BEST MANAGEMENT PRACTICES FOR PLACER MINING

TECHNICAL REPORT

BY:

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Best Management Practices for Placer Mining Technical Report

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INTRODUCTION

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1.0
INTRODUCTION

This report presents best management practices (BMP's) for placer mining that are designed to minimize nonpoint-source pollution and to promote and enhance the natural recovery of the site. This document details and presents some of the supporting information behind the BMP's. Numerous references to publications containing more detailed information are included when addressing the various subjects in the document. A second document, Best Management Practices for Placer Mining Reference Manual, presents a summary of the BMP's in a user-oriented format that is more suitable for design use.

1.1 OBJECTIVE

This project was funded by the Alaska Department of Fish and Game with the primary objective of providing information to enhance the Department's ability to carry out its responsibilities for protection of fish and wildlife habitats and populations affected by placer mining. Specifically, the BMP's are designed to provide guidance to the Department of Fish and Game and other state and federal resource management agencies reviewing placer mining applications, with particular emphasis placed on the control of nonpoint-source pollution and site rehabilitation.

Although the mining industry was not intended as the primary audience for the BMP documents, the BMP's should also be useful to placer miners and their technical consultants in developing their mining plans to include the design elements and details that may be required by resource management agencies.

1.2 SCOPE

The development of the BMP's was based on a review of literature in the fields of mining engineering, drainage and erosion control, hydrology and hydraulics, aquatic and terrestrial biology, and aquatic and terrestrial habitat rehabilitation. The literature review focused on references with application to stream valleys in Alaska or other northern environments. Technical evaluation or analyses of the information obtained, and the experience of the project team, provided the basis for applying or adapting this information to placer mining BMP's for Alaska. Although several active placer mine sites were visited during the course of this project, site-specific scientific data were not collected, since the wide variety of site conditions found in Alaskan floodplains do not require major alterations to the concepts and designs presented herein. Economic and time constraints prevent this report and the associated manual from being all-inclusive. The user is encouraged to collect site-specific data to support the design recommendations presented in this report and to refer to the literature cited for additional information.

Design recommendations are provided; few construction techniques are provided, since they will depend upon the equipment that is available at any particular mine site.

This report presents recommendations and supporting information for preparing a mining plan, controlling nonpoint-source pollution, and rehabilitating a site. The mining plan chapter provides recommendations for what information should be included in the plan and provides specific criteria for site descriptions, design, operation, and rehabilitation.

Chapters on controlling nonpoint-source pollution concentrate on temporary features that are used primarily during preparation and operation of the site, but should be incorporated into final design features during site rehabilitation. Topics covered include drainage control, site grading, and stockpile placement and protection.

The design of permanent features that continue to control nonpoint-source pollution and that enhance recovery of the site is the subject of the site rehabilitation chapters. Topics covered include stream-channel rehabilitation, fish-habitat rehabilitation, and floodplain rehabilitation. The stream-channel and fish-habitat rehabilitation chapters recommend design features for a final channel configuration below bankfull level. The floodplain rehabilitation chapter provides design recommendations for that portion of the valley above the bankfull channel and includes the riparian zone, inactive floodplain, terraces, and benches.

1.3 REPORT ORGANIZATION

This BMP technical report is divided into three major divisions plus appendices. The major divisions are:

- Mining Plan
- Nonpoint-Source Pollution Control
- Site Rehabilitation

The accompanying reference manual uses a parallel format to present its technical recommendations.

The first major division of this technical report is the mining plan. It provides a brief checklist of the important components of each sequential step in the planning, design, operation, and rehabilitation of a placer mine site. These components should be described in a mining plan and submitted with the permit application.

The second major division of this report presents design recommendations for temporary features to minimize nonpoint-source pollution from the site. These pollution-control features are temporary measures that are used during preparation and operation of the site. References to the site rehabilitation chapters of the report are provided to encourage the user to consider final site rehabilitation features when selecting the location and design of temporary features.

The third major division of this report discusses site rehabilitation and provides design recommendations for permanent features that will enhance recovery of the site. These chapters describe those mitigative measures that should be implemented as final site work following the completion of all mining operations.

Three appendices are included in the report:

- Appendix A. List of references cited in this report
- Appendix B. Glossary of terms used in this report
- Appendix C. Maps of mean annual precipitation

BEST MANAGEMENT PRACTICES FOR PLACER MINING

TECHNICAL REPORT

MINING PLAN

MINING PLAN

2.0
MINING PLAN

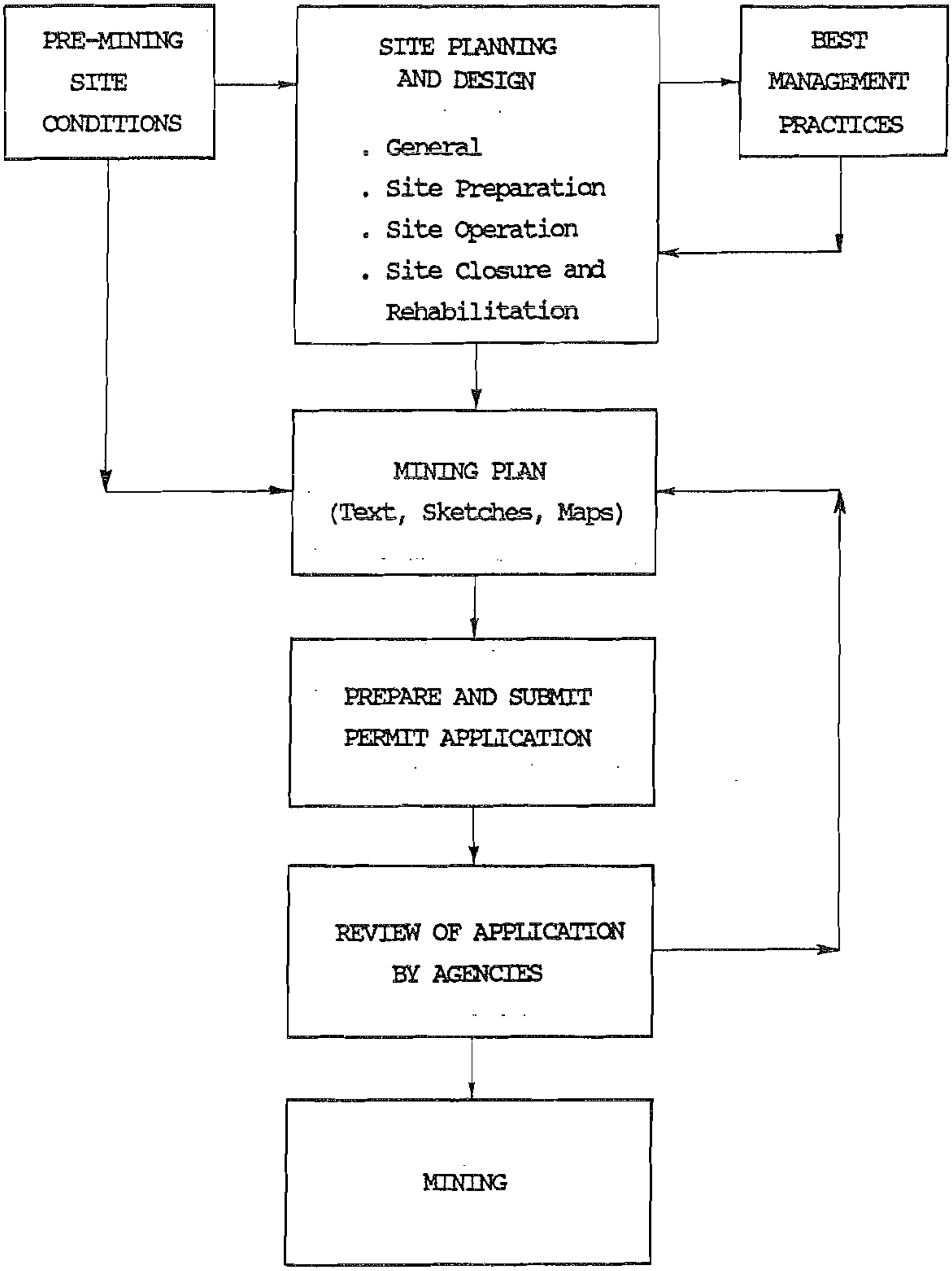
Placer mining applications should include a mining plan. It is generally agreed that a thorough mining plan filed at the start of a new operation benefits both the applicant, by providing better knowledge and recognition of solutions to potential site problems, and the reviewers of permit applications, by allowing a more thorough understanding of how the site is to be sequentially operated and rehabilitated (Figure 1). Adequate site assessment work in the form of test-pitting, trenching, drilling, or other prospecting methods can lead to a well-planned operation that minimizes surface disturbance and excavation requirements. Development of a detailed mining plan familiarizes the miner with the best management practices and promotes more accurate costing of annual activities.

The mining plan should include two major parts:

1. Description of pre-mining site conditions to guide the development and rehabilitation of the site

2. Site planning and design including site preparation, operation, and rehabilitation

A list of items to be included in the mining plan is presented in this chapter of the report. Subsequent chapters include best management practices (BMP's) for designing those elements of the mining plan related to nonpoint-source pollution control and site rehabilitation. The mining plan should be completed in sufficient detail to provide accurate descriptions and designs of site features. These written descriptions and designs should be supported with scaled sketches showing both plan views and cross-sectional profiles of



MINING PLAN RELATIONSHIPS

ENTRIX | FIGURE 1

proposed site work and locations. A minimum of five site maps is recommended to illustrate features discussed in the following sections of the mining plan:

1. Pre-mining site conditions
2. General site planning
3. Site-preparation plan
4. Site-operation plan
5. Site-rehabilitation plan

Where possible, ground or aerial photographs of site conditions prior to the proposed activity should also be submitted. The mining plan should be prepared following site inspection by the applicant.

If the proposed mining is to be a multi-year operation, the plan also should describe the progression and sequence for both temporary and final locations of major site features such as settling ponds, stream channels, and stream diversions. The plan should also address seasonal site closure to protect site features from spring flooding. For multi-year sites the plan should recognize that encountered site conditions or other factors may dictate that the original proposals may need to be altered. If alterations to the mining plan are necessary, supplemental plans describing these changes should be submitted to the permitting agency in time to allow review prior to the next mining season.

While several formats may be appropriate for a detailed mining plan, the recommended approach is to submit a narrative description with site sketches and photos that is attached to the application form. This plan should address, in recommended order, the following points.

2.1 PRE-MINING SITE CONDITIONS

Describe and map the existing condition at the proposed mine site and immediately upstream and downstream of this site. The site description should be based on a site visit by the applicant.

A. Site Conditions

A description of known previous mining activity, if any, should be provided. A site base map should be prepared for each claim to scale at a convenient scale large enough for the site to fill an 8 1/2 x 11 inch or larger sheet of paper (e.g. 1 in. = 200 ft). A copy of this base map should be used to mark the location and approximate size of existing site features such as streams, ponds, abandoned settling ponds, and tailing piles. Knowledge of aufeis occurrence and location should be noted.

B. Biological Characteristics

The amount and type of vegetation in the mine site should be described and marked on the base map containing site conditions. The presence of fish in the stream should be discussed, if known by the applicant. Stream surveys for fish presence are usually not necessary, since the Alaska Department of Fish and Game has inventoried numerous streams throughout the state and would be knowledgeable about the likelihood of fish in any particular stream.

An important element of site planning and the preparation of a mining plan is assessing the risks associated with flooding and erosion at the site. The pre-mining site condition section should address the value of the stream for aquatic habitat at and downstream of the mine site in sufficient detail to evaluate the acceptable level of risk for design purposes, as discussed in Section 8.2.1. Coordination with ADF&G is recommended for this task. The level of risk identified will affect the design of the temporary erosion control features discussed in later sections of this report.

C. Stream Characteristics

A description of the stream and local drainage is an important element of the site description. The configuration of the stream, or stream pattern, is an important feature to describe and should be drawn to scale on the site map containing existing site features. If the stream has more than one channel at a normal summer flow, the number of channels should be noted and the percent of stream length in the site with more than one channel should be estimated.

The water quality characteristics should be noted based on visual observations. Turbidity is the most obvious characteristic and can be assessed visually. The seasonality and magnitude of flood events should be described based on discussions with local residents or miners in the area. Flood debris in the mine site should be described and the extent and elevation noted. Local drainage patterns through the mine site including creeks and gullies, should be described and noted on the base map containing existing site features.

D. Legal Claim

The location of the boundaries of the mining claim should be described and plotted on the base map containing existing site features.

2.2 SITE PLANNING AND DESIGN

2.2.1 General

This section of the mining plan should present descriptions and sketches of yearly and multiple-year work area locations and boundaries. The overall plans and schedules for sequential site operation and rehabilitation should be presented for the duration of mining at the site.

A. Site Boundaries

The overall boundaries of the claim as described in the previous section should be transferred to a clean copy of the scale base map. This map will be used only for general site planning. On this map, delineate the placer-bearing zones identified during the site exploratory program consisting of digging test pits or trenches, drilling, or other techniques. Use these zones and the operation plans to plan the boundaries of each series of cuts and the total boundary for the year. Such planning may reduce surface disturbance and increase profits by minimizing excavation requirements. For multi-year sites, outline and label the planned operational boundaries for subsequent years. Although these boundaries will likely change slightly, they still provide valuable information for designing drainage-control structures.

