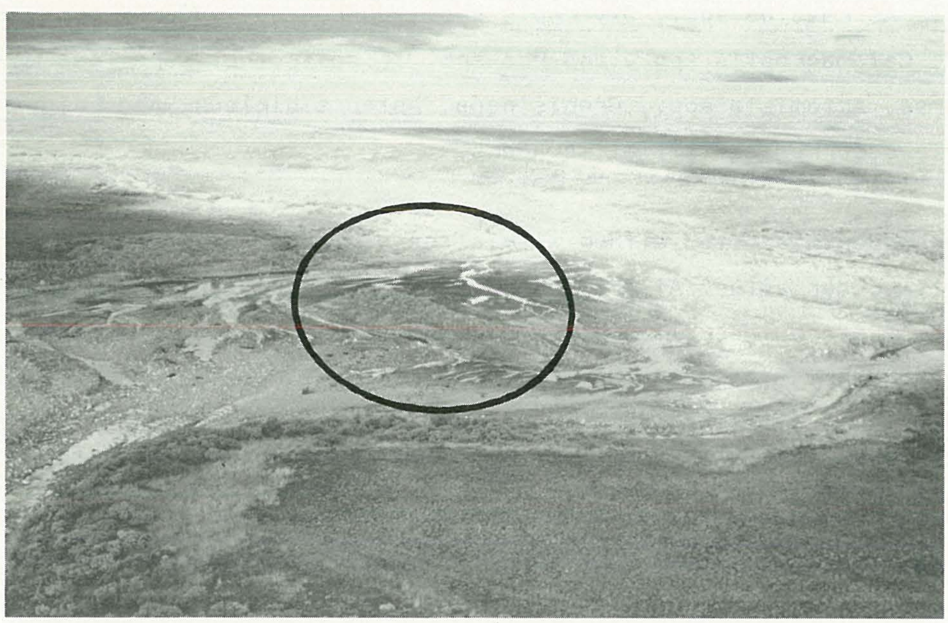
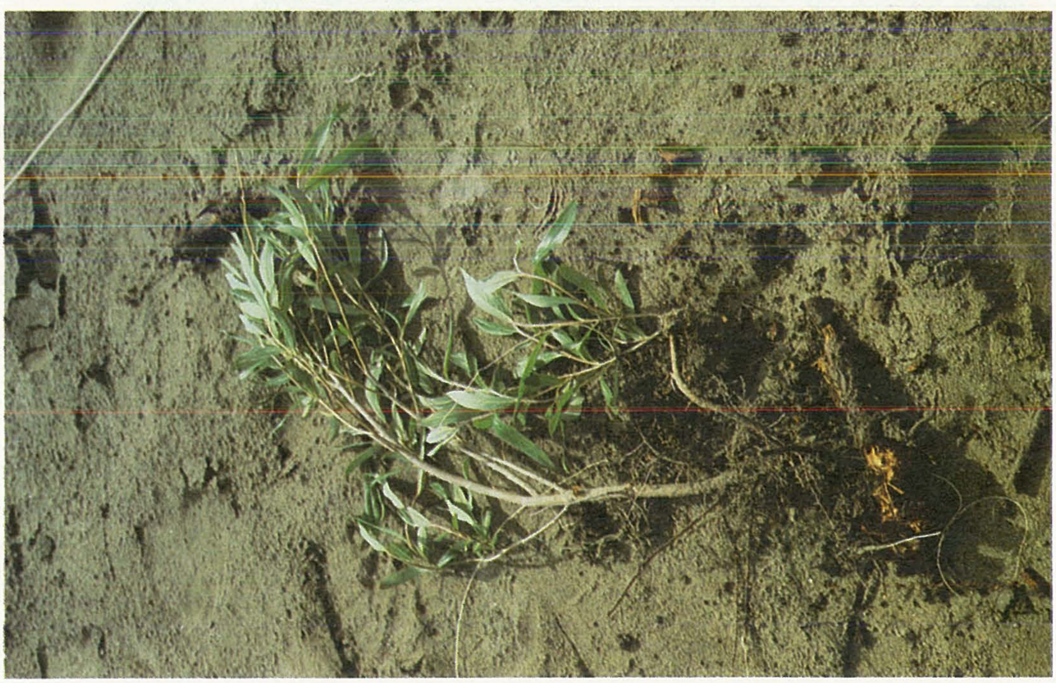


Figure 67. Washington Creek mined area showing vegetative recovery only present on the overburden pile 13 years after gravel removal.

shrub development was through adventitious stems (Figure 68). Willows, primarily S. alaxensis, most frequently developed from old slash and root stocks.

a. View of broadcast slash and 2-year-old stems.



b. View of old root stock with new stem.

Figure 68. Woody revegetation occurring through development of adventitious stems.

Similar rapid development of woody shrubs through adventitious stem development occurred in 1- to 2-ha areas at both Middle Fork Koyukuk River-Downstream and Aufeis Creek study sites. However, at these sites the slash and woody debris were not piled, but were spread over the ground at the edge of the disturbed areas (Figure 69).

Figure 69. Distribution of woody slash debris and other organics over the ground on the edge of the gravel removal area at Aufeis Creek.

At the Tanana River-Downstream site overburden from the 5-ha pit was placed in contoured banks surrounding the flooded pit. These overburden piles were approximately 2 to 3 m deep inversely piled (top material covered by bottom material), and consequently contained no organics or woody remains near the surface. However, an early shrub community dominated by Populus balsamifera, S. alaxensis, and Alnus crispa, with a density of 230 stems per 0.004 ha, was present during the fourth growing season following gravel removal. This shrub community developed from seed and invaded in mass during the first growing season. The shrubs occurred in uniform density over approximately 60 percent of the gently-sloped, 20 to 25 m wide overburden banks surrounding the pit.

Rapid natural recolonization of disturbed areas was not always limited to overburden piles. At the Jim River, West Fork Tolovana River, and Prospect Creek, pioneer communities were well developed at the end of the first full growing season following disturbance. At these sites the communities were developing on the contoured side slopes of the permanently ponded areas. An average of 13 species, with a range of 7 to 21 species, occurred in 0.0004-ha sample plots located in these habitats during the second (Jim River and Prospect Creek) and third (West Fork Tolovana River) growing seasons following disturbance. Willows, alders, birch, and spruce occurred with the herbaceous taxa in these habitats at all three sites. Although these sites have not been inspected since 1978, the pioneer communities will probably develop unimpeded and quickly lead to early and advanced seral stage shrub communities.

The Tanana River-Upstream site was very similar to the West Fork Tolovana River site with respect to Physical Site Characteristics and Gravel Removal Area Characteristics. The mined site was 10 years old during site inspection, and 13 years old at the time of data collection (summer 1978). Shrub thickets dominated by Salix arbusculoides and Alnus tenuifolia had developed surrounding much of the pit and on spits and islands which remained above the water level of the upper pit (Figure 70). These communities had

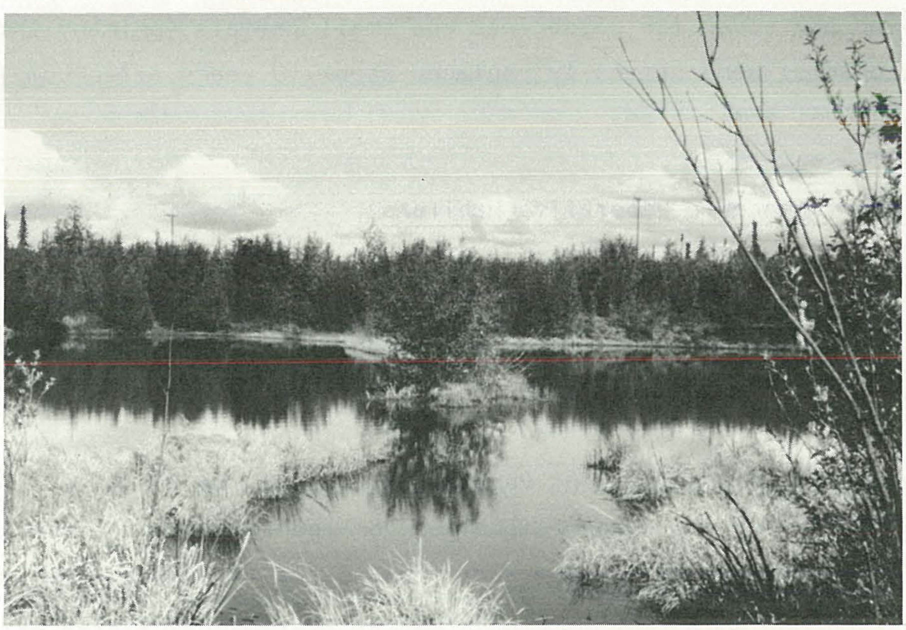


Figure 70. View of the upper pit at Tanana River-Upstream showing diversity of shoreline configuration and development of woody and herbaceous vegetation 13 years after gravel removal.

reached an advanced shrub stage with densities as high as 990 stems per 0.004 ha by the 13th year. Thickets averaged 2 to 3 m in height. During site inspection these thickets most likely were equally as dense and practically as tall.

At most above mentioned sites, following rapid invasion and development of pioneer communities (both by seed and adventitious stems), early shrub communities usually were well established in 3 to 5 years. The majority of these areas were small (0.5 to 2 ha) and were usually scattered throughout the scraped sites or surrounding the flooded sites. Usually only one to three isolated patches of early shrub communities occurred in the scraped sites. Those sites that were of sufficient age (including Penny River, Oregon Creek, Washington Creek, Sinuk River, McManus Creek, and Tanana River-Upstream) began to provide sufficient cover for nesting and feeding passerines and summer and winter cover for small mammals about 10 years after initial disturbance.

Thus, at sites that provide areas (of various sizes) for revegetative growth without severe stresses from flooding or aufeis scour, habitats that provided food and cover for passerines and small mammals (primary shrub thicket occupants) were naturally replaced about 10 years after completion of gravel removal activities.

No Significant Change in Vegetative Habitats

Contrasted to long-term loss of habitat and short-term alteration of habitat structure are gravel removal operations that resulted in no measurable change in the vegetative structure of the study areas.

Gravel mining did not affect vegetation at 5 of the 25 study sites, either because of the disturbance location, or the floodplain characteristics, or both (Table 28). At two additional sites, the Nome River and Kavik River, only slight reductions in vegetative cover were observed.

Three of the five sites with no vegetative disturbance were large floodplains with large- and medium-width channels flowing in braided patterns. At all three sites large quantities of gravel were removed by shallow scraping surface layers over a broad area. Specifics on these sites are:

Study site	Scraped surface area	Quantity of gravel removed
Ivishak River	40 ha	120,000 m^3
Kuparuk River	14 ha	42,000 m^3
Phelan Creek	70 ha	575,000 m^3

Although Phelan Creek was a wide (approximately 1,000 m) unvegetated floodplain, and the Ivishak and Kuparuk Rivers also had extensive unvegetated gravel bars, the latter two sites also contained numerous islands with densely vegetated shrub thicket stands (Figure 71). At the Ivishak River and

Figure 71. View of the Ivishak River floodplain looking downstream showing typical braided channel characteristics with extensive gravel bars and isolated, vegetated islands.

Kuparuk River sites, operators conformed the configuration of their gravel removal areas to avoid the vegetated islands. At the Phelan Creek site, gravel was scraped from a uniformly shaped and contiguous area, because the floodplain was entirely unvegetated within the work area.

The best example of avoiding disturbance to vegetated areas on a meandering or sinuous river occurred at the Shaviovik River study site (Figure 72). This river flowed in a medium width, single channel and in a sinuous

Figure 72. View of both undisturbed (background) and mined (foreground) reaches of the Shaviovik River. Note that gravel removal maintained natural point bar contours and shapes and did not disturb riparian vegetative zones.

configuration. With these characteristics the floodplain consisted of broad (averaging approximately 40 to 50 m in width) unvegetated point bars at every inside bend and numerous unvegetated lateral bars located between point bars. Gravel removal consisted of shallow scraping on every point bar and lateral bar over a distance of several river kilometers. Small quantities were taken from each location, however, a total of 116,000 m^3 was removed.

The actual scraping of unvegetated gravel deposits throughout most of the Shaviovik River site was conducted in a manner that caused minimal, or no biological disturbance. Gravel bars were scraped only in their unvegetated portions and riparian shrub thickets were not disturbed. Also, the mining operation maintained natural contours and shapes on gravel bars and did not mine adjacent to the river. Thus, the Shaviovik River has maintained its natural channel and configuration.

FACTORS AFFECTING VEGETATIVE RECOVERY RATE

Several factors found to be influencing vegetative recovery already have been discussed. The composition of faunal communities using disturbed areas was directly related to the habitat types available, thus, an understanding of how factors at the study sites influenced the rate of natural vegetative recovery warrants further discussion. Overburden piles, woody slash, and debris, an abundant seed source, and displaced organic mats enhanced recovery rate. Hydraulic stress such as aufeis development, permanent ponding, actual channel shifts, and increased flooding impeded development. Soil conditions and growing season, depending upon site specific characteristics, either enhanced or impeded vegetative recovery.

Impediments

Among the factors believed to be impeding vegetative recovery, hydraulic stress influenced most sites and had the strongest and most long-term effect. These stresses resulted from changes induced by gravel removal in floodplain elevations, dimensions, and configurations. They included:

- Permanent or annual flooding,
- Increased frequency and duration of temporary flooding,
- Long-term channel changes (increased braiding and channel width and decreased channel stability), and
- New or increased aufeis development.

The specific known causes for these induced hydraulic changes are presented in detail in EFFECTS OF GRAVEL REMOVAL ON RIVER HYDROLOGY AND HYDRAULICS. In general, they most frequently resulted because sites were excavated too deeply (excluding pit sites) without maintaining buffers or stable channel banks, or because the gravel removal method and characteristics were not correct for the chosen location.

At 13 sites the gravel removal method led to significant hydraulic changes that secondarily impeded the vegetative recovery rate (Table 30). Permanently ponded water and aufeis development caused the most significant impediment. Permanently ponded water occurred at those sites where the mining plan called for excavated pits, but also at sites where depressions were scraped below summer water levels. The latter occurred at sites that were directly connected to an active channel (Jim River); at sites that were not directly connected to an active channel (Penny River); and at sites that were originally not connected, but where gravel extraction caused an active channel to reroute through the deep depression (Dietrich River-Downstream).

Aufeis impeded vegetative recovery at four sites (Washington Creek, Oregon Creek, Middle Fork Koyukuk River-Downstream, and Jim River), all of which were directly connected to active channels. Aufeis development is believed to occur annually at all sites, and affects the entire disturbed area at Washington Creek and Oregon Creek and most likely affects much of the disturbed areas at Jim River and Middle Fork Koyukuk River-Downstream.

Two additional factors were impediments to vegetative recovery under certain conditions: soil condition and length of growing season. Vegetative recovery was occurring to some degree under a wide variety of soil type, texture, nutrient, and moisture levels. Differences in the degree of development and the species composition reflected the wide range of xeric and mesic soil conditions. Soil nutrients were not found to be limiting factors at any site regardless of its age, original condition, or final condition. However, vegetative invasion was restricted by very compacted surface layers at several of the more recent sites. These areas most frequently were associated with access routes over gravel surfaces leading to and from the mined sites. At Dietrich River-Downstream, heavy equipment compacted the floodplain gravels approximately 25 cm adjacent to the gravel removal area (Figure 73). This site was visited 3 years after completion and vegetation had not invaded this access road although the unflooded banks of the material site were supporting pioneer communities.

Another soil condition which restricted vegetative development 13 years after site work, occurred at Oregon Creek. Inorganic materials were scraped

Table 30. Quantification of Change in Selected Hydrology Parameters Which Were Impeding Vegetative Recovery at Study Sites[a]

Study site - Age in years	Hydrology parameter				
	Braiding	Channel width	Flooded area	Ponded area	Aufeis potential
Sinuk River - 10	-	-	9	8	-
Washington Creek - 13	10	8	10	10	10
Oregon Creek - 13	9	10	9	8	10
Penny River - 11	9	10	10	10	-
Nome River - 20	10	10	10	7	-
Ugnuravik Creek - 7	-	-	10	8	-
Aufeis Creek - 5	9	8	10	10	-
Skeetercake Creek - 11	-	-	8	10	-
Sagavanirktok River - 3	10	8	10	-	-
Dietrich River-Downstream - 3	-	-	7	7	-
Middle Fork Koyukuk R.-Upstream - 4	10	7	9	8	-
Middle Fork Koyukuk R.-Downstream - 2	8	9	10	7	8
Jim River - 2	-	10	10	8	8

[a]Refer to EFFECTS OF GRAVEL REMOVAL ON RIVER HYDROLOGY AND HYDRAULICS for explanation of parameters and quantification of change values.

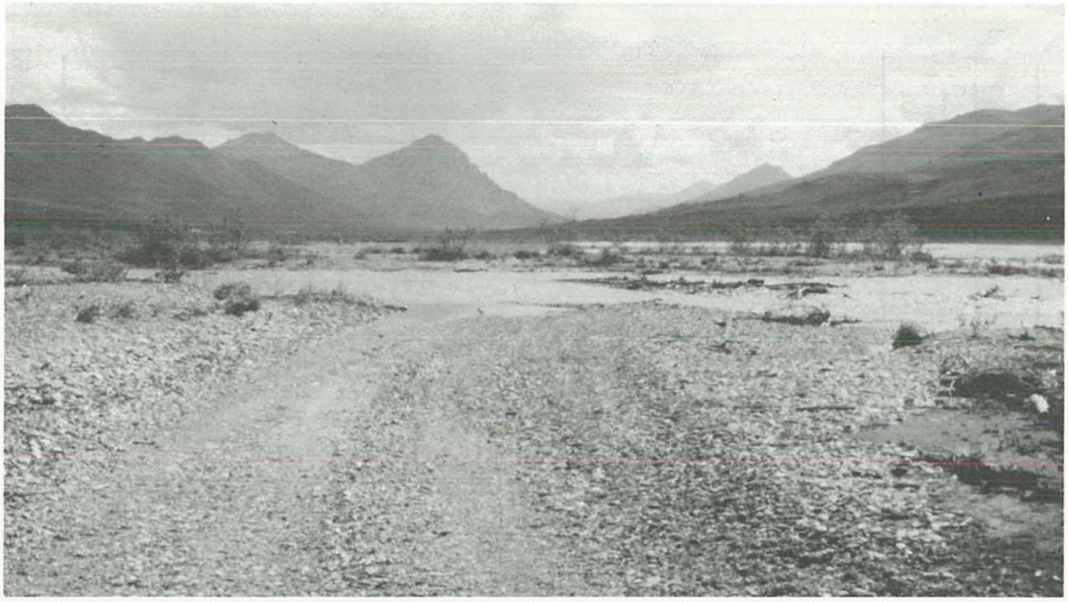


Figure 73. Compacted surface gravels in an access road leading to the Dietrich River-Downstream site.

from the site and placed in piles along the northern boundary of the mined area (Figure 74). Piles of this material supported no growth, while adjacent

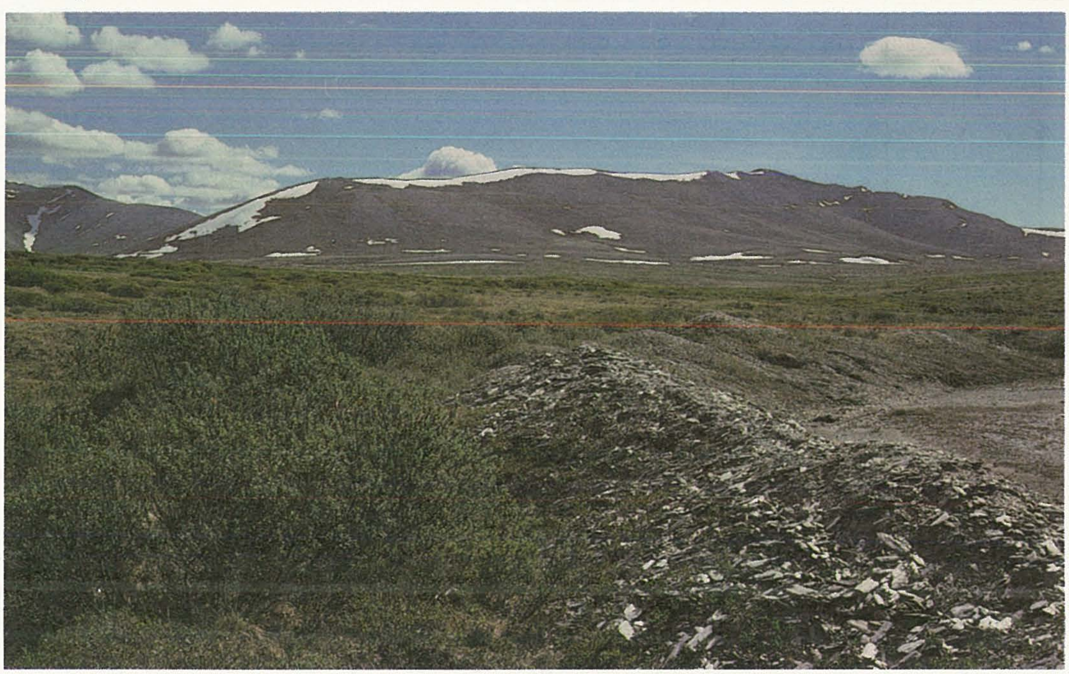


Figure 74. Inorganic overburden piled on the edge of the Oregon Creek site which supported no vegetation 13 years after gravel removal.

piles of organics, silts and sands supported advanced seral stage shrub thickets. The undesirable material was of unknown substance, but appeared to be a mica-like material.

The average growing season varies from approximately 130 to 150 days in the Souther Interior, from 100 to 120 days on the Seward Peninsula, and from 75 to 95 days on the North Slope (Mitchel personal communication). This factor was believed to be strongly influencing the rate of vegetative recovery at the two most northern study sites (Ugnuravik and Kuparuk Rivers). Both sites were only 6 km inland from the Arctic Ocean and at both sites vegetative recovery in nonflooded areas was progressing very slowly even when compared to similarly aged North Slope sites (7 and 9 years) located 80 to 90 km inland.

Enhancements

Several factors were found to enhance vegetative recovery, the most significant of which appeared to be the presence of organic soil with woody slash and debris. This material was most effective when placed in piles that were higher than frequent flood levels, or broadcast in those portions of the disturbed site where it would not get washed downstream or frequently flooded by high water.

Overburden piles occurred at 11 of the 25 study sites, however, only at those sites where this overburden contained organics with fine textured soils (silts and sands) and woody slash and debris, was vegetative recovery most enhanced. Instead of being placed in piles, this material was broadcast over the surface at two additional sites (Aufeis Creek and Middle Fork Koyukuk River-Downstream). At both sites, this material was placed in areas where it was not stressed by high water levels. At both sites these 2- to 4-ha areas were the first to begin natural revegetation and supported the most diverse and most developed communities. Revegetation began the first growing season following completion of gravel removal at both sites. Development of adventitious stems was the prime method of revegetation by willow (Figure 75).

Figure 75. Close-up of dense and diverse vegetative development in an area of surface broadcast of woody slash and organics. Note the willow adventitious stem development.

Other factors that enhanced vegetative recovery were the presence of silt deposits, an abundant seed source, and the deposition or grounding of displaced organic vegetative mats.

At several sites (including Kavik River, Skeetercake Creek, Kuparuk River, Sagavanirktok River, and Dietrich River-Downstream) the deposition of pockets of silt in low depressions within the disturbed areas quickly led to the development of a pioneer community dominated by wetland plants adapted to wet and silty soils. These areas frequently were dominated by <u>Carex</u> spp., <u>Juncus</u> spp., <u>Eriophorum</u> spp., <u>Equisetum</u> spp., and <u>Salix</u> spp. (Figures 76 and 77). Their size was highly variable and dependent upon river characteristics (suspended load) and site characteristics (disturbed area profiles and shapes).

At several of the permanently ponded sites (Jim River, Prospect Creek and West Fork Tolovana River) the development of herbaceous and woody plants was found to be frequently most concentrated at old and recent high water

Figure 76. Distant view of a large silt depositional area at the Sagavanirktok River study site.

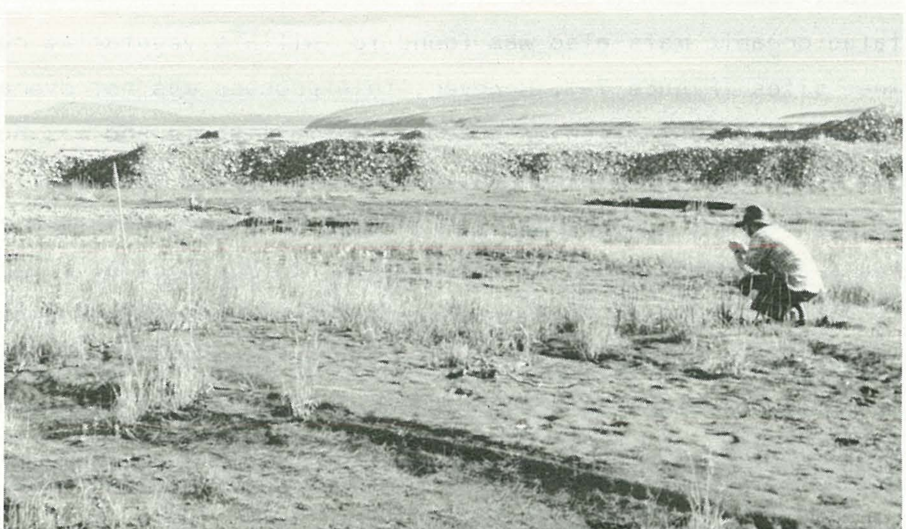


Figure 77. A silt depositional area of the Kavik River supporting a well-developed pioneer vegetative community.

lines (Figure 78). These water bodies concentrated available seeds on their surfaces and then deposited them along the shoreline.

Figure 78. Close-up of a concentration of willow seedlings at the shoreline of the Jim River ponded area.

The erosion, downstream transport, and subsequent deposition of large, intact vegetated organic mats also was found to initiate vegetative recovery of gravel mined sites (Figure 79). However, this process was not overall significant because it most often occurred on a small scale and was not widespread. It most frequently occurred in the larger more dynamic rivers. Most observations of this occurrence were of mats that were believed to have been deposited 1 or 2 years prior to site visits. In the type of river where they most frequently occurred, they were vulnerable to continued downstream movement during floods. However, in a few locations the root systems of woody species had penetrated the underlying gravels and these mats appeared to be firmly established.

FAUNAL COMMUNITY CHANGES AT GRAVEL REMOVAL SITES

Terrestrial fauna either displayed no response to gravel removal operations or displayed one of four different reactions depending upon fauna

Figure 79. Vegetated organic mats that were washed downstream and grounded during high water on Toolik River floodplain gravel bars.

type, habitat preferences, and home range size. Most responses were directly related to the removal of floodplain vegetation. A response was recorded at 19 of the 25 study sites (Table 28). In all cases where no differences in populations (particularly birds and small mammals) were recorded, vegetation was either not removed (Kuparuk, Ivishak, and Shaviovik Rivers and Phelan Creek) or only very sparse vegetative cover was removed (Ugnuravik River and Middle Fork Koyukuk River-Downstream).

At those sites where significant quantities of floodplain vegetation were removed, faunal responses basically consisted of four different reactions:

- Population Reductions - passerines and small mammals responded to the loss of vegetative habitats.

- Population Increases - water birds and ground squirrels responded to the removal of heavy vegetative cover, and, in the case of ground squirrels, also to the presence of overburden piles.

- Altered Distribution - overwintering moose and ptarmigan most likely responded to the reduction of food and cover habitat provided by floodplain thickets, by either increasing their winter reliance upon adjacent undisturbed thickets, or by shifting their local winter distribution and movement patterns.

- No Apparent Response - large mammals (such as caribou, bears, and wolves) showed no significant response to floodplain alterations created by gravel removal operations.

Population Reductions

At 18 of the 25 study sites significant areas of vegetated habitat were removed prior to gravel mining. These habitats usually were of advanced or mature vegetative stages and were dominated by a diverse and abundant passerine and small mammal community in all four regions. In Southern and Northern Interior regions red squirrels also were dominant members of these communities at sites that contained stands of mature spruce, or mixed spruce and birch.

On the North Slope and Seward Peninsula, the passerine populations inhabiting riparian shrub thickets most frequently were dominated by yellow warblers, Wilson's warblers, orange-crowned warblers, white-crowned sparrows, fox sparrows, tree sparrows, gray-cheeked thrush, American robins, common redpolls, and yellow wagtails. Although population sizes were not estimated, at sites with extensive development of riparian shrub thickets as many as 50 individual birds of 13 species were present in an area of approximately 3.5 ha (Penny River). In Southern and Northern Interior sites, many of the above passerines were joined by yellow-rumped warblers, gray jays, black-capped chickadees, dark-eyed juncos, and alder flycatchers.

At many sites small mammals also were common to abundant in heavily vegetated habitats. Tundra voles were the most frequently captured species, and were recorded in all four regions. They were captured in a wide variety of vegetated habitats and appeared to be more tolerant than other small mammals of the low-lying habitats which frequently contained water saturated soils. Singing voles and red-backed voles also were commonly captured in all regions. Most singing voles were captured in habitats that were more removed from the active portions of the floodplains, while red-backed voles were most abundant in the mature spruce-birch forest of the Interior sites.

The most important aspect of clearing advanced and mature shrub thickets and spruce-birch stands was the loss of feeding, nesting, and cover habitats for passerines and small mammals. No small mammals were observed or captured in unvegetated or sparsely vegetated portions of disturbed areas at any of the 25 study sites. Also, passerines displayed no direct association with these areas, and only were observed on a few occasions feeding or drinking in these habitats. As identified in previous sections, characteristics of the gravel removal operations and subsequent hydraulic changes most frequently resulted in long-term loss of terrestrial habitats. Thus, the local passerine and small mammal populations, primarily at the larger sites, most likely were significantly reduced as a result of lost habitat.

Population Increases

At some sites the gravel removal operation created habitats that were more desirable to some species than predisturbance habitat conditions. Population levels of water birds (including waterfowl, shorebirds, gulls, and terns) increased within the disturbed area at 12 sites (Table 28). These sites included those where mining resulted in permanently ponded areas (such as Jim River, West Fork Tolovana River, or Tanana River-Upstream) and where mining removed dense vegetation creating ponded water or backwater areas and/or mud flat and gravel bar habitats (Penny River and Aufeis Creek). These habitats provided the preferred feeding and nesting areas for these birds.

Many of the most significant increases occurred at sites where the adjacent upstream and downstream floodplain was heavily vegetated, and the gravel excavation provided habitats that were not readily available in the immediate floodplain vicinity (Penny River, West Fork Tolovana River, and Tanana River-Upstream). Birds that were most frequently associated with gravel and mud flat habitats in material sites included semipalmated plovers, Arctic terns, western sandpipers, ruddy turnstones, spotted sandpipers, glaucous gulls, northern phalaropes, and semipalmated sandpipers. At sites that provided desirable conditions, primarily abundant food supplies, the disturbed areas supported abundant shorebird populations. At the Penny River, 56 individuals of 8 species of water birds were using the 15-ha mined site during the nesting season, while at Aufeis Creek 100 individuals of 13 species of water birds were present within the site during the post-nesting period. At both study sites, these numbers were a several factor increase over the numbers of individuals and species present in the undisturbed reaches of these floodplains.

Flooded pits provided feeding and/or nesting habitat for waterfowl (most frequently green-winged teal, mallard, red-breasted merganser, pintail, bufflehead, and Barrow's goldeneye). Tree, violet-green, and bank swallows, Arctic terns, mew gulls, and herring gulls also were frequently observed feeding in these pits.

At seven sites ground squirrels were found to be more abundant within the disturbed areas than within adjacent undisturbed zones (Table 28). At six of the seven sites this response was directly related to the presence of overburden piles located within or at the edge of the material sites. These piles provided denning sites, convenient observation posts, and the first available food source (through vegetative development) within the mined site. At several sites (Washington Creek, Penny River, and Skeetercake Creek) the only ground squirrels observed were in the mined site.

In addition, at West Fork Tolovana River, Tanana River-Downstream, and Tanana River-Upstream, beaver were actively using the ponded waters in these pits. Muskrat also were encountered at the Tanana River-Upstream pit.

Altered Distribution

Moose and ptarmigan concentrate many of their winter activities in dense floodplain thickets. Evidence of their past presence was recorded at most sites and in all four regions. These animals normally move throughout large areas, hence the localized removal of vegetated habitat was not believed to have significantly affected their population levels. However, at sites where large areas of vegetation were removed (including Dietrich River-Upstream, Sinuk River, Sagavanirktok River, Penny River, and Jim River) the loss of habitat may influence the winter distribution and movement patterns of these animals.

No Apparent Response

Mammals that have large home ranges (including bears, caribou, wolves, and foxes) generally displayed no apparent attraction to or avoidance of the disturbed floodplain areas. Hence, the only apparent effects of gravel removal on these animals would be those associated with reducing their cover and food supplies (vegetation, small mammals, passerines, and fish) or increasing their cover and food supplies (water birds, ground squirrels, and fish).

An exception to this pattern was recorded at a few of the sites located along the Trans-Alaska Pipeline corridor. At these sites (Jim River, Dietrich River-Upstream, West Fork Tolovana River, and Middle Fork Koyukuk River-Downstream) individual bears and wolves have become attracted to these areas by associating them with discarded food and garbage.

FACTORS AFFECTING RECOVERY RATE OF FAUNAL COMMUNITIES

For species whose populations were reduced as a result of gravel mining, specifically passerines and small mammals, the rate at which they began to recolonize disturbed areas was directly related to redevelopment of vegetative habitats. Vegetative recovery was most directly influenced by hydraulic parameters as discussed in previous sections.

At sites that were of sufficient age and contained sufficient vegetative recovery, passerines did not begin to again use the disturbed areas as nesting and feeding habitat until shrub thickets of an intermediate stage with densities approaching 200 to 300 stems per 0.004 ha and 1.0 to 1.5 m in height were present. In addition, small mammals did not begin to use vegetated areas as primary habitats until the ground cover developed to a multilayered cover with densities of at least 60 to 70 percent surface coverage.

As stated in discussions of vegetative recovery, some sites began to provide habitat of this level in portions of the disturbed areas approximately 10 years after disturbance. Most frequently this occurred in overburden piles. At four sites (Sinuk River, Washington Creek, Penny River, and Kavik River), the only significant use of the disturbed area by passerines and small mammals occurred at the overburden piles even though these sites averaged over 10 years in age. Thus, at sites where gravel removal created a site subject to frequent hydraulic stresses, overburden piles not only provided areas for rapid vegetative recovery, but frequently provided the first useable nesting, feeding, and cover habitat for passerines and small mammals. All vegetated overburden piles were found to be of sufficient size to support at least one pair of nesting passerines and one resident small mammal. The smallest overburden pile sampled was approximately 9 m x 15 m, while the largest was approximately 15 m x 100 m. As was anticipated, the larger piles supported the larger populations.

PERMANENTLY PONDED SITES

Many gravel removal operations resulted in significant long-term loss and reductions in vegetative habitats and associated passerine and small mammal populations. However, one gravel removal method frequently led to an increase in local habitat diversity, even though it resulted in a permanent change from original habitat conditions. This increased habitat diversity also frequently led to increased fauna diversity. This method created permanent aquatic habitat either by excavating a pit separated from the active floodplain or by scraping a deep depression adjacent to an active channel. Eight sites provided this lacustrine habitat. (Note: the Kavik River and Ugnuravik River pits were not considered in this evaluation; the Kavik River pit had filled in prior to the site visit and the Ugnuravik pit was very small (10 to 15 m in diameter) and primarily covered with main channel flow.)

Several parameters at pit sites were qualitatively evaluated (Table 31). Increased fauna use was associated with those ponded waters that had high border cover, irregular pit shape, vegetated or graveled islands, high food availability, and a diversity of water depths. Also, pit size apparently was a limiting factor, because both Penny River and Prospect Creek

Table 31. Qualitative Evaluation of Habitat Quality and Fauna Use at Permanently Ponded Gravel Removal Sites

Site	Rank by habitat value (diversity)[a]	Age	Pit size	Border cover	Pit shape	Islands present	Water depth	Food availability	Detrital organics present	Fauna use
Tanana River-Upstream	1	13 yrs	7.5 ha	High & diverse	Very irregular & diverse	Vegetated gravel	Diverse	Abundant & diverse	High	Very high & diverse
Dietrich River-Downstream	4	3 yrs	6.5 ha	Low	Irregular	None	Shallow	Abundant benthos	High	Medium water birds
West Fork Tolovana River	2	3 yrs	4.5 ha	Medium & diverse	Irregular	Gravel	Diverse	Abundant & diverse	High	High & diverse
Tanana River-Downstream	8	4 yrs	4.25 ha	Medium but low quality	Regular	None	Very deep	Low	Very low	Very low
Jim River	3	2 yrs	4.1 ha	Medium & diverse	Irregular	None	Shallow	Abundant & diverse	High	High water birds
Dietrich River-Upstream	7	2 yrs	1.8 ha	Low	Regular	None	Deep	Very low	Very low	Very low
Prospect Creek	6	2 yrs	1.0 ha	Medium & diverse	Regular	None	Shallow	Abundant & diverse	High	Low
Penny River	5	11 yrs	0.6 ha	Low	Regular	None	Shallow	Abundant & diverse	High	Low

[a]A subjective evaluation and relative ranking of overall habitat quality based upon habitat parameters of border cover, pit shape, presence of water depth, food availability, and presence of detrital organics.

appeared to provide adequate habitat with sufficient food supplies but both received low fauna use. They were both 1.0 ha or less in size.

The Tanana River-Upstream pit, which was 13 years old, provided the most desirable lacustrine habitat. This 7.5-ha pit had a very irregular shoreline with heavy vegetative cover; contained numerous shrub-thicket vegetated islands in its southern half (upper pit) and graveled islands in its northern half (lower pit); had an abundant food supply dominated by fish and macroinvertebrates; and had a variety of deep and shallow water zones (Figure 80). During the site visit 147 individual birds of 39 species were

Figure 80. Tanana River-Upstream showing shoreline diversity and vegatative development in the upper pit.

recorded in the entire study area and four individual beaver, at least two muskrats, and three moose were observed using the pits. The avifauna observed are identified in Table 32.

The West Fork Tolovana River pit was smaller (4.5 ha) and not as old (3 years) but otherwise was similar to the Tanana River-Upstream pit. Avifauna observed at this site are identified in Table 33. Due to the young age and sparse vegetative cover, the avifauna in the disturbed area included few

Table 32. Bird Observations by Habitat Type Within the Control and Disturbed Areas at Tanana River-Upstream 3-7 June, 1978. Numbers Indicate Minimum Individuals Known to Occur in Each Habitat Type.

Control			Disturbed	Gravel removal area			
Mature spruce	Intermediate-aged mixed deciduous	Deciduous swamp	Intermediate-aged mixed deciduous	*Carex* wetland	Bare gravel/ mud flat	Early willow/ herbaceous	Ponded water in pits
Gray jay (3) Yellow-rumped warbler (3) Alder flycatcher (3) Dark-eyed junco (2) Common raven (1)	Yellow warbler (5) Dark-eyed junco (2) Fox sparrow (2) Gray-cheeked thrush (1) Black-capped chickadee (1) American robin (1) Ptarmigan (1)	Northern waterthrush (2) Belted kingfisher (1)	Yellow warbler (4) Gray-cheeked thrush (2) Yellow-rumped warbler (1) Common flicker (1) Dark-eyed junco (1) Ptarmigan (1)	Rusty blackbird (2) Spotted sand-piper (2) Lesser yellowlegs (1) White-crowned sparrow (1) Savannah sparrow (1) Common snipe (1)	Herring gull (8) Mew gull (4) Arctic tern (2) Semipalmated plover (2) Spotted sand-piper (2) Lesser yellowlegs (1) Bald eagle (1) American golden plover (1)	White-crowned sparrow (2) American robin (1) Savannah sparrow (1) Spotted sand-piper (1)	Tree swallow (10) Barrow's goldeneye (10) Herring gull (8) Bank swallow (8) Violet-green swallow (6) Bufflehead (5) Mew gull (4) Lesser yellowlegs (3) Canada goose (2) Red-breasted merganser (2) Arctic tern (2) Semipalmated plover (2) Northern phalarope (2) Spotted sandpiper (2) Green-winged teal (2) American golden plover (1) Bald eagle (1) Western sandpiper (1) Belted kingfisher (1) Pintail (1) Greater scaup (1) Mallard (1)
Totals 5 (12)	7 (13)	2 (3)	6 (10)	6 (8)	8 (21)	4 (5)	22 (75)

Table 33. Bird Observations by Habitat Type Within the Control and Disturbed Stations at West Fork Tolovana River 9-11 June, 1978. Numbers Indicate Total Individuals Known to Occur in Each Habitat Type.

Control				Gravel removal area		
Mature spruce/ deciduous	Riparian shrub/ backwater slough	Intermediate-aged deciduous	River shoreline and water surface	Bare gravel islands and spits	Flooded area of pit	Incised bank of pit
Gray jay (4)	Spotted sandpiper (4)	Dark-eyed junco (3)	Spotted sandpiper (2)	Bufflehead (13)	Bufflehead (14)	Bank swallow (5)
Dark-eyed junco (4)	Northern waterthrush (4)	Wilson's warbler (3)	Canada geese (2)	Spotted sandpiper (4)	Bank swallow (5)	
Black-capped chickadee (3)	Fox sparrow (3)	Black-capped chickadee (3)	Red-breasted merganser (1)	Semipalmated plover (2)	Bonapart's gull (3)	
Alder flycatcher (3)	Rusty blackbird (3)	Alder flycatcher (2)		Green-winged teal (2)	Mew gull (3)	
Hermit thrush (2)	Yellowlegs (2)	White-crowned sparrow (2)		Mallard (2)	Canada geese (2)	
Varied thrush (2)	Yellow warbler (1)	American robin (2)		Canada geese (2)	Mallard (2)	
American robin (2)		Yellow warbler (1)		Mew gull (2)	Green-winged teal (2)	
Common ravin (2)		Hermit thrush (1)		Common goldeneye (1)	Common goldeneye (1)	
Common flicker (2)				Red-breasted merganser (1)	Red-breasted merganser (1)	
American kestrel (1)						
Totals						
10 (25)	6 (17)	8 (17)	3 (5)	9 (29)	9 (33)	1 (5)

passerines. However, vegetative recovery had become well established on the gravel islands and shoreline and it is believed this site will soon provide the same quality of habitat as the Tanana River–Upstream. One colony of beaver also were using the West Fork Tolovana River pit.

Permanently ponded material sites of sufficient size (at least larger than 1 to 2 ha) will provide a high quality habitat if they have:

- A diversity of shoreline configuration and water depth,
- Dense border cover,
- Islands or peninsulas or both, and
- An abundant fish and macroinvertebrate food supply.

SIMILARITIES OF RESPONSE BETWEEN BIOTIC AND STUDY SITE PARAMETERS

A computer analysis for similarities in response between terrestrial biotic parameters and study site characteristics was conducted (Table 34). Ten biotic parameters were selected for analysis. The analysis demonstrated that responses of biotic parameters could be categorized into three groups. Each parameter within each group displayed a similar reaction to specific gravel removal operations. When comparing the responses of the biotic parameter groups for all 25 sites, 5 site response combinations were found (Table 34). After these analyses, the material site characteristics were compared for each site response group.

Biotic Parameters

The biotic parameters reacted in three groups of similar response to gravel removal induced changes. Group I included passerines, shrub thickets, moose habitat, and ptarmigan habitat; Group II included soil nutrients, ground squirrels, early shrub communities, and small mammals; and Group III included soil texture and water birds.

Table 34. Two Way Coincidence Table Displaying a Hierarchical Clustering of Similar Sites and Similar Biotic Parameters[a]

	Biotic parameters										
	Group I				Group II		Group III				
	Ptarmigan habitat	Moose habitat	Shrub thickets	Passerines	Soil nutrients	Ground squirrels	Early shrubs	Small mammals	Soil texture	Water birds	Site response group[b]
Shaviovik R											
Phelan Ck											
Ugnuravik R											
Kuparuk R											
Ivishak R											A
M.F. Koyukuk R-DS											
Nome R				-	-			-			
Dietrich R-DS			-	-			-			+	
Kavik R					-			+		-	
McManus Ck								+			B
M.F. Koyukuk R-DS			-	=			+	+	+		
Tanana R-DS			+	=			+		+		
Oregon Ck	-	-	=	=			-	-	+		
Dietrich R-US	=	=	=	=			-	-	+		
W.F. Tolovana R	=	=	=	=			-		+	*	C
Sagavanirktok R	=	=	=	=	-		-	=	+	+	
Jim R	=	=	=	=			-	=	+	*	
Prospect Ck	-	-	-	=			-	=	+		
Aufeis Ck	-	-	=	=				+		*	
Tanana R-US	-	-	=	-			-	+	+	*	D
Penny R	=	=	=	=		+	+	+	+	*	
Gold Run Ck	-	-	-	-			*	=	+		
Washington Ck	-	-	=	=		+	+	-	*		E
Sinuk R	=	=	=	=		+			+	-	
Skeetercake Ck	-	-	=	-		*	+				

[a] Symbols used for computer analysis were adapted from quantification of change ratings (Table T-1) as follows: (0,1) equals =; (2,3) equals -; (4,5,6) equals b; (7,8) equals +; and (9,10) equals *. Note: all b's (no response or weak response) were eliminated from this table to remove clutter.

[b] Responses by group were:
A - essentially no response.
B - minor decreases in biotic parameter Group I; minor increases in biotic parameter Groups II and III.
C - significant decrease in biotic Group I; minor decrease in biotic Group II; increase in biotic Group III.
D - significant decrease in biotic Group I; increase in biotic Group II; significant increase in biotic Group III.
E - decrease in biotic Group I; increase in biotic Groups II and III.

In general, Group I parameters either showed no response, or displayed a significant decrease resulting from gravel removal induced changes. This was directly related to clearing of significant quantities of vegetation which passerines, moose, and ptarmigan used as primary habitat.

Group II parameters displayed no response at sites where vegetative habitats were not disturbed. However, all parameters except soil nutrients decreased at sites that were subjected to permanent or frequent hydraulic stresses (aufeis, ponding, and flooding) and did not contain overburden piles. At sites that were subjected to hydraulic stress but which contained overburden piles, small mammals, ground squirrels, and early shrubs increased. Soil nutrients basically displayed no response.

Group III parameters either displayed no response at sites where the floodplain character was not significantly disturbed, or they increased. Both parameter responses were once again directly related to removal of extensive vegetative cover. Water birds increased in response to the increase in aquatic, gravel bar, and mud flat habitats, while soil texture increased due to the removal of organic, silt, and sand overburdens and the exposure and deposition of coarse gravels and cobbles.

Physical Site Characteristics

The Physical Site Characteristics that were analyzed are those identified in the Major Variable Matrix Table (Table I). They included: drainage basin size, channel width, channel configuration, channel slope, and stream origin.

Responses of biotic parameter groups at the 25 study sites displayed five basic combinations. These are labeled Site Response Group A through E on Table 34. Eight sites occurred in Group A, where no significant responses were measured in any of the biotic parameter groups. These sites were mostly of medium to large channel widths, of braided or sinuous configuration, and of mountain or foothill origin. However, these site characteristics were not considered to have significantly contributed to the minimal disturbance at these sites. Of greatest significance was the minimal vegetative disturbance which occurred during the gravel removal operations.

Site Response Groups B through E did not display any apparent similar Physical Site Characteristics. Thus, it was judged that drainage basin size, channel width, channel configuration, channel slope, or stream origin were not significant factors in governing the responses of terrestrial biota.

Gravel Removal Area Characteristics

The most significant similarities in Gravel Removal Area Characteristics were those that led to permanent or frequent hydraulic influence within the disturbed area. This annual stress led to a significant and often long-term impediment of site vegetative recovery. Two similar Gravel Removal Area Characteristics were observed that produced this result. They were: scraping within the active channel at any location along the river coarse; and scraping adjacent to an active channel primarily on an inside bend, and without an adequate buffer along the channel.

Scraping Within the Active Channel. Wherever gravel was scraped from within the active channel, the scraping also extended beyond the original channel to adjacent gravel bars. In these areas gravel was scraped to depths equal to or slightly below normal water levels. This characteristic produced a long-term decrease in Biotic Group I (primarily shrub thickets and passerines). The hydraulic changes that occurred in these areas were the prime factor found to be influencing site vegetative recovery. These changes are discussed in further detail in EFFECTS OF GRAVEL REMOVAL ON RIVER HYDROLOGY AND HYDRAULICS.

Scraping Adjoining the Active Channel on an Inside Bend. At seven sites gravel removal occurred on a point bar or inside meander but did not extend into the adjacent active channels. All sites were of sinuous or meandering configuration and were scraped on sharp inside bends. At five of these sites (Penny River, Ugnuravik River, Skeetercake Creek, Middle Fork Koyukuk River-Upstream, and Middle Fork Koyukuk River-Downstream) the scraping occurred to within or below the water level. Except at Middle Fork Koyukuk River-Upstream, no buffer was maintained between the scraped area and the main river channel. At the Middle Fork Koyukuk River-Upstream site a 30-m wide vegetated buffer was maintained. However, within a few years the rivers had formed cut-off channels through the scraped areas at all five sites.

Thus, scraped sites located on sharp inside bends led to the formation of cut-off channels unless extensive vegetated buffers (Jim River) or naturally contoured channel slopes (Shaviovik River) were maintained during the gravel removal operation. These cut-off channels subjected the mined areas to frequent or permanent ponding and flooding which impeded vegetative recovery.

Additional Similarities. Overburden piles, as previously discussed, were a positive addition at sites annually subjected to ponding, flooding, and *aufeis* development. At sites where piles occurred, Biotic Group II (primarily small mammals, ground squirrels, and early shrub communities) increased (Site Response Group B, D, and E, Table 34). However, at sites where overburden piles did not occur, but the site received annual hydraulic stress of flooding, permanent ponding, or *aufeis* development, Biotic Group II decreased (Site Response Group C).

Overburden piles occurred in a variety of shapes and sizes and were placed in various locations within the material site. From a revegetative viewpoint the most effective pile compositions were those with a mixture of silts, organics, woody slash, root stocks, and debris. These piles only occurred at the older sites and all were at least 1 to 1.5 m above normal water levels. It is not known if additional piles of lower height originally occurred and had been eroded and removed by flood waters. Also, all piles that were within the central portions of the mined areas were either not directly in the path of main currents or were placed in windrows oriented parallel to the current. Overburden piles that remained in the middle of large scraped sites were judged to be of more overall benefit than those placed on the edge of the disturbed areas. These piles provided immediate denning habitat for ground squirrels and, within several years, began to provide cover and nesting habitat for small mammals and passerines within the central portions of large mined areas.

The effectiveness of natural buffers was related to their location and dimensions in relation to river size and configuration. Twelve of the 25 study sites included some use of buffers. Two types were employed:

- Undisturbed gravel bars separating scraped sites in active floodplains from active channels, and

- Incised banks and associated riparian zones separating scraped and pit sites located in inactive floodplains and terraces from active floodplains.

The level of understanding that was obtained regarding the effectiveness of these buffers does not allow conclusions to be drawn. Accurate data describing original buffer characteristics (such as width, height, vegetative structure, and soil composition) were not available for many sites, however, several trends were observed.

At smaller rivers of sinuous and meandering configuration, buffers (primarily incised banks and associated riparian zones) of widths in the range of 10 to 15 m were effective in containing active channels at sites that were 5 to 16 years old (Figure 81).

Figure 81. Undisturbed buffer along the original stream channel at Aufeis Creek (downstream disturbed area only).

In larger rivers, most natural buffers that were maintained to protect scraped sites in active floodplains failed within a couple years. At Middle Fork Koyukuk River-Upstream a 30-m wide, 1- to 1.5-m high heavily vegetated buffer protecting an inside meander site was breached in 1 year; at Sagavanirktok River, a 30-m wide, 0.5-m high gravel buffer protecting a mid-channel site was breached in 1 year; and at Dietrich River-Downstream a 50-m wide and 0.5- to 1-m high gravel and sparsely vegetated buffer protecting a site on the edge of the active floodplain of a braided river was breached in 2 years. These buffer failures have all created permanent channel changes through the mined areas of these sites.

At pit sites located in inactive floodplains and terraces, buffers composed of incised banks and heavily vegetated riparian zones ranging from 50 to 90 m in width were sufficient in protecting the pits from active channel diversion at sites up to 13 years old. However, most of these sites (three of five) are located on smaller rivers with relatively stable channels and are on the inactive side of the floodplain. On the other hand, at the oldest pit site (Tanana River-Downstream) a 50-m wide buffer separated the pit from an erosional zone of a side-channel of this braided river. During 1977 and 1978 this buffer was being actively eroded. It is not known how wide the buffer was at the completion of the mining activity.

One mining method (pits) and one site location (separated from the active floodplain) frequently led to the creation of high quality habitat that resulted in an increase of water birds (Biotic Group III). As previously discussed, this method created a habitat type that frequently was not readily available in adjacent floodplain reaches. The quality of this habitat was related to its size, shoreline diversity (configuration), water depth diversity, shoreline cover, presence of islands, and food availability.

Other characteristics occurred that were not directly related to the location or operation of the material site but that reduced detrimental impacts to the terrestrial biota. At those sites where access to the floodplain had to pass an incised bank, gravel fill ramps (Figure 82) reduced the overall impact. At sites where incised banks were cut for access severe

Figure 82. Gravel fill ramp used to protect the incised bank at the Sagavanirktok River study site.

erosion frequently resulted. In permafrost areas both thermal and hydraulic erosion induced by surface travel on unprotected banks can, and at the Ugnuravik River site did, create uncontrollable problems (Figure 83). At sites separated from active channels by buffers, a heavy layer of rip rap on the buffers significantly increased their effectiveness (Figure 84).

Figure 83. Thermal and hydraulic erosion of permafrost induced by multiple passes of a tracked vehicle across an unprotected incised floodplain bank and adjacent tundra.

Figure 84. Armored bank protecting the West Fork Tolovana River pit from a channel diversion into the mined site.

SUMMARY AND CONCLUSIONS

Overall, gravel removal from floodplains frequently had a detrimental long-term effect upon local terrestrial biota. Specific site locations coupled with the depth of scraping proved to be the most influencing factors.

VEGETATIVE REMOVAL

At 18 of the 25 study sites gravel removal operations cleared significant quantities of riparian vegetated habitat. This loss most significantly affected passerines and small mammals which rely upon these riparian zones for primary feeding, nesting and cover habitats. At most of these sites this habitat reduction led to long-term changes in fauna utilization and community structure.

At 4 of the 25 sites, gravel removal operations did not alter existing vegetative communities, and consequently did not lead to changes in local faunal communities. Three of these sites were located in floodplains with large and medium width channels that flowed in a braided pattern. At all three sites large quantities of gravel were removed by shallow scraping of surface layers over a broad area. The fourth occurred on a sinuous to meandering river. At this site a large quantity of gravel also was removed by shallow scraping unvegetated portions of lateral bars and point bars. This scraping maintained natural point bar profiles and subsequently did not induce any channel changes.

MINING DEPTH AND LOCATION

Gravel removal operations that scraped to within or slightly below the water table and that occurred at inside bends or immediately adjacent to, or within the active channel also produced a long-term negative response (decrease in numbers) from terrestrial biota. At 13 of the 25 study sites gravel removal operations with these characteristics caused hydraulic changes (such as permanent channel shifts, aufeis development, or increased flooding) that impeded subsequent vegetative recovery of the disturbed areas. However, at those sites where gravel removal created permanently ponded areas, or extensive gravel and mud flat habitats with pockets of ponded water or backwater areas, water birds (including waterfowl, shorebirds, gulls, and terns) frequently increased utilization of the area.

OVERBURDEN

Overburden piles containing silts, organics, and woody slash and debris facilitated rapid and continued vegetative recovery within the mined site. These areas provided islands of useable passerine and small mammal habitat within a relatively short-term period. At many sites overburden piles were providing vegetated habitats that were being used by these species within 10 years after gravel removal. Ground squirrel populations frequently showed immediate response to available denning habitat provided by overburden piles. At most sites where piles occurred these animals were significantly more abundant within the mined site than in adjacent floodplain reaches.

When this overburden material was broadcast over the ground in areas where it would not be washed downstream it was equally effective in facilitating rapid vegetative recovery and development.

PERMANENTLY PONDED HABITATS

At eight sites the gravel removal operation (primarily through pit excavation) created permanently ponded habitats. Although this operation led to a long-term change from natural terrestrial conditions, at several sites this mining result led to the development of a diverse habitat that provided high quality feeding, nesting, and cover areas for passerines, small mammals, water birds, and furbearers. Factors that were found to influence the fauna response to these areas were: shoreline configuration, shoreline vegetative cover, water depth profiles, presence of islands, pit size, availability of food, and connection to an active channel. Fauna utilization of the area significantly increased at several sites with a high diversity of these factors.

RECOMMENDATIONS

Gravel removal operations in floodplains should attempt to incorporate the following recommendations into site selection and site operation decisions in order to minimize long-term disturbance to terrestrial flora and fauna:

1. Whenever possible, avoid vegetated habitats.

2. When scraping in active or inactive floodplains, maintain buffers that will contain active channels to their original locations and configurations.

3. When small quantities are required (approximately 50,000 m^3), select sites that will scrape only unvegetated gravel deposits.

4. When large quantities are required (approximately in excess of 50,000 m^3), select large rivers containing sufficient gravel in unvegetated areas, or select terrace locations on the inactive side of the floodplain and mine by pit excavation.

5. If pit mining, design a configuration with high shoreline and water depth diversity and provide islands.

6. If mining in vegetated areas, save all overburden and vegetative slash and debris to use during site rehabilitation to facilitate vegetative recovery. This material should be piled or broadcast in a manner so it will not be washed downstream.

Detailed elaboration and expansions of these recommendations are presented in the Guidelines Manual.