B. General Schedule

The general schedule of site activity should be described for each year of mining. The estimated dates of moving equipment to and from the site should be provided. List the planned mining activities and note in which month(s) the activity is likely to occur. Examples of activities that should be listed include, but are not limited to, clearing, constructing settling ponds, sluicing, grading of tailing piles, constructing and maintaining drainage-control structures, and site rehabilitation. Although work in or near stream or diversion channels is discouraged, some such work may be required. Any such work should be described, and the planned dates and duration of such activity should be provided.

C. Site Facilities

All site facilities should be described and drawn on the general site planning map. Access routes into and within the site should be identified. The location and description of work areas and housing should be included. The methods of domestic waste storage, treatment, and disposal should be described in this section of the mining plan. The storage and handling of fuels or other toxic materials should be described and the storage site marked on the map.

2.2.2 Site Preparation

This section of the mining plan should present more specific information on how the site will be prepared for each year of mining. The level of detail should be greatest for the upcoming mining season. Note that if major revisions of the mining plan occur, the agencies should be informed. Narrative, with frequent plan view and profile sketches, should be provided.

A. Clearing and Stockpiling

A plan for clearing the mine site prior to mining activity should be developed. The plan should describe the method of clearing and the schedule for clearing relative to when the area is to be mined. The amount of each type of material to be cleared should be estimated and the storage locations should be drawn on a copy of the base map for illustrating site-preparation features. It is recommended that the miner develop a site-rehabilitation plan (Section 2.2.4) prior to selecting locations of stockpiles so that the stockpiles can be placed to minimize handling before or during site rehabilitation. Stockpiles may be required for a variety of materials, including trees, woody slash and debris, organic material, inorganic overburden, fine silts, and oversized materials. The mining plan should also include a description of the approach for protecting the stockpiles from erosion.

Clearing a site can cause aufeis to form. Aufeis, also referred to as an icing, naled, or glacier, is composed of ice that has formed on the surface of any substance (e.g., ground or river ice), usually followed by the progressive buildup of ice upon itself. Aufeis most commonly occurs in areas containing permafrost ground, but the existence of permafrost is not required for its formation. Aufeis may form downstream of a spring, with flow from the spring feeding the growth of the aufeis. Aufeis may also form when a flow of water (e.g., groundwater or streamflow) is constricted between the annual frost or ice layer on top and a layer with relatively low permeability (e.g., permafrost, bedrock, or streambed) on the bottom. The constricted water supply builds up pressure and may relieve the pressure by flowing to the surface through a crack. This flow freezes on the surface. A continuous water source can continue to emerge and freeze on the surface throughout the winter. Clearing a site can cause a spring to develop, thus increasing the potential for aufeis. Aufeis may also result from the removal of the insulating effect of the vegetative mat, allowing deeper growth of the annual frozen layer.

B. Site Drainage Control

The site drainage-control plan is one of the most important elements of the mining plan. Completion of the site-rehabilitation plan is recommended prior to developing the site drainage-control plan. Included in the drainage-control plan should be the designs and locations of settling ponds, diversion channels, bedrock drains, and diversion and containment berms. The locations of these structures should be selected so that they can function effectively for the maximum length of time before they must be relocated. Review of the base maps depicting site conditions, general site planning, and site rehabilitation will aid in the selection of locations for drainage control structures.

The diversion channel should be located to minimize the number of times that the stream must be moved. While not moving the stream at all is the preferred alternative, moving it once into a final location is preferred for those situations where the stream must be moved. A temporary diversion channel should only be necessary if the entire stream valley bottom is to be mined.

While drainage-control structures may reduce the potential for aufeis to form within the site, aufeis growth at a drainage-control structure may decrease the effectiveness of the structure. The diversion channel, bedrock drain, and gravity ditch system may all cause aufeis to form in their channels, reducing the capacity of the channels to transport their design flows. This potential should be evaluated and, if aufeis is likely, the reduced capacity should be considered when designing the channel.

2.2.3 Site Operation

The operation plan should present the details of how the actual mine area will be worked, including reference to the specifics of how material will be handled, processed, and discharged.

A. Mining Activities

The mining plan should include a discussion of mining activities such as equipment types, area of activity, and resultant material-size classifications. The area and depth of each cut should be listed for each cut to be made during the mining season. The sequence of cuts should be noted on the base map for site operation. The equipment used for each mining operation should be listed in the plan. Details should be provided on the size classes of material produced in the mining operation and whether these materials will be mixed back together as mining progresses. Plans for saving certain quantities of some size classes for site rehabilitation should be discussed. The required quantities of materials should be based on estimates developed for the site rehabilitation plan (Section 2.2.4).

B. Site Drainage-Control Maintenance

Inspection and maintenance of drainage-control structures is important to minimize nonpoint-source pollution. The plan should identify the expected frequency and methods of cleaning or protecting settling ponds. It should identify the location and design of additional ponds, if such are required. The sites should be drawn on the operation base map. The diversion channel should be inspected at least once each month and after each flood event for damage from erosion or for excessive sediment deposition. The plan should identify what materials and methods would be available for making repairs to the diversion channel if required. The schedule for constructing bedrock drains and surface flow-control structures should be outlined. The maintenance of the bedrock drain and surface erosion-control structures should also be described.

C. Erosion-Control Measures

Erosion-control measures that will be carried out concurrently with mining activities should be presented in this section of the mining plan. Site sloping and contouring measures should be described and the schedule relative to other mining activities should be noted. The location and protection of stockpiles of classified material and the schedule for setting these materials aside should be described.

2.2.4 Site Closure and Rehabilitation

The site-closure discussion should focus on describing and mapping the details of final site-rehabilitation measures and emphasize what steps will be taken to expedite site recovery and enhance the value of rehabilitated areas to fish and wildlife.

A. Stream Rehabilitation

The stream rehabilitation plan should include the details of the channel design up to the bankfull level. The plan view of the stream channel should be drawn to scale on the base map for site rehabilitation, showing the stream pattern, location in the floodplain, locations of pools and riffles, and locations of fish-habitat features. A side view of the stream channel design should be provided to show the planned sequence of pools and riffles. End views, or cross sections, should be provided with dimensions for typical pools and typical riffles. Design drawings of fish-habitat features should be included in the plan. A list of parameters and their values should be provided, including but not limited to, drainage basin size, mean annual precipitation, design recurrence interval and discharge, valley slope, channel slope, and bed material size.

B. Floodplain Rehabilitation

The floodplain-rehabilitation plan should include the details of site rehabilitation above the bankfull level of the stream channel. The plan should describe in detail the methods for rehabilitating settling ponds. The final configuration of all drainage-control structures should be sketched in plan, end, and side views. A description of the utility of any structures planned to be left in place should be included. Final site sloping and contouring should be described in detail and drawn in plan, end, and side views. This should include discussions of terraces, sediment basins, overflow channels, and other site features relevant to the site. The distribution of stockpiled material should be mapped on the base map. Revegetation efforts should be described and mapped on the base map.

BEST MANAGEMENT PRACTICES FOR PLACER MINING

TECHNICAL REPORT

NONPOINT-SOURCE POLLUTION CONTROL

INTRODUCTION TO NONPOINT-SOURCE POLLUTION CONTROL

3.0
INTRODUCTION TO NONPOINT-SOURCE POLLUTION CONTROL

3.1 OBJECTIVE AND SCOPE

The primary objective of this major division of the report is to provide design recommendations for temporary control measures that can be used during site preparation and operation to minimize nonpoint-source pollution at an active placer mine site. These control measures are temporary in nature, since they typically require modification or replacement during final site rehabilitation. A secondary objective is that the site be prepared and operated in a manner that facilitates final restoration of the site. Final site rehabilitation, including long-term control of nonpoint-source pollution, is discussed in Chapters 6.0 to 9.0.

For this report, the term "nonpoint-source pollution" includes all stream turbidity, suspended sediment, and siltation (deposition of solids on the stream bed) resulting from soil erosion caused by human activity that cannot be traced to a single discharge point. Point-source pollution, in contrast, is highly localized, and the origin can be traced to an identifiable point where the polluted discharge reaches a body of water. For example, turbid effluent from the outlet of a settling pond is point-source pollution, while sediment washed off an exposed hillside is nonpoint-source pollution. Another common point-source of potentially large quantities of sediment pollution is erosion of abandoned settling ponds. Unstabilized tailing piles and steep slopes along streams are the predominant causes of nonpoint-source pollution (Vesilind and Peirce 1982). These definitions of point and nonpoint-source pollution may not conform to the definitions used by state and federal agencies.

3.2 SUMMARY

The approach to controlling nonpoint-source pollution is to identify the causes of erosion and to plan and operate the site from the beginning of the project to include measures to avoid excessive erosion and to include treatment methods for that erosion that does occur. This section and Table 1 summarize the key issues and typical solutions.

Nonpoint-source pollution of adjacent streams can occur during all phases of placer-mine development and operation. Frequently, when mining begins at a site, particularly at a previously undisturbed site, vegetation and the surface layers of organic and inorganic soils are removed. This site preparation exposes large areas of silts and fines to potential erosion. In addition, the organic stockpile (consisting principally of woody vegetation and soil) is susceptible to erosion either by rain events or surface drainage. Finally, unvegetated tailings piles left after site closure can contribute sediment to adjacent streams.

The amount of erosion that occurs at a site depends upon local hydrologic and topographic characteristics such as the amount of rainfall or snowmelt, the type of vegetation and soil, the characteristics of surface drainage, and the length and steepness of slopes (Beasley 1972). A decrease in rainfall or snowmelt will likely reduce the amount of erosion. The removal of vegetation will increase erosion as the soil is no longer protected by its organic cover. In addition, rain falling directly on the bare soil will loosen the soil particles (Beasley 1972). The type of soil also affects erosion as some soils erode more readily than others. The steepness and length of an exposed surface are factors which can be manipulated to reduce erosion. A decrease in the length and/or steepness of the slope will reduce erosion.

If appropriate erosion control procedures for surface water drainage, grading, and stockpiling are outlined during the planning phase and implemented during site operation, nonpoint-source pollution can be substantially minimized. Appropriate measures most often include development of drainage systems; construction, maintenance, and rehabilitation of an adequate settling-pond

Mining Activity	Issues	Summary of Pollution Control Techniques
Removing vegetation and organic material	. timing . stockpile location . stockpile protection	. minimize time between stripping and mining . collect and treat runoff from exposed slopes . stockpile stripped material .. locate so as to minimize erosion potential .. armor sides of stockpile if erosion potential exists .. locate to minimize rehandling requirements .. collect and treat stockpile runoff
Drainage system design/construction	. exposure of natural water to mine site	. divert natural streams around site . install settling ponds--water contacting excavated areas must go through settling ponds
Cutting and working slopes	. minimizing erosion	. divert surface runoff around site . decrease length/steepness . furrow steep slopes . minimize removal of vegetation . grade in same season of mining
Other	. minimizing erosion	. stabilize dewatered settling ponds .. vegetation .. coarse material . roughen exposed soils to minimize . wind erosion . evaluate effects of aufeis

NONPOINT-SOURCE POLLUTION CONTROL

ENTRIX | TABLE 1

system; proper diversion of stream channels; grading of tailings piles; and siting and protection of stockpiles.

A drainage system is usually required to divert surface water around the mining site and to retain sediment-laden water within the site. Before mining commences, particularly when working adjacent to streams, channel diversions should be constructed to reroute streams and surface runoff around the site (Section 4.3). Water that comes into contact with excavated areas will require routing through the settling pond system, since the water will likely contain sediments (Section 4.2). An investigation of the drainage pattern before mining will assist in identifying areas with a greater potential for erosion (Toups Corporation 1978).

Grading of tailing piles and overburden concurrently with seasonal mining activity will improve erosion control and reduce efforts during site rehabilitation. Annual grading plans should be included in the overall mining and restoration plans. Material which is not stockpiled for later use (Section 10.3) should be regraded as soon as possible. Constructing floodplain terraces and furrows along steep side slopes while grading will reduce the effective lengths of the slopes and limit erosion (Section 5.2). In addition, slope failures in graded sites are less likely (Section 5.2). Final site grading (Section 10.2) should be performed prior to site closure.

Removal of vegetation and the layers of organic and inorganic materials is usually the first activity that takes place before placer gravels can be processed. The amount of time between the stripping operation and the mining of the underlying gravels should be minimized. This will reduce the amount of time that soils are subjected to surface runoff and hence will reduce soil erosion. If stripping must be done in advance of mining to thaw the permafrost soils, the clearing should be done early in the summer so that depth of thaw can be maximized; this will help to reduce the potential for aufeis development. Containment berms should be installed near the base of the slopes to isolate streams from runoff from stripped slopes. Once removed, vegetation and soil should be stockpiled (Chapter 6.0) in areas where the potential for erosion of the material is minimized. Stockpiling materials assists in reducing nonpoint-source pollution and helps to retain material that will be beneficial in later revegetation efforts (Section 10.4). Stockpiles may need to be protected from erosion by armoring the sides of the piles (Section 8.5.3). Runoff containment berms may need to be constructed to direct runoff from the stockpiles through a treatment system.