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EFFECTS OF GRAVEL REMOVAL ON WATER QUALITY

L. L. Moulton

INTRODUCTION

Water quality parameters were measured in conjunction with the aquatic biological studies at the 25 gravel removal sites. Since the sites were visited from 2 to 20 years after gravel removal had been completed, the results of the monitoring program reflect only long-term effects on water quality conditions. The sites selected for study represented a broad range of Physical Site Characteristics and Gravel Removal Area Characteristics, which are described in the Major Variable Matrix (Table 1). Instruments and procedures used are described in APPROACH AND METHODOLOGY. Changes in water quality during gravel extraction were not measured because active gravel removal sites were not available for study. A review of available information on this aspect was included in an earlier report (Woodward-Clyde Consultants 1976).

Table 35. Selected Alaska Water Quality Standards

Parameter	Beneficial use		
	Water supply	Aquatic life	Recreation
Dissolved oxygen (mg/ℓ)	>75% saturation or >5 mg/ℓ	>7 mg/ℓ	>5 mg/ℓ
Temperature (°C)	<18°C over	<2.2 °C over natural, no changes if naturally <18°C	
Dissolved solids (mg/ℓ or µmhos/cm)	<500 mg/ℓ (≈800 µmhos/cm) specific conductance)	Avoid chronic toxicity	
Turbidity (JTU)	<5 JTU	<25 JTU except when natural degradation	<25 JTU except when natural degradation
Suspended solids (mg/ℓ)		80 mg/ℓ[a]	

[a]Not an Alaska Standard, but 80 mg/ℓ is considered potentially hazardous; 25–80 mg/ℓ also has potentially detrimental effect on aquatic life (National Academy of Sciences 1973).

Table 36. Water Quality Parameters Measured at Gravel Removal Sites Which Exceeded Alaska Water Quality Standards (Values are the Average of Two to Eight Measurements)

Study site	Area	Specific conductance (μmhos/cm)	Turbidity (JTU)	Suspended solids (mg/ℓ)
Dietrich-Upstream	Upstream	275	---	56.0[b]
8 July 1978	Mined	365	---	1.2
	Downstream	342	---	56.0[b]
Dietrich-Downstream	Upstream	324	---	11.0
11 July 1978	Mined	340	---	29.0[b]
	Downstream	330	---	18.0
MF Koyukuk-Downstream	Upstream	320	6.30[a]	---
20 August 1976	Mined	300	5.20[a]	---
	Downstream	300	2.60	---
Phelan Ck	Upstream	77	---	154.0[a]
21 August 1978	Mined	79	---	270.0[a]
	Downstream	56	---	186.0[a]

[a]Value exceeds Alaska water quality standard for a defined beneficial use (see Table 35).

[b]May have some effect on aquatic life (see Table 35).

RESULTS AND DISCUSSION

POST-MINING EFFECTS OF GRAVEL REMOVAL OPERATIONS

General Water Quality Conditions

Temperature, dissolved oxygen, specific conductance, turbidity, suspended solids, oxidation-reduction potential (ORP), and pH were measured upstream, downstream, and within the gravel removal area at most sites. Measurements were taken in conjunction with the aquatic biological surveys. Temperature, specific conductance, turbidity, and suspended solids values varied substantially among the different sites. However, dissolved oxygen, ORP, and pH values were relatively similar at all sites. The parameter values measured at each study site were compared to the Alaska Water Quality Standards (Table 35). The water quality standards were established to protect various beneficial uses of receiving waters. The most important beneficial uses associated with arctic and subarctic streams include water supply, aquatic life, and recreation. At the 25 study sites, aquatic life was the most common beneficial use being supported. Alaska does not have a water quality standard for suspended solids, but a value of approximately 80 mg/ℓ suspended solids is usually considered potentially hazardous for aquatic life. Waters containing 25-80 mg/ℓ suspended solids have been shown to have a lower yield of fish than water with less than 25 mg/ℓ (National Academy of Sciences 1973).

Water quality standards were exceeded for turbidity, and suspended solids at a few river sites (Table 36) while temperature, dissolved oxygen, specific conductance, and pH criteria were not exceeded. The high suspended solids value at Phelan Creek was due to the glacial origin of the creek; the sample site was approximately 9 km downstream from the foot of the glacier. Other high suspended solids and turbidity values were recorded at the Dietrich and Middle Fork Koyukuk River sites.

Turbidity measurements recorded at the Middle Fork Koyukuk River-Downstream site exceeded water quality criteria for water supply. The only other beneficial use standard exceeded was the aquatic life standard for turbidity at Phelan Creek. This parameter was exceeded by approximately 340 percent during August. Phelan Creek water should still be considered consumable, depending on other (unmeasured) parameters. Most values exceeding the Alaska Water Quality Standards reflected a natural situation with only suspended solids at Dietrich River-Downstream possibly induced by gravel removal.

The pH and ORP values measured at all sites reflected a basic condition that was neither oxidizing nor reducing. The ORP values were relatively high because of the high dissolved oxygen concentrations. The pH and ORP values showed that there were very little organics in the monitored waters and that most of the heavy metals would be insoluble. Some of the pH values were slightly high (i.e., at Tanana River-Upstream, pH = 8.5-9.0 in the two pits) and may be associated with some heavy metal solubilities.

Water Quality Changes at Gravel Removal Sites. Most of the water quality changes observed as the receiving waters passed through the abandoned gravel removal sites can be associated with physical changes in the stream. A major change was reduced water velocity within the mined area promoting sedimentation, warming of the water, and stratification. At other sites physical changes affecting water quality conditions include a steepening of the bottom gradient through the mined site, which would increase the velocity of the water and increase the scour of the bottom sediments.

Turbidity and suspended solids changes were observed between the upstream and mined, mined and downstream, and upstream and downstream study areas at 19 of the sites (Table 37). The changes are expressed as the percentage change occurring from the upstream samples to the downstream

Table 37. Changes in Turbidity and Suspended Solids Between Sample Areas at Selected Study Sites

Study site		Percent change in turbidity: Upstream to mined	Percent change in turbidity: Mined to down-stream	Percent change in turbidity: Upstream to down-stream	Percent change in suspended solids: Upstream to mined	Percent change in suspended solids: Mined to down-stream	Percent change in suspended solids: Upstream to down-stream	Site characteristics: Years since mining	Site characteristics: Channel slope (m/km)	Site characteristics: Volume removed (m^3)
Seward Peninsula										
Gold Run Ck		5	35	42	--	--	--	11	6.8	7,740
Sinuk R		14	0	14	--	--	--	10	2.1	174,000
Washington Ck		158	29	233	-33	187	100	13	12.4	20,500
Oregon Ck	June	34	--	--	620	--	--	13	11.8	20,500
	August	3	--	--	-67	--	--	13	11.8	20,500
	September	-32[a]	--	--	25	--	--	13	11.8	20,500
Penny R	June	188	--	--	5900	--	--	11	4.5	50,700
	August	122	-24	70	0	-17	-17	11	4.5	50,700
	September	45	-24	10	40	-43	-20	11	4.5	50,700
Nome R		73	-78	-63	17	7	25	20±	2.6	unknown
North Slope										
Ugnuravik R		--	--	--	-48	192	52	7		23,000
Aufeis Ck	July	53	-10	42	0	0	0	5	3.0	288,000
	August	--	--	--	-25	-83	-87	5		288,000
Kuparuk R		--	--	--	260	0	260	9		41,300
Skeetercake Ck		11	-33	-25	0	0	0	11	2.0	38,000
Sagavanirktok R		--	--	--	-32	93	32	3		431,000
Ivishak R		-15	-10	-24	-85	275	-43	3	2.1	119,000

Continued.

Table 37. (Concluded)

Study site	Percent change in turbidity: Upstream to mined	Percent change in turbidity: Mined to downstream	Percent change in turbidity: Upstream to downstream	Percent change in suspended solids: Upstream to mined	Percent change in suspended solids: Mined to downstream	Percent change in suspended solids: Upstream to downstream	Site characteristics: Years since mining	Site characteristics: Channel slope (m/km)	Site characteristics: Volume removed (m^3)
Shaviovik R	-5	-5	-10	-75	100	-50	5	2.8	116,000
Kavik July	3	-7	-5	29	11	43	5	7.0	247,000
early August	41	-40	-15	29	11	43	5	7.0	247,000
late August	-8	4	-4	0	-12	-12	5	7.0	247,000
Northern Interior									
Dietrich-Downstream	--	--	--	164	-38	64	3		128,600
MF Koyukuk-Upstream	--	--	--	0	50	50	4		135,000
MF Koyukuk-Downstream	-17	-50	-59	--	--	--	2	1.3	215,000
Southern Interior									
McManus Ck June	0	3	3	42	-41	-17	16	22.4	75,000
July	-24	34	3	-25	33	25	16	22.4	75,000
September	0	3	3	-12	37	56	16	22.4	75,000
Phelan Ck	--	--	--	75	-31	21	3	--	575,000

samples. Negative values signify a decrease in the parameter while a positive value indicates an increase. The column entitled "upstream to downstream" for each parameter indicates the net affect of the mined site on the water quality during the site visit. There was significant seasonal variation, as indicated by the results from Oregon Creek, Penny River, Kavik River, and McManus Creek, which makes complete analysis of the data of questionable value. There appeared to be some sedimentation associated with remnant instream depressions and this sediment was subject to scour during high flow.

Changes in other parameters were observed with temperature and dissolved oxygen showing the greatest frequency of change (Table 38). The temperature and dissolved oxygen changes resulted from the reduction of velocity and spreading of flow over the mined area, a situation which occurred at many of the study sites. The ORP values did not change significantly, indicating the absence of heavy organic loading. Conductivity values changed in the mined area at several study sites, possibly indicating the exposure of a spring. The differences, judging by the age of the mined areas (i.e., 2 to 11 years), were probably not caused by the dissolving or precipitation of substances in the mined area. Spring sources were identified at Penny River and Dietrich River- Upstream, both of which showed altered conductivity. A spring source may be indicated at the Aufeis Creek and Skeetercake Creek mined areas, but the conductivity change at McManus Creek may have been a meter malfunction because the change was not observed during the other two site visits.

The water quality parameters in inundated pits were generally quite different from those in the associated river (Table 39). Summer temperatures were normally higher and dissolved oxygen levels lower in the pits. An exception was the Dietrich River-Upstream pit where spring flow kept the water temperature low throughout the summer. Thermal and oxygen stratification were evident at the West Fork Tolovana River and Tanana River-Upstream pits.

Table 38. Relative Change of Water Quality Parameters Between Upstream and Downstream Sample Areas at Selected Study Sites (5=no Change, 0-4=Decrease in Downstream Parameter, 6-10=Increase in Downstream Parameter)

Study site		Dissolved oxygen	Temperature	Conductivity	Turbidity	Suspended solids	Oxidation-reduction potential
Seward Peninsula							
Gold Run Ck		8	4	5	6	-	-
Sinuk R		7	6	5	5	-	-
Washington Ck		5	3	5	10	9	5
Oregon Ck	June	1	8	5	7	10	5
	August	2	10	7	5	2	5
	Sept.	6	5	6	4	6	5
Penny R	June	9	3	3	10	10	5
	August	3	9	6	9	4	5
	Sept.	4	9	3	5	4	5
Nome R		5	5	6	3	6	5
North Slope							
Ugnuravik R		7	2	5	-	7	-
Aufeis Ck	July	3	9	10	7	5	-
	August	7	7	10	-	1	-
Kuparuk R		4	6	5	-	10	5
Skeetercake Ck		2	9	10	4	5	5
Sagavaniktok R		5	7	5	-	6	7

Continued

Table 38. (Concluded)

Study site		Dissolved oxygen	Temperature	Conductivity	Turbidity	Suspended solids	Oxidation-reduction potential
Ivishak R		8	1	5	4	3	-
Shaviovik R		3	6	5	5	2	5
Kavik R	July	6	5	5	5	7	-
	August	8	5	5	5	7	-
	Sept.	7	2	5	5	5	-
Northern Interior							
Dietrich R-Upstream		9	0	8	-	1	5
Dietrich R-Downstream		3	10	5	-	8	6
MF Koyukuk R-Upstream		4	7	6	-	7	4
MF Koyukuk R-Downstream		-	7	5	2	-	-
Southern Interior							
McManus Ck	June	5	7	5	5	4	-
	July	6	1	10	5	6	5
	Sept.	5	3	5	5	7	5
Phelan Ck		5	8	4	-	6	4

Table 39. Average Measured Values of Selected Water Quality Parameters at Study Sites with Inundated Pits[a]

Study site	Parameter (units)	Inundated pit surface	Inundated pit bottom	Active channel (upstream)
Penny R	T (°C)[b]	2.0	--	4.0
6 June 1977	DO (mg/ℓ)[c]	12.8	--	12.0
	Cond (μmhos/cm)[d]	140	--	65
8 August 1977	T (°C)	12.1	--	10.6
	DO (mg/ℓ)	9.8	--	11.6
	Cond (μmhos/cm)	510	--	250
Dietrich-Upstream	T (°C)	4.5	4.2 (5.8m)	14.1
8-11 July 1978	DO (mg/ℓ)	10.6	9.7 (5.8m)	8.5
	Cond (μmhos/cm)	400	--	275
Jim River	T (°C)	13.2	--	9.1
3-5 July 1977	DO (mg/ℓ)	9.8	--	10.2
	Cond (μmhos/cm)	60	--	55
Prospect Ck	T (°C)	16.7	--	11.5
7 July 1977	DO (mg/ℓ)	8.4	--	11.9
	Cond (μmhos/cm)	70	--	55
WF Tolovana R	T (°C)	17.8	7.1 (4.3m)	7.5
8-12 June 1978	DO (mg/ℓ)	--	--	11.4
	Cond (μmhos/cm)	320	--	225
11-13 Sept. 1978	T (°C)	10.4	7.5 (4.3m)	8.0
	DO (mg/ℓ)	9.3	0.2 (4.3m)	10.2
	Cond (μmhos/cm)	185	--	235
Tanana R-Downstream	T (°C)	13.0	12.9 (7.2m)	7.0
9-10 Sept. 1976	DO (mg/ℓ)	10.2	9.9 (7.2m)	12.7
	Cond (μmhos/cm)	280	--	85
Tanana R-Upstream	T (°C)	17.2	14.0 (2.7m)	--
4 June 1978	DO (mg/ℓ)	10.7	9.8 (2.7m)	--
	Cond (μmhos/cm)	288	--	--
18 August 1978	T (°C)	15.2	8.2 (2.7m)	--
	DO (mg/ℓ)	9.4	5.6 (2.7m)	--
18 Sept. 1978	T (°C)	9.0	6.2 (1.4m)	--
	DO (mg/ℓ)	10.0	4.6 (1.4m)	--
	Cond (μmhos/cm)	280	--	--

[a]Sample sizes and variance estimates omitted to simplify Table.

[b]T = temperature.

[c]DO = dissolved oxygen.

[d]Cond = conductivity.

SUMMARY AND CONCLUSIONS

Few changes in water quality parameters were measured that could be attributed to gravel removal; most of the observed changes were within the range of that expected by natural variation. The major reason for a lack of measurable effects was the age of the sites, as most were visited several years after mining had ceased. The few changes that were observed were related to physical changes in the rivers, generally due to a reduction in velocity and spreading of flow.

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EFFECTS OF GRAVEL REMOVAL ON AESTHETICS

D. K. Hardinger[a]

INTRODUCTION

Aesthetics pertains to manmade modifications of natural landscape features to a degree that public concern may be expressed. Aesthetic concerns of State and Federal government include maintenance of visual resource values by minimizing undesirable modifications to natural landscapes.

Visual resource values of natural landscapes are the particular physical components of an area that have been identified as having high value based on any number of measurable criteria. These could include unique cultural, historical, recreational, geological, or biological significance. Typically the management objectives of an agency having statutory powers for maintaining visual resource values are to protect land areas identified as having high aesthetic values. The agencies may do this by diverting proposed construction to less valued locations, modifying the construction plan, or requiring the application of mitigating measures where construction-related visual impact proves unavoidable.

Maintenance of visual resource values has become increasingly important to the American people. Federal legislation has recognized this concern by establishing the visual resource as an integral and coequal resource under the multiple-use concept of land management. At the same time, there is an increasing demand for other resource developments that may not be compatible

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[a] This section was reviewed and input was provided by B. Sharky of Land Design North.

with the management of visual resources. In order to resolve potential conflicts, it has become necessary to develop a system than can identify visual resources and provide measurable management standards that are practical to implement.

Numerous systems for identifying visual resource values and evaluating visual impact have been developed. The systems vary considerably both in procedures followed and criteria applied. On Federal lands there are two principal visual resource management (VRM) systems in use today. One was developed by the U.S. Forest Service and the other by the U.S. Bureau of Land Management (BLM). Both systems have the capability to:

- Identify areas of significant visual resource value;
- Establish land units with each unit having measurable, homogeneous qualities; and
- Prioritize the land units through establishment of units of low visual quality, hence requiring minimal management protection, and units having high visual quality requiring maximum management protection.

The major components of each system involve a systematic field inventory including (1) scenic quality or visual variety, (2) visual sensitivity, and (3) degree of visibility. Generally, the field inventories are conducted from an on-the-ground perspective. Visibility from the air is generally not considered except under specialized circumstances.

Definitions of the three key VRM inventory components of scenic quality, visual sensitivity, and degree of visibility follow. Inventoried systematically using the BLM system, these components yield a land unit rating system divided into five classes. Each class provides various degrees of resource management control over prospective resource development proposals, including gravel removal operations from arctic and subarctic floodplains.

SCENIC QUALITY

Establishing a scenic quality rating begins by using physiographic provinces to distinguish landscape character units having common visual qualities and to provide a regional context for the specific area being evaluated. Within each major landscape unit there may be areas having significant visual differences. These differences might include variations of typical landforms that would be classified as character rating units. Each rating unit is further classified according to the degree of scenic quality or variety as being distinctive, common, or minimal. Generally any landscape has recognizable parts that can be described in terms of form, line, color, and texture. These basic visual elements exert various degrees of influence and their composition will determine the scenic quality of a given landscape unit. The premise is that landscapes with the most variety or diversity have the greatest potential for high scenic value.

Several key factors are inventoried in determining the scenic quality of the landscape and are used to delineate VRM land classes.

- Land form.
- Vegetation.
- Water.
- Color.
- The influence of adjacent scenery.
- Scarcity (distinctive features) or uniqueness.

VISUAL SENSITIVITY

Visual sensitivity levels measure the public concern for the scenic quality of the landscape and for the changes that may alter the existing landscape character. The degree of sensitivity is determined by user attitude and use demand (volume). User attitude can be measured by a survey of private citizens and public officials, or indirectly by public documents such as recreation plans, trail systems, scenic highways, and other items. These documents indicate areas of general concern. Use volume identifies areas of pedestrian and motorized vehicular use and rates them high, medium, or low based upon frequency and duration of use. User attitude and use demand are frequently combined in a matrix to determine final sensitivity levels.

DEGREE OF VISIBILITY

A distance zone is the area that can be seen from a sensitivity area, and is described as foreground, middleground, background, or seldom seen. Distance zones are delineated on the premise that the ability to perceive change or detail in the landscape is a function of distance.

Specific site information (Scenic Quality, Visual Sensitivity, and Degree of Visibility) is initially displayed on separate topographic maps. A hierarchy of importance is established and the maps are combined. The resulting classifications are the basis for defining minimum management objectives and the degree of acceptable alteration for each landscape classification. The determination of the degree of acceptable alteration for each landscape unit is defined utilizing a numerical rating system that enables a decision maker to see exactly what feature (landform, water, vegetation, structures) is being affected and to what extent. This method allows some flexibility in determining appropriate mitigation measures.

APPROACH

The aesthetic analysis of gravel removal from the 25 project study sites utilized the premises and criteria of the VRM system developed by the Bureau of Land Management. However, an actual VRM inventory and classification was conducted on a site by site basis rather than on a regional basis as would normally occur. Each project study site was analyzed for scenic quality, visual sensitivity, and degree of visibility. Project aerial and on-site ground photography, USGS togography maps, and project site descriptions were the primary data source for the scenic quality and degree of visibility analysis. Visual sensitivity data sources are limited in Alaska; therefore, user attitude and use volume were interpreted from the public documents cited in the bibliography and by communications with persons familiar with the locations under study. After the sites in each general region were inventoried for existing visual resources, a contrast evaluation was conducted. The contrast evaluation outlines specific visual effects of gravel removal according to BLM definitions.

THE VISUAL RESOURCES OF THE STUDY REGIONS

Characteristic landscape descriptions are needed in order to assess the degree of change or contrast that is created by floodplain gravel removal. The following section describes the physical characteristics of each region or site location in terms of the basic visual elements of form, line, color, and texture. Although site specific physical descriptions are found elsewhere in this text, the purpose here is to create an overall impression of the landscape quality in the vicinity of the study sites. When available, information documenting public concern and use (or visual sensitivity) in each region is also included in this section.

SEWARD PENINSULA

Scenic Quality

Seward Peninsula sites include Gold Run Creek, Sinuk River, Washington Creek, Oregon Creek, Penny River, and Nome River. The typical landform in the vicinity of all sites is characterized by broad, smooth textured, rolling hills with moderate to gentle slopes (Figure 85). The hills are separated by sharp V-shaped valleys near stream headwaters; these valleys become wider near the coast. All study sites on the Seward Peninsula are located in narrow valleys or at the point where a narrow valley opens into a broad valley. The panorama at these sites includes both gentle and moderately steep slopes. Angular, rugged mountains are visible in the distance from all Seward Peninsula sites, but do not significantly influence or enhance the local scenic quality.

The study site rivers on the Seward Peninsula usually flow in sinuous configuration with moderate to swift currents. The Sinuk River is the largest

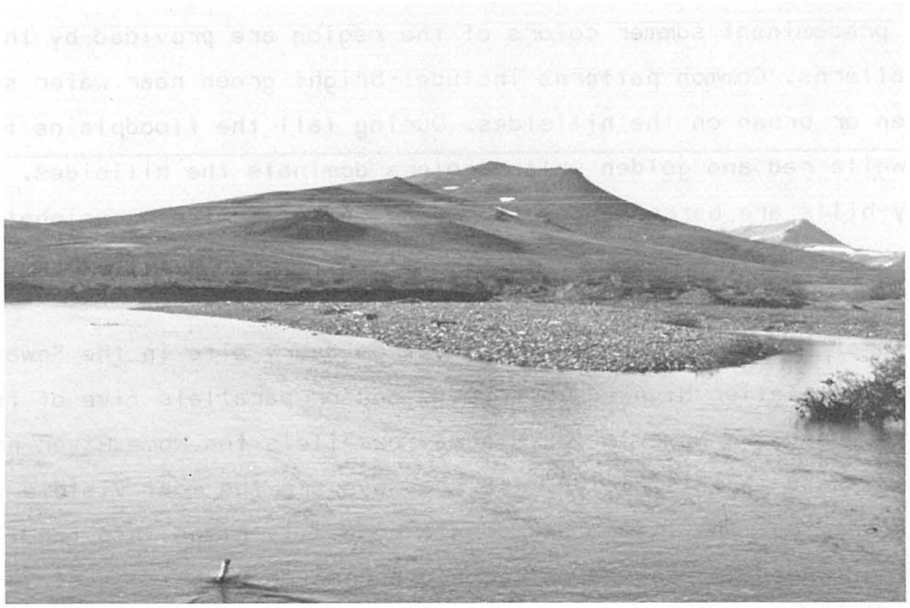

Figure 85. Typical Seward Peninsula landform at Penny River.

river and it flows in braided pattern through the study reach. The other rivers have a single well-defined active channel with occasional side channels or islands. The presence of occasional reaches of steeply eroded river bank do not create strong, visibly apparent vertical lines. Some river edges are of coarse texture with cobbles and boulders. All river systems enhance the scenic quality of the immediate surroundings, but they are not the most dominant element in the large scale landscape.

In the Seward Peninsula, riparian vegetation grows in various densities and heights. In most cases low-growing shrubs (1-2 m) are interspersed with other ground cover species (herbaceous and woody). Islands frequently are vegetated with similar vegetative communities. The Penny River in particular has extensive, wide bands of tall (2 to 3 m) riparian willow. The greener shrub thicket vegetation also extends up adjacent valleys providing a sharp color and texture contrast with the matted brown tundra on the surrounding hillsides. Dense shrub thickets also are a common feature along old diversion ditches, seeps, and other water sources; these create contrasting bands and clumps of dense green color across the brown hillsides.

The predominant summer colors of the region are provided by the vegetative patterns. Common patterns include: bright green near water sources and dull green or brown on the hillsides. During fall the floodplains turn bright yellow, while red and golden yellow colors dominate the hillsides. Ridges of nearby hills are barren and appear gray in color with occasional dark brown rock outcrops.

Cultural modifications are visible from every site in the Seward Peninsula. The Nome-Teller Highway intersects and/or parallels five of the region's study sites, and the Nome-Taylor Highway parallels the Nome River near the sixth study site in this region. The roadways are the most visible cultural modifications, but the lines they create generally blend into the lines of surrounding landscape. Several streams are crossed by bridges of varied design. These bridges create vertical and horizontal lines that are not frequently found in these landscapes. Access roads frequently lead from main highways to river floodplains. Drainage ditches constructed during early gold mining periods frequently can be seen as they follow the contours of adjacent hillsides. These ditches were constructed to collect and provide water at upland gold mining sites. Several trails traverse the local terrain and are visually disruptive. Some cabins are situated within sight of roadways, but none are noticeable from within the study sites. There also is evidence of other gravel removal and gold mining sites throughout the region.

Visual Sensitivity and Degree of Visibility

The Seward Peninsula study sites are located within immediate or foreground view of the Nome-Teller and Nome-Taylor Highways. There are only three established highways for vehicle travel on the Seward Peninsula and all radiate from Nome, the largest population center on the peninsula. All of the study sites are within a 40 km radius of Nome. There is an established BLM campground about 24 km north of the Nome River study site. This campground and the historical gold mining districts near Nome attract additional summer tourist travel along these routes. Commercial tours of the peninsula usually begin in Nome and branch out along these roadways. Any changes or alterations of the landscape that occur in the foreground along these roadways would be highly visible. However, lower use volume than in other parts of the State, and less resource agency concern for the quality of this landscape (no wildlife refuges, wild and scenic rivers, etc.), give the study areas only a moderate visual sensitivity.

NORTH SLOPE

Scenic Quality

North Slope study sites include the Ugnuravik River, Aufeis Creek, Kuparuk River, Skeetercake Creek, Sagavanirktok River, Ivishak River, Shaviovik River, and the Kavik River. The Kuparuk River and the Ugnuravik River sites are located on the Arctic Coastal Plain which is characteristically flat to slightly rolling. The steeply incised river banks accentuate the strong horizontal line of the coastal plain and also provide vertical relief (Figure 86). The remaining sites are located in the Arctic Foothills

Figure 86. Typical view of an Arctic Coastal Plain floodplain.

which is a transition area between the coastal plain and the Brooks Mountain Range. Gentle, undulating slopes with occasional isolated, round and rolling hills characterize the landform of the foothills (refer to Figures 4 and 5 in DESCRIPTION OF STUDY RIVERS). Incised river banks or terrace banks establish horizontal lines that contrast with the characteristic undulating terrain. The landform features appear to be smooth with few surface rock outcrops.

Rivers, tributaries, lakes, and ponds are common features of the North Slope landscape. On the coastal plain the abundance of these water features comprise approximately 75 percent of the land's surface. However, no single landform or water feature stands out or is visually significant. The braided river systems with their islands create variations in line, texture, and color that contrast with the surrounding homogeneous landscape. The rivers of foothill region study sites are more visually significant elements in the landscape due to the diminishing frequency of other water features and their prominent, focal location traversing foothill valley floors.

The vegetation of the North Slope study sites is relatively rich in color and texture. Riparian vegetation usually consists of low-growing communities of dense willow thicket interspersed with herbaceous and woody ground cover species. These riparian communities develop irregular outlines created by irregular channel patterns and uneven texture. Occasionally there are concentrated stands of taller, more mature willow that become a visual focus due to the contrast in height with surrounding low-growing vegetation.

The color variation of the North Slope landscape is varied particularly in the fall. The most significant color contrast exists between the greens of the riparian shrub thickets and the tans and browns of unvegetated floodplains.

Some form of cultural modification is evident near all North Slope sites. Most modifications are the result of oil and gas exploration. Several gravel access roads parallel and intersect the floodplains near many of the study sites. Gravel drill pads, camp pads, and airstrips are adjacent to several sites. These surface materials with various buildings sharply contrast the form, line, color, and texture of the surrounding undisturbed landscape.

In addition, the Trans-Alaska Pipeline and Haul Road are within 11 km and 1.5 km, respectively, of the Ivishak and Sagavanirktok River sites. These features are visible from the floodplain banks at both sites. The dominant visual feature of elevated sections of the Trans-Alaska Pipeline consists of the vertical pipe supports and the horizontal pipe. The rigid lines of both elements contrast sharply with surrounding undulating landscape.

The North Slope scenery is unusual and intriguing. This vast landscape with its subtle variety provides a sustaining viewer interest and, therefore, yields a fairly high scenic quality rating.

Visual Sensitivity and Degree of Visibility

At the present time, there is little visitor or public use near the North Slope study areas. However, several sites are located within or adjacent to areas identified by various groups as lands of national interest. The Ivishak River, for instance, has been recommended as a wild and scenic river. These designations do not guarantee increased public use, but they are an expression of public concern for preservation of scenic quality. Increased use could result if and when the Haul Road is opened for public access. Material sites within view of the Haul Road would have increased degree of visibility and therefore higher visual sensitivity.