Wind erosion also may contribute to nonpoint-source pollution. Wind, like water, has the power to detach and transport soil particles (Troeh et al. 1980). The amount of wind erosion is related to the type of soil, the amount of wind, the vegetation, and the unsheltered distance along the prevailing wind direction (Beasley 1972). Roughening the soil surface will assist in minimizing wind erosion. Wind erosion may also be decreased by siting tailing piles in sheltered areas (Toups Corporation 1978). Fine material is likely to be carried aloft by the wind as dust until a coarser layer is formed (Troeh et al. 1980). Dewatered settling ponds and any fine material removed from the ponds should be stabilized by revegetation or by placing coarser material over the finer materials.

DRAINAGE CONTROL

4.0
DRAINAGE CONTROL

4.1 OBJECTIVES AND SCOPE

Prior to the initiation of mining activity, a drainage plan should be developed which delineates the surface flow pattern through the site. Drainage control has two objectives: to divert water around a mine site to minimize the amount of water that contacts erodible material within the site and to collect all turbid water within the site to allow for treatment prior to discharge to the stream. Methods of drainage control include:

- Settling Ponds (4.2)
- Stream Diversion (4.3)
- Bedrock Drains (4.4)
- Overland Flow (4.5)

Water in contact with surfaces disturbed by mining will become sediment laden and turbid. Therefore, water that is not diverted around the site will require treatment in the settling pond system (Section 4.2) prior to discharge. Settling ponds should be designed to retain all sediments originating on the site. Efforts to prevent water from becoming sediment laden appear to be more efficient than efforts to treat sediment-laden water (Vesilind and Peirce 1982).

Active streams running through the mining site should be diverted around the site. If mining in a stream channel is necessary, the surface flow should be diverted and isolated from the activity occurring within the site. Section 4.3 details the criteria to be considered in stream diversion. Surface runoff from the valley walls also should be intercepted and diverted around the site. Gullies or other topographical features which may concentrate runoff can provide significant amounts of flow during or after rainfall events. Section 4.5 describes measures to reduce overland flow contributions to nonpoint-source pollution.

Groundwater flow should also be diverted around the mining site. Bedrock drains (Section 4.4) located upstream of the excavation area may be used to divert groundwater before it seeps into the excavation area. The water collected in an upstream bedrock drain can be routed into the stream. However, groundwater or surface water which contacts unstabilized slopes or enters the excavation area should be channeled through the settling pond system (Section 4.2). Combinations of both surface and subsurface drainage control will likely provide better and more economical results (USSCS 1979).

Concurrent with mining activity, or at least at the end of each mining season, the overland flow drainage pattern should be reestablished and stabilized. Surface water control is the primary concern in the design of the drainage pattern. Any water that is detained or impounded within the site will reduce the rate and amount of surface runoff (Beasley 1972) and thus reduce erosion. Storage of water will occur when small depressions or terraces along the contours are constructed (Frank Moolin and Associates 1985). Chapter 5.0 and Section 10.2 describe the grading of the floodplain to reestablish a drainage pattern to limit sediment contributions to the system.

4.2 SETTLING PONDS

Although settling ponds are essential to the control of point-source pollution, settling ponds are also an important aspect of nonpoint-source pollution control. Settling ponds are used to clarify water which has been used in mining activities such as sluicing or hydraulicking which produce point-source pollution. Settling ponds should also be used to clarify sediment-laden surface water and seepage from excavated or stripped areas which would otherwise contribute to nonpoint-source pollution. Surface water and seepage from the mining area must be controlled to limit nonpoint-source pollution; all sediment-laden water produced on the site should be routed through the settling pond system. However, the flow of clean water into a settling pond should be minimized to increase the settling pond efficiency.

Settling ponds should be located, designed, and protected to meet the acceptable risks of flooding during site operation. The acceptable risks at the site should be assessed as described in Section 8.2.

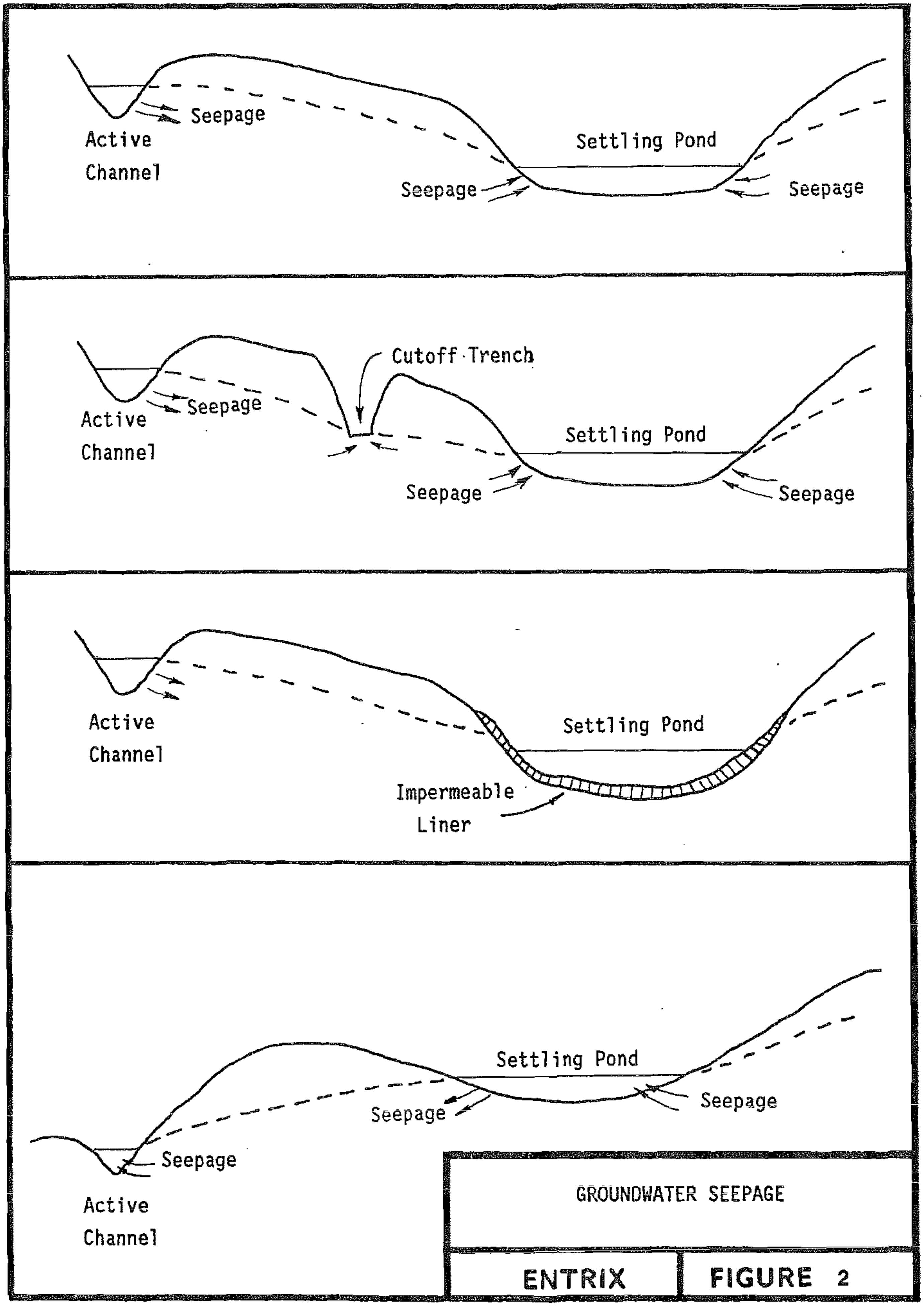
Settling ponds should be rehabilitated to prevent future contributions to both point-source and nonpoint-source pollution. Settling ponds located within the active floodplain must be cleaned of all sediments and rehabilitated when no longer required for use (Section 4.2.5).

4.2.1 Settling-Pond Siting

Potential settling pond locations should be identified during the planning phase. The arrangement and size of the settling pond system is dependent on the type of mining activity and the physical parameters of the site. Settling ponds may have permanent locations for the duration of the mining operation or may be moved with the mining activity. The location of the active floodplain of the final stream channel is the most important physical parameter which should be considered, since any settling pond located within the active floodplain must have all sediments removed during rehabilitation.

Settling ponds should be sited to minimize the amount of clean water entering the ponds. Surface water should be routed outside the site to the greatest extent practicable as settling pond efficiency will be increased by minimizing the volume of surface drainage entering the pond (Bell 1974). Section 4.5 describes overland flow contributions to nonpoint-source pollution. Groundwater seepage may also substantially increase the amount of water entering the settling pond if the pond is located in a low-lying area (Figure 2). Groundwater seepage may be reduced by installing a cut-off trench between the settling pond and the source of water to divert clean water around the settling pond. Alternatively, an impermeable liner of plastic or clay is suggested to prevent or minimize groundwater seepage into the pond.

Settling ponds should not be located within the active floodplain unless the stream has been adequately diverted (Section 4.3) and all sediments will be removed from the settling pond during rehabilitation. The settling pond must be protected to a level appropriate for the acceptable risks at the site



GROUNDWATER SEEPAGE

ENTRIX

FIGURE 2

(Section 8.2). Washouts of settling ponds will result in both point-source and nonpoint-source pollution as large amounts of previously deposited sediments will be entrained and subsequently deposited downstream (Guy 1979). The fine material which becomes deposited in the settling pond will be readily eroded by water moving rapidly through the pond. Erosion within a washed-out pond may continue to add fine sediments to the stream for several years (Cook and King 1983). Therefore, any settling pond located in the active floodplain must be protected and must have all sediments removed during rehabilitation (Section 4.2.5).

4.2.2 Settling-Pond Design

Settling ponds should be designed to obtain the residence time necessary to allow fine sediments to deposit. The Alaska Department of Environmental Conservation (ADEC) Placer Mining Settling Pond Design Handbook (R&M Consultants 1983) describes the proper design, construction, and operation of settling ponds. The size of the settling pond should be selected according to the volume of water, including surface water and seepage, to be clarified, the amount of sediment to be removed, and the physical configuration of the site. An easily cleaned presettling pond is recommended below the sluice tailrace to minimize sediment inflow to the settling pond.

Alternative settling pond configurations should be considered. Long settling ponds may be constructed along the contours of valley walls to minimize the problems associated with settling pond washouts located within the active floodplain. However, since low water velocities enhance particle settling, the velocity of the water moving through a long pond should be evaluated to certify that excessive velocities are not produced in these narrow-cross-sectioned ponds. The relationship $Q = AV$ where Q = the volume of water flowing through the pond (cfs), A = cross-sectional area (ft^2) and V = the velocity of the water (fps) should be used. The forward water velocity is incorporated into the detention time within a basin; R&M Consultants (1983) identified the importance of the forward water velocity when describing the overflow rate.

4.2.3 Settling-Pond Construction

Before material washing commences, the settling pond system must be in place and able to retain sediment-laden water. In some cases, particularly when making the first cut in a new site, the pond may be excavated in virgin ground. Placer material present at the settling pond site may be stockpiled to be washed at a later time, while non-placer-bearing material may be used in dam construction. Excavated material should be properly compacted when constructing the dam (Bell 1974). If the dam is built of tailing sand and gravel, seepage through the dam is common (Yukon Department of Indian and Northern Affairs 1979). Excessive seepage through the dam may cause the failure of the dam (Brawner 1975). Cutoff trenches and anti-seep collars around culverts may be installed to limit seepage. Turbid seepage from the settling pond should be minimized by increasing the length of the seepage path (Bell 1974). The length of seepage path required to clarify the water is dependent on the material used to construct the dam. The outlet from the settling pond should be armored with coarse material to prevent erosion at the toe of the dam. Detailed descriptions of the construction of settling pond dams are available (R&M Consultants 1983, Wilson 1981, U.S. Bureau of Reclamation 1977).

4.2.4 Settling-Pond Operation

Material deposited in the sluice tailrace will consist of coarser sands and small gravels and should be removed frequently. The sand and gravel mixture will be useful in site rehabilitation (Section 10.3). The approximate quantities required during rehabilitation should be roughly determined during the development of the rehabilitation plan and stockpiled as described in Chapter 6.0. Water from the presettling pond should be channeled into the main settling pond where finer material will settle out.

During the mining season, materials which are deposited in the settling pond should be removed when sediments accumulate to 60% of the design sediment-storage volume (Guy 1979), or when sediments are less than 2 ft from the water surface (Alaska Department of Environmental Conservation No Date). Sediments removed from settling ponds should be handled and stockpiled in a manner to minimize contact with surface waters (Chapter 6.0). Flow through the settling pond should be halted during cleaning as disturbances in settling ponds will have adverse impacts on downstream water quality (Shannon and Wilson 1985). If sediments cannot be removed, design and construct a new settling pond and rehabilitate the old pond.

4.2.5 Settling-Pond Rehabilitation

Settling-pond rehabilitation is suggested during site operation or site rehabilitation when the settling pond is no longer needed. Rehabilitation of the settling ponds should be considered during the selection of the settling-pond locations (Section 4.2.1). Three options are available for settling-pond rehabilitation. The selection of the option depends on site-specific conditions, such as the location of the settling pond relative to the final rehabilitated stream channel (Chapter 8.0) and the amount of organic and fine inorganic material available at the site. The risks of flooding should be assessed (Section 8.2), and the settling ponds should be protected accordingly by riprapping nearby streambanks to prevent the lateral movement of the stream into the pond.

One option available for settling-pond rehabilitation is the removal of all fine sediments from the settling pond. Sediment removal is suggested if ponds are located in the active floodplain of the final rehabilitated stream or if the pond is to be used for fish rearing (Section 10.2.2). The pond should be dewatered and all sediment-laden water should be treated elsewhere. A dragline can remove deep sediments, or sediments in thin layers can be removed with front-end loaders. Frozen sediments can be ripped and removed with bulldozers or front-end loaders. The resulting depression should be filled during site grading (Chapter 5.0) or rehabilitated as a fish rearing pond (Section 10.2.2). Sediment removal is expected to be very difficult and siting the pond to avoid the active floodplain may be the preferred alternative.

Settling ponds may also be rehabilitated in place if the pond is above the active floodplain and little organic or fine-grained inorganic material is available on site. Some sediments should be removed from the settling ponds and placed in areas of revegetation priority. The perimeter of the pond should be made irregular by adding and removing sediments as described in Section 10.2.2.

The third option for settling pond rehabilitation consists of stabilizing the sediments in place. This option is preferred if the pond is out of the active floodplain and a large amount of organic or fine-grained inorganic material is available on site. Oversize material should be placed over the fine sediments to a 3-ft or greater thickness. The oversize material should be graded to conform to the surrounding topography (Chapter 5.0). Prevent lateral migration of the stream channel into the rehabilitated settling pond if necessary using riprap (Section 8.5.3).

Sediments removed from the ponds should be stockpiled in an area that will not drain directly into the stream or other clearwater drainages. Containment berms constructed between the sediment stockpile and the stream will prevent silts from being washed into the stream. Stockpiles should be located in areas where they are protected from streamflow and surface drainage to reduce erosion as described in Chapter 6.0.

4.3 STREAM CHANNEL DIVERSION

At sites where mining activity will take place within an active floodplain, the stream channel may need to be diverted to minimize water flow through the excavation area. The diversion should be sited, designed, constructed, and operated to avoid excessive erosion or deposition, to contain floods within the range of acceptable risks (Section 8.2), and to meet fish passage requirements if fish are present (Section 9.3).

4.3.1 Diversion-Channel Siting

The location for the diversion channel should be identified during the planning phase and will depend on the physical parameters of the site, the equipment available to construct the channel, the proposed sequence of site operation, and the acceptable risk of flooding. In a narrow valley, the channel diversion may be routed along the valley walls or along one side of the floodplain. The general guidelines presented for channel diversion should be applied to site-specific conditions to properly design a diversion unique to each mining site.

Preferably, the stream should be placed permanently into a newly constructed or rehabilitated stream channel. At sites where mining cuts as wide as the entire floodplain are not necessary, a permanent stream channel could be constructed on the mined portion of the floodplain prior to mining the other portion. Design recommendations for permanent stream channels are presented in Chapter 8.0. The stream would be diverted only once and impacts to fish and wildlife would be minimized. The mining area should be protected as necessary by constructing levees with stable side slopes (3 to 1 recommended). If a permanent relocation is not possible, a temporary diversion channel should be designed, constructed, and rehabilitated as described in the following sections.

4.3.2 Diversion-Channel Design

The actual design of a temporary diversion channel involves the interaction of hydrology, hydraulic engineering, and geotechnical engineering. This interaction may be complex, and the miner may be well advised to seek the assistance of engineers knowledgeable in the design and construction of open channels. However, the following guidelines represent a simplified approach to the design of channel diversions suitable for use at placer-mining operations. Additional information may be obtained in the Surface Mining Water Diversion Design Manual (Simons, Li and Associates 1982).

Diversion channels should be designed for reaches of relatively constant slope. Therefore, if the channel slope changes, a separate design will be necessary. If the diversion channel is placed along the valley wall, the upstream and downstream ends of the channel will likely have different slopes and will require separate designs. Transitions between the sections should be gradual. Note that deposition can be expected in the diversion channel if the slope is substantially less than the slope of the original channel. If deposition is expected, increasing the freeboard of the diversion channel and periodic maintenance of the channel should ensure that the diversion channel retains adequate capacity. The designer should also consider the potential for aufeis buildup in the channel and consequent loss of channel capacity; increased freeboard may be required in this case.

A channel diversion should be designed to discharge a specified volume of water while resisting erosive forces of the flow. This volume of water can be estimated from hydrologic conditions upstream from the mining site. Section 8.2 describes the methods of estimating the volume of water for a given flood. The flood for use in design (design flood) is selected on the basis of the acceptable risks at the site (Section 8.2) and the period of time during which the channel diversion will be used (the design life). The probability of occurrence of a flood can be used to evaluate the consequences and risks associated with the design life of the channel diversion. Section 8.2 provides information on the selection of the design recurrence interval of stream-channel diversions constructed for more than one mining season.

After the design-flood discharge (Q) of the channel has been estimated, the channel size may be evaluated. The relationship $Q=A_{min}V_e$ is used to evaluate the minimum area of the channel cross section, where Q=design-flood discharge (cfs), A_{min}=minimum cross-sectional area of the channel (ft^2), and V_e=maximum permissible mean velocity in the channel (fps). The maximum permissible mean velocity in the channel is defined as the velocity to avoid the erosion of the bed and bank material. Table 2 presents the maximum permissible mean velocities to avoid erosion in diversion channels. The number and sharpness of bends in the channel affects the design velocity because an increase in channel curvature decreases the mean velocity associated with a given maximum velocity (Chow 1959, Simons, Li and Associates 1982). In addition, the requirements for fish passage evaluated at the mean annual flow (Section 8.2) may limit the permissible velocity in the channel. Fish passage requirements are discussed following the initial design of the channel.

Table 2. Maximum permissible mean velocities to avoid erosion in the diversion channel.

Material	Max. Velocity in feet per second: Channel With Few, Mild Bends	Channel With Many, Sharp Bends
Very light loose sand	1.4	1.1
Average sandy soil	1.8	1.5
Average loam or alluvial soil	2.2	1.9
Stiff clay or ordinary gravel	3.6	3.0
Coarse gravel or cobbles	4.3	3.5
Conglomerate, cemented gravel, soft rock	6.3	5.3
Boulders 1 ft in diameter	9.0	7.5
Boulders 2 ft in diameter	12.0	10.0
Bedrock	12.0	10.0

Reference: Simons, Li and Associates (1982), Neill (1973), Chow (1959)

A trapezoidal channel shape is suggested (Simons, Li and Associates 1982) with bank slopes selected to avoid erosion and slope failure while minimizing the amount of excavation. Table 3 lists the suggested maximum bank slopes for unlined channels. Slopes of 2 to 1 or 3 to 1 are recommended for most channels.

Table 3. Suggested maximum bank slopes for unlined channels.

	Horizontal to Vertical
For cuts in firm rock	nearly vertical
For cuts in fissured or partly disintegrated rock, rough hard pan.	1/2 to 1
For cuts in cemented gravel, stiff clay soils, ordinary hard pan.	3/4 to 1
For cuts in firm, gravelly, clay soil, or for side-hill cross section in average loam	2 to 1
For cuts or fills in coarse gravel to cobbles	1 to 1
For cuts or fills in average or gravelly soils	1 1/2 to 1
For cuts or fills in loose sandy soils	2 to 1
For cuts or fills in boulders	2 to 1
For cuts or fills in very sandy soil	3 to 1

Reference: Simons, Li and Associates (1982)

The dimensions of the diversion channel should be evaluated given the channel size and shape. The standard design procedure using maximum permissible velocity can result in a very wide and shallow channel, which is generally not desireable. Empirical formulas have been developed that provide guidance in assessing the practicality of a channel design based on the size of a trapezoidal channel (Simons, Li and Associates 1982). Using the minimum cross-sectional area (A) and side slopes (Z) obtained above, the following equations can be solved for recommended channel depth (d) and recommended bottom width (b) (Figure 3):

$$d = 0.5\ A^{0.5}$$

$$b = (4-Z)\ d$$

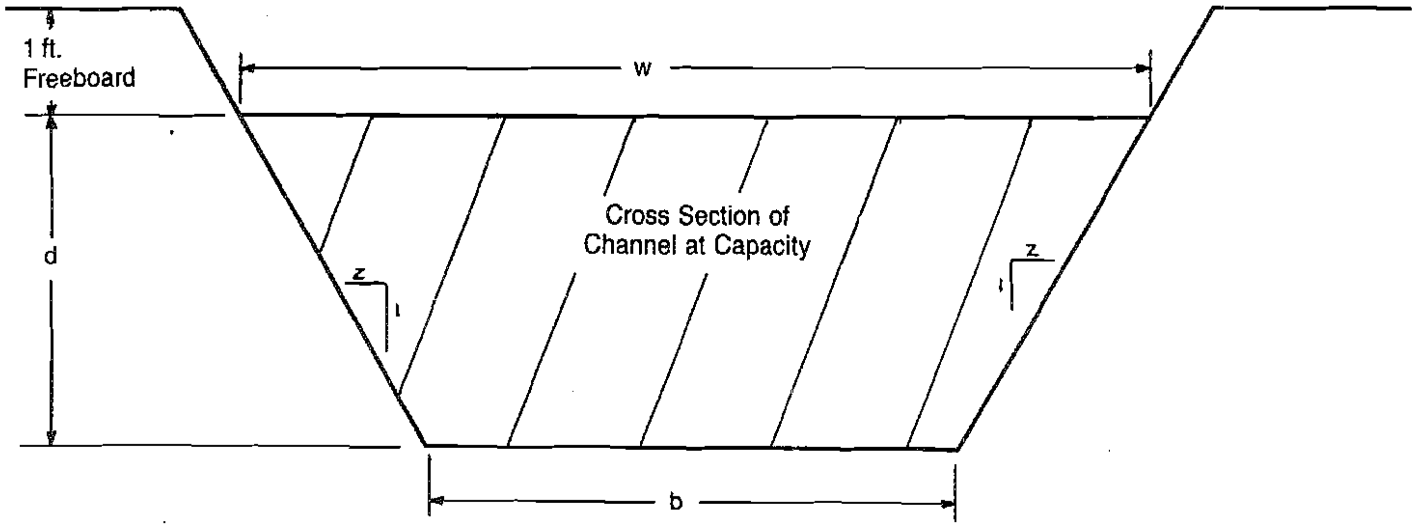
With the channel dimensions known, the hydraulics of the channel should be checked with Manning's Equation. This requires first to calculate the wetted perimeter and hydraulic radius as follows:

$$P = b + 2d(1 = Z^2)^{0.5}$$

$$R = \frac{A}{P}$$

where P = wetted perimeter (ft)
b = bottom width (ft)
Z = side slope, Z horizontal to 1 vertical
d = channel depth (ft)
R = hydraulic radius (ft)
A = cross-sectional area (ft)

Next, a Manning roughness coefficient must be selected for the channel. Manning's roughness coefficient is a function of the type of material in the channel cut or to be used to line the channel. Table 4 lists a range of roughness coefficients for constructed channel conditions.



Area $= A = (b + zd)d$
Wetted Perimeter $= P = b + 2\sqrt{1+z^2}\,d$
Hydraulic Radius $= R = A/P$

DIMENSIONS OF A CHANNEL DIVERSION

ENTRIX | **Figure 3**

Table 4. Manning's coefficients of channel roughness.

Constructed Channel Condition	Values of n Minimum	Maximum	Average
Gravel bottom with riprap or rubble sides	0.023	0.036	0.033
Clean gravel	0.022	0.030	0.025
Gravels and cobbles	0.030	0.050	0.040
Cobbles to boulders	0.040	0.070	0.050
Dragline-excavated or dredged	0.025	0.033	0.028
Earth channels, straight and uniform	0.017	0.025	0.022
Rock channels, straight and uniform	0.025	0.035	0.033
Rock channels, jagged and irregular	0.035	0.045	0.045

Reference: Simons, Li and Associates (1982), Chow (1959)

The channel slope (S) should be evaluated from surveys or topographic maps showing the location identified for the diversion channel. The diversion-channel bed elevation should be matched to the stream bed at the upstream and downstream ends of the diversion.

The mean velocity that would be expected during the design flood can be calculated using Manning's equation:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where V = mean flow velocity (fps)
R = hydraulic radius (ft)
S = channel slope (ft/ft)

Graphical methods for the evaluation of Manning's equation are available (Joyce et al. 1980).