NORTHERN INTERIOR

Scenic Quality

The landscape of the Northern Interior is among the most spectacular scenery in Alaska. It includes the Dietrich River (two study sites), Middle Fork Koyukuk River (two study sites), Jim River, and Prospect Creek. The sites on the Dietrich River and Middle Fork Koyukuk River-Upstream are located in flat glaciated valleys surrounded by steep, rugged mountainous terrain (Figure 87). The steep angular mountain walls are often crested with massive light colored rock outcrop and cut by jagged ravines. Near the Middle Fork Koyukuk River-Downstream site and the Jim River and Prospect Creek sites

Figure 87. Dietrich River valley.

the valley widths fluctuate and mountainous features diminish in visual dominance (Figure 88). The slopes are more gentle and the surrounding mountains are more rounded in form.

Figure 88. Lower Middle Fork Koyukuk River valley.

River systems of the Northern Interior exert varying degrees of influence on overall scenic quality. The large, active floodplain of the Dietrich River covers nearly one half of the valley floor. This river flows in braided pattern over much of its length. Numerous light colored unvegetated gravel bars in the active floodplain sharply contrast with the remaining vegetated valley floor and valley walls. The Middle Fork Koyukuk River varies from a large, sinuous single channel to a braided system with a large main channel. Throughout, there are many abandoned channels, vegetated islands, and terraces. Both Jim River and Prospect Creek are smaller, sinuous to meandering and less dominant in local scenic quality than the Dietrich and Middle Fork Koyukuk Rivers. All Northern Interior study sites are in an enclosed landscape where the rivers become a focal point given their prominent and central location.

The vegetation along the floodplains and hillsides is a diverse mixture of coniferous and deciduous trees of varying ages and densities. Dark-green white spruce trees contrast with the rounded, lighter green deciduous trees and willow thickets. High-water and abandoned river channels have created broken patterns in the vegetation throughout the floodplain. A rich, complex visual texture has developed because of the variable heights and colors of the vegetative communities.

Color variety is further enhanced by the gravel deposits in the floodplains, local patterns of vegetation, and in some areas extensive rock outcrops. During fall, vegetative changes introduce another dimension of color variety with the seasonal colors of red, orange, and yellow added to the landscape.

The most noticeable cultural modifications in the Northern Interior are those associated with the Trans-Alaska Pipeline System. Facilities adjacent to the study sites include construction and maintenance camps, airstrips, material and disposal sites, and elevated and buried pipeline. Spur dikes have been built into the floodplain in several locations along the Dietrich and Middle Fork Koyukuk Rivers. The light colored gravel materials used to construct the pipeline work pad, Haul Road, and camp facilities sharply contrast with the rich natural color variety of this region. The pipeline and Haul Road often create contrasting lines in the natural landscape.

The scenic quality of the Dietrich and Middle Fork Koyukuk Rivers can be characterized as a region of high diversity. This diversity is a result of a rich and complex texture of color, landform, and contrasts. The degree of diversity provides the region with a somewhat unique capability of accommodating limited manmade encroachments in comparison with the North Slope landscape where manmade structures would produce highly visible results.

Although the scenic quality is not as distinctive, Jim River and Prospect Creek have greater recreation potential than the Dietrich and Middle Fork Koyukuk Rivers. This recreation potential may have an overriding influence on the final outcome of the visual analysis.

Visual Sensitivity and Degree of Visibility

The Northern Interior (at the time of this evaluation) is accessible to the recreation and tourist oriented public only by air or by foot; hence, public use is limited at the present time. The Bureau of Land Management has several proposals that would affect the use patterns in this region if the Haul Road is opened to the public. Most development would be restricted to presently disturbed areas with an emphasis on maintaining scenic quality. Not all study sites are easily visible from the Haul Road because of screening qualities of the natural vegetation. However, current and proposed river recreation use would increase the amount of visible area. In addition, lands of national and State interest are adjacent to the Trans-Alaska Pipeline System Utility Corridor (proposed "d-2" lands). Hence, there is strong public interest in maintaining the scenic quality of this region.

SOUTHERN INTERIOR

Scenic Quality

Most study sites of this region (West Fork Tolovana River, McManus Creek, and Tanana River) have some similar landform characteristics. Rounded foothills with moderately steep slopes surround the flat-bottomed West Fork Tolovana River valley and the narrow McManus Creek valley (Figure 89). Lower, gently rolling hills border one side of the Tanana River, while the opposite

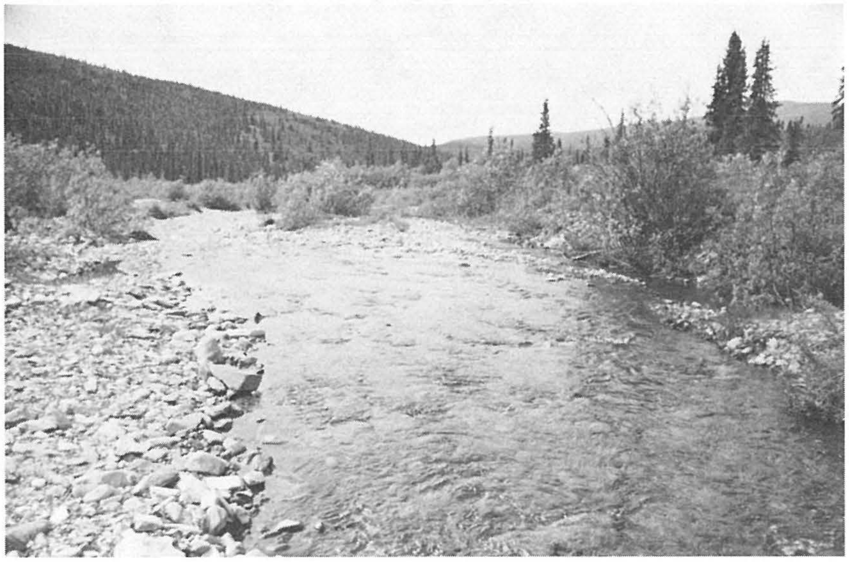

Figure 89. McManus Creek valley.

side consists of a broad, flat plain. Rock outcrops and barren soil are usually confined to the tops of the higher foothills surrounding these sites.

Phelan Creek, however, is located in a mountainous river valley (Figure 90). The valley walls are steep and angular with rugged ridges of rock outcrop. Mountain glaciers provide added visual interest to the surrounding landscape.

The Tanana River and Phelan Creek flow in braided configuration. The Tanana River has numerous gravel bars and vegetated islands in the active floodplain that contrast with each other in visual appearance. On the other hand, Phelan Creek has a gravel floodplain with little contrasting vegetation. The contiguous gray-white color sharply defines the Phelan Creek valley floor.

Figure 90. Phelan Creek valley.

The West Fork Tolovana River and McManus Creek flow in sinuous configuration through heavily vegetated, more narrow floodplains and do not strongly dominate the surrounding landscape.

The vegetation at most Southern Interior locations is a diverse mixture of deciduous-coniferous forest and riparian shrub thickets. The rounded deciduous shrubs and trees contrast with the dark, slender white spruce. The West Fork Tolovana River and Tanana River floodplains have a particularly lush understory that increases the variety of texture patterns. The valley walls near most Southern Interior sites are less obviously patterned with a more sparse understory except near drainages. However, contrasting patches of dark and light green can still be seen in most locations.

The color variety near the Southern Interior sites includes a complex mixture of greens, browns, grays, and tans with fall vegetative foliage adding reds, oranges, and yellows.

The Southern Interior sites are in the vicinity of many manmade modifications. The Trans-Alaska Pipeline System is near the West Fork Tolovana River and Phelan Creek sites, with State highways, rural communities, and recreational facilities present in the vicinity of all Southern Interior sites. These facilities, with their modifications of landform and vegetation patterns, detract from the overall scenic quality of the surrounding natural landscape.

Southern Interior sites, with the exception of Phelan Creek, have minimum or common scenic qualities because landforms are not unique and there are a relatively high number of cultural intrusions. Phelan Creek has more landform variety and in some sections is highly distinctive.

Visual Sensitivity and Degree of Visibility

The Southern Interior sites are located in the vicinity of some of the most heavily used recreation, tourist, and scenic areas in Alaska. In addition, most sites are close to major Alaskan highways connecting the largest population centers in the state. Increasing recreational use of rivers (leading to increased view area) is facilitated by convenient road access. Nearby campgrounds and waysides increase the viewing time in the landscape. All of these factors contribute to high visual sensitivity in the Southern Interior.

EFFECTS OF GRAVEL REMOVAL ON VISUAL RESOURCES

Gravel removal activities caused alterations in the landscape that in many cases were not visually harmonious with the surrounding landscapes. These alterations are discussed in this section in terms of contrast. Contrast is determined by the change in the form, line, color, and texture of characteristic landscape features such as landform, water, vegetation, and structures. The degree of contrast can vary widely; however, the significance of each contrast will depend upon the scenic quality and visual sensitivity of the characteristic landscape. The contrasts presented in the following sections generally denote a negative effect unless otherwise stated. Similar contrasts frequently exist at separate study sites in each region, hence discussions have been grouped by region with exceptions noted.

SEWARD PENINSULA

Gravel removal activities in the Seward Peninsula created the most significant contrasts in local landform and water features of all study areas. The uneven texture or angular lines, or both, of gravel stockpiles and overburden piles present at most Seward Peninsula sites, visually disrupt the existing smooth lines of the surrounding homogeneous landscape.

Scraping and pit excavation have left contrasting rigid, rectangular lines at several site locations. The presence of water located throughout much of the gravel removal areas in unnatural shapes and configurations accentuates this contrast. The construction of access roads has introduced an additional contrasting form and line in this landscape. These features are particularly disruptive if there are several at one site (Nome River, Oregon Creek). Landform contrasts are more evident in this region because the vegetation is relatively low growing and cannot effectively screen gravel removal activities. The overall color contrast has been increased at all sites by removing riparian vegetation. However, gravel removal has not created significant overall contrasts with the form, line, and texture of the existing vegetation patterns except at Penny River where the vegetation is much taller. Rigid blocks of vegetation now define some borders of the gravel removal area at Penny River, thus producing a contrast with the existing random pattern and height variations of the natural vegetation.

NORTH SLOPE

Very few significant contrasts are visible on the braided rivers of the North Slope. The rivers are large enough to visually absorb the changes in channel and island configuration. The banks, however, are a strong visual focus in many places and are more visually sensitive to change. The height of incised banks necessitated the use of gravel fill ramps in many locations. Some ramps were partially removed after mining was completed and the remnants are still visible. In either case, the ramps produce a moderate contrast with the form and line of the river bank. The Kavik River is an example of strong contrast in the form and line of the landform-water feature. Large portions of the bank were altered at this site. In addition, a large rectangular scraped area adjoins the river. These lines are not unlike those of the nearby airstrip, but in this case they disrupt the visual linear flow of the river's edge. The removal of vegetation and overburden in this area has produced a color contrast that accentuates the unnatural rectangular lines of the disturbed area.

Gravel removal created stronger contrasts along the smaller and/or single channel rivers in the North Slope region. The creation of additional water channels and/or ponds at the Aufeis Creek and Skeetercake Creek has significantly disrupted the natural lines of each system. Removal of vegetated overburden and stockpiling of gravel created additional contrasts in color and texture. The resulting broken textures and configurations at these sites contrast sharply with the existing natural landform and vegetation patterns.

NORTHERN INTERIOR

The Northern Interior sites are generally located in areas where patterns of manmade activity already exist and are visibly apparent. Gravel removal sites in vegetated floodplains developed the most significant visual contrasts. Rectangular excavation boundaries contrast with the curvilinear shape of naturally vegetated floodplains.

The removal of vegetation and overburden created color contrast at the Dietrich River-Upstream, Middle Fork Koyukuk River-Upstream, Jim River, and Prospect Creek. This contrast distinguishes the rectangular lines of the disturbed areas from the surroundings. Color contrast would not be as significant at these sites if the disturbed area boundaries were developed in configuration to reflect surrounding landform and vegetative patterns.

Sites that have filled with water (Prospect Creek, Jim River, Dietrich River-Upstream, and Dietrich River-Downstream) have produced line and form contrasts because ponding is not a common element in the floodplains of this region. Angular diversion channels at Dietrich River-Upstream were equally contrasting with natural channel patterns. The abrupt and block-like shape of existing gravel stockpiles at Dietrich River-Upstream sharply contrasted with the flat terrain of Northern Interior river valleys.

SOUTHERN INTERIOR

The presence of tall white spruce-paper birch stands associated with specific site locations make the study sites of this region less visible from public roadways than sites studied in other regions. However, the Southern Interior is a high recreational use area and natural screens between roads and gravel removal areas are not totally sufficient to keep the disturbed areas from public view.

Landform contrast is the most obvious change in visual quality resulting from gravel mining at the Southern Interior sites. The West Fork Tolovana River, Tanana River-Upstream, and Tanana River-Downstream sites have rectangular, flooded pits with steeply sloped banks. The angle of bank slope and pit shape contrast with the natural flat floodplain form and the curvilinear lines of the river systems. Where gravel stockpiles remain within the visible portions of the study site (such as at Phelan Creek) they create a contrasting unnatural form.

SUMMARY

After studying the effects of gravel removal on visual resources at specific sites, some overall generalizations can be made. Certain landscape features or conditions will be similarly effected by gravel removal in all regions. The deciding factor in determining total impact will be the relative public sensitivity to the specific landscape. The same impact in two different areas may be judged differently depending upon public priority. Theoretically, the landscapes that are highly visible and highly regarded by the public will be more seriously affected than landscapes of lesser priority. The following summarizes the effect of gravel removal on generalized landscape features and briefly discusses public priority.

Small, single channel rivers bordered with low-growing vegetation experienced the most dramatic visual impact. The location of gravel deposits on these rivers usually requires the removal of riparian vegetation and overburden along incised banks. Along meandering and sinuous systems this procedure frequently results in significantly altered river configuration. The vegetation removal causes a color change that clearly brings attention to the disturbed area. The remaining low-growing shrub vegetation is not of sufficient height to screen the disturbed area.

Braided rivers with or without vegetated islands usually can visually absorb mining induced changes if the gravel removal occurs between the floodplain banks. Any changes to the banks create noticeable visual contrasts. The most frequently observed contrast to river banks result from access roads and fill-ramps, cut banks, and mined banks.

Tall, dense vegetation buffers surrounding the work area often screen many mining sites from public view at ground level. However, the removal of

vegetation from buffer areas at most study sites has caused unnatural line and color contrasts that draw attention to the disturbed areas. Color contrasts are more visible from an elevated position where a viewer is looking down onto the site.

Rectangular, water-filled excavation pits, due to their unnatural shape, generally create significant contrasts in all floodplain landscapes. The contrast is accentuated when the vegetation bordering the pit is tall and conforms to the rectangular shape.

Sites that can be viewed from above, where the viewer is able to look down onto a site, generally results in high visibility potential particularly in areas of sparse or low-growing vegetation.

Access roads also have resulted in significant contrasts in many study sites. Access roads frequently create a high degree of visual prominence and contrast where they traverse perpendicularly across existing slope contours. This contrast is more disruptive in regions of rolling or steep terrain, having sparse or low-growing vegetation, as exists on the Seward Peninsula and North Slope. The presence of more than one access road can produce a multiplying effect with respect to increasing visual prominence.

The presence of stockpiled gravel and overburden piles often increase visual prominence to a site. Often due to their height or linear shape, or both, the piled material tends to attract the viewer's attention to a site even though the site itself may not be clearly visible. Large stockpiles are detractive in most landscapes although less noticeable in broad floodplains surrounded by tall, highly patterned, mixed stands of vegetation. Tall vegetation and terrain features can provide a visual screening effect particularly where the viewing location is at ground level.

Areas having more or less homogeneous vegetation and terrain generally are more highly visible than those areas that are more diverse. The diverse landscape character types generally can accommodate gravel removal particularly at locations where the potential viewer is at a substantial distance from the site or is at a similar elevation (ground level with respect to the site).

Visual prominence of a site tends to increase where vegetative clearing occurs along straight, long lines. This pattern is generally true in regions of both high and low landscape character diversity. Less visual contrast results where irregular clearing patterns have been accomplished. Site visibility is further reduced where natural vegetative recovery has occurred on sites cleared on irregular patterns.

Four different regions of Alaska were included in this study and each region evokes a different public response to visual resources. The regions that appear to be the most publicly sensitive to change are the Northern and Southern Interior regions because of exceptional scenic quality or intensive public use. The visual effect of gravel mining activities is expected to be more scrutinized by the public in those areas. Visual standards for gravel removal areas should recognize this public sensitivity.

GEOTECHNICAL ENGINEERING CONSIDERATIONS OF GRAVEL REMOVAL

H. P. Thomas and R. G. Tart, Jr.

INTRODUCTION

The initial geotechnical effort on the project consisted of a literature review and evaluation of questionnaires sent to highway departments around the United States. Results of this effort were presented in a preliminary report (Woodward-Clyde Consultants 1976). This section presents the findings of a geotechnical review that consisted of an office evaluation of the limited data from the 25 study sites made available to the project geotechnical engineers. This section identifies general geotechnical considerations that should be considered in gravel removal projects. The major data sources were: the mining plans that varied greatly in detail from site to site (for some sites no mining plans are available); aerial photography that varied from site to site in scale, coverage (both historical and areal), and quality; and site photographs collected during biological and hydrological field inspections. This section is, in many cases, generic and general in its treatment because of the limitations of the available data.

The objectives of this evaluation were to identify:

1) Engineering techniques that led to efficient development and operation of gravel removal areas;

2) Engineering techniques that mitigated environmental disturbance; and

3) Engineering techniques that could have been used in various conditions that would have led to more efficient operation with less environmental disturbance.

Volumes of gravel removed from each site ranged from approximately 8,000 m^3 to 630,000 m^3, with the largest volumes removed from Dietrich River-Upstream, Phelan Creek, Aufeis Creek, and Sagavanirktok River. Refer to Table 4. Scraping was the most common removal method used, but four sites were operated as pits and another four sites were operated as combinations of scrapes and pits. Nine of the sites were developed in connection with construction of the Trans-Alaska Pipeline System. Most North Slope sites were opened in connection with oil exploration and drilling activities, while all Seward Peninsula and most Southern Interior sites were developed in connection with local highway projects. More detailed information on site use is presented in DESCRIPTION OF STUDY RIVERS.

Permafrost conditions at most of the study sites are unknown. There normally is a thaw bulb associated with rivers in permafrost areas. In continuous permafrost, the thaw bulb may be a transitory feature present only during summer flows. However, in discontinuous permafrost and for large rivers in continuous permafrost, the thaw bulb persists year-round although it may shrink considerably in winter. A 1969 study on the Sagavanirktok River 11 km south of Prudhoe Bay (Sherman 1973) showed that in summer the thaw bulb associated with the main channel was 12 m deep and had a cross-sectional area of 762 m^2. In winter, this thaw bulb shrank to 167 m^2 with a maximum 7 m depth. Depending especially on whether underflow occurs, thaw bulbs may or may not be present outside the main channel.

A major gravel use in arctic and subarctic Alaska is directly related to the need to provide a gravel overlay sufficient to carry traffic and to prevent permafrost degradation (progressive thawing). The minimum overlay thickness to prevent thawing can be calculated as a function of the local thawing index. The thickness is 1.5 m at Prudhoe Bay and increases as one moves southward (e.g., it is 2.1 m at Galbraith Lake and in Fairbanks it would approach 6 m). A 1.5 m gravel overlay has generally been used for roads, drillpads, airstrips, and other permanent facilities at Prudhoe Bay. However, it has been shown that a 60-cm thick gravel overlay with 5 to 10 cm of polystyrene insulation is thermally equivalent to 1.5 to 2.1 m of gravel. This represents a 60 percent reduction in gravel thickness and a 64 percent reduction in gravel quantity, considering a typical gravel pad with $1\frac{1}{2}$:1 side slopes and a crest width of 10 m. Gravel needs during construction of the Trans-Alaska Pipeline System were reduced by using this solution for 110 km of the pipeline workpad on the North Slope. Depending upon relative costs of gravel and insulation, synthetically-insulated embankments may or may not be less costly than their all-gravel counterparts (Wellman et al. 1976).

APPROACH

The main factors considered in the geotechnical evaluation were site selection, access, operation, and rehabilitation. Primary information reviewed for each site included mining plan information from permitting agencies, aerial photographs, ground photographs, and field notes taken by the project hydrologists.

Early in the review effort, a geotechnical fact sheet and evaluation form were developed and filled out for each site. The purpose of these forms was to assemble relevant information, to draw out observations of project personnel who had visited the sites, and to generally focus the review effort. Although the geotechnical data base was very limited at a number of the study sites, it was believed to be sufficient overall to allow certain meaningful judgments to be drawn.

The following sections contain geotechnical discussions related to gravel removal during principal stages in the life of a material site.

SITE SELECTION AND INVESTIGATION

Selection of a gravel removal site often begins with a comparison of candidate floodplain and/or upland sites in the immediate use area. Upland sites are beyond the scope of this report and will not be further considered. The site selection process includes preliminary selection, site investigation, final selection, and mining plan preparation.

PRELIMINARY SITE SELECTION

Preliminary selection of one or more candidate sites results from assembling and reviewing available information followed by implementation of an appropriate selection procedure.

Sources of Information

Primary sources of information used in preliminary site selection are topographic maps, surficial geologic maps, and aerial photographs.

Topographic maps of 1:250,000 and 1:63,360 scale are available from the U.S. Geological Survey (USGS). Similar topographic maps are also available for Canadian arctic and subarctic regions. From these maps, one can obtain a general impression of the size and type of river, potential gravel availability, desirable access routes, and proximity to the use area.

The only currently available surficial geologic map of Alaska is the 1964 USGS map entitled "Surficial Geology of Alaska". With a scale of 1:1,584,000, this map does not show much detail. However, USGS recently published a potentially useful set of maps which cover the Trans-Alaska Pipeline route from Prudhoe Bay to Valdez.

Aerial photographs frequently are the most useful sources of information. Stereo pairs are needed to show relief (e.g., height of banks) and a scale of not more than 1:12,000 is preferred. Color photographs are available for some areas of the State, and black and white photography is available for most areas of the State. For some areas, pre-existing aerial photo coverage can be purchased from local aerial survey companies. However, it is frequently worthwhile to have the area in question flown and photographed in order to obtain the needed coverage. From adequate aerial photographs, one can normally distinguish such features as the physical characteristics of the floodplain (e.g., channel configurations, flow regime, gravel availability, vegetation patterns) and can select potential access routes and facility locations.

Preliminary Selection Procedure

The procedure for selecting a gravel removal site usually involves identifying two or three alternative sources that appear to have sufficient quantities of gravel. These alternates are then compared either in an informal basis (usually minimizing haul distance) or in a more formal procedure involving establishing criteria, evaluating significant factors, and ranking sites. The criteria would be specific to the situation, however, factors that may be considered include physical properties of the material available, haul distance, material site size and configuration needed to produce desired quantities, equipment available and equipment needed, required site preparation (e.g., ramps, berms, dikes, overburden), river hydraulics, and floodplain access from nearest point. At this stage the anticipated life-span of the material site also should be considered. If it is desired to use the site for several consecutive years, or for two or more periods separated by inactive periods, the potential bed-load replenishment rate should be incorporated into site selection. It is generally assumed (See EFFECTS OF GRAVEL REMOVAL ON RIVER HYDROLOGY AND HYDRAULICS) that rivers of glacial and mountain origin, particularly near their headwaters, have greater potential for gravel replenishment than streams of foothill or coastal plain origin. Non-engineering aspects of site selection are discussed in other sections of this report.

SITE INVESTIGATION

The importance of an adequate on-the-ground site investigation cannot be overemphasized. At the Ugnuravik River site, the investigation stopped with an interpretation of aerial photographs. Subsequent site operations discovered that the gravel was merely a veneer and not present in sufficient quantities to meet project needs. In contrast, before construction of the Trans-Alaska Pipeline System rather extensive site investigations were conducted which significantly increased the knowledge of site gravel quantity and quality.

Types of Data

Several different types of data need to be obtained in a material site investigation.

Aerial Extent and Depth of Deposit. Estimating the volume of material available depends on establishment of the aerial extent and depth of the deposit in question. If this volume is less than the needed volume, the site will be inadequate to satisfy the material needs. Hence, this is one of the most important types of data to be obtained.

Thickness and Aerial Extent of Overburden. Gravel sites frequently have a covering of silt or organic material, over all or part of the site, which must be removed in order to expose underlying gravel. Mining may not be economical if more than about 1 m of overburden is present over most of the site.

Homogeneity of Deposit. A deposit which appears suitable on the surface may be unsuitable at depth. This change in deposit quality frequently is a result of fluvial processes involving channel shifting, alternating erosion and deposition, and overbank flows associated with periodic flooding. Test pits or borings from several locations within the site should be analyzed to determine deposit quality.

Groundwater Table. It is important to establish the depth to the groundwater table together with spatial and temporal variations in this parameter. Groundwater conditions may vary widely throughout the year in response to changing river levels, thus, several measurements are preferable. The date of measurements should be carefully recorded.

Extent of Permafrost. Although permafrost occurrence in the vicinity of rivers and streams can be highly erratic, it should be anticipated in arctic and subarctic regions. The presence or absence of permafrost can be an important factor in developing a gravel removal site.

Field Techniques

Both borings and test pits can be used for geotechnical exploration. Test pits are generally preferred in granular soils because of the difficulties of drilling and sampling in small-diameter borings. However, borings can provide a good indication of overburden thickness, water table, permafrost conditions, and presence and extent of unacceptable (e.g., silty) materials. These borings or test pits should extend to the depth of the anticipated gravel removal. The number of pits or borings would depend upon the size and variability of the site.

Laboratory Testing

The required laboratory testing effort varies. Sieve analyses are needed, as a minimum, to classify the material and establish its suitability for its intended use. For these tests, rather large (50 to 100 kg) bulk samples are desirable. Other tests that may be needed include hydrometer tests (if frost-susceptibility is a concern) and compaction tests if the gravel will be used to support structures.

FINAL SITE SELECTION

The final site selection is based upon the criteria analysis of the alternative sites. This analysis compares the characteristics of the materials found at the available sites to the needs of the project. A major portion of this analysis is the cost-benefit trade off of the options developed during the site investigation process. Sites further from where the material is needed may have gravel that requires less processing; the reduced processing cost may lower total costs despite the added cost of transport and road construction. In another case a more distant site may have an existing access road which would, on a cost basis, justify use of the more distant site rather than a closer site. In some instances, such as pipeline bedding and padding, rounded well-graded gravel might be preferable. Specific gradation requirements may be necessary for subsurface drains. Uniformly graded angular gravel may be a requirement for asphalt pavement aggregate. In final site selection the engineer makes trade offs to choose the site that will provide the required material at the least cost.

This engineering analysis is then reviewed and biological resources, hydraulic factors, and aesthetic concerns are considered before the final site selection.

MINING PLAN PREPARATION

The agency having jurisdiction will generally require preparation and submittal of a mining plan. Minimum elements of the mining plan are:

- Planned use of gravel,
- Basis for determination of material quality and quantity (e.g., borings, test pits, laboratory tests.)
- Site configuration and depth,
- Quantity limits,
- Project schedules,
- Overburden presence,
- Access to site,
- Buffer locations,
- Operation plan, and
- Rehabilitation plan.

Specifically, the mining plans should include at least the following information:

- A site sketch drawn to scale showing:
  project location
  cross-sections of borrow areas,
  gravel source locations,
  existing or planned haul road locations,
  test pit or boring locations (if any);
- An estimate of the volume of material that is needed;
- An estimate of the volume of material that is anticipated at the available sites;
- An estimate of the properties of the material required;
- An estimate of the properties of the in-situ materials;
- An estimate of the type and amount of processing that will be required;
- Project schedules for all major activities;
- Preliminary design features of any required support structures, such as access roads, processing plants, culverts, and bridges; and
- Description of operational and rehabilitational aspects of site use.

Plans prepared as described above should provide sufficient information to evaluate the appropriateness of the planned development of the gravel sources.

Mining plans were prepared and submitted to the appropriate government agency for most of the 25 study sites. However, no mining plan information was found for the Washington Creek, Nome River, or Skeetercake Creek sites. The mining was apparently a trespass action at the upstream Aufeis Creek site and for initial gravel removal at the Kavik River site. Only results of a very limited site investigation were found for the Penny River site; only some correspondence was found for the Ugnuravik River site; and only a right-of-way permit was found for the McManus Creek site. Mining plan information reviewed ranged from sketchy (for the Seward Peninsula sites) to quite detailed (in the case of the Trans-Alaska Pipeline System sites).

SITE PREPARATION

Having selected and gained approval to develop a gravel removal site, site preparation activities can begin. These activities may include construction of access roads, removal of overburden, and construction of channel diversions and settling ponds.

ACCESS

As a part of most floodplain gravel removal operations, haul roads must be built to connect the site to the use location or existing roads. This construction poses no special engineering problems in non-permafrost areas or in areas where the permafrost is thaw-stable. However, in areas of ice-rich permafrost, protection of the tundra is of vital importance. From an engineering standpoint, tundra-insulated permafrost, as long as it remains frozen, is an excellent base or foundation for structures whether they be drill pads, roadways, pipelines, or other structures. When the permafrost begins to thaw two critical things happen. First, there is a tremendous loss in strength, and second, the thawing process is very difficult to stop. Thus, after the tundra is disturbed enough to allow the permafrost to begin this progressive thawing, the same area that formerly was an excellent base for structures becomes a very difficult, if not impossible, foundation problem for any engineering purpose. Drainage and other related problems also begin to develop and these can have significant adverse impacts on engineered structures.

Access roads traversed ice-rich permafrost at several of the study sites with varying degrees of success. In general, where at least 0.5 m of gravel depth was used, permafrost integrity was maintained. However, at several sites (Ugnuravik River, Aufeis Creek, Skeetercake Creek, and Kuparuk

River) the access roads were less than 0.5 m in depth and subsidence frequently occurred.

Access roads to a given site should be limited in number and confined to prepared surfaces. Both season of operation and long-term effects need to be considered in planning. Access to most of the study sites seemed to be appropriate and usually consisted of short gravel ramps and haul roads, sometimes including gravel bars within the river floodplain.

The practice of constructing temporary gravel ramps, as at the Kuparuk, Sagavanirktok, Ivishak, and Shaviovik Rivers sites to provide access over incised permafrost river banks, reduces bank disturbance (Figure 91). However, cutting into permafrost banks, as was done at the Kavik River, can lead to severe thermal erosion and is not recommended.

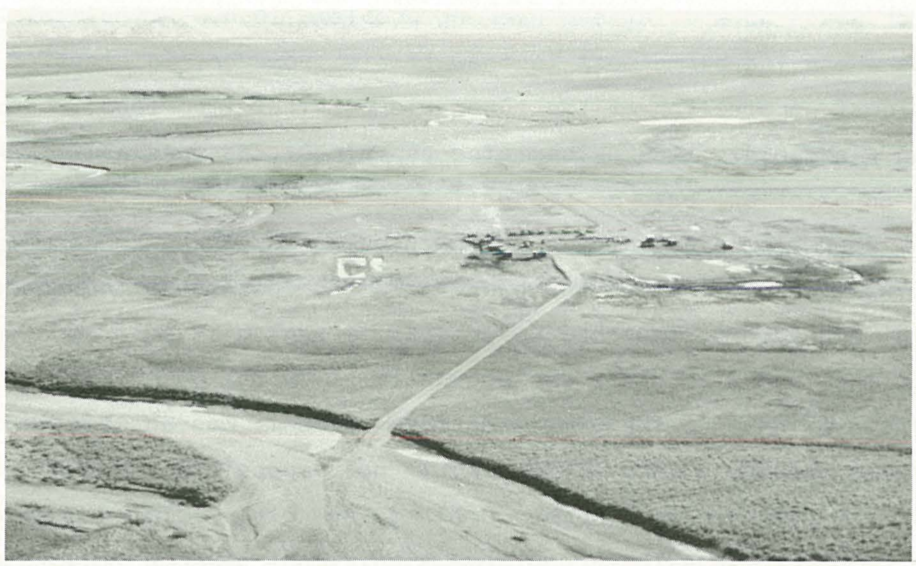

Figure 91. Gravel ramp at Shaviovik River site providing access over a permafrost river bank.

Winter-Only Access

Winter access to a floodplain site is generally easier than summer access because the surrounding terrain is frozen and river levels are low. However, even frozen organic mats need to be protected from mechanical crushing and ripping created from multiple passes over an unprotected access road while building snow or ice roads.

The Ugnuravik River site provides an example of adverse long-term effects: access to the site was via a temporary winter trail across the frozen North Slope tundra. As far as is known, the trail was used only during the last week of March 1969. However, as was commonly done, the tussocks may have been bladed off to provide a smoother riding surface. Compaction and destruction of the vegetative mat started an irreversible process of thermal erosion. When the site was visited in summer, 1977, the road had eroded to a depth of 1.5 to 2.5 m over a distance of 90 to 120 m. Erosion was continuing, and a permanent scar had been created on the landscape (Figure 92; also refer to Figure 83). Based on the current state of

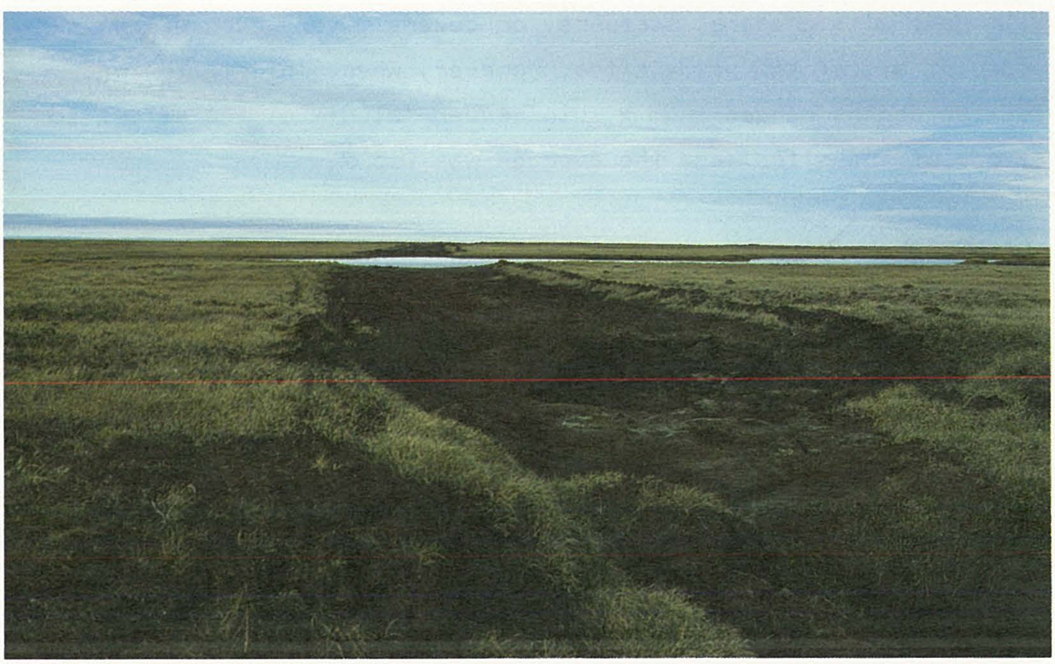

Figure 92. Thermal erosion near Ugnuravik River resulting from compaction and destruction of the vegetative mat overlying ice-rich permafrost soils.

knowledge, a better solution would have been to construct a snow or ice road (Adam 1978).

Year-Round Access

A substantial gravel (1-3 m thickness) overlay is required where year-round access to a site is needed over ice-rich permafrost. However, placement of insulation beneath the gravel would reduce the thickness of overlay required. Year-round access roads must also be above flood stage of the river, which may require placement of culverts at high-water channels crossed by the road.

OVERBURDEN REMOVAL

The stripping of overburden involves the removal of any material covering the gravel deposit. The overburden material, usually topsoil and organics, is normally removed from the site and either stockpiled for later use in site rehabilitation or hauled to approved disposal sites. Stripping is normally done with graders, scrapers, or dozers. Overburden depths were not recorded at all of the study sites. However, where information was available, the depths ranged from a thin veneer (at six of the sites) to 0.9 m (at one of the sites) and the average was 0.3 m.

CHANNEL DIVERSION

For efficient gravel removal at some floodplain sites, it may be desirable to divert river flows, especially those associated with subchannels, away from the area from which gravel is to be removed. This diversion is normally done by constructing earthen dikes or levees upstream from the site. Armoring of the upstream face and outer end of these structures may be necessary to provide erosion resistance. Erosion prevention is discussed further in EFFECTS OF GRAVEL REMOVAL ON RIVER HYDROLOGY AND HYDRAULICS.

SETTLING PONDS

It is necessary to wash gravel if the mined material has an appreciable silt content. When gravel is washed, it is essential that settling ponds be provided to allow silt to settle out before the wash water re-enters the river. These ponds should be of sufficient capacity to handle the daily volume of wash water or stream flow, or both, considering the settling velocity of the entrained silt particles. Design considerations for settling ponds can be found in Appendix F of the Guidelines Manual.

SITE OPERATION

The basic elements of a gravel removal operation are excavation, transportation, and material processing. The details of equipment selection, scheduling, and operation procedures are dependent on the composition of the gravel, the season of operation, the topography, the haul distance, and the environmental characteristics of the site.

EXCAVATION

The two basic gravel removal techniques used at the 25 study sites were scraping and pit excavation. Table I identifies the technique used at the respective sites.

Ripping and Blasting

Frequently, site operators prefer removing gravel in winter because water levels are low and access is easier. However, winter mining means excavating gravel in a frozen, possibly ice-saturated condition. At the study sites, if the gravel deposits were well above water levels and were low in frozen moisture, excavation by scraper was normally not difficult. Ripping frozen gravel was required at at least three of the sites (Middle Fork Koyukuk River-Upstream, Prospect Creek, and Phelan Creek). It is not known if blasting was utilized to remove gravel at any of the sites.

Scraping

Scraping at larger sites is usually done with belly-dump scrapers. At smaller sites or remote sites, or both, D-9 or smaller caterpillar tractors are frequently used. Scraped sites are usually dry when worked, however, caterpillar tractors can work in shallow water (possibly up to 0.5 m).

Pit Excavation

Pit excavation is generally done with draglines or backhoes. Dewatering may or may not be necessary. At the study sites some of the more shallow pits were dewatered, but deeper pits, e.g., Dietrich River-Upstream, West Fork Tolovana River, and Tanana River-Downstream were excavated underwater.

Comparison of Techniques

Some engineering and economic advantages and disadvantages of removing gravel via pits versus scraping are listed below.

Advantages of Pits Versus Scraping

- Greater quantity from smaller area.
- Can work within confined property limits (if necessary).
- Less clearing required.
- Less stripping required.
- Can provide silt trap.

Disadvantages of Pits Versus Scraping

- Dewatering or underwater excavation required.
- May provide less gravel per unit time than scraper operation.
- Cannot be restored as closely to original condition.

TRANSPORTATION AND STOCKPILING

Transportation of gravel from the material site to the stockpile or processing plant may be done with scrapers or front-end loaders and dump trucks. Stockpiling gravel removal operations greatly reduces scheduling problems. It is possible to load trucks directly for long-haul transport to ultimate-use areas without stockpiling, but a great deal of coordination is required between the excavating and transporting activities. It is advantageous to maintain a stockpile of at least moderate size to serve as a buffer between excavating and transporting. Gravel stockpiles remained on or immediately adjacent to nine of the study sites, however, only Dietrich River-Upstream, Jim River, and Phelan Creek stockpiles were still being used.

PROCESSING

Gravel processing can involve screening, washing, crushing, mixing, or combinations of these. Materials of the study sites frequently were fairly uniform, subrounded to well-rounded, hard gravels with varying amounts of sand and cobbles. Such materials are suitable for road embankments with little or no processing. However, silt content should be limited to approximately 10 percent to minimize frost susceptibility. Processing apparently was only conducted at those study sites used for construction of the Trans-Alaska Pipeline System where screening and some crushing were done to produce bedding and padding material for the below-ground pipeline.

SITE REHABILITATION

Engineering concerns contribute to rehabilitation mainly if future site development (e.g., erecting of structures) is planned. In this situation, long-term integrity of structures is the primary concern of site rehabilitation. Otherwise, the primary purpose of site rehabilitation is erosion control. The main function of erosion control is to prevent degradation of disturbed and adjacent areas.

Some rehabilitation was done at all study sites worked since 1972. There was no evidence of rehabilitation having been done at any of the older sites. Where final site grading was conducted, it typically included sloping or flattening of stockpiles and overburden piles to blend with the terrain, contouring the site to a maximum 2:1 slope, and removal of gravel ramps (not done at the Ivishak and Shaviovik Rivers).

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INTERDISCIPLINARY OVERVIEW OF GRAVEL REMOVAL

E. H. Follmann[a]

INTRODUCTION

This chapter presents a general overview of the effects of gravel removal in contrast to the preceding disciplinary chapters that rely more heavily on analytical treatments of data collected at the 25 study sites. Each of the Major Variables identified in the Matrix (Table I) is discussed relative to its influence on the effects of a gravel removal operation. These characteristics directed the early phases of the study, including the site investigations, and form, for the most part, the framework of the gravel removal guidelines. The disciplinary chapters on gravel removal effects did not necessarily treat each of these characteristics because some were not relevant or they did not influence the evaluations or syntheses sufficiently to warrant individual attention. Thus, this overview chapter constitutes the functional bridge between the Guidelines Manual and the Technical Report.

Few problems were encountered in the discussion of the Physical Site Characteristics and their interaction with gravel removal projects because the categories are mutually discrete, i.e., a river cannot be both meandering and straight within the study reach. The categories under each of the Gravel Removal Area Characteristics, however, are not mutually exclusive and, thus, cause difficulty in the development of that discussion. The sites selected encompassed at least several individual locations from which gravel

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was removed. Sites such as Aufeis Creek on the North Slope and Penny River on the Seward Peninsula each included 8 of the 12 specific site locations that were possible (Table 1). This complexity made it difficult to identify any specific floodplain changes with specific gravel removal locations. For these sites, the overall effect on the floodplain resulted from the total gravel removal operation and specific effects were masked. The problem of sites with multiple Gravel Removal Area Characteristics was unavoidable because almost all of the over 500 sites originally considered reflected the same situation. The major result is that, in some cases, generalities are discussed with little or no reference to specific material sites. If none of the sites clearly exhibited the relationship being discussed, none were cited as examples. However, the generalities discussed are considered accurate because of the analyses and conclusions reached in the preceding disciplinary chapters.

PHYSICAL SITE CHARACTERISTICS

The Physical Site Characteristics considered in this project were: drainage basin size, channel width, channel configuration, channel slope, and stream origin (Table I). Following study of the 25 material sites and analyses of data, it was established that channel configuration was the most important floodplain characteristic affecting environmental change when combined with gravel removal activities. Drainage basin size (channel width) was found to be less significant, and channel slope and stream origin were found to have little influence on the effects of gravel removal. The following discussion is subdivided according to these categories.

CHANNEL CONFIGURATION

The channel configuration or pattern of a river is the shape of the river channel(s) as seen from the air. The channel configurations considered in this study were braided, split, meandering, sinuous, and straight.

Braided

A river with a braided channel pattern typically contains two or more interconnecting channels separated by unvegetated gravel bars, sparsely vegetated islands and, occasionally, heavily vegetated islands. Its floodplain is typically wide and sparsely vegetated and contains numerous high-water channels. The lateral stability of these systems is quite low within the boundaries of the active floodplain.

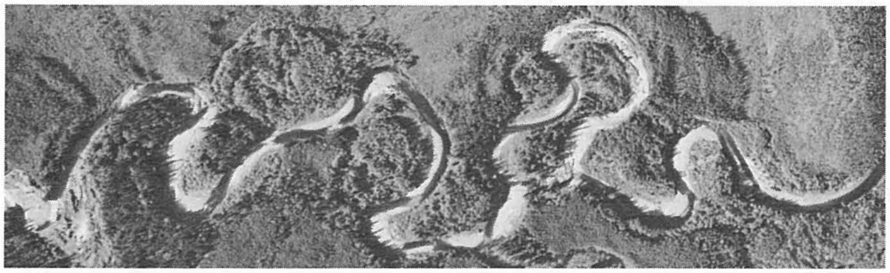
Four braided systems used for material sites were studied. Ivishak River on the North Slope, Dietrich River in the Northern Interior, and Tanana River and Phelan Creek in the Southern Interior. These systems usually contain large quantities of gravel and, therefore, are often utilized as gravel sources (Figure 93). The bed load carrying capacity of these rivers is large, thus facilitating the replenishment of extracted gravels after site closure.

Braided river systems are dynamic and lateral shifting of channels from year-to-year is common, therefore, any channel shifting resulting from lowering bars through gravel removal would be similar to the natural processes. For example, any diversion of a channel through an area that was lowered by the removal of gravel possibly would have occurred naturally sometime in the future. Material sites in these areas typically are scraped because required quantities of gravel usually can be obtained over large areal extents and it is more efficient to work a site above the existing water level. Due to the bed load carrying capacity of these systems, the typical shallow scraped sites are subject to sedimentation rates similar to natural depressions occurring in these floodplains. Therefore, the minded sites can return relatively quickly to near natural conditions. This recovery is particularly true if the site is located near the active channel. An example of rapid recovery is the Ivishak River site, which was shallow scraped over a large area of unvegetated gravel bars. After several years the only evidence of gravel mining is the presence of access roads and fill ramps that connected the material site with an airstrip and drill pad.

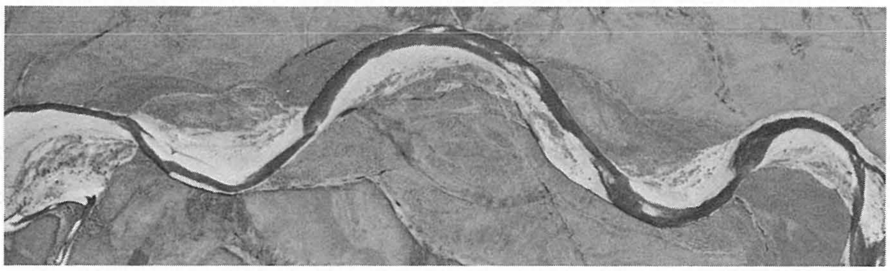
Long-term effects of gravel removal on water quality were not evident at the four sites located in braided systems. Due to the relative instability of channels in a braided river system, any channels routed through an abandoned material site probably would be affected in a manner similar to a channel being rerouted due to natural hydraulic processes. An exception would be where an aliquot of a material site was used as a settling pond during a gravel removal operation. The accumulated fines could be suspended during subsequent high flows if this material was not armored and was left in the depression during site closure. None of these situations was encountered at the study sites, however, the possibility would exist in similar site conditions.

Braided

Split



Meandering



Sinuous

Straight

Figure 93. Configurations of study rivers.

The aquatic organisms in braided systems are adapted to the seasonal dynamics of the channels and, therefore, any channel changes resulting from gravel removal operations provide situations for which the organisms are already adapted. An exception to this generalization occurs where a pit is separated from the active channel (Tanana River-Downstream) or is within the floodplain (Dietrich River-Upstream) and connected to an active channel. In these cases, organisms that are more adapted to lentic environments become established. Also, certain fish species may use the calmer waters of these pits for spawning, rearing, and feeding areas. These pit sites are the exception, because scraping is the usual procedure selected to excavate sites in braided systems. Excavating aspects are discussed further in the following section on Types of Gravel Removal.

Terrestrial species that utilize braided river systems similarly are little affected by the usual scraping operation. Since non-vegetated bars are favored gravel removal sites, few small mammals or passerines are affected. The water-associated birds that use the various channels and backwaters for feeding are also little affected by the material sites because the usual result of these operations is to provide habitats already present.

Due to the dependence of small mammals and passerines on vegetated islands, gravel bars, and banks present in braided systems, any removal of vegetation to expose a gravel deposit would totally displace birds and eliminate small mammals from the disturbed site. Similarly, these areas, which often have associated dense shrub thickets, are used by moose and ptarmigan, especially during winter. Loss of this habitat would cause localized displacement of these animals.

Maintenance of the scenic quality of an area can be achieved by designing a material site to complement the natural setting. Material sites in braided systems did not detract from the visual quality of the floodplain where gravel removal was restricted to unvegetated gravel bars. The expansive floodplains typical of these systems are somewhat uniform in appearance, yet the numerous channels and gravel bars endow these areas with a complexity that permits material sites to be located with little effect.

The usual mining technique for these sites is to scrape unvegetated gravel bars rather than to excavate deeply, thus, any rearrangement of channels through an abandoned site would closely resemble the natural annual processes of lateral channel migration.

In summary, braided river floodplains can be desirable locations for extracting gravels (Table 40). The abundance of well graded materials and the potentially small effect on the physical, biological, and aesthetic characteristics suggest the desirability of these areas for material sites. This conclusion assumes that the procedures of shallow scraping of unvegetated gravel bars with minimal disturbance to active channels, banks, and vegetated areas, and complete rehabilitation of sites during site closure, are adhered to.

Split Channel

A river with a split channel pattern has numerous islands dividing the flow into two channels. The islands and banks are usually heavily vegetated and stable (Figure 93). The channels tend to be narrower and deeper and the floodplain narrower than in a braided system. Four split channel rivers were included in this study: the Kavik, Kuparuk, and Sagavanirktok Rivers on the North Slope and the Sinuk River on the Seward Peninsula.

Although the bed load carrying capacity of split channel rivers is less than for braided systems, they often have a greater carrying capacity than equivalently sized meandering or sinuous rivers. The narrower floodplains and lack of numerous gravel bars restrict the extent of potential gravel removal areas. Channels, islands, and banks are often used for extraction, as was the case at the four sites studied. Islands and banks typically are vegetated and relatively stable, consequently, there is a direct effect on small mammals, passerines, ptarmigan, and moose utilizing these areas. The long-term terrestrial disturbance is directly related to the extent of vegetation removal and the rehabilitation practices used during site closure.

Table 40. Interdisciplinary Rating of Cumulative Effect of Scraping, Using Various Indices of Change, on Selected Study Sites Visited from 1976 to 1978[a]

River type	Study site	Location	Hydraulic effects: Increased braiding	Hydraulic effects: Degree of hydraulic alteration	Aquatic effects: Fish habitat diversity	Aquatic effects: Macroinvertebrate standing crop	Terrestrial effects: Riparian vegetation	Terrestrial effects: Water bird habitat	Index of Environmental change
Braided	Ivishak R	North Slope	6	6	5	8	5	5	1.8
	Dietrich R-US	Northern Interior	5	5	8	5	1	6	1.3
	Dietrich R-DS	Northern Interior	6	6	7	3	3	8	1.8
	Phelan Ck	Southern Interior	5	5	5	5	5	5	0.0
Split	Sinuk R	Seward Peninsula	6	7	2	5	1	6	1.8
	Kuparuk R	North Slope	6	6	2	1	5	5	1.5
	Sagavanirktok R	North Slope	8	7	8	9	1	8	3.2
	Kavik R	North Slope	8	7	3	3	4	6	1.8
Meandering	Aufeis Ck	North Slope	9	8	1	5	1	7	2.8
	Skeetercake CK	North Slope	7	8	4	5	1	6	1.8
Sinuous	Gold Run Ck	Seward Peninsula	5	6	5	5	3	5	0.5
	Washington Ck	Seward Peninsula	10	9	0	2	1	6	3.7
	Penny R	Seward Peninsula	10	10	2	4	1	9	3.7
	Nome R	Seward Peninsula	10	8	4	8	4	5	2.2
	Ugnuravik R	North Slope	7	7	5	10	4	5	1.7
	Shaviovik R	North Slope	5	6	5	5	5	5	0.2
	M.F. Koyukuk R-US	Northern Interior	9	7	9	2	3	7	2.8
	M.F. Koyukuk R-DS	Northern Interior	7	7	4	9	3	6	2.0
	McManus Ck	Southern Interior	5	7	5	5	4	5	0.5
Straight	Oregon Ck	Seward Peninsula	10	8	0	3	1	6	3.3

[a](5 = no change, 0-4 = decrease in parameter, 6-10 = increase in parameter)

[b]Index of environmental change (IEC) = $\sum_{i=1}^{6} \frac{|x_i - 5|}{6}$ where x_i = rating values of disciplinary indices; IEC ranges from 0-5.

Lowering islands and banks by removing gravel, even if maintained above the existing water level, can result in reduced stability of channels during high water. Material sites will then be inundated at least temporarily. Spreading water over a broader area reduces its velocity, causing deposition of suspended and bed load materials. Some of this reduced velocity may function to replenish materials in the abandoned material site but this process would probably require a longer period than would be expected in a braided system.

Spreading of water and reduction of velocity is conducive to changing water temperatures during the open water season. Altered water temperatures may influence the abundance and diversity of aquatic biota by altering the amount of usable habitat for particular species.

The reduced stability of the channels that could occur after site closure could be detrimental to the establishment of permanent biotic populations, in particular, benthic organisms. In addition, entrapment of fish in pockets and pools in the disturbed site may occur as water recedes into the active channels following high-water conditions.

The increased deposition of both suspended and bed load materials could be detrimental to the establishment of benthic communities. Fine materials would likely be deposited in these areas, thus changes in the structure of benthic communities could be expected. These changes would be from organisms adapted to coarse substrate to those able to exist on finer less stable substrate.

Changing channel configuration by removing islands, removing gravel deposits from banks, and locally widening the active floodplain will affect the scenic quality of an area. This aesthetic effect was quite noticeable at the Sinuk and Kavik River sites where care was not taken to preserve natural contours and channel configurations. In addition, stockpiles and remnants of diversion berms were left in place. The net effect of these conditions was to form a major contrast with the natural conditions occurring both upstream and downstream of the site.

In summary, the split channel system is one that contains a relatively large quantity of gravel material, but its narrow floodplain with stable islands and banks restricts the areal extent where gravel can be easily obtained. Use of vegetated areas will directly affect terrestrial organisms by either complete removal or displacement to undisturbed areas. Similarly, the tendency for localized widening of the floodplain will reduce lateral stability of channels, facilitate the possible formation of a braided channel pattern, decrease water velocity, increase sedimentation rates and, perhaps, increase water temperature. These changes will affect aquatic organisms by increasing secondary productivity, by changing benthic community structure, by providing rearing areas for some species of fish, and perhaps by affording situations conducive to fish entrapment (Table 40).

Meandering

A meandering river winds back and forth within the floodplain. The meandering channel shifts downvalley by a regular pattern of erosion and deposition. Few islands are found in this type of river and gravel deposits typically are found on the point bars at the insides of meanders (Figure 93). Sediment transport in meandering systems is usually less than for braided and split-channel river systems of equivalent size.

The size of individual gravel deposits in a meandering river depends on the size of the river. On a large river, point bars can be quite extensive while on smaller rivers the point bars are characteristically smaller. The areal extent of these gravel bars determines, to a large extent, the degree of change which gravel extraction has on a meandering system. For example, if a large point bar is used to supply gravel for a small project, the operation of a material site may cause little change to the river system. However, when projects with large gravel requirements are situated close to a small meandering river or where the gravel requirements exceed that available on a large point bar, potential effects to the river system increase greatly. The alternative mining procedures are to completely remove the point bar, use several point bars, or remove vegetated deposits back from the channel. In all cases, varying degrees of impact can be expected, but all will depend on the manner in which the gravel is extracted.

Four material sites on meandering systems were studied on this project (Table 1). Two were dug as pits and two were scraped.

Pit Sites. The material sites at Prospect Creek and West Fork Tolovana River were dug in abandoned channels. In neither case was there a change in the lateral stability of the active channel. There was loss of terrestrial vegetation and associated fauna because the material sites were located back from the active channels. Aquatic fauna in the active channel apparently did not change. Change, if any, was due to the presence of an adjacent flooded pit. Similarly, water quality did not change in the active river channels but, as expected, water quality in the pit was different from that in the active channel. These differences and changes are discussed in the section on Type of Gravel Removal because they were not unique to meandering systems.

Formation of a permanently flooded pit within a floodplain, that otherwise contains few ponds or lakes, changes the appearance of the area by increasing the diversity of physical features. These pits are quite visible when seen from the air or from a high terrestrial vantage point. Tall vegetation in the areas of these two material sites contributed greatly to blocking view of the sites.

Many meandering river floodplains contain a multitude of oxbow lakes that are formed by channel cutoffs. In these cases, a pit could blend easily into the natural landscape, thus greatly reducing the visual effect of gravel removal operations. However, most pits are dug with angular perimeters which create a visual contrast in the floodplain. This contrast is a generic problem and will be discussed further under Type of Gravel Removal.

Scraped Sites. The material sites on Aufeis Creek and Skeetercake Creek were scraped. The environmental changes were quite different at the two sites resulting principally from differences in their locations relative to the channel (Table 40). The gravel at Aufeis Creek was scraped from across the entire channel, which changed the channel from a single to a braided configuration. The short-term influence was so severe that surface flow was nonexistent the year following site closure but, over 3 years surface flow was re-established. Although the site was not studied when surface flow was absent, the effect on fish would have been to prohibit passage. Epibenthic communities would have been reduced due to the lack of surface water. Following re-establishment of surface flow, benthic communities characteristic of riffle zones would be most common due to channel spread and reduced water depth.

The change from a single channel to a braided channel can significantly affect the local distribution of aquatic organisms. The altered community would be similar to that typically found in a naturally braided system. Reduced water velocity enhances sediment deposition and can alter water temperatures. During the study, changes in water temperature were noted between the upstream and disturbed sample areas, but a difference in suspended solids was not found.

The impact on the terrestrial environment frequently entails removal of vegetation and other habitats along the bank. Little change to the terrestrial environment would be expected when gravel is mined only on unvegetated gravel bars, unless the hydraulic characteristics of the channel are changed significantly following site closure. Also, little change would be expected in the scenic quality of an area as a result of gravel removal, unless vegetation is removed. At Aufeis Creek, changes in both the terrestrial environment and scenic quality resulted from the gravel removal operation because of the area disturbed, the site location, and operating procedures that were used, none of which complemented the floodplain characteristics.