The expected velocity calculated with Manning's equation should be compared with the maximum permissible velocity to avoid erosion in the diversion channel. If the calculated velocity is less than or equal to the design velocity, then the channel dimensions, slope, and bed and bank material should be appropriate for the selected design flood. However, if the calculated velocity exceeds the maximum permissible, it would be likely for erosion to occur during the design flood, possibly destroying the diversion channel. Thus, the channel should be redesigned in this case.

Channel redesign involves modifying one or more of the design parameters and repeating the design computations to check the recomputed velocity against the maximum permissible velocity. Design parameters that may be changed include channel cross-section dimensions, materials that line the channel, and the channel slope.

Channel cross-section dimensions may be modified by increasing width and decreasing depth to retain approximately the same cross-sectional area. Adjustments should be limited to a maximum of 20% increase in bottom width and 5% decrease in channel depth to retain a desirable width to depth ratio. This order of magnitude of change will make relatively small adjustments to the velocity (on the order of 10%).

Small adjustments can also be made to the velocity by reducing the slope of the diversion channel by lengthening the channel. Realigning the channel to increase length by putting more bends in the channel will decrease the calculated velocity. However, if many sharp bends are introduced to the channel, the maximum permissible velocity may need to be reduced (Table 2).

Larger adjustments can be made to the velocity if larger materials are available to use as a channel liner. Larger bed and bank materials allow a larger maximum permissible velocity and also decrease the computed velocity due to increased roughness and smaller hydraulic radius.

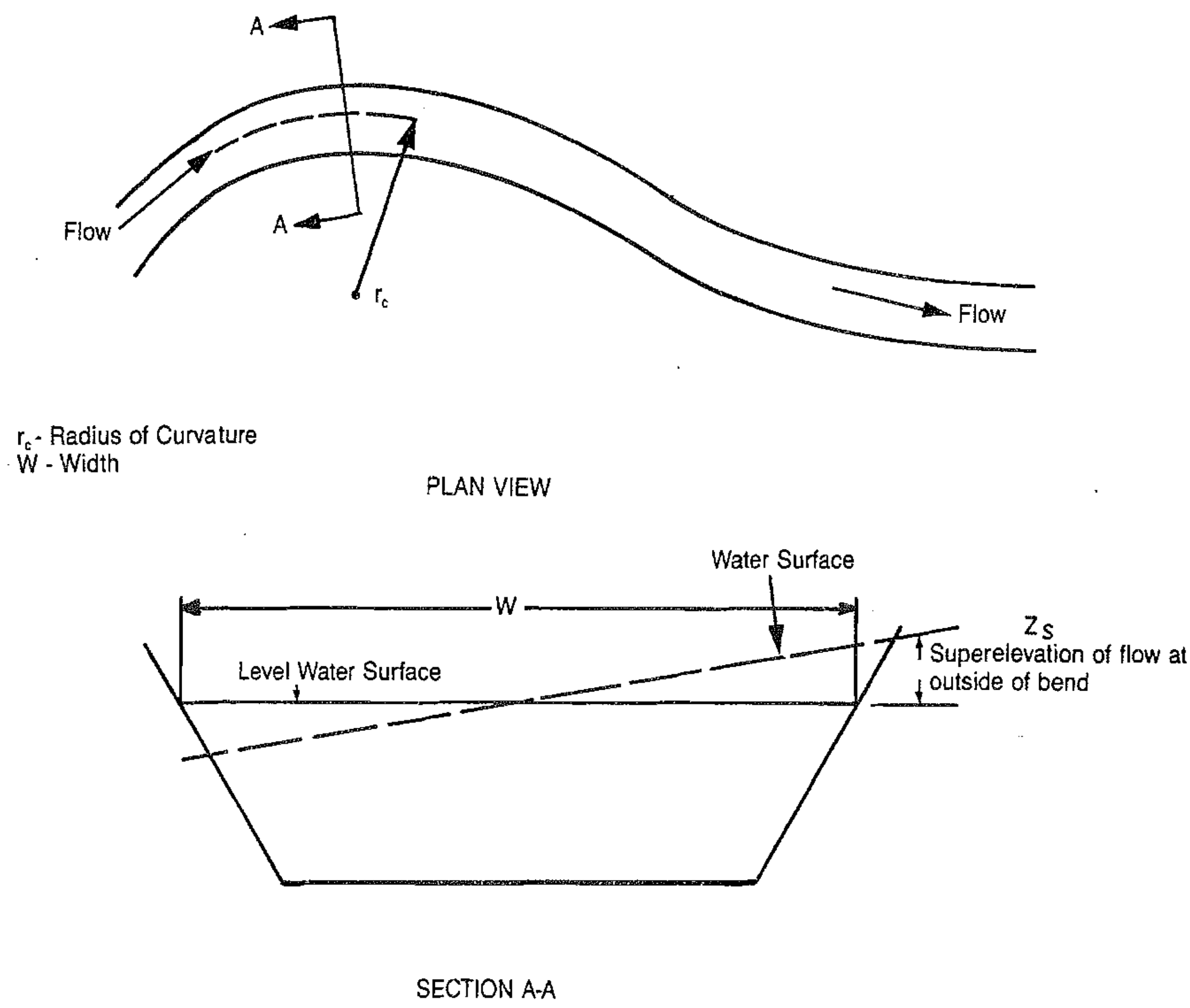
The channel slope can be reduced by designing drop structures for the diversion channel to allow a more gradual slope between the drop structures. This technique allows economical material to be used over much of the channel length while larger bed and bank materials are required at each drop structure. Special design may be required if this technique is used for a diversion channel requiring fish passage. The design of drop structures is presented in Section 8.4.2.A.

An approach that is generally not recommended is to use a fabric liner in the diversion channel. Such liners would increase maximum permissible velocities in the channel. Special design may be required if the diversion channel is to be used for fish passage. Manufacturer's recommendations on design and construction should be followed.

Fish passage should be considered in the design if maintenance of fish passage is required. If a stream has been identified as a fish stream at, or upstream from, the mining site, fish passage must be maintained throughout the mining season. Section 9.3 identifies the depth and velocity requirements which are necessary to maintain passage of anadromous or resident fish. Fish passage should be assessed for the mean annual flow (Sections 8.2 and 9.3). Manning's equation should be solved to evaluate the area corresponding to the mean annual discharge. The velocity and the depth of flow should then be determined. Tables to assist in obtaining the velocity and depth values are presented in U.S. Bureau of Reclamation (1974). If the velocity is too large, the channel must be redesigned with a larger bottom width. If the depth is too small to permit fish passage, a trench 0.5-ft deep should be dug in the channel bottom to channelize the flow under low-flow conditions.

A freeboard should be provided in the channel. A 1-ft minimum freeboard is recommended for all channels (Chow 1959). If the slope of the channel is shallow relative to the original stream slope, the freeboard should be increased to account for potential sediment deposition. The freeboard should also be increased to account for the area occupied by ice if aufeis is expected to form in the diversion channel.

The superelevation of the water at bends must be considered. Superelevation is a special problem at channel junctions and at intermediate channel bends (Simons, Li and Associates 1982). The change in flow direction at bends results in centrifugal forces that cause a higher water surface at the outside bank and a lower water surface at the inside bank (Figure 4). A relationship is used to evaluate the change in elevation at high flows:



SUPERELEVATION OF FLOW CAUSED BY BEND IN CHANNEL

ENTRIX	Figure 4

$$Z_s = V^2W/gr_c$$

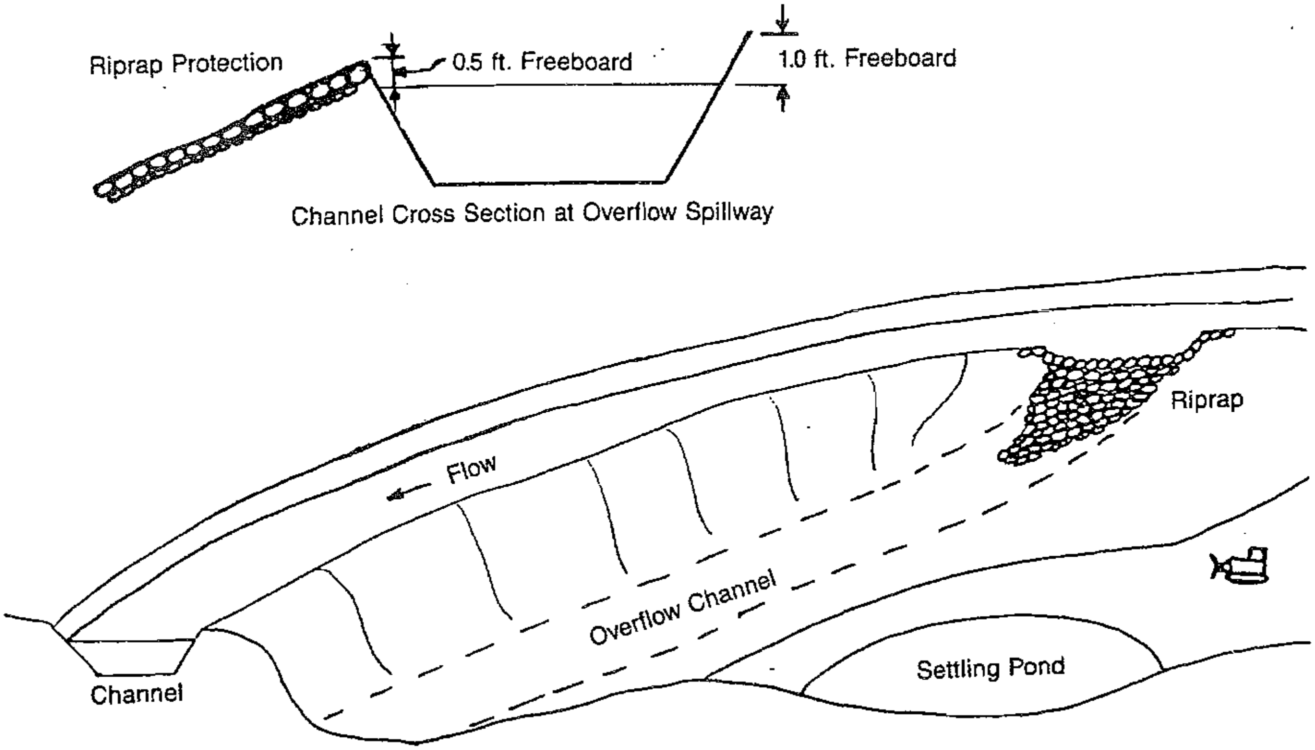
where
Z_s = change in elevation (ft)
V = velocity (fps)
W = top width of channel (ft)
g = 32.2 (ft/sec^2)
r_c = radius of curvature to the center of the stream (ft)

The berm height, especially at the upstream junction of the channel diversion, should be great enough to contain the superelevated flow and provide a 1-ft-minimum freeboard.

A low area in the diversion berm should be provided as a potential overflow spillway for flows which exceed the design high flows. The overflow should be located near the upstream junction of the channel diversion to minimize damage to the diversion channel (Figure 5). The low area should have a 0.5-ft freeboard instead of a 1-ft freeboard. The berm should be armored with large rocks on both sides to reduce erosion. Where possible, the overflow spillways should be routed into a depression running through the mine site but separated from the active operation and settling ponds. The upstream bedrock drain (Section 4.4) is one alternative. Overflows must be diverted around settling ponds. For multiple-year operations with a high potential for aufeis growth in the diversion channel, a diversion around the settling ponds should be constructed at the end of each mining season to divert flood waters displaced by excessive aufeis growth in the channel during the breakup of the following year.

4.3.3 Diversion-Channel Construction

The channel diversion should be completed prior to the initiation of mining activities within the original channel. The bed elevation of the channel diversion should match the bed elevation of the natural channel (Simons, Li and Associates 1982) when possible. The channel diversion may be excavated or a levee may be constructed from the downstream end to allow water seeping into the diversion to drain downstream. A plug should separate the channel diversion from the active channel at both ends until the diversion structure



OVERFLOW SPILLWAY

ENTRIX | FIGURE 5

is almost complete (Figure 6). Then the downstream channel plug can be removed and the diversion channel cleaned of any accumulated sediments. Materials necessary for diverting the stream should be stockpiled near the upstream junction. The upstream plug can then be removed to allow the stream to flow through the diversion channel. The upstream end of the stream should be blocked with a dam after the plugs are removed. Riprap protection may be necessary on the diversion dam (Section 8.5.3). A pulse of sediment-laden water will occur as the stream is moved into the channel diversion. However, this pulse should be of short duration if channel banks are properly stabilized and diversion is accomplished as rapidly as possible.