At Skeetercake Creek the hydraulic changes were somewhat different. The exposed gravel deposits were limited because this was a small river. Thus, gravel was mined from vegetated areas in the floodplain, with concomitant effects on the terrestrial fauna. The gravel removal activity affected channel stability by facilitating a channel cutoff, however, the channel did not braid due, at least in part, to the restricted floodplain. The cutoff formed an oxbow lake in the abandoned site. The floodplain in this reach of the river had few oxbow cutoffs, consequently, mining changed the appearance of the area, However, the presence of overburden and gravel stockpiles detracted far more than the altered channel.

Aquatic habitat changes at Skeetercake Creek were not as great as would be expected if the channel had become braided. The narrowness of the natural channel imparted a greater significance to the value of bank vegetation. Loss of this cover can change the distribution of fishes. The change from an incised channel to a shallow riffle area through the abandoned site caused the water temperature, during the study, to be higher in the disturbed area than upstream. However, changes in suspended solids were not noted.

Summary. Scraping point bars can have little environmental effect assuming that the operation is conducted in a manner that minimizes changes to the hydraulic characteristics of the channel and adjacent vegetated areas. If change is minimized, the effects on aquatic and terrestrial biota, and water and scenic quality are greatly minimized.

Meandering rivers provide usable deposits of gravel from point bars, in inactive floodplains, and terraces. The potential effects on such a system vary depending on whether only point bars are used or whether the adjacent inactive floodplain and terrace also are mined. Sites in inactive flood-plains and terraces often are dug as pits while point bars in active flood-plains are scraped.

Pit sites remote from the active channel have caused some problems during spring breakup at sites visited during site selection, but not studied as primary sites in this project (unpublished data). When channels are blocked with ice, melt water must flow over the ice and may overflow the bank and spread across the entire floodplain. Pits located in these flood-plains are then subject to filling which can facilitate diversion of flow through the site. This diversion is particularly possible where pits are dug within the inside of a meander. Depending on the size and inherent stability of the undisturbed buffer between the pit and channel, the flow may cut through the buffer zone and permanently divert flow. Ultimately, the meander will be cut off through sediment deposition and form an oxbow lake.

Other effects can be anticipated when pits are dug in the floodplain of meandering systems, however, they are characteristic of pit mining. Therefore, these aspects are discussed under Type of Gravel Removal.

Sinuous

Sinuous channels are similar to meandering channels except that the winding pattern is less pronounced. The channel may contain smaller point bars and have less tendency for downvalley shifting. Also, the channels are more stable with respect to lateral shifting.

Ten of the sites studied on this project were on sinuous rivers (Figure 93). Their similarity to meandering channels suggests that the effects from gravel extraction are also similar, with the major influence determined primarily by the site location and the removal method. Due to this similarity only a few characteristics of mining gravel at sinuous channels are discussed.

The smaller point bars in sinuous rivers, as compared to meandering rivers, limit the quantity of exposed gravel that is locally available for removal. This limitation can magnify the need for using multiple point bars or vegetated areas back from the channel to fulfill the gravel requirements of larger projects.

Floodplain areas adjacent to the channel contain gravel deposits that are typically overgrown with vegetation. Floodplain width usually is roughly equivalent to the meander belt width, thus, the floodplain of a sinuous river tends to be narrower than in a meandering system. Therefore, the area in the floodplain that is available for gravel extraction is more limited. This places restrictions on the areal extent of potential gravel resources, and may require that a greater length of floodplain be used to extract gravel.

The potential effects of removing gravel from sinuous channel rivers are increased because of these limitations. If point bars are scraped too deeply, or if incised banks and the adjacent floodplains are disturbed, the potential for decreasing channel stability is greatly enhanced. The initial disturbance from site clearing, and the changes resulting from a poorly located and operated site, will have multiple effects.

The decreased channel stability and tendency for braiding will affect both benthos and fish by altering aquatic habitats. Benthic communities adapted to riffles, fine sediment bottoms, and a relatively unstable bottom, will become established. Loss of bank cover and potentially reduced current in the disturbed site will affect fish distribution and perhaps species composition. In addition, reducing water depth and velocity could change water temperatures and affect the level of dissolved oxygen. Fish could become trapped in the disturbed site when water recedes following high flows.

Terrestrial vegetated habitat will be destroyed when the floodplain adjacent to the channel is used as a material site. This destruction of vegetation will cause either elimination or displacement of terrestrial fauna. If the stream banks are affected the decreased hydraulic stability in the area could reduce the potential for re-establishment of vegetative communities, thus creating a long-term rehabilitation problem.

Gravel removal from a sinuous river will have effects on the scenic quality similar to those discussed for a meandering system. The degree of effect is fully dependent on the diversity of landforms in the area of the site and the amount of disturbance. Single channel river systems are scenically more sensitive than multiple channel systems particularly those single channel rivers located in areas with low growing vegetation, such as on the North Slope.

In summary, the amount of environmental change that can be anticipated in a sinuous river system is largely dependent on the location of the material site and the methods of operation. Anticipated effects are similar to those for a meandering system but, because floodplains generally are more narrow and contain smaller point bars, the potential for permanent alteration is generally greater (Table 40). Proper placement of the material site and operational procedures can minimize permanent change and these should be selected to prevent or minimize changes to the hydraulic characteristics of the channel.

Straight

Straight channel patterns are less common than other types. The thalweg of a straight river typically winds back and forth within the channel. Gravel bars form opposite where the thalweg approaches the side of the channel (Figure 93). These gravel bars may not be exposed during high flow. Banks of straight systems typically are stable and floodplains are usually narrow. These river systems are considered to be an unusual configuration in transition to some other configuration. Only the material site studied at Oregon Creek was situated on a straight channel system.

As with other types of single channel systems the major potential effect from scraping floodplain gravels is decreased stability of the channel and a tendency to develop a braided configuration. These are probable occurrences because of the typically narrow floodplains and the limited number of exposed bars available. Often the adjacent floodplain will have to be disturbed, or even the channel itself, because of the limited area available. The Oregon Creek site typified the extensive long-term changes that can occur when gravel is removed from within the channel and the adjacent floodplain (Table 40). The channel stability was greatly reduced and the channel had become braided within the confines of the abandoned site. These conditions exist 13 years after the site was closed and probably will remain in that condition for many more years.

The change from a single to a braided channel alters water quality parameters and aquatic biota as discussed in previous sections on sinuous and meandering systems. These alterations include the potential for changing water temperature and increasing sedimentation in the disturbed site where the water fans out and becomes shallower and slower in velocity. Dissolved oxygen and conductivity levels can also be altered. Benthic communities may change from a community associated with the relatively stable channel of a straight river to one that is better adapted to the less stable substrate characteristic of braided areas. Removal or alteration of vegetated banks and changes in pool:riffle ratios can alter the distribution of fish within the immediate vicinity of the disturbance. Fish passage is obstructed if the spreading of water sufficiently reduce its depth.

The disturbances at the Oregon Creek site provided a situation conducive to the formation of aufeis. Aufeis could have direct effects on fish by eliminating or greatly reducing the flow downstream from the ice field, thus threatening overwintering areas and spawning beds. Similarly, during breakup, delayed thawing of the ice field could obstruct fish passage. Benthic communities would be later in establishing at the disturbed site due to the delayed melt of the ice field.

The terrestrial environment will almost always be subject to disturbance for any site situated on a straight channel river. This vulnerability is due to the rarity of large exposed gravel bars in the channel which necessitates mining the adjacent vegetated floodplain banks or terrace. At the Oregon Creek site the vegetated overburden was removed and placed in a row at the edge of the terrace. The gravel was removed from the exposed area and from within the channel causing extensive spreading of the flow through the exposed floodplain. Inundation of this area during high flow and the build-up of an aufeis field greatly minimized the potential for stabilization and revegetation of the disturbed area. This stabilization and revegetation had not occurred after 13 years, thus the likelihood of the site revegetating in the near future is remote.

The appearance of the floodplain was greatly affected at the Oregon Creek site. This altered appearance will exist for a long time and will only diminish when the channel begins to narrow and when adjacent areas revegetate. The potential for major changes in the appearance of a straight channel floodplain, that is mined, is great because of the limited availability of exposed gravels, which necessitates the disturbance of adjacent vegetated areas. The magnitude of effect increases with a decrease in river size.

In general, the rarity of straight channel rivers probably is fortunate from the standpoint of gravel requirements. The relatively few exposed gravel deposits and the narrow floodplains suggest the major problems that can result from gravel removal operations in these systems. Major disturbances probably will occur in any river of this type unless precautions are taken to protect the area. When mining is restricted to exposed gravel deposits a major length of floodplain will be disturbed if gravel requirements are large. The latter problem can be prevented by restricting mining to the adjacent vegetated floodplain. Straight channel systems should be avoided where it is possible to select alternate areas to mine.

DRAINAGE BASIN SIZE (CHANNEL WIDTH)

Drainage basin size and channel width are closely related from a hydrological standpoint and analysis of only the former would be sufficient for assessing change from gravel removal activities. However, channel width was included in the Major Variable Matrix (Table I) because it is a measurement easily obtainable in the field while drainage basin must often be estimated from topographical maps. Because of the close relationship between these two parameters, the following discussion applies to both.

Drainage basin size (channel width) was considered to be the second most important Physical Site Characteristic influencing the amount of change in a floodplain from gravel removal activities. In general, the effects of mining were considerably greater on small rivers than on large ones. The determining factor is the amount of exposed gravel material available within the floodplain. In larger systems, gravel deposits can be numerous and any given deposit usually contains a large quantity of material. The situation is the opposite in a small river - the few exposed deposits generally do not contain much material.

In large rivers, a given amount of gravel can be removed from exposed deposits with relatively less effect on the floodplain than at a small river. If gravel requirements are very large, the alternatives are to use multiple gravel deposits along the channel, or to expand the areal extent of one site to include adjacent vegetated areas. In a small river system, there are no real options. Gravel has to be removed from adjacent vegetated areas, or from the active channel, or both. This solution was the case for seven of the small rivers studied. The Gold Run Creek site exhibited less change than the other small river systems (except for the site at Phelan Creek where vegetation was not removed). At Gold Run Creek the gravel removal operation was restricted principally to gravel bars and an island in the channel. A bank was removed but the degree of floodplain disturbance was less than for the sites on Washington, Oregon, and McManus Creeks, and Penny River. At these latter sites, extensive adjacent floodplain disturbances tended to either greatly expand the channel width or divert the channel.

Phelan Creek is a braided system and has a small drainage basin above the material site. Although the site is situated near the headwaters, the channel is of medium width because of flow carried in the summer during glacial melt. In this case the large exposed gravel deposits were scraped and the material site included neither vegetated areas nor channels carrying flow. Even though this is a small river system, the long-term effects are minimal because of other overriding factors. Minimal effects are usually not the case, however, on small rivers.

Location of the material site is most critical on small river systems because of the limited availability of exposed gravel deposits and the relatively narrow floodplain. Extensive damage can occur to the entire floodplain reach being mined in these systems, while on large rivers the effects are not as great because the material sites cover a smaller proportion of the floodplain. Location of sites and potential effects are discussed in a subsequent section.

CHANNEL SLOPE AND STREAM ORIGIN

Neither of these Physical Site Characteristics was found to greatly influence the effects of gravel removal in floodplain environments. Both channel slope and stream origin are closely related to such factors as drainage basin size and channel configuration, therefore, their influence on the effects of gravel removal are dependent on these factors. The Physical Site Characteristics are discussed separately because of specific implications involved.

Channel Slope. Removal of gravel from a channel will affect the channel slope within the site and, perhaps, immediately upstream and downstream. Usually this effect entails increasing the slope, which can have localized effects on the floodplain. The main effect is to increase water velocity.

Localized changes that can be expected due to the relationship of increased velocity and increased slope are scour and alterations of aquatic communities. Increased scour in a disturbed site can increase downstream deposition of bed load materials where the water slows to the velocity characteristic of the undisturbed channel. The greater scour potential in the disturbed site decreases the stability of bed materials thus affecting habitat for benthic organisms.

Increased water velocity can directly affect benthic organisms by displacing those not adapted to higher velocities and favoring those adapted to these conditions. Similarly, fish may become redistributed locally because of water velocity changes. Those fish species or age groups preferring lower velocities may displace to areas upstream or downstream.

Altered velocity is not expected to change the terrestrial environment or the scenic quality of an area. Indirectly, an effect might occur to water-associated birds that are dependent on benthic organisms as a food source. Any alterations to benthic communities could alter feeding sites for these birds.

Significant changes in slope most often reflect changes in channel length. If a channel is shortened by mining then the slope is increased; if the channel is lengthened, the slope is decreased. At all study sites the slope was either unchanged or it increased. The likelihood of decreasing channel slope by lengthening the channel is slight because water tends to flow downvalley over the shortest distance. However, if channel lengthening should occur by diversion through a site, then the effects would reflect reduced velocities.

Stream Origin. The origin of the stream was found to have little or no relationship to the effects of gravel removal activities. Origin can influence, at least in part, other characteristics of a river system, e.g., channel configuration and shape. Therefore, the preceding discussions are indirectly related to this characteristic. The origin of a stream determines greatly the quality and quantity of gravel materials available in downstream areas.

The original purpose for including stream origin in the study was to maximize diversification of the types of sites to be studied. The origins of streams included were mountain, foothill, coastal plain, and glacial. Twelve of the sites studied were of mountain origin, 9 were of foothill origin, and only 4 were of glacial or coastal plain origin.

The availability of gravels in streams of coastal plain origin is generally low and the materials are finer in texture than those found in other systems. Within the geographical limits of our study, only the Seward Peninsula and North Slope have coastal plains. The coastal plain of the Seward Peninsula is so narrow it precludes the existence of such river systems. On the North Slope material sites were located on the Sakonowyak, Putuligayuk, and Ugnuravik Rivers, but only the latter was studied. Generally, these sites are not favored and are only used if alternative sites are not available. The lack of rock in the headwaters and the low mean annual discharges are the reasons that gravel materials are only minimally available in coastal plain streams. If these sites are utilized, the potential for replacement of gravel sources is very low even over extended time periods. The minimal areal extent of exposed gravel bars also generally leads to extensive damage to the river system either by use of extended lengths of river channel or by disturbing vegetated floodplains.

Glacial origin streams are not common in the area of study; only three sites situated on this type of river were studied. These were on Phelan Creek and the Tanana River. Because these systems are of mountain origin, the availability of weathered parent materials is not limiting and usually large quantities are available. The Phelan Creek site was situated near the glacier and gravel was abundant across a wide area. The proximity of the site to the glacier strongly influenced the seasonal fluctuations in discharge. During winter, water flow from the glacier is greatly reduced and is supplemented by that from associated springs. This reduced flow exposes vast expanses of gravel for extraction.

The Tanana River sites are well downstream from the river origin, therefore, water flows throughout the year because of the numerous spring- and groundwater-fed tributaries entering the river. Affects include those associated with braided channels that flow in winter. In these systems, however, ice cover on channels is more of a factor than on a system like Phelan Creek, near its origin.

The availability of gravels in glacial origin rivers makes them a viable source of materials even when needed in large quantities. This is basically true for systems of all sizes although on smaller rivers the localized deposits are more restricted.

Most rivers in northern and interior Alaska are of mountain or foothill origin. The weathered parent material in the headwaters provides large quantities of gravels, particularly in the mountain systems. These rivers are fed by springs, melt water, and runoff and, therefore, discharge fluctuates seasonally. Spring-fed systems can be expected to have at least intergravel flow in winter. Moderate to steep channel slopes are normal in the headwaters but these slopes are influenced by the length of the river and the topography through which it flows. Bed load movements are usually higher than in rivers with mild slopes. These rivers generally have large quantities of gravel available even near the mouth. The size of the system and other hydrological and hydraulic factors also influence availability of gravel. The abundance of mountain and foothill origin rivers and the frequent availability of suitable gravel materials generally combine to favor the location of material sites in these systems. The geographical location of these rivers, and the topography through which they flow, directly affect the type of channel configuration, a factor discussed in a previous section.

GRAVEL REMOVAL AREA CHARACTERISTICS

In the preceding section on Physical Site Characteristics it was apparent that not all characteristics were important in evaluating the potential floodplain change caused by gravel removal activities. In contrast, all of the factors discussed in this section were found to greatly influence the amount of change to a river system. The three main features discussed are type of gravel removal (pit or scrape), location of the material site relative to the active channel(s), and the occurrence of dikes and stockpiles. Singularly and in combination these factors caused varying degrees of change at the 25 study sites, in some cases, irrespective of the specific physical site characteristics.

TYPE OF GRAVEL REMOVAL

There are two basic types of material sites: pits and scrapes. Pits are dug deeply, usually with draglines or backhoes, and are flooded year-round after site closure. In many cases pits are flooded during gravel extraction unless water is pumped out to keep the site relatively dry. Eight pit sites were studied and they represented two types, those connected to an active channel and those completely separated from an active channel by a buffer zone. Pits usually are situated away from an active channel.

In a scraping operation, gravel deposits are removed with bulldozers or scrapers in active and inactive floodplains and terraces. Gravel is extracted by successive removal of thin layers, and scraping depths usually are sufficiently shallow to minimize the occurrence of surface water. At certain study sites, gravel was extracted below the water table, thus water ponded in the site. This situation is not conducive to a scraping operation and, therefore, is usually avoided unless it is required for other reasons.

Pits

Pits are usually excavated away from an active channel and cause little or no change to the natural hydraulic processes of the channel. Where pits are connected to a channel, either year-round or seasonally, some change to the hydraulics of a river can occur. The most obvious alteration occurs when spring breakup or other high water flows spread throughout the floodplain; much of the water can flow out of the channel because it is often filled with ice. A pit in the floodplain probably would fill during high flows and then, through erosional processes at the upper and lower ends, function as a channel. The inlets or outlets (or both) connecting the pit to the channel could enlarge significantly and reroute flow through the excavated pit. Depending on site conditions this could be only temporary, for example, where a pit is adjacent to a relatively straight reach of channel. In this case, following high breakup flows, the water would again flow down the original channel because the downvalley distance is shorter than if the water flowed through the channel formed by the pit.

A permanent alteration to flow is more likely to occur where a pit is located on the inside bend of a meandering stream. Even with undisturbed buffer zones separating the pit from the channel, spring breakup flows can overflow the pit and exit into the downstream reach of the meander surrounding the pit. If the stability of the buffer zone is low, erosion can breach the buffer zone, thus, connecting the pit to the active channel. The downvalley distance is shorter through the pit, consequently, there would be a tendency for permanent redirection of flow through the pit and eventual cut off of the meandering channel.

Excavation of a pit separate from the channel does not affect the water quality of the active channel. As would be expected, however, the water quality is different in a flooded pit than in the channel. In comparison to channel waters, pit waters typically have higher temperatures during ice free conditions, the dissolved oxygen levels are lower, and sometimes there is stratification of both temperature and dissolved oxygen. Differences in water quality parameters could be less in situations where channel flow is through a pit. This difference depends on the size of the pit and the amount of mixing. A pit could facilitate deposition of suspended and bed load materials if flows are through a pit and velocity is decreased.

The aquatic biota of pits differ depending on whether there is an opportunity for exchange between the pit and the active channel. Those pits that are separated (e.g., Tanana River-Downstream) or have little potential for exchange (Dietrich River-Upstream) typically are unproductive. The Tanana River-Downstream pit is situated in the middle of an island and is completely surrounded by a broad undisturbed (except for an access road) timbered buffer zone. The likelihood for injection of nutrients and organisms into this pit is remote, except during high flows. The aquatic surveys reflected this. The occurrence of a few fish suggests that overflow may occur at irregular intervals. The Dietrich River-Upstream pit, on the other hand, is connected by its outlet to the channel. A spring, exposed during excavation, floods the pit and exits through a channel. The pit system has been used by overwintering fish but the pit itself is relatively unproductive.

All other pits studied were highly productive and the diversity of the fish community was usually increased over that in the river channel. All of these pits were connected to the river channel through either inlets or outlets and thus exchange was possible between the two systems. The still waters in the pit, which are warmer than the river water, provided conditions more suitable for primary and secondary productivity. Fish such as Arctic grayling entered presumably to utilize the pit as a feeding area. This situation is particularly good for feeding by fish of younger age classes because of the greater supply of food available and the lack of a current.

Fish well suited to a still water environment, such as northern pike and burbot, also did well in some of these pits and, being piscivorous, had an abundance of young age classes of other fish to feed upon as they entered the pits to feed and rear. Northern pike also utilized two of the pits as spawning areas. The potential for the pits to provide a more diversified fish community in the river also exists because of the connection between the two systems. This increased community diversity may be restricted to the area of the channel in the immediate vicinity of the pit.

Pit depths are important to fish utilization. Obstructions to movement are not a factor during open water periods if either an inlet or outlet are available for fish movement between the river and the pit. A potential for fish entrapment exists, however, during winter when ice cover is present on the river, the pit, and the interconnecting channel. In the latter situation the pit must be sufficiently deep so it does not freeze to the bottom and decomposition of aquatic vegetation does not decrease the oxygen content of the water below that necessary for fish survival.

The creation of a pit in a floodplain constitutes a major change to the local terrestrial environment. Pits are usually situated on vegetated floodplains, consequently, terrestrial habitat is almost always destroyed. The depth of excavation and the permanent inundation that results also greatly retards or prevents on the long-term, the re-establishment of predisturbance conditions. What most frequently occurs, however, is the creation of a more diverse habitat with concomitant changes in faunal communities.

The creation of a pit in meandering river floodplains, that contain oxbow lakes, merely adds to the habitat diversity in a localized area. Where pits are located in floodplains lacking natural lakes and ponds, the effect is again principally local, but has implications that affect a much larger system. In these cases, the newly formed body of water can attract migrant waterfowl and shorebirds and perhaps even provide habitat suitable for nesting and rearing that did not previously exist. The higher aquatic productivity of many of these ponds could afford a significant food source for those species adapted to feeding in pond and lake environments.

The effect of creation of a pit, on the scenic quality of an area, is totally dependent on the diversity of the floodplain environment. A pit will have less effect where lakes and ponds occur naturally than where these types of aquatic systems do not occur. Where lakes and ponds do not occur location should be selected so that view of the site is blocked from vantage points. For example, the Tanana River-Downstream pit, which is large and contains very clear water, is in a floodplain where the river channels are highly turbid, thus, offering a dramatic visual contrast. However, the site is situated on an island completely surrounded by a heavily wooded buffer zone which blocks view of the site from the Richardson Highway. The pit is visible only from the air.

Pits are often excavated with angular perimeters that ignore natural land contour. Since angularity is not characteristic of naturally formed aquatic systems the usual pit site offers some contrast even in areas where lakes and ponds occur naturally. Excavating these sites with perimeters that blend with natural land contours, such as in abandoned river channels, decreases the visual diversity that will result from development of pit sites. The West Fork Tolovana River and Tanana River-Upstream sites are excellent examples of this management technique (refer to Figures 63 and 70).

Pit sites require considerably less area to obtain a given amount of gravel than do areas that are surface scraped. Because of the depths normally required, subsurface waters are exposed, usually filling the pit during site operation. This water poses problems for the efficient extraction of materials but, since draglines or backhoes are usually used for excavation, the presence of water does not prevent the removal of gravels. Pumping is the only method used to eliminate the water but even this is impossible in some systems because of the volume of subsurface flow through floodplain gravels. During mining, the water in a pit is usually highly turbid and should not be pumped into adjacent channels.

In summary, there is little doubt that the excavation of a pit material site creates significant change in a floodplain environment (Table 41). If situated and operated properly, the hydraulics of the river system are little affected whereas significant changes occur to the terrestrial system and the scenic quality of the area. Differences in water quality and aquatic biota can be expected between a pit and the adjacent channel regardless of whether they are connected. The increase in both aquatic and terrestrial

Table 41. Interdisciplinary Rating of Effects of Pits on Associated Floodplains at Selected Study Sites Visited from 1976 to 1978 Using Various Indices of Change[a]

River type	Study site	Location	Potential for flow diversion		Aquatic habitat		Terrestrial habitat		
			Partial (relative frequency[b])	Full (potential buffer life)[c]	Fish habitat diversity[d]	Benthos standing crop[e]	Disturbance to riparian vegetation	Water bird habitat	Pit suitability index
Braided	Dietrich R-US	Northern Interior	3	4	2	2	1	7	3.2
	Tanana R-DS	Southern Interior	9	8	3	1	0	7	4.7
	Tanana R-US (lower)	Southern Interior	10	6	5	4	1	8	7.8
	Tanana R-US (upper)	Southern Interior	10	8	10	9	1	9	5.7
Split	None studied								
Mean-	Prospect Ck	Northern Interior	4	9	7	10	3	6	6.5
dering	W.F. Tolovana R	Southern Interior	6	10	10	5	1	9	6.8
Sinuous	Penny R	Seward Peninsula	1	4	5	3	2	6	3.5
	Ugnuravik R	North Slope	0	0	0	2	4	5	1.8
	Jim R	Northern Interior	0	3	3	10	1	9	4.3
Straight	None studied								

[a](Unless otherwise defined below, 5 = no change, 0-4 = decrease in parameter, 6-10 = increase in parameter.)

[b]Estimated frequency of some flow being diverted through site ranges from 0 = frequent (1 or more times per year) to 10 = infrequent (5-10 years).

[c]Estimated potential length of time before buffer becomes ineffective ranging from 1 = within a decade to 10 = greater than 3 decades.

[d]Relative to pits studied.

[e]Mean of the six ratings at a particular pit, potential range = 0-10.

[f]Scraped side channel acquired some characteristics of a pit following rehabilitation.

habitat diversity is reflected in a more diverse faunal community. Pit sites are a viable alternative for material extraction in areas where changes to the river hydraulics can be avoided or greatly minimized. When major hydraulic changes occur the effects on the environment can be damaging from many standpoints.

Scraped Sites

Scraped sites can occur essentially anywhere in a floodplain from within the active channel to vegetated areas in the inactive floodplain and terrace. Location of the site greatly affects the potential impacts that can be expected from a scraped site. Although scraping implies that material sites are operated by shallow removal of gravel, certain sites studied on this project were excavated below the water table and thus resulted in permanent flooding. These sites, however, were worked with scrapers or bulldozers and not draglines or backhoes as might be implied by depth of excavation.

Scraped sites have several operational advantages; usually the sites are dry, providing better working conditions and more efficient gravel extraction. Additionally, excavated materials require less handling when using scrapers to remove the gravel because only one machine is normally used to excavate, transport, and deposit at the construction site. This is not feasible using a bulldozer on a scrape or when digging pits with draglines or backhoes.

Given the same gravel requirement, the scraped site will generally disturb a larger area than a pit site because the excavation is more shallow. In the study sites, the large area affected was often the greatest problem of scrape-mining because there were few restrictions regarding avoidance of channels and areas adjacent to channels. Locations of extraction sites are discussed in the subsequent section.

Scrapes are generally situated in active floodplains adjacent to active or high-water channels. Lowering these areas spreads water flow, at least during high flows, and in some cases forms a braided configuration through the disturbed site. When this occurs on unvegetated gravel bars in braided systems, the effect on the floodplain is relatively minor because the effects are similar to natural hydraulic processes. After site closure, unless stockpiles or dikes are present, the disturbed site can return to a rather natural configuration within a maximum of a few years. This, however, is not the case where lateral bars are excavated to include removal of adjacent banks. Bank removal is discussed in the subsequent section.

The potential for causing braiding from scraping operations within the active floodplain, is usually insignificant in a river system that already has a braided channel configuration. However, in split channel and single channel systems braiding constitutes a significant change to the aquatic environment and alters the aquatic biota; species which benefit are those better adapted to riffle areas, to less stable substrates and, perhaps, to substrates less granular than those found in the natural system. These habitat changes primarily affect the distribution of organisms. This study generally found a local decreased diversity of the fish community as a result of braiding. There is a potential of blockage to fish passage, at least during low flow conditions, as occurred at the Aufeis Creek site because the water flows over a wider area than in the undisturbed channel. Blockage is most severe if the entire active floodplain is disturbed, not just the lateral bars. Entrapment of fish, in depressions created by scraping, is also possible during periods when water is receding from high flows.

Effects on the terrestrial environment depend greatly on the river type involved and on the location of the work area within the floodplain. In braided systems mined in the active floodplain, there essentially is no effect. However, on split and single channel systems, braiding caused by gravel mining can provide feeding habitat for shorebirds that utilize benthic organisms. Destruction of banks with associated vegetation removes habitat used by terrestrial fauna; the effects are the same as removal of vegetation for pit sites.

The potential for re-establishment of natural configurations and flow patterns after site closure are totally dependent on the degree of change to the hydraulic processes characteristic of the river system. Long-term effects can be expected where major changes to the stability of channels occur. The major terrestrial effect of scraping resulted where deep scrapes occurred in areas immediately adjacent to the channel. Channel flow often diverted through these depressions and caused year-round ponding which retarded the re-establishment of vegetation. These deep scrapes usually were inadequate as quality habitat for waterfowl and shorebirds and unsuitable for fish. To minimize short- and long-term effects, scraped sites should not be excavated beyond certain depth limits. These restrictions are discussed in the Guidelines Manual.