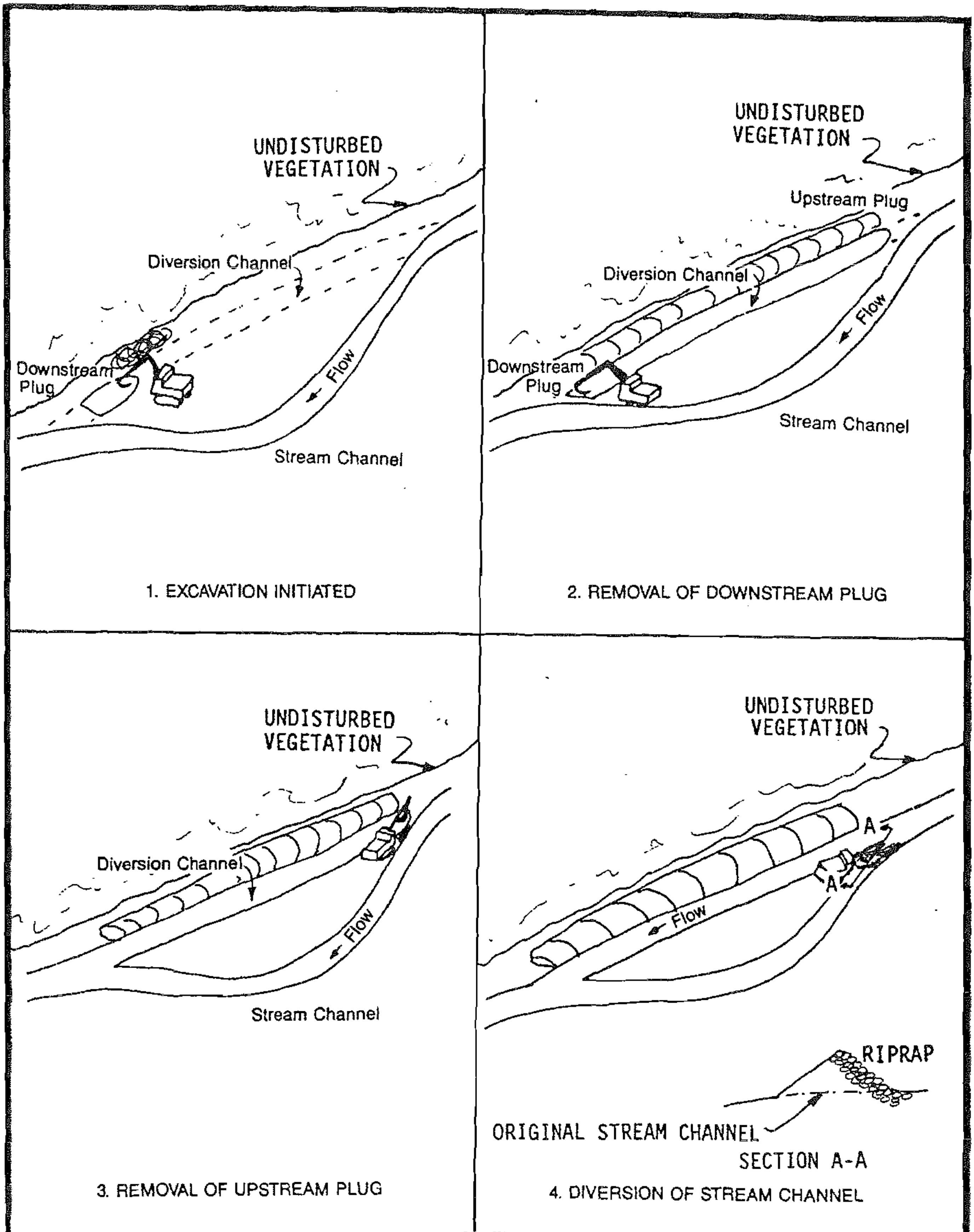
4.3.4 Diversion-Channel Rehabilitation

Diversion channels should be rehabilitated at site closure. After construction of the permanent rehabilitated stream channel (Chapter 8.0), the stream should be diverted from the diversion into the rehabilitated stream channel. The diversion-channel structure on the valley walls should be graded into a backsloping terrace as described in Section 10.2. Diversions on the valley bottom should be rehabilitated to conform to the overall final rehabilitation plan and may range from complete backfilling to leaving in place to form a large capacity high-water channel.

4.4 BEDROCK DRAINS

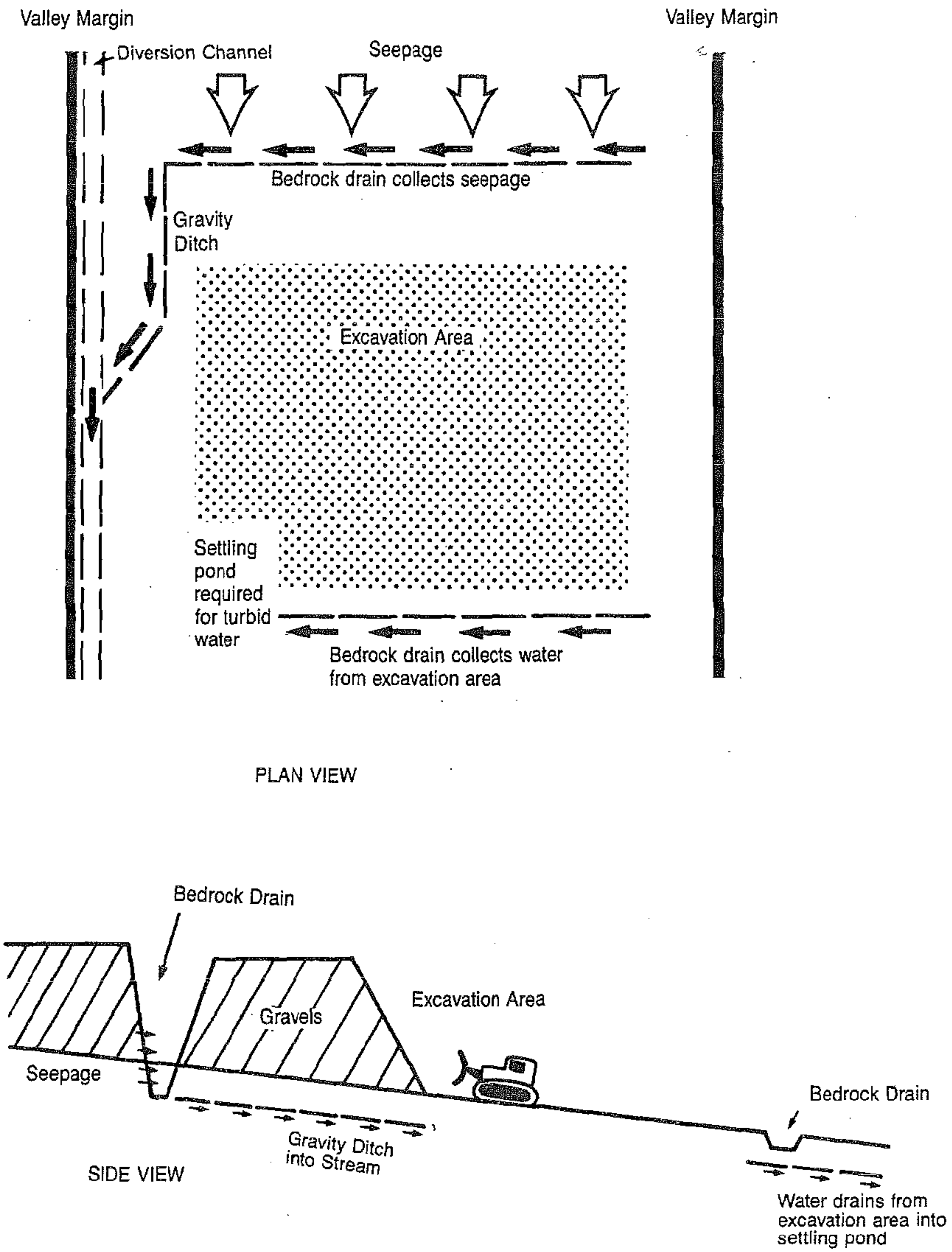
Bedrock drains are primarily used to collect groundwater which infiltrates into the mine area. In the winter, bedrock drains may reduce the potential for aufeis in areas downvalley of the site by lowering the groundwater levels. In general two types of drains can be constructed; one which intercepts clean flow above the mine area and diverts it into the stream or diversion channel and one which collects muddy water from within the work area and routes it to settling ponds.

Groundwater infiltration into the mining area may be minimized by collecting non-contaminated groundwater seepage upstream from the mining site and diverting it around the mine area (Bishop and Hanna 1979). For this purpose, a trench may be dug perpendicular to the stream channel as shown in Figure 7.



DIVERSION CHANNEL CONSTRUCTION

ENTRIX | FIGURE 6



BEDROCK DRAIN SYSTEM WITH GRAVITY DITCH

ENTRIX	Figure 7

A trench excavated to a depth of 4 ft into the bedrock was found to be effective in reducing groundwater infiltration into the excavation area (Peele 1941). While the trench should generally be only deep enough to prevent seepage from flowing into the active mining area, the drain should be designed to have sufficient capacity for aufeis growth. A gravity ditch can be used to divert the flow from the trench around the mine site to a location downstream of the site. The groundwater-diversion channel should not be routed near the stream or diversion until the beds of both channels are approximately equal to minimize seepage losses in the surface-water channel. A pump may be used to dewater the trench into a runoff-diversion ditch or the diverted stream channel. Although a pump system will remove water faster, the costs will be greater (Sowers 1979). The trench may be backfilled with cobbles and large gravels to act as a french drain (Sowers 1979). A series of groundwater-diversion channels may be dug throughout the mining site to collect additional groundwater infiltration from the valley walls (Peele 1941). The groundwater-diversion channel will be most cost effective when built in an area that will eventually be mined. Bedrock drains can be backfilled and graded when no longer needed to dewater the site.

Any turbid groundwater seepage or rainfall within the mine site should be collected and routed to the settling-pond system. Water ponding in the excavation area should be avoided. Within the mine site, an effective bedrock drain will slope downhill along the bedrock from the working face of the mining excavation (Figure 7). Water will drain from the excavation area and should be routed through a settling pond as the water in the excavation area during mining will become turbid and sediment laden.

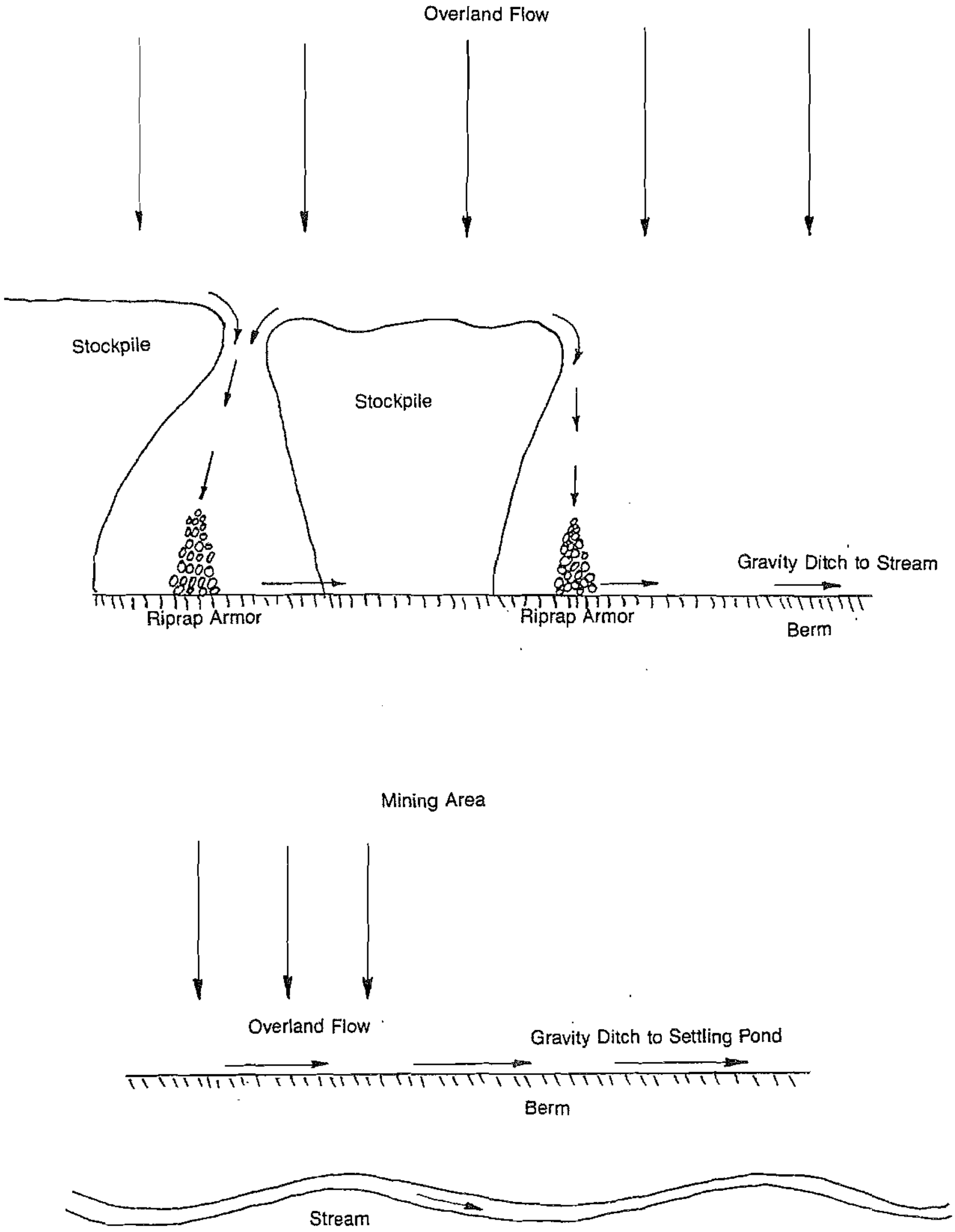
4.5 OVERLAND FLOW

Overland flow from rainfall and snowmelt on the valley walls and terraces should be diverted around the mining site to limit nonpoint-source pollution. Overland flow originating within the mining site should be collected and routed through the settling-pond system. Overland flow can result from melting permafrost, groundwater seepage, rainfall, and snowmelt. A gravity-flow drainage system can divert most of the overland flow around the mining site and retain the remaining sediment-laden water within the site.