The effects of scraping operations on the scenic quality of a braided floodplain can be minimal if the material sites are restricted to the active floodplain. Where banks and vegetated areas are altered, significant effects can be anticipated. In split and single channel systems the establishment of a braided configuration in the disturbed area produces an unnatural condition in the floodplain, thus affording a visual contrast. Properly located scraping operations that avoided or minimized disturbances to the hydraulic characteristics of a river, minimized long-term environmental change. However, where sites were poorly located and caused significant changes to the channel hydraulics, major long-term effects were evident on the scenic quality of the area.

In summary, scraping operations typically occurred in both active and inactive floodplains. Both vegetated and unvegetated areas were used but the fewest long-term disturbances occurred where only exposed gravel deposits were scraped. The potential for broadening or diverting channel flow in split and single channel systems is great if depths of excavation are excessive and locations of sites are poor. The potential for braiding in these situations was increased with concomitant changes in aquatic biota. Terrestrial effects were greatest when the depth of excavation was excessive and led to permanent ponding which retarded recovery to predisturbance conditions. Visual effects of scraping operations depend greatly on the type of river system, the location of the site, and the areal extent of the site within the floodplain.

LOCATION OF GRAVEL REMOVAL

Location of a gravel removal operation in relation to the channel of a river was found to be the most important aspect influencing long-term change to a floodplain environment. Whether a pit or scrape, in general, the location of the site was a more important consideration than the type of site. Site location in this section is discussed with minimal reference to the type of site although the latter is a factor influencing the extent of change.

In-Channel Locations

As used in this project, in-channel gravel removal includes areas in the active channel, high-water channels, and abandoned channels. Fourteen of the sites studied on this project were situated in high-water channels and 7 of the 8 sites located in the active channel also included areas in high-water channels. From hydraulic and hydrological standpoints, material sites in active and high-water channels caused the greatest long-term change to the floodplain environment.

Active Channel. Gravel removal operations in the bed of an active channel cause a series of changes all basically related to changes in the depth and location of the thalweg. The degree of change depends on the type of channel configuration, principally whether it is a braided or a single channel. In a braided system the channels generally shift throughout the active floodplain on an annual basis. This is due to the lateral instability of the individual channels. In these systems removal of gravel has the effect of perhaps causing greater instability in the area of the disturbance. Changes occurring in a single channel river caused by removing bed material are unknown because all seven sites with this mining location had substantial alteration to adjacent deposits or banks.

Removing gravel from within the channel is accomplished either by dredging or by scraping the bed after flow has been diverted. Either method can result in a deepening of the thalweg and, if the edges of adjacent gravel bars or banks are removed, a widening of the channel. Depending on the location of the material site, this operation could alter the pool: riffle ratio in the river.

Where the channel is dredged, turbidity in and downstream of the site will increase greatly during mining. Turbidity should reduce quickly after the operation has ceased. If the channel is diverted during mining, the effects on water quality entail suspension of the fines exposed during mining when water is diverted back through the site. This suspension will result in a temporary increase in turbidity.

Reduction in the velocity of water entering the excavated hole will cause sedimentation of both bed load and suspended materials. This will aid in rapid replenishment of the gravel materials removed from the site. Being in the active channel, the replenishment rate is considered high compared to other areas in the floodplain.

Excavation of the channel bed can remove spawning areas. During a dredging operation fish probably will redistribute to less turbid waters. Benthic organisms adapted to silt-laden areas will establish following excavation and remain until the natural gravel bed becomes established.

Assuming that the disturbances resulting from gravel removal are restricted to the channel, and do not include the banks or edges of gravel bars, little long-term effect on the terrestrial environment is expected. Changes could occur if hydraulic changes in the channel affect adjacent banks.

Aesthetically, the in-channel material site has little or no effect. Hydraulic changes resulting from in-channel disturbance that affects banks can cause some effect.

High-Water Channel. High-water channels flow only during high-water periods. The hydraulic effects of removing gravel from high-water channels are not as great as they are in the active channel where the disturbed area is subjected to flow throughout the year. The changes that can be expected are similar to those described for the active channel although they occur only during the period when the site is subjected to flow.

Effects on water quality are only evident during the high-flow period. Localized widening or deepening of the high-water channel would slow the water velocity and thus facilitate deposition of both bed load and suspended materials. Depending on the degree of change to the channel this deposition would reduce the time required to re-establish near-natural conditions in the area. Also, any fines exposed during mining would be available for suspension during high flows.

Removing gravel from a high-water channel could trap fish and benthic organisms in the depressions of the disturbed areas as flow recedes. Many benthic organisms that are adapted to a riffle community and most fish species would not be able to survive in such a habitat.

Since high-water channels are subjected to less flow than active channels, they tend to be more stable and are usually bordered by established terrestrial vegetation. Any disturbance to these channels causing lateral instability during high flows could facilitate erosion of adjacent banks and thus serve to reduce the areal extent of vegetated areas. Loss of habitat would cause localized elimination of small mammals and displacement of birds and larger mammals. Having water pooled in the high-water channel during low-flow periods could attract shorebirds, particularly where a benthic fauna has become established to serve as a potential food source.

The most serious effect from a gravel removal operation in a high-water channel is bank destruction which often occurs with this type of operation. This aspect is discussed in a subsequent section on removing gravel from banks.

The effect of mining gravel from a high-water channel on the scenic quality of an area is minimal if the disturbance is restricted to the channel. If banks are destroyed the effect would be more significant. Since the high-water channel is active only part of the year re-establishment of pre-existing conditions will require a longer time. Formation of pits in high-water channels would have effects similar to those described in the section on Type of Gravel Removal.

Abandoned Channel. Abandoned channels carry water only during major flood events. Normally, these channels are considered to be dry during most years. Since they represent old river channels they usually contain reasonably large quantities of gravel, depending on the type of river with which they are associated. Only two of the sites studied were located on an abandoned channel, Prospect Creek and West Fork Tolovana River, both in meandering systems. Abandoned channels are common in this type of floodplain because of the formation of cutoffs that result from the fluvial processes of meandering channels.

Location of material sites in abandoned channels causes little problem with regard to changes in river hydrology and hydraulics because the sites are separated from active flow. Where pits are dug in abandoned channels and are connected to the active channel, flow can be diverted through the site during high flows. The magnitude and duration of this change is dependent on the nature of the connection between the material site and the channel and the integrity of the undisturbed buffer zone separating the site from the active channel. Where the once-abandoned channel carries water annually during high-flow stages, the effects to the floodplain would be similar to those described for sites in high-water channels.

Where an abandoned channel is scraped and the water table is not reached, water quality does not become a problem. Where pits become flooded, the water quality would be different than that occurring in the active channel, as is discussed in the section on pits.

Aquatic biota will not be affected in a scrape operation located in an abandoned channel, however, if a pit is dug, aquatic biota could become established. In these cases the effect depends on whether the gravel removal operation alters the site sufficiently to cause it to be subjected to annual high flow or whether it is connected to the active channel. In the former case, there is potential for entrapment of fish during high flow as was discussed for high-water channels. In the case of a site connected to a channel, the effects are those discussed in the section on pits.

The effects of removing gravel on the terrestrial environment can be greater in an abandoned channel than in other in-channel locations. Abandoned channels are rarely subjected to hydraulic forces, consequently, vegetation usually is established, and the stage of succession is dependent on the time since the channel ceased to carry flow. Thus, vegetation must be removed from these sites to expose gravel deposits. Removal of this habitat results in a loss of feeding, nesting, and cover habitat for those small mammals and passerines that utilize riparian shrub thickets. Larger mammals, being more mobile, are displaced to adjoining areas.

If the abandoned channel is scraped above the water table, the disturbed site will initiate primary plant succession following site closure. The time required to reach the predisturbance stage of vegetational succession is dependent on the geographical region and the vegetative characteristics of the area. This process is the same as occurs in other recently abandoned high-water channels and entails the same vegetational and faunal communities. If the site is a pit that is permanently flooded, the site would not return to a terrestrial environment in a relatively short time. However, overall habitat diversity is increased. Further discussion of these aspects is included in the section on pits.

The effects of siting a gravel removal operation in an abandoned channel, on the scenic quality of an area, reflect the changes occurring to the terrestrial vegetation. The short-term effect is to expose an area that was previously vegetated. The long-term effect in a scraped site depends on the rate of revegetation of the disturbed area. Where a pit is dug the alteration is long-term but, in fact, could blend more with the interspersion of cutoffs and lakes occurring naturally in the floodplain.

Adjoining Channel Locations

The Major Variable Matrix (Table I) includes four subdivisions under adjoining channel locations. These are: point bar, lateral bar, mid-channel bar, and bank. To thoroughly characterize the 25 study sites it was necessary to utilize all of these subdivisions but the gravel removal effects are similar for some. Therefore, the following discussion combines the three bar locations and discusses banks separately. Remember, at a given material site these bars and banks are associated with one of the three channel types discussed in the previous section.

Point, Lateral, and Mid-Channel Bars. This discussion only considers removing gravel from unvegetated bars with exposed gravel deposits. All three gravel bars are usually numerous in braided systems but, in single channel systems, usually only point and lateral bars are found.

The effect of removing gravel from a bar is to lower the elevation of the bar thus allowing flow to inundate an area that was previously above the low-flow water line. These sites are usually scraped. Maintenance of the integrity and conformation of the bar will cause little permanent change to channel hydraulics and will facilitate replenishment of the gravel during subsequent high flows. Changes in the active channels can and probably will occur where bar integrity is not maintained. In a braided river system this change will be similar to the natural processes and the long-term effects will be minimal. In a single-channel system redistributing flow by removing bars can have long-term effects by changing the local hydraulics of the channel. This hydraulic change could either decrease the lateral stability of the channel or widen or deepen the flow because the cross-sectional area is larger. Where the banks are stable, the river eventually will equilibrate itself by reforming gravel bars as upstream bed load materials become available during subsequent high flows. Where banks are less stable it is possible that subsequent high flows will cause erosion due to the hydraulic forces acting on the once protected banks. This could significantly alter the local reach of a river.

This effect is less likely to occur in straight and perhaps sinuous river systems because the flow is relatively unidirectional down the floodplain and direct hydraulic forces on the banks would be less than in a meandering system. The effect on a meandering river could be to facilitate the formation of cutoffs by increasing the hydraulic force on the inside bank at the upstream end of a meander.

Removal or lowering of gravel bars will facilitate the spreading of river flow when water levels are higher than during the gravel removal operation. This flow spread has the effect of reducing the depth and velocity of the water and will increase sedimentation rates of both bed load and suspended materials. Additionally, water temperature and dissolved oxygen contents could change. Benthic communities would develop that are adapted to riffles and less stable substrate. Fish would become redistributed with younger age classes perhaps being attracted to the disturbed site where currents would be less.

The effects to the terrestrial environment, of removing gravel from a bar, are minimal if the integrity of the bar is basically maintained. The only changes that could be expected are if the hydraulic regime of the river channel is altered, thus, causing changes in adjacent vegetated areas. The spreading of flow between the banks when bars are removed might attract shorebirds for purposes of feeding. These effects would only be expected in single-channel systems.

Removing gravel from isolated material sites using accepted mining techniques from bars in braided river systems would have little or no effect on the scenic quality of a floodplain. The lateral instability of the channels that characterize these systems would cause any changes resulting from gravel removal to blend in with natural processes. Removal of bars in a single channel system will locally affect the appearance of the river system, the magnitude of effect depending completely on the degree to which the bar was disturbed. Any significant changes to the hydraulic geometry of the reach causing subsequent disturbance to adjacent vegetated areas will locally alter the appearance of the floodplain.

Banks. Probably the most consistent long-term changes to a floodplain occurred when banks were destroyed or greatly modified during a gravel removal operation. In these cases significant changes to the hydraulic geometry of the river occurred. Banks typically are stable and function to restrict the flow of the river to the channel except during high flows. When these are removed or disturbed the river is no longer contained and it begins to wander and erode the adjacent floodplain. This wandering results from the hydraulic forces of the river impinging on newly exposed bank material. Where banks are made of stable materials the degree of erosion should not be greater on the newly exposed bank than what occurred naturally before the site disturbance. Where the newly exposed bank materials are not stable erosion will occur at a rate faster than occurred previously. Also, if the newly exposed bank is situated at an angle to the flow different than what occurred naturally in that reach of the river, erosion could be aggravated because of the increased hydraulic force on the bank.

Generally, channel width increases with bank destruction. Previous discussion identified that increased channel width can result in reduced water velocity, reduced water depth, changes in water temperature, and dissolved oxygen, and increased sedimentation. Aquatic biota would reflect these altered habitat conditions by changes in benthic communities to those that are adapted to riffle areas with unstable substrate and changes in distribution of fish in the reach affected by the disturbance. Undercut and vegetated banks are heavily utilized by fish as cover and removal of this habitat can greatly reduce the local abundance of certain species.

The effects on the terrestrial environment include destruction of riparian habitat during site clearing with resultant effects on faunal distribution. The decreased lateral stability of the channel can cause more destruction after site closure if hydraulic forces erode newly exposed areas. In addition, even if the newly exposed banks are stable the hydraulic forces occurring over the disturbed site would retard the re-establishment of terrestrial floodplain habitat.

The effect on the scenic quality of the area will reflect the changes occurring to the terrestrial environment and to the hydraulic geometry of the river channel. Major changes to these aspects will greatly alter the appearance of the floodplain in the affected reach.

Locations Separated From Active Channel

The five specific site locations identified in the Major Variables Matrix (Table I) that are separated from the active channel are not mutually discrete locations. That is, a site can exhibit a combination of these locations by for example, being located near the channel on the outside of a meander. Hence it is more difficult to assess the potential impact for these locations than for those previously discussed. The following discussion has been separated into two sections: inside and outside of meanders, and islands. These then are discussed from the standpoint of whether a material site is near or distant from the active channel.

The essential factor with sites in all of these locations is whether diversion of the water out of the active channel and through the site is possible. The distance between the material site and the active channel is of major concern, but the height of the intervening bank certainly would be a necessary consideration in this evaluation.

Inside and Outside of Meanders. The location of a site on the outside of a meander is possible on any sized river system regardless of the areal extent of the material site. This, however, is not the case on the inside of meanders. In small river systems the areal extent of the floodplain or terrace circumscribed by the meander can be quite small. In cases where these were used for material sites, the surrounding areas, including the channel, were often disturbed by the gravel removal operation. Therefore, to limit activities to the inside of a meander and maintain undisturbed buffers the site must be located on at least a medium sized river.

Any activity inside a meander, that would reduce the integrity of the banks or weaken the cross-sectional area, could lead to premature cut off of the meander. In many Alaskan rivers during breakup, water often flows over the ice in the channel and, if sufficiently high, over the banks and down the floodplain. A depression resulting from a material site located near the channel on the inside of the meander would aid in channeling the water through the site. Depending on the erodability of the soil separating the material site from the channel, a channel could erode at both the upstream and downstream portion of the meander and thus eventually establish a cut-off. The erodability of the soil would govern the length of time required for this natural event to occur. When a pit material site is connected to the active channel, the probability of a cutoff occurring could be enhanced greatly, even in a very short time. Such an event occurred at Skeetercake Creek on the North Slope. The inside of a meander of this small river was mined for gravel and when the site was studied 11 years after site closure, a cutoff had occurred. The time required for this event to occur is unknown.

A pit visited during site selection, but not studied in this project, that showed a potential for channel diversion, was located at Hess Creek in the Southern Interior region. The buffer strip was breached during the first spring breakup following site opening while the site was being operated. The initial breach was temporary and the water remained in the active channel when the flow receded.

The key point of concern when mining in the inside of a meander is maintenance of a sufficiently wide undisturbed buffer zone between the active channel and the perimeter of the material site. The size will depend greatly on factors such as the discharge of the river, flood frequency, and soil erodability and must, therefore, be determined on a site-specific basis. In order to maintain the integrity of the channel over the long-term it may be necessary to dig deeper to obtain needed gravel volumes, rather than decrease the buffer width.

Buffer zones are similarly important to separate the active channel from material sites located on the outside of meanders. A breach occurring in this situation would lengthen the meander. This breach probably would be a temporary event during high flow periods and the river would maintain its main flow through the active channel during lower water levels because of the shorter downvalley distance. Periodic and aggravated damage to the area between the material site and the active channel and perhaps the creation of a backwater area in the material site, would occur from an outside meander breach.

It is obvious that the closer a material site is to the active channel the greater the probability of a permanent breach occurring in a short time.

Placement of a material site either on the inside or outside of a meander has no effect on water quality, regardless of the distance separating the site from the channel. However, if water is ponded the water in the pit would differ from that in the channel, as described in the section on pits. Changes in water quality could result if a breach occurs. These also are discussed in the section on pits.

Change will not occur to aquatic biota when material sites are located away from the active channel. However, if high flow conditions reach a material site, and cause either temporary or permanent ponding, fish could become trapped in the site when the water recedes. Effects similar to those described for connected pits could occur where the buffer is breached and a pit site becomes connected to the active channel.

In general, locating material sites back from the active channel will necessarily entail destruction of vegetative habitat. This will result in localized loss of small mammals and displacement of birds and larger mammals. If the area is scraped and does not become flooded during high water the site eventually will return to the predisturbance condition through processes of primary and secondary plant succession. The length of time required will depend on the regional characteristics. If the site is flooded because it was dug as a pit, or because depressions are at least temporarily flooded, vegetative re-establishment will be retarded.

Because of the soil binding characteristics of vegetation, maintenance of the vegetation on the buffer zone between the material site and the active channel is important. The wider this zone the less the likelihood of a breach. If a buffer breaches, the progressive erosion of soils and loss of overlying vegetation will result in prolonged impact to the terrestrial environment. Concern for maintenance of the natural hydraulic geometry in the floodplain while selecting a material site location, and while operating the site, will limit terrestrial change to the area of the disturbance.

The usual need to remove vegetation to operate a site away from the active channel will affect the scenic quality of the floodplain environment. The magnitude of effect will depend much on the shape of the site, whether it conforms to natural land forms, and what the vegetative structure is in the area. If the site is not visible from a road or other accessible vantage point, the overall impact will occur only from the air. The distance of the site from the active channel would not necessarily be related to the magnitude of impact on the scenic quality but this would be determined on a site-specific basis.

Islands. Material sites located on islands require the removal of vegetation. The distance between the perimeter of the material site and the active channel is the major consideration in the development of these sites. Islands are situated in the active channel most of the time, thus, the maintenance of buffer zone intregity is of greatest concern. If buffer zones are removed or greatly disturbed the net long-term effect could be the loss of the island, perhaps changing the hydraulic geometry significantly enough to cause other changes within the floodplain.

Sites that have been located on islands where the banks were disturbed or eliminated have had greater effect on the floodplain than those where the site was developed totally separate from the channel (e.g., Tanana River-Downstream). In the latter case there was no change detectable to the hydraulic regime of the channel. In the other cases, induced erosion of the disturbed banks has had more prolonged effects than where this erosion has not occurred. Again, of prime concern with material sites on islands, as with other sites separated from the channel, is maintenance of the natural hydraulic geometry of the river channel. If natural hydraulic forces erode islands in a given reach of a river, the presence of a material site, whether a pit or scrape, will weaken the integrity of the island after natural bank erosion reaches the perimeter of the site.

Development of material sites on islands where the perimeters of the sites are separated from the channel, will have little effect on water quality and aquatic biota. If the material site is flooded because it was deeply dug, the contained water will be different than the water in the active channel, as discussed under pit sites. If the site is flooded regularly during high-flow conditions there is a potential for fish entrapment as the water recedes. The long-term effect on aquatic biota depends on whether the site is permanently flooded and the depth of the water. If the site becomes connected to the active channel by breaching of the buffer zone, the effect may be development of a braided section with the accompanying changes. Flooding of depressions in the disturbed area could cause fish entrapment before the establishment of a braided pattern.

Terrestrially, the loss of vegetated habitat would result in loss of both small mammals and perhaps some larger ones. Loss would depend on the size relationship of the material site to the island, but would occur regularly where a large proportion of the island is disturbed for the material site. The mortality would occur as a result of animals not being able to cross the river channel(s) to adjacent floodplain habitat.

The loss of vegetation on an island reduces the amount of bird nesting habitat. This could affect the total productivity of an area more than if an equivalent amount of vegetation were removed along the edges of the floodplain. This assumes that the island provides some protection from mammalian predators unable to cross the intervening channels. Otherwise, the mobility of birds allows them to redistribute in the floodplain just as large mammals do that are dependent on floodplain habitat.

Material sites on islands will affect the scenic quality of the floodplain, but the type of vegetation characteristic of the area would determine the long-term visibility of the site. Where stands of timber block view of the site except from the air, as with the Tanana River-Downstream site, little change would occur. Where such timber is not present the material site could be quite conspicuous and affect the appearance of the floodplain environment more than if the site was located along the edge of the floodplain. In either case, maintenance of an undisturbed buffer zone between the material site and the active channel reduces the induced disturbances that could further detract from the natural appearance of the floodplain.

Summary. The problems associated with material sites located separate from the active channel are essentially dependent upon maintenance of the integrity of intervening buffer zones. Where this is maintained, and the hydraulic geometry of the river is not affected, very little or no change would be expected relative to hydrology-hydraulics, water quality, and aquatic biota. The terrestrial system and scenic quality of the floodplain will be affected because usually vegetation must be removed to expose underlying gravel deposits. Generally, sites located back from the channel are favored from a practical standpoint because they can be operated in a dry condition making for a more efficient and easier operation. Excavating a pit would be an exception because the depths of excavation would normally be below the water table.

DIKES AND STOCKPILES

The location of certain material sites and the gravel removal operations require the construction of a protective structure and/or the stockpiling of overburden and gravel in or near the material site. Protective structures prevent water from entering the material site and include channel plugs and diversion dikes. Overburden piles consisting of brush, slash, groundcover, and organic soil are located either permanently or temporarily, usually at the edges of sites. Gravel stockpiles are considered to be temporary and are located within the material site. Dikes and stockpiles of unused gravel were sometimes left intact when the site was abandoned, thus, contributing to the long-term effect of the gravel removal operation.

Any dikes or stockpiles deflecting or otherwise modifying flow patterns could aggravate the long-term hydraulic effects of the material site. Flow alterations could significantly modify the hydraulic forces in the local reach of the affected floodplain and cause other damage. Alterations to natural flow patterns in the winter could induce or aggravate aufeis formation.

The water quality of an area could be affected by the location of these structures in the floodplain. Any erosion of overburden piles by active flow could introduce large quantities of organic materials for suspension and eventual downstream deposition. Also, any structures that would impound waters, after high flows have receded, would result in differences in the water quality between the active channel and impounded waters.

Aquatic biota could be affected by the presence of obstructions. Fish could become entrapped behind any structures that impound water. The suspension of fines in the water column as a result of erosion could cause redistribution of fish and reduction of riffle invertebrates.

Overburden piles provided a nucleus for revegetation of abandoned material sites. The organics, and particularly the root stocks and slash, facilitated re-establishment of vegetation in localized areas of the site. Overburden piles were used for denning by ground squirrels and, because they were vegetated, provided habitat for small mammals and nesting passerine birds. Abandoned stockpiles of gravel were less prone to provide these conditions.

In the long-term, any alterations of flow patterns that resulted from abandoned structures probably would be detrimental to vegetative recovery on the site. Revegetation in these cases would only occur on the area above the high flow levels.

Abandoned structures in most cases further detract from the already affected scenic quality of a floodplain. Where the site is hidden from view except from the air abandoned structures would not alter the overall impact. However, in places characterized by tundra and low riparian vegetation, these abandoned structures can attract attention to the floodplain site.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

Not all of the major variables used to characterize the 25 material sites were significant determinants of gravel removal effects.

Among the Physical Site Characteristics, channel configuration was the most important. Potential floodplain change is least for a braided river and greatest for a straight river. Size of channel is a significant factor, with the least change to be expected in a large system and the greatest in a small system. This assumes equally sized material sites. Combining these two variables, (channel configuration and size) gravel removal operations can be expected to have the least effect on large braided rivers and the greatest effect on small straight rivers.

Influencing Physical Site Characteristics related to configuration and size are the availability and size of unvegetated gravel bars, floodplain width, and the distance that can be maintained between the mining site and active channel. For example, in a small straight river system the floodplain is narrow and gravel bars are neither plentiful nor large. Thus, to extract gravel, either a significant length of active floodplain or the adjacent inactive floodplain and terrace must be disturbed. In the latter case the narrowness of the floodplain forces the operation to closely encroach upon the active channel. In large river systems these problems can be less significant because gravel bars are larger and, if the inactive floodplain or terrace are used, the wider floodplain allows maintenance of a broader undisturbed buffer zone between the material site and active floodplain.

In the present study, channel slope and stream origin did not correlate with changes resulting from gravel mining. However, channel slope influences the bed load carrying capacity of a stream -- steeper slopes indicate greater carrying capacity. This relationship is useful in evaluating potential replenishment rates in a disturbed site after mining. Also, stream origin has an influence because rivers of mountain and glacial origin characteristically have larger quantities of gravel available than do rivers of coastal plain origin.

All of the Gravel Removal Area Characteristics were found to significantly influence the effects of gravel mining. The location of the material site relative to the active channel is considered to be the most important factor. Whether a material site is scraped or pit-excavated is important, but often pits are located away from an active channel, avoiding the types of changes that can be associated with scraping in active floodplains.

The major effects of pit sites located in inactive floodplains and terraces are the loss of vegetated habitat, the possibility for fish entrapment, a change in the appearance of the floodplain, and long-term delay in the re-establishment of predisturbance conditions. Where pit sites are situated well away from active channels they have little effect on the active channel and, there is little chance of contributing to channel diversion. When situated close to active channels, particularly on the inside bends in meandering systems, the possibility exists for diversion of the channel through the pit, eventually forming a channel cutoff in the meander. This problem highlights the importance of providing a buffer between the material site and the active channel. Where pit sites are of suitable size, of sufficient depth, and have contoured perimeters, they can increase local habitat diversity and provide conditions suitable for fish and various species of terrestrial fauna.

Scraped material sites in active floodplains have minimal effects on the floodplain environment when exposed gravel bars are only excavated above the water level and slope and contours are maintained resembling those of natural bars. Removal of vegetated areas or banks, which results in decreased lateral stability of active channels, or allows water to spread over a large area, is not desirable. Decreased water depth and velocity increases sedimentation rates, alters water temperature, and alters dissolved oxygen levels. These changes in aquatic habitat usually affect the local distribution and community structure of benthos and fish.

The effects of scraping in vegetated areas of inactive floodplains and terraces can be similar to those described for pits. However, long-term changes typically are minimal because the lack of standing water in the closed site will facilitate re-establishment of pre-mining vegetation conditions.

In-channel locations that are dredged have the potential for causing the least change to channel hydraulics, terrestrial biota, and aesthetics; however, they can have the greatest effect on water quality and aquatic biota. Gravel replenishment rates are highest in this location. Mining exposed gravel bars in active floodplains potentially has the least effect on terrestrial systems. Sites in inactive floodplains and terraces affect the terrestrial biota and scenic quality most, but potentially have no affect on the aquatic system. In general, the farther a material site is located from a channel the greater the potential effect on the terrestrial biota and scenic quality and the smaller the effect on the channel hydrology-hydraulics, aquatic biota, and water quality. This relationship constitutes the major tradeoff consideration in locating material sites in floodplains.

If material sites are located and operated to prevent or greatly minimize effects on channel hydraulics, and to utilize only exposed gravel bars, the probability of major localized changes to a floodplain is generally greatly reduced. Where exposed gravel bars are not available or are inadequate, a tradeoff decision between sites must be made that weighs the potential effects of aquatic disturbances against terrestrial disturbances. In these cases, minimization of hydraulic change to active channels should be important in the decision -- major hydraulic changes can have a greater long-term effect on terrestrial systems than the controlled disturbances associated with a site located in a vegetated inactive floodplain or terrace.

Dikes and stockpiles of gravel and/or overburden left in a material site after closure, have potential effects on the floodplain. These structures can alter channel hydraulics locally if they are subject to high flows. During high water the fines and organic debris may be introduced into the water and result in downstream sedimentation. Depending on their position and orientation relative to flow, dikes and stockpiles can also cause fish entrapment. Where overburden piles are above high-water levels, they can facilitate the establishment of vegetation after site closure. This vegetation provides habitat for small mammals and passerine birds. In some cases, revegetation at a site was found only on such overburden piles. This observation suggests that, as long as the piles are situated where they are not subject to inundation or hydraulic erosion, they can provide a source for revegetation of the site. Overburden piles may detract from the scenic quality of a floodplain.

RECOMMENDATIONS

The recommendations developed for each of the disciplines are generally in agreement, with several exceptions. All recommendations are generally designed to minimize change to the floodplain and to enhance re-establishment of predisturbance conditions.

1. River types that should be used in order of decreasing preference are: braided, split, meandering, sinuous, and straight. The major consideration in this preference is the availability of gravel from exposed bars. The largest volumes are available from braided systems and the least from straight systems. An additional factor is the decreasing floodplain width of the configuration series identified above. If areas adjacent to the channel must be used for gravel mining, greater overall change will result in straight systems.

2. River sizes that should be used in order of decreasing preference are: large, medium, and small. The rationale is the availability of gravels and width of floodplain. Larger systems have more gravel. The proportionally smaller disturbance in large systems will reduce the overall effect of gravel removal.