Overland flow originating outside the site should be diverted. Upslope berms, approximately 2 ft in height, may be used to divert water around the site (Herricks et al. 1974, Becker and Mills 1972). Gravity ditches should drain the intercepted flow around the site (Kenney 1972). In areas of permafrost, gravity ditches should follow the contours closely and have a maximum slope of 0.25 ft to 100 ft to avoid degradation. Overland flow may also be diverted by stockpiles of strippings and overburden pushed uphill out of the active mining area as shown in Figure 8. Riprap should be placed as needed to avoid erosion. The berms and ditches should be inspected after heavy rainfall events and may require maintenance during the mining season.

Overland flow within the site should be isolated from clearwater streams. Downslope berms and gravity ditches should route turbid overland flow into settling ponds. When feasible, the amount of time of exposure of stripped slopes should be minimized to reduce erosion. Aufeis may also form on exposed slopes.

Drainage structures in areas of permafrost will likely transport significantly larger amounts of water than those constructed in non-permafrost areas, and should be sized accordingly. In areas with permafrost-underlain terrain, the amount of overland flow from precipitation is expected to be large. Areas of permafrost exhibit rapid responses to precipitation. In a study of similar sized streams with and without permafrost, Slaughter et al. (1983) found that the presence of permafrost resulted in greater amounts of overland runoff.



OVERLAND FLOW

ENTRIX FIGURE 8

SITE GRADING

5.0
SITE GRADING

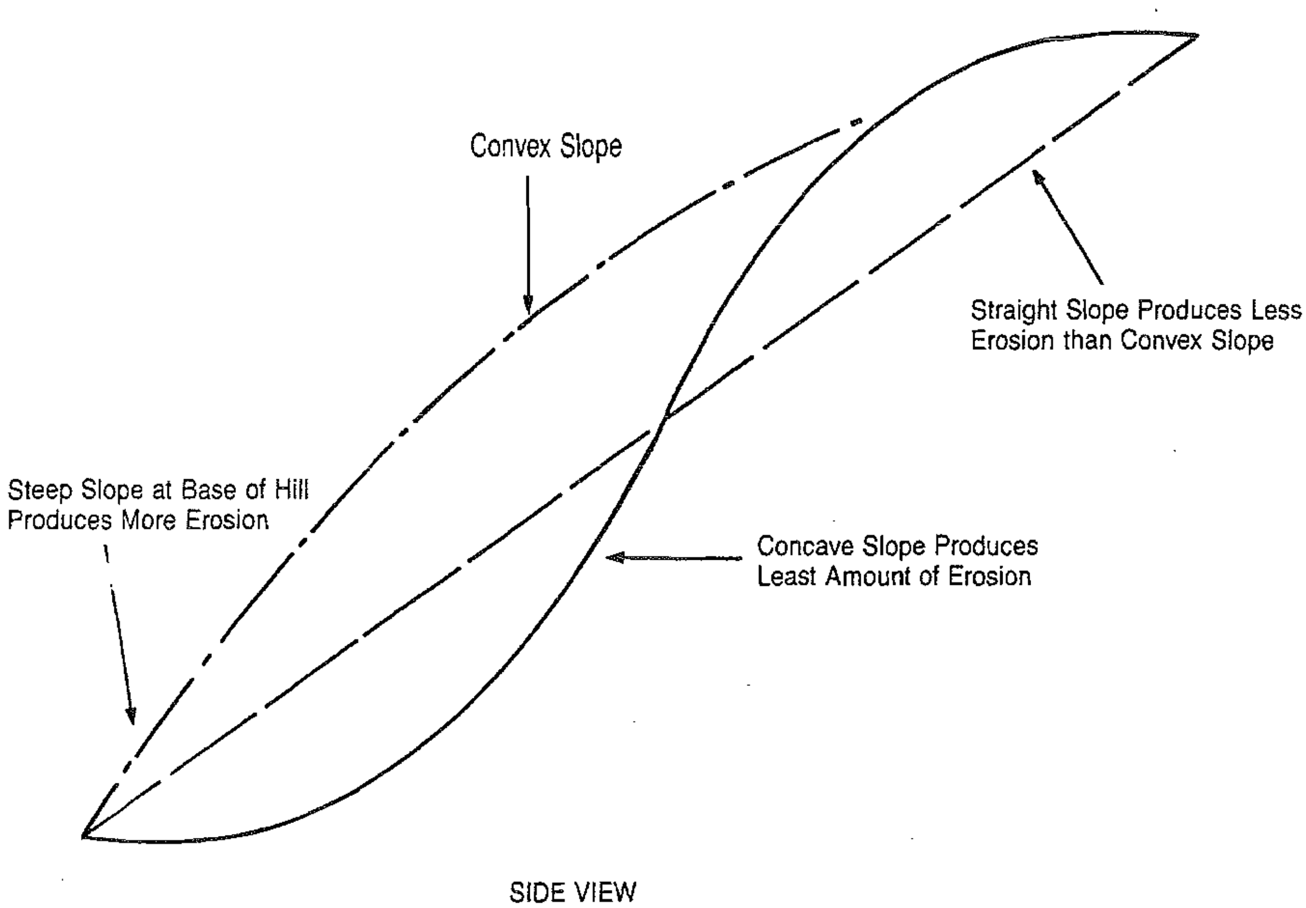
5.1 OBJECTIVES AND SCOPE

Grading the tailing piles and steep excavated slopes within the mining site will reduce erosion and encourage revegetation (Becker and Mills 1972). A grading plan should describe the site grading to be done concurrent with mining activity, at the conclusion of each cut, or at least at the end of each mining season. If tailings are properly placed and graded during mining, additional grading will not be necessary upon site closure.

5.2 PROGRESSIVE SITE GRADING

Grading of tailing and overburden piles at a mining site is integral to erosion reduction. The mining plan should include a temporary and final plan for sloping and contouring which addresses the reestablishment of desired elevations within the site and provides for an appropriate drainage pattern. Grading during mine operation will benefit seasonal erosion control.

Steep slopes and tailing piles should be graded as soon as possible. Surface erosion from slopes is greatest during the first year following disturbance (Cook and King 1983). Reducing the steepness of tailing piles will significantly reduce surface-water pollution (Vesilind and Peirce 1982). A slope of 3 horizontal to 1 vertical, or less is recommended (Becker and Mills 1972, Dryden and Stein 1976). Large piles of stripped loess with thawing ice lenses should be graded to slopes of 3 to 1 when placed. Slopes that are steeper toward the top and shallower toward the bottom are preferred as they have been shown to have less sediment loss than flat slopes or slopes that are steepest at the base (Haan and Barfield 1978, Meyer and Romkens 1976) as shown in Figure 9.



SLOPE EFFECT ON THE AMOUNT OF EROSION

ENTRIX	Figure 9

Grading steep slopes will also reduce potential slope failures which can release large amounts of sediments into nearby streams. Slope failures are generally avoided with 3 to 1 slopes (Schwab 1982). In addition, earthmoving equipment such as front end loaders and bulldozers are able to operate on slopes as steep as 3 to 1 (Johnson 1966). Permafrost terrain that will be worked after thawing should be graded to a shallow grade to minimize erosion of the materials as they thaw. Permafrost terrain that will not be worked should be excavated as a cut face for the duration of adjacent mining operations. This will minimize the surface area of the permafrost exposed to warm air, water, or radiation and will minimize disturbance to the insulating vegetation on the top of the cut bank. Tailings should be pushed up against the cut face following the conclusion of mining at that location.

Terracing and furrowing parallel to the contours should be incorporated in site grading, particularly outside the active floodplain, to reduce the effective length of the slope and thus decrease further erosion. Backsloping terraces perpendicular to the slope should have minimum widths of 14 ft and a maximum slope length between terraces of 100 ft (Beasley 1972). Small furrows (trenches) approximately 0.5 ft in depth and spaced closely together along the contours of the slope can effectively reduce erosion (Doyle 1976, Becker and Mills 1972, Cuskelly 1969).

Tailing piles and steep slopes should be roughened or scarified to reduce erosion by increasing water infiltration, minimizing slope failures, and encouraging natural revegetation (Rutherford and Meyer 1981, Troeh et al. 1980). Tailing piles should be reduced in height. Section 10.2 provides additional information on site grading to be completed prior to site closure.

The mining site should be graded throughout mining to cause surface water from erodible areas to flow through the settling pond system. However, an overflow channel near the diversion channel should be maintained to divert potential flood flows around the settling ponds. The overflow channel should match the acceptable risks specified for the settling ponds and any other structures, such as the camp, to be protected by the overflow channel. The overflow channel can function as a site access road except during periods of flood flow in excess of the diversion channel design flood.

Site grading during site operation most likely will be more cost effective and efficient than site grading at the end of each mining season since the equipment will already be in the immediate vicinity and grading at the completion of each cut rather than at the end of the mining season will discourage repeated handling of material. Moving and handling material will increase the time and costs involved in grading. In addition, a lesser amount of material will be handled at one time. Tailing piles and overburden may be mixed and graded together unless stockpiled for use in site rehabilitation; the quantities necessary for rehabilitation should be roughly determined during rehabilitation planning (Chapter 8.0 and Section 10.3). Progressive site grading can realize the benefits of improved erosion control and vegetation reestablishment (Johnson 1966).

STOCKPILE PLACEMENT AND PROTECTION

6.0 STOCKPILE PLACEMENT AND PROTECTION

6.1 OBJECTIVES AND SCOPE

Proper placement and protection of stockpiles will minimize erosion of the stockpiles, ensure maximum retention of materials for site rehabilitation (Chapter 10.0), and minimize distances that stockpiled materials must be moved during site rehabilitation. Thorough knowledge of the site-rehabilitation plan is required for implementation of the best management practices for stockpile placement and protection.

Stockpile placement and protection, if properly planned and executed, will help to control erosion. Stockpiles should not be located near an active channel or within the active floodplain where high flows could erode the sediments. Areas of concentrated surface runoff should also be avoided. Organic material and settling pond fines may have a high moisture content and may require containment berms around the perimeter of these stockpiles. Stockpile locations should be identified after consideration of drainage patterns and the eventual use of the material (Section 10.3). Stockpiles should be located in areas where they can be easily protected and where rehandling will be minimized. The amount and type of material required during site rehabilitation should be estimated to determine the quantities of each material to be stockpiled.

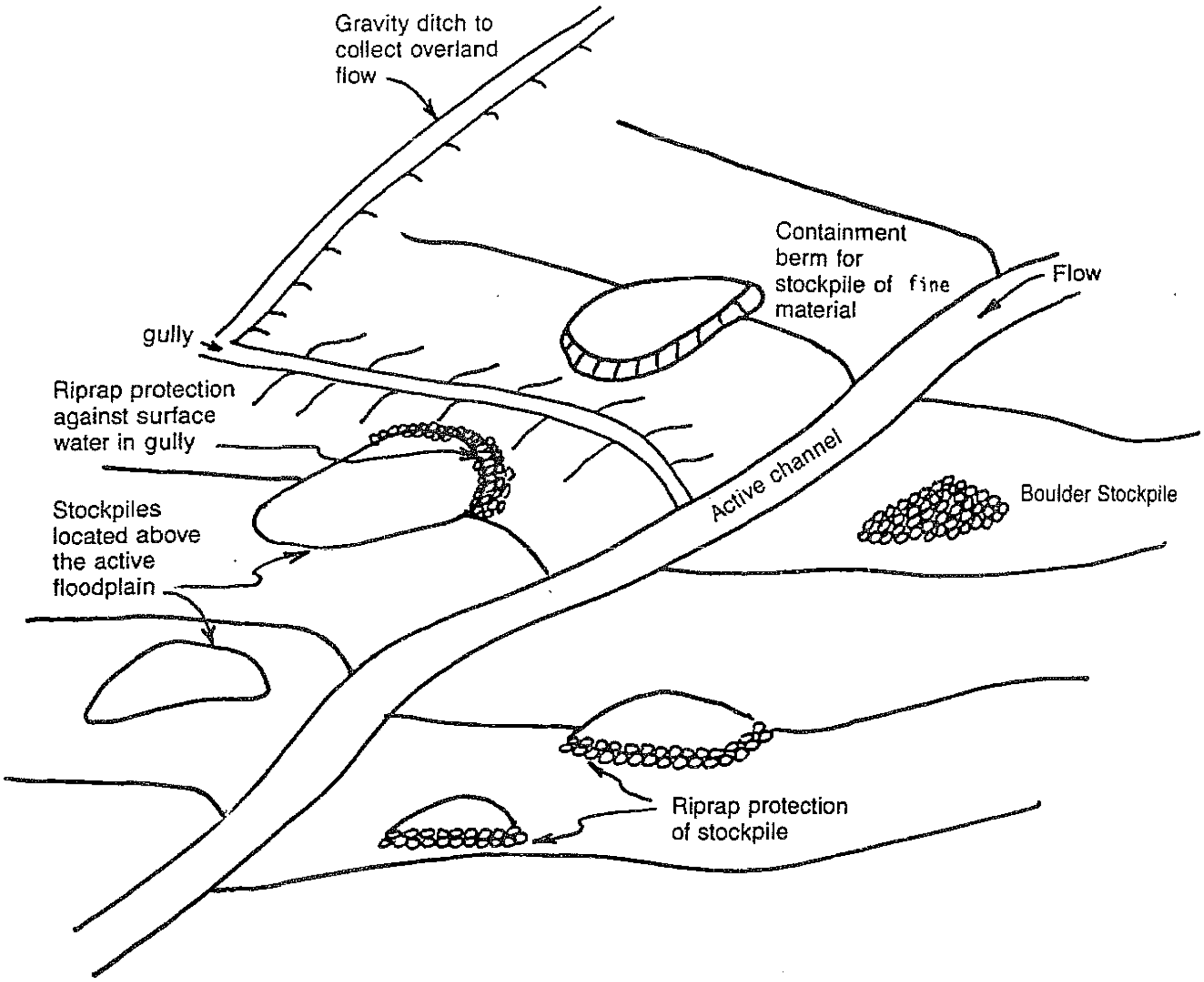
6.2 STOCKPILING

Materials to be stockpiled include six types of material that can be removed from a work area to be stored for use in site rehabilitation. These are: 1) trees (greater than 6 inches in diameter at breast height); 2) small trees, shrubs, and grasses with the top layer of organic soil; 3) shallow soils, often containing a mixture of fine organic and inorganic material; 4) large quantities of fine inorganic material, such as deep loess deposits; 5) oversize inorganic material such as large boulders; and 6) fines removed from settling ponds. If the top layer of organic soil is very thin, the upper six inches of the surface material should be removed and stockpiled with the shrubs and grasses. Depending on the area of the state where the mine is located, one or more of these categories may not be present.

Nonpoint-source pollution from stockpiles can be minimized through proper siting and containment procedures. The principal objective in selecting sites for stockpile placement is to place the material in a location where the material is protected from surface flow, including active stream channels and runoff from rain or snow melt. Stockpiles should be located and protected according to the acceptable risks at the site (Section 8.2). Stockpiles should generally be located in elevated areas away from flood waters such as on the valley walls or in flat areas where flood waters often have shallow depths and low velocities (Figure 10). Armoring the lower slopes of the stockpiles with riprap and large rocks is suggested if protection is needed. An armoring layer of cobbles or riprap may inhibit the erosion of fine sediments. Stockpiles should preferably be located where the results of the site assessment work indicate unproductive material.

Location of stockpiles should also be based on minimizing handling. Properly choosing washplant, screening plant, grizzly, or stacker locations and the directions in which tailings are pushed can result in stockpiling in the proper location without expending additional equipment time for material redistribution.

Large trees require the least protection since surface flow past a stockpile of trees will not substantially contribute to nonpoint-source pollution. Stockpiles of trees should be placed in an area where they will not interfere with the mining operation and be available to enhance stream and floodplain habitats after the site is closed. As described in Section 10.3, trees will be used separately from other types of organic material during site rehabilitation. Therefore, large trees should be stockpiled separately from other types of material and not mixed with other organic material during



STOCKPILE PROTECTION

ENTRIX

Figure 10

temporary storage. In some cases, the trees can be used to construct log crib containment berms for smaller organic material.

The most common forms of vegetation that are removed during a placer mining operation are the small trees and shrubs that occupy previously undisturbed floodplain riparian zones. Proper stockpiling and protection of this material is important since it will serve as the stock for natural revegetation, and since the material is easily eroded. The small trees, shrubs, and grasses should be piled with the top layer of organic soil. Placing these two types of materials together accomplishes several objectives. First, the woody material will provide some protection for the organic soil from wind and surface water erosion. Second, many species of shrubs and grasses will continue to grow within the stockpile. This will improve the survival rate of vegetation placed during site closure. Third, when the shrub layer and surface soil are removed together, disturbance of the root zones will be reduced, thus enhancing survival of the vegetation. This material should be kept moist to maintain the viability of the woody slash.

The shallow soils often consisting of fine organic material, sands, and perhaps some gravel and cobble should be piled separately from the trees and the shrub-organic soil piles. This material should be protected since it can be eroded easily. If necessary, large rocks can be used for containment along the side slopes of the piles. Containment berms may also be constructed around the stockpiles.

At some locations deep deposits of loess, or fine inorganic soil, must be removed to expose placer-bearing gravels. In these situations the large volume of material that must be handled dictates that it be moved a short distance and only handled once. Typically, the most efficient handling of this material is to push it up the valley side slopes into fan-shaped, flat-topped mounds (Figure 8). At sites where large volumes of this material must be handled, final stockpile locations should provide maximum protection from wind and surface-water runoff since this material is easily eroded. If organic rehabilitation material is limited at the site, portions of this loess material may be used both as a leveling layer and as a seedbed to enhance vegetative recovery (Section 10.3).

Oversize inorganic material, including large boulders, should be stockpiled separately. The large rocks available on site may be used to temporarily armor other stockpiles if necessary (Section 8.5.3). During stream rehabilitation, the large boulders will be useful as riprap for bank and channel stabilization (Section 8.5) or as fish habitat features (Sections 9.4.1 and 9.4.2). The larger cobble sizes, such as the material segregated by grizzlies, may also be used during stream rehabilitation as streambed material (Chapter 8.0). Stockpiling this material may not be necessary during bench mining.

In situations where highly erodible stockpiled material cannot be protected using berms and riprap as described, temporary seeding and fertilizing using annual grasses may be useful to help stabilize this material.

BEST MANAGEMENT PRACTICES FOR PLACER MINING

TECHNICAL REPORT

SITE REHABILITATION

INTRODUCTION TO SITE REHABILITATION

7.0
INTRODUCTION TO SITE REHABILITATION

7.1 OBJECTIVE AND SCOPE

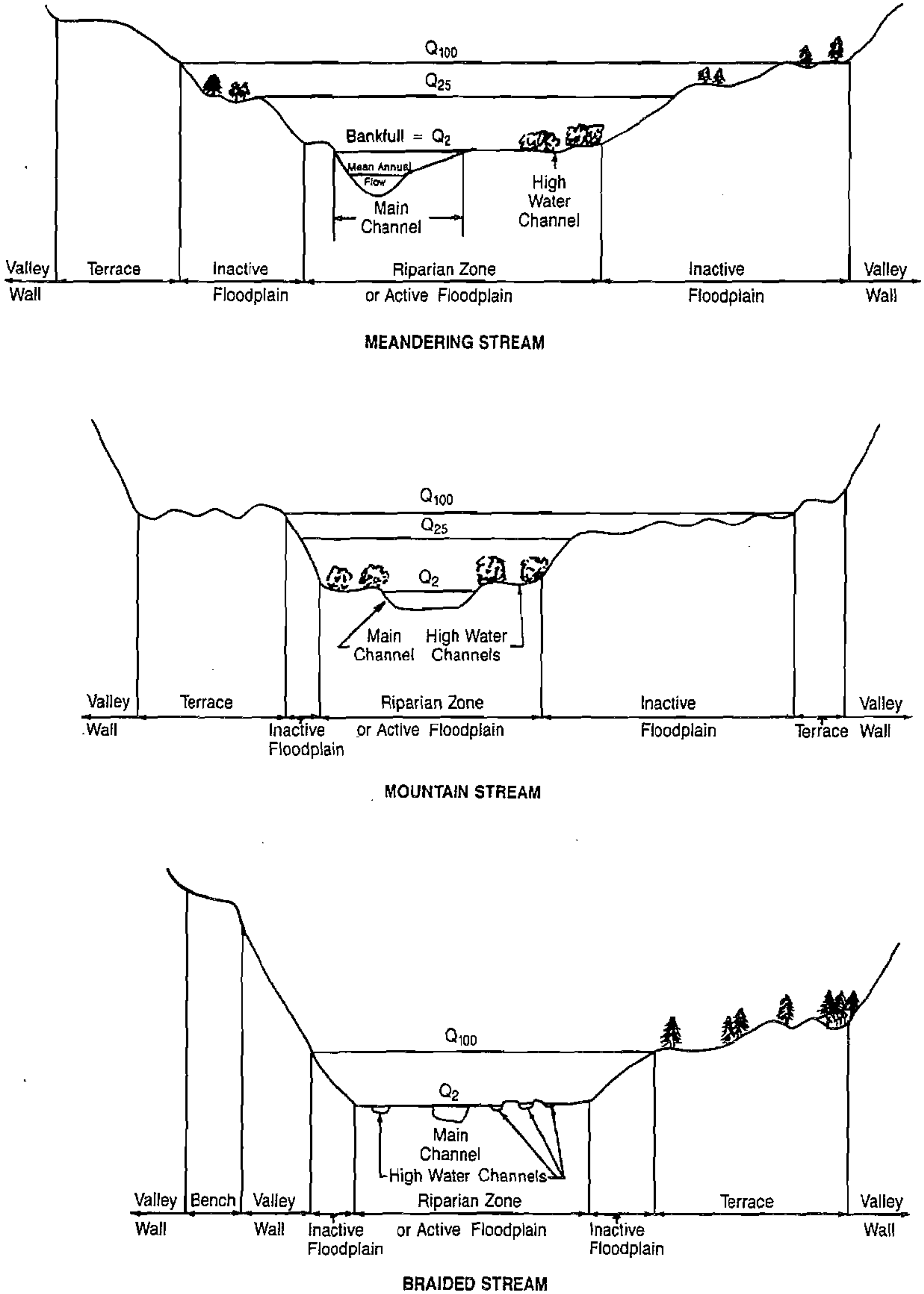
The objective of the site-rehabilitation BMP's is to present design recommendations for permanent features that will promote and enhance the natural recovery of aquatic and terrestrial habitats disturbed by placer mining operations.

The site-rehabilitation BMP's are separated into three chapters discussing stream, fish habitat, and floodplain rehabilitation. Discussions in each chapter present preferred locations and designs for stream and floodplain features. Figure 11 shows floodplain cross sections for meandering, mountain, and braided streams identifying the riparian zone, inactive floodplain, valley terrace, and valley bench.

Stream rehabilitation covers design flows, stream pattern and placement, hydraulic design, and channel stability. A stream rehabilitated following these recommendations will be similar to the natural stream occurring above and below the mine site.

The fish-habitat-rehabilitation BMP's can be used to refine the stream design to improve habitat quality. Physical characteristics that affect fish habitat are discussed. Habitat requirements are presented for anadromous and resident fish in order to provide the basis for designing appropriate habitat features.

The floodplain-rehabilitation BMP's address the riparian zone, the inactive floodplain, and valley terraces and benches. Recommendations for site grading and dispersement of stockpiles of overburden and organic soils in each of



CROSS-SECTION SKETCHES DEFINING TOPOGRAPHIC FEATURES

ENTRIX | **Figure 11**

these areas are provided. Finally, techniques for revegetation to enhance natural recovery of each site are discussed.

7.2 SUMMARY

Site rehabilitation at placer mines includes providing areas within the disturbed site that can rapidly recover to provide productive habitat for local fish and wildlife. A summary of important issues and design objectives that should be addressed in site rehabilitation is presented in Table 5.

Stream rehabilitation following the completion of mining should provide a stream channel with proper configuration, size, and profile to safely pass a 2-year flood event. If fish are present in the stream, or if there is a high potential for fish to return to the stream from elsewhere in the drainage basin, then the stream design should also incorporate features to restore fishery habitat. Design recommendations are provided for streams of meandering, mountain, and braided configurations that create areas with proper velocity, depth, substrate, and cover for selected fish.

In general, final channel designs for fish streams should emphasize development of habitat for juvenile rearing, adult and juvenile feeding, and adult and juvenile passage. It is difficult to create spawning areas for species whose eggs incubate for long periods in redds that are highly dependent upon intragravel flow. The replacement of lost spawning habitat is extremely important to local populations, particularly where such habitat is the dominant factor limiting a population. In areas where spawning habitat did not exist, habitats for other life stages should be emphasized. Replacement of spawning gravels for broadcast spawners such as grayling has a greater probability of providing usable habitat and is thus more easily justified.

Floodplain rehabilitation consists of final sloping and contouring of disturbed areas, and dispersement of stockpiled vegetative slash, overburden, and organic material to enhance site revegetation. Final site grading, if not done concurrently with mining activities, should focus on removing or reducing tailing piles to recommended slopes, providing controlled site drainage

Table 5. Summary of Issues and Design Objectives for Site Rehabilitation.

Activity	Issues	Design Criteria
Stream rehabilitation	. channel structure	. meandering, mountain, or