3. Mining gravel from active channels should be avoided to reduce detrimental effects on water quality, aquatic habitat, and biota. However, if hydraulic changes can be minimized, in-channel sites will replenish more rapidly than other areas and effects on the terrestrial biota and scenic quality of the floodplain will be avoided or greatly minimized.

4. Changes to channel hydraulics should be avoided in all cases, especially the establishment of a braided configuration in the disturbed site.

5. When possible, exposed gravel bars in large active floodplains should be considered for mining. A properly operated material site in these areas can minimize changes to channel hydraulics during low-flow periods, minimize changes to water quality and aquatic biota, minimize or eliminate affects on terrestrial biota, and maintain the scenic quality of the floodplain. In addition, the probability of gravel replenishment is increased.

6. Although pits reflect a major change from predisturbance conditions, they can increase local habitat diversity if suitably located and developed. They should be located to minimize the probability of channel diversion through the site. Adequate undisturbed buffers should be maintained between the material site and the active channel.

7. Organic debris and overburden should be spread over or piled in the abandoned site to promote revegetation and establishment of predisturbance conditions. This procedure must be conducted only in situations where there is a low likelihood of this material being eroded into active channels.

RECOMMENDED FUTURE STUDIES

During the present study a number of subject areas were identified that should be investigated.

1. Evaluation of gravel mining from coastal and upland sources; and, preparation of guidelines for users of these sources. These alternatives to floodplain sources have not been studied.

2. Evaluation of the effects of multiple sites on one river system. Such an investigation should be aimed at determining the critical, spatial, and temporal relationships of multiple sites. Gravel replenishment rate predictions should be an integral part of this investigation.

3. Several floodplain gravel removal sites should be investigated before, during, and after mining to assess the adequacy of the Guidelines Manual.

4. Several specific topics of the Guidelines Manual should be studied in detail to assess their adequacy, i.e., buffers, pit design, and active channel dredging.

APPENDIX A

Scientific names of flora and fauna identified in the text are presented in Tables A-1 through A-5. References are:

Herbaceous Vegetation - Hulten, E. 1968. Flora of Alaska and Neighboring Territories. Stanford Univ. Press. 1,008 pp.

Woody Vegetation - Viereck, L. A., and E. L. Little, Jr. 1972. Alaska Trees and Shrubs. U.S. Dept. Agric. Handbook 410. 265 pp.

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Birds - American Ornithologists' Union. 1957. Check-list of North American Birds. Port City Press, Inc., Baltimore. 691 pp.

American Ornithologists' Union. 1976. Thirty-third supplement to the AOU check-list of North American Birds. Auk 93(4):875-879.

Fish - Alaska Department of Fish and Game. 1978. Alaska's Fisheries Atlas. Vol. I and II. Alaska Dept. Fish and Game, Juneau, Alaska. 83 pp. + maps.

Bailey, R. M., J. E. Fitch, E. S. Herald, E. A. Lachner, C. C. Lindsey, C. R. Robins, and W. B. Scott. 1970. List of Common and Scientific Names of Fishes from the United States and Canada. Third edition. American Fisheries Soc. Spec. Publ. No. 6. 150 pp.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater Fishes of Northwestern Canada and Alaska. Fish. Res. Bd. Canada. Bull. No. 173. 381 pp.

Morrow, J. E. 1974. Freshwater Fishes of Alaska. Alaska Northwest Publishing Co., Anchorage, Alaska. 78 pp.

Table A-1. Vegetation Identified in the Text

Common Name	Scientific Name
Horsetail	Equisetum variegatum
Reed Bent Grass	Calamagrostis spp.
Poa	Poa spp.
Cotton Grass	Eriophorum spp.
Sedge	Carex spp.
Rush	Juncus spp.
Balsam Poplar	Populus balsamifera
Feltleaf Willow	Salix alaxensis
Littletree Willow	Salix arbusculoides
Paper Birch	Betula papyrifera
American Green Alder	Alnus crispa
Thinleaf Alder	Alnus tenuifolia
Chickweed	Stellaria spp.
Milk Vetch	Astragalus spp.
Oxytrope	Oxytropis spp.
Sweet Pea	Hedysarum Mackenzii
Dwarf Fireweed	Epilobium latifolium
Siberian Aster	Aster sibiricus
Fleabane	Erigeron spp.
Wormwood	Artemisia spp.
Hawk's Beard	Crepis nana

Table A-2. Mammals Identified in the Text

Common Name	Scientific Name
Arctic Ground Squirrel	*Spermophilus undulatus*
Red Squirrel	*Tamiasciurus hudsonicus*
Beaver	*Castor canadensis*
Tundra Vole	*Microtus oeconomus*
Singing Vole	*Microtus miurus*
Muskrat	*Ondatra zibethicus*
Gray Wolf	*Canis lupus*
Black Bear	*Ursus americanus*
Grizzly Bear	*Ursus horribilis*
Moose	*Alces Alces*
Caribou	*Rangifer tarandus*

Table A-3. Birds Identified in the Text

Common Name	Scientific Name
Whistling Swan	*Olor columbianus*
Trumpeter Swan	*Olor buccinator*
Canada Goose	*Branta canadensis*
Black Brant	*Branta nigricans*
Mallard	*Anas platyrhynchos*
Pintail	*Anas acuta*
Green-winged Teal	*Anas carolinensis*
Common Goldeneye	*Bucephala clangula*
Barrow's Goldeneye	*Bucephala islandica*
Bufflehead	*Bucephala albeola*
Red-breasted Merganser	*Mergus serrator*
Semipalmated Plover	*Charadrius semiphalmatus*
Ruddy Turnstone	*Arenaria interpres*
Semipalmated Sandpiper	*Caldris pusillus*
Western Sandpiper	*Caldris mauri*
Spotted Sandpiper	*Actitis macularia*
Northern Phalarope	*Lobipes lobatus*
Glaucous Gull	*Larus hyperboreus*
Herring Gull	*Larus argentatus*
Mew Gull	*Larus canus*
Arctic Tern	*Sterna paradisaea*
Alder Flycatcher	*Empidonax alnorum*
Tree Swallow	*Iridoprocne bicolor*
Violet-green Swallow	*Tachycineta thalassina*
Bank Swallow	*Riparia riparia*
Gray Jay	*Perisoreus canadensis*
Black-capped Chickadee	*Parus atricapillus*
American Robin	*Turdus migratorius*

continued

Table A-3. (Concluded)

Common Name	Scientific Name
Gray-cheeked Thrush	Catharus minima
Yellow Wagtail	Motacilla flava
Orange-crowned Warbler	Vermivora celata
Yellow Warbler	Dendroica petechia
Yellow-rumped Warbler	Dendroica coronata
Northern Waterthrush	Seiurus noveboracensis
Wilson's Warbler	Wilsonia pusilla
Common Redpoll	Acanthis flammea
Dark-eyed Junco	Junco hyemalis
Tree Sparrow	Spizella arborea
White-crowned Sparrow	Zonotrichia leucophrys
Fox Sparrow	Passerella iliaca

Table A-4. Fish Species Reported and Caught or Observed in Major Geographical Areas Represented by the Twenty-Five Sites

Common and scientific names[a]	Seward Peninsula		North Slope		Northern Interior		Southern Interior	
	Historical record[b]	Present study[c]	Historical record	Present study	Historical record	Present study	Historical record	Present study
Arctic lamprey *Lamptera japonica*	+		+		+		+	24[d]
Arctic cisco *Coregonus autumnalis*			+					
Bering cisco *C. laurettae*	+		+		+		+	23
Broad whitefish *C. nasus*			+		+		+	
Humpback whitefish *C. pidschian*	+		+		+		+	24
Least cisco *C. sardinella*	+		+		+		+	24
Round whitefish *Prosopium cylindraceum*	+		+	11	+	15,16,17,18,20	+	
Inconnu *Stenodus leucichthys*			+		+	17	+	
Pink salmon *Oncorhynchus gorbuscha*	+	2,5	+	9				
Chum salmon *O. keta*	+	2,5	+		+	18	+	24
Coho salmon *O. kisutch*	+	4,5,6			+		+	
Sockeye salmon *O. nerka*	+	5						
Chinook salmon *O. tshawytscha*	+				+	17,18,19,20	+	23
Arctic char *Salvelinus alpinus*	+	1,2,3,4,5,6	+	11,12,13,14	+	15	+	
Lake trout *S. namaycush*			+		+		+	

Continued

Table A-4. (Concluded)

Common and scientific names[a]	Seward Peninsula Historical report[b]	Seward Peninsula Present study[c]	North Slope Historical record	North Slope Present study	Northern Interior Historical record	Northern Interior Present study	Southern Interior Historical record	Southern Interior Present study
Arctic grayling *Thymallus arcticus*	+	1,2,6	+	8,9,10,11 12,13,14	+	15,16,17,18, 19,20	+	21,22
Pond smelt *Hypomesus olidus*	+							
Rainbow smelt *Osmerus mordax*	+		+					
Alaska blackfish *Dallia pectoralis*		5	+				+	
Northern pike *Esox lucius*	+		+		+	20	+	21,24
Lake chub *Couesius plumbeus*						17,18	+	24
Longnose sucker *Catostomus catostomus*	+		+		+	17,18	+	23,24
Burbot *Lota lota*	+		+		+	19,20	+	24
Ninespine stickleback *Pungitius pungitius*	+	4,5	+	7,9,13				
Slimy sculpin *Cottus cognatus*	+	2,3,4,5,6	+	9,11,12	+	15,16,17,18, 19,20	+	22
Fourhorn sculpin *Myoxocephalus quadricornis*	+		+	7				
No. of species reported	20		21		17		19	
No. of species captured		8		7		11		11 (or 12)

[a] Common and scientific names from Bailey et al. (1970).
[b] Primarily from McPhail and Lindsey (1970), Morrow (1974), and Alaska Department of Fish and Game (1978).
[c] Numbers refer to rivers as listed:

1 = Gold Run Ck	6 = Nome R	11 = Sagavanirktok R	16 = Dietrich R-DS	21 = W F Tolovana R
2 = Sinuk R	7 = Ugnuravik R	12 = Ivishak R	17 = M F Koyukuk R-US	22 = McManus Ck
3 = Washington Ck	8 = Aufeis Ck	13 = Shaviovik R	18 = M F Koyukuk R-DS	23 = Tanana R-DS
4 = Oregon Ck	9 = Kuparuk R	14 = Kavik R	19 = Jim R	24 = Tanana R-US
5 = Penny R	10 = Skeetercake Ck	15 = Dietrich R-US	20 = Prospect Ck	25 = Phelan Ck

[d] Possible lamprey observed at upper pit.

Table A-5. Aquatic Macroinvertebrates Caught at Study Sites During 1976-1978 Field Sampling

Taxon	Common name
Nematoda	round worms
Oligochaeta	earthworms
Plecoptera	stoneflies
Alloperla	
Arcynopteryx	
Capnia	
Diura	
Hastaperla	
Isogenus	
Isoperla	
Nemoura	
Paraperla	
Ephemeroptera	mayflies
Ameletus	
Baetinae	
Caenis	
Callibaetis	
Centroptilum	
Cinygmula	
Epeorus	
Ephemerella	
Heptagenia	
Rhithrogena	
Siphlonurus	
Odonata	dragonflies and damselflies
Enallagma	
Ischnura	
Libellulidae	
Trichoptera	caddisflies
Apatania	
Arctopsyche	
Brachycentrus	
Ecclisomyia	
Glossosoma	
Homophylax	
Hydatophylax	
Lepidostoma	
Leptocella	
Limnephilus	

Continued

Table A-5. (Concluded)

Taxon	Common name
Oecetis	
Onocosmoecus	
Phryganea	
Platycentropus	
Polycentropus	
Pseudostenophylax	
Psychoglypha	
Rhyacophila	
Hemiptera	water bugs
Corixidae	waterboatman
Coleoptera	beetles
Dytiscidae	diving beetle
Haliplidae	
Diptera	flies
Athericidae	
Ceratopogonidae	biting midge
Chironomidae	midge
Ephididae	
Empididae	
Psychodidae	
Simuliidae	blackfly
Tipulidae	crane fly
Hydracarina	mites
Mollusca	molluscs
Lymnaea	snail
Physidae	snail
Pisidium	fingernail clam
Planorbidae	snail
Valvata	snail
Amphipoda	amphipods
Gammaridae	

APPENDIX B

GLOSSARY

abandoned channel -- A channel that was once an active or high-water channel, but currently flows only during infrequent floods.

active channel -- A channel that contains flowing water during the ice-free season.

active floodplain -- The portion of a floodplain that is flooded frequently; it contains flowing channels, high-water channels, and adjacent bars, usually containing little or no vegetation.

aesthetics -- An enjoyable sensation or a pleasurable state of mind, which has been instigated by the stimulus of an outside object, or it may be viewed as including action which will achieve the state of mind desired. This concept has a basic psychological element of individual learned response and a basic social element of conditioned social attitudes. Also, there can be ecological conditioning experience because the physical environment also affects the learning process of attitudes.

algae -- Primitive plants, one or many-celled, usually aquatic and capable of elaborating the foodstuffs by photosynthesis.

aliquot -- A portion of a gravel removal area that is worked independently, often sequentially, from the other portions of the area.

alluvial river -- A river which has formed its channel by the process of aggradation, and the sediment by which it carries (except for the wash load) is similar to that in the bed.

arctic -- The north polar region bounded on the south by the boreal forest.

armor layer -- A layer of sediment that is coarse relative to the material underlying it and is erosion resistant to frequently occurring floods; it may form naturally by the erosion of finer sediment, leaving coarser sediment in place or it may be placed by man to prevent erosion.

aufeis -- An ice feature that is formed by water overflowing onto a surface, such as river ice or gravel deposits, and freezing, with subsequent layers formed by water overflowing onto the ice surface itself and freezing.

backwater analysis -- A hydraulic analysis, the purpose of which is to compute the water surface profile in a reach of channel with varying bed slope or cross-sectional shape, or both.

bank -- A comparatively steep side of a channel or floodplain formed by an erosional process; its top is often vegetated.

bank-full discharge -- Discharge corresponding to the stage at which the overflow plain begins to be flooded.

bar -- An alluvial deposit or bank of sand, gravel, or other material, at the mouth of a stream or at any point in the stream flow.

beaded stream -- A small stream containing a series of deep pools interconnected by very small channels, located in areas underlain by permafrost.

bed -- The bottom of a watercourse.

bed load -- Sand, silt, gravel or soil and rock detritus carried by a stream on, or immediately above its bed.

bed load material -- That part of the sediment load of a stream which is composed of particle sizes found in appreciable quantities in the shifting portions of the stream bed.

bed, movable -- A stream bed made up of materials readily transportable by the stream flow.

bed, stream -- The bottom of a stream below the low summer flow.

braided river -- A river containing two or more interconnecting channels separated by unvegetated gravel bars, sparsely vegetated islands, and, occasionally, heavily vegetated islands. Its floodplain is typically wide and sparsely vegetated, and contains numerous high-water channels. The lateral stability of these systems is quite low within the boundaries of the active floodplain.

carrying capacity, biological -- The maximum average number of a given organism that can be maintained indefinitely, by the habitat, under a given regime (in this case, flow).

carrying capacity, discharge -- The maximum rate of flow that a channel is capable of passing.

channel -- A natural or artificial waterway of perceptible extent which periodically or continuously contains moving water. It has a definite bed and banks which serve to confine the water.

configuration -- The pattern of a river channel(s) as it would appear by looking vertically down at the water.

contour -- A line of equal elevation above a specified datum.

cover, bank -- Areas associated with or adjacent to a stream or river that provide resting shelter and protection from predators - e.g., undercut banks, overhanging vegetation, accumulated debris, and others.

cover, fish -- A more specific type of instream cover, e.g., pools, boulders, water depths, surface turbulence, and others.

cover, instream -- Areas of shelter in a stream channel that provide aquatic organisms protection from predators or a place in which to rest, or both, and conserve energy due to a reduction in the force of the current.

cross section area -- The area of a stream, channel, or waterway opening, usually taken perpendicular to the stream centerline.

current -- The flowing of water, or other fluid. That portion of a stream of water which is moving with a velocity much greater than the average or in which the progress of the water is principally concentrated (not to be confused with a unit of measure, see velocity).

datum -- Any numerical or geometrical quantity or set of such quantities which may serve as a reference or base for other quantities. An agreed standard point or plane of stated elevation, noted by permanent bench marks on some solid immovable structure, from which elevations are measured, or to which they are referred.

dewater -- The draining or removal of water from an enclosure or channel.

discharge -- The rate of flow, or volume of water flowing in a given stream at a given place and within a given period of time, expressed as cu ft per sec.

drainage area -- The entire area drained by a river or system of connecting streams such that all stream flow originating in the area is discharged through a single outlet.

dredge -- Any method of removing gravel from active channels.

drift, invertebrate -- The aquatic or terrestrial invertebrates which have been released from (behavioral drift), or have been swept from (catastrophic drift) the substrate, or have fallen into the stream and move or float with the current.

duration curve -- A curve which expresses the relation of all the units of some item such as head and flow, arranged in order of magnitude along the ordinate, and time, frequently expressed in percentage, along the abscissa; a graphical representation of the number of times given quantities are equaled or exceeded during a certain period of record.

erosion, stream bed -- The scouring of material from the water channel and the cutting of the banks by running water. The cutting of the banks is also known as stream bank erosion.

fines -- The finer grained particles of a mass of soil, sand, or gravel. The material, in hydraulic sluicing, that settles last to the bottom of a mass of water.

flood -- Any flow which exceeds the bank-full capacity of a stream or channel and flows out on the floodplain; greater than bank-full discharge.

floodplain -- The relatively level land composed of primarily unconsolidated river deposits that is located adjacent to a river and is subject to flooding; it contains an active floodplain and sometimes contains an inactive floodplain or terrace(s), or both.

flood probability -- The probability of a flood of a given size being equaled or exceeded in a given period; a probability of 1 percent would be a 100-year flood, a probability of 10 percent would be a 10-year flood.

flow -- The movement of a stream of water or other mobile substances, or both, from place to place; discharge; total quantity carried by a stream.

flow, base -- That portion of the stream discharge which is derived from natural storage - i.e., groundwater outflow and the draining of large lakes and swamps or other sources outside the net rainfall which creates the surface runoff; discharge sustained in a stream channel, not a result of direct runoff and without the effects of regulation, diversion, or other works of man. Also called sustaining flow.

flow, laminar -- That type of flow in a stream of water in which each particle moves in a direction parallel to every other particle.

flow, low -- The lowest discharge recorded over a specified period of time.

flow, low summer -- The lowest flow during a typical open-water season.

flow, uniform -- A flow in which the velocities are the same in both magnitude and direction from point to point. Uniform flow is possible only in a channel of constant cross section.

flow, varied -- Flow occurring in streams having a variable cross section or slope. When the discharge is constant, the velocity changes with each change of cross section and slope.

fork length -- The length of a fish measured from the tip of the nose to the fork in the tail.

freeze front -- A surface that may be stationary, which has a temperature of $0^{\circ}C$ and is warmer on one side of the surface and colder on the other.

frequency curve -- A curve of the frequency of occurrence of specific events. The event that occurs most frequently is termed the mode.

gage -- A device for indicating or registering magnitude or position in specific units, e.g., the elevation of a water surface or the velocity of flowing water. A staff graduated to indicate the elevation of a water surface.

geomorphology -- The study of the form and development of landscape features.

habitat -- The place where a population of animals lives and its surroundings, both living and nonliving; includes the provision of life requirements such as food and shelter.

high-water channel -- A channel that is dry most of the ice-free season, but contains flowing water during floods.

hydraulics -- The science dealing with the mechanical properties of fluids and their application to engineering; river hydraulics deals with mechanics of the conveyance of water in a natural watercourse.

hydraulic depth -- The average depth of water in a stream channel. It is equal to the cross-sectional area divided by the surface width.

hydraulic geometry -- Those measures of channel configuration, including depth, width, velocity, discharge, slope, and others.

hydraulic radius -- The cross-sectional area of a stream of water divided by the length of that part of its periphery in contact with its containing channel; the ratio of area to wetted perimeter.

hydrograph -- A graph showing, for a given point on a stream, the discharge, stage, velocity, or another property of water with respect to time.

hydrology -- The study of the origin, distribution, and properties of water on or near the surface of the earth.

ice-rich material -- Permafrost material with a high water content in the form of ice, often taking the shape of a vertical wedge or a horizontal lens.

impervious -- A term applied to a material through which water cannot pass or through which water passes with great difficulty.

inactive floodplain -- The portion of a floodplain that is flooded infrequently; it may contain high-water and abandoned channels and is usually lightly to heavily vegetated.

island -- A heavily vegetated sediment deposit located between two channels.

large river -- A river with a drainage area greater than 1,000 km^2 and a mean annual flow channel top width greater than 100 m.

lateral bar -- An unvegetated or lightly vegetated sediment deposit located adjacent to a channel that is not associated with a meander.

Manning's equation -- In current usage, an empirical formula for the calculation of discharge in a channel. The formula is usually written

$$Q = \frac{1.49}{n} R^{2/3} S^{1/2} A.$$

mean flow -- The average discharge at a given stream location computed for the period of record by dividing the total volume of flow by the number of days, months, or years in the specified period.

mean water velocity -- The average velocity of water in a stream channel, which is equal to the discharge in cubic feet per second divided by the cross-sectional area in square feet. For a specific point location, it is the velocity measured at 0.6 of the depth of the average of the velocities as measured at 0.2 and 0.8 of the depth.

meander wave length -- The average downvalley distance of two meanders.

meandering river -- A river winding back and forth within the floodplain. The meandering channel shifts downvalley by a regular pattern of erosion and deposition. Few islands are found in this type of river and gravel deosits typically are found on the point bars at the insides of meanders.

medium river -- A river with a drainage area greater than 100 km^2 but less than 1,000 km^2 and a mean annual flow channel top width greater than 15 m but less than 100 m.

microhabitat -- Localized and more specialized areas within a community or habitat type, utilized by organisms for specific purposes or events, or both. Expresses the more specific and functional aspects of habitat and cover that allows the effective use of larger areas (aquatic and terrestrial) in maximizing the productive capacity of the habitat. (See cover types, habitat).

mid-channel bar -- An unvegetated or lightly vegetated sediment deposit located between two channels.

parameter -- A variable in a mathematical function which, for each of its particular values, defines other variables in the function.

permafrost -- Perennially frozen ground.

pit excavation -- A method of removing gravel, frequently from below overburden, in a manner that results in a permanently flooded area. Gravels are usually extracted using draglines or backhoes.

point bar -- An unvegetated sediment deposit located adjacent to the inside edge of a channel in a meander bend.

pool -- A body of water or portion of a stream that is deep and quiet relative to the main current.

pool, plunge -- A pool, basin, or hole scoured out by falling water at the base of a waterfall.

profile -- In open channel hydraulics, it is the water or bed surface elevation graphed aganist channel distance.

reach -- A comparatively short length of a stream, channel, or shore.

regional analysis -- A hydrologic analysis, the purpose of which is to estimate hydrologic parameters of a river by use of measured values of the same parameters at other rivers within a selected region.

riffle -- A shallow rapids in an open stream, where the water surface is broken into waves by obstructions wholly or partly submerged.

riparian -- Pertaining to anything connected with or adjacent to the banks of a stream or other body of water.

riparian vegetation -- Vegetation bordering floodplains and occurring within floodplains.

riprap - Large sediments or angular rock used as an artificial armor layer.

river regime -- A state of equilibrium attained by a river in response to the average water and sediment loads it receives.

run -- A stretch of relatively deep fast flowing water, with the surface essentially nonturbulent.

scour -- The removal of sediments by running water, usually associated with removal from the channel bed or floodplain surface.

scrape - A method of removing floodplain gravels from surface deposits using tractors or scrapers.

sediment discharge -- The volumetric rate of sediment transfer past a specific river cross section.

sinuous river -- Sinuous channels are similar to meandering channels with a less pronounced winding pattern. The channel may contain smaller point bars and have less tendency for downvalley shifting. The channels are more stable with respect to lateral shifting.

sinuousity -- A measure of the amount of winding of a river within its floodplain; expressed as a ratio of the river channel length to the corresponding valley length.

slope -- The inclination or gradient from the horizontal of a line or surface. The degree of inclination is usually expressed as a ratio, such as 1:25, indicating one unit rise in 25 units of horizontal distance.

small river - A river with a drainage area less than 100 km^2 and a mean annual flow channel top width of less than 15 m.

split river -- A river having numerous islands dividing the flow into two channels. The islands and banks are usually heavily vegetated and stable. The channels tend to be narrower and deeper and the floodplain narrower than for a braided system.

stage -- The elevation of a water surface above or below an established datum or reference.

standing crop -- The abundance or total weight of organisms existing in an area at a given time.

straight river -- The thalweg of a straight river typically winds back and forth within the channel. Gravel bars form opposite where the thalweg approaches the side of the channel. These gravel bars may not be exposed during low flow. Banks of straight systems typically are stable and floodplains are usually narrow. These river systems are considered to be an unusual configuration in transition to some other configuration.

subarctic -- The boreal forest region.

suspended load -- The portion of stream load moving in suspension and made up of particles having such density of grain size as to permit movement far above and for a long distance out of contact with the stream bed. The particles are held in suspension by the upward components of turbulent currents or by colloidal suspension.

talik -- A zone of unfrozen material within an area of permafrost.

terrace -- An abandoned floodplain formed as a result of stream degradation and that is expected to be inundated only by infrequent flood events.

thalweg -- The line following the lowest part of a valley, whether under water or not; also usually the line following the deepest part or middle of the bed or channel of a river or stream.

thermokarst -- Landforms that appear as depressions in the ground surface or cavities beneath the ground surface which result from the thaw of ice-rich permafrost material.

top width -- The width of the effective area of flow across a stream channel.

velocity -- The time rate of motion; the distance traveled divided by the time required to travel that distance.

wash load -- In a stream system, the relatively fine material in near-permanent suspension, which is transported entirely through the system, without deposition. That part of the sediment load of a stream which is composed of particle sizes smaller than those found in appreciable quantities in the shifting portions of the stream bed.

water quality -- A term used to describe the chemical, physical, and biological characteristics of water in reference to its suitability for a particular use.

wetted perimeter -- The length of the wetted contact between the stream of flowing water and its containing channel, measured in a plane at right angles to the direction of flow.

wildlife -- All living things that are neither human nor domesticated; most often restricted to wildlife species other than fish and invertebrates.

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16. Abstract (Limit: 200 words)

A 5-year investigation of the effects of floodplain gravel mining on the physical and biological characteristics of river systems in arctic and subarctic Alaska is described. Twenty-five sites were studied within four geographic regions. The sites were selected such that within each of the regions the group of sites exhibited a wide range of river and mining characteristics. The field data collection program covered the major disciplines of hydrology/hydraulics, aquatic biology, water quality, and terrestrial biology. In addition, geotechnical engineering, and aesthetics site reviews were conducted. A wide range of magnitude and type of physical and biological changes were observed in response to mining activity. Little change was observed at some sites, whereas other sites exhibited changes in channel morphology, hydraulics, sedimentation, ice regime, aquatic habitat, water quality, benthic macroinvertebrates, fish utilization, vegetation, soil characteristics, and bird and mammal usage.

Two major products of the project are a Technical Report which synthesizes and evaluates the data collected at the sites, and a Guidelines Manual that aids the user in developing plans and operating material sites to minimize environmental effects.

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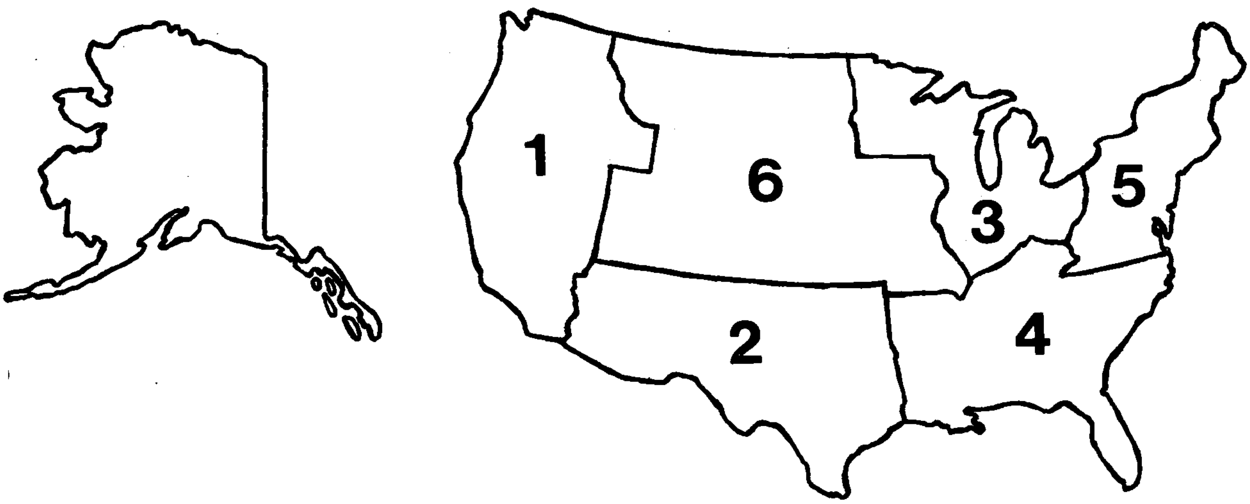

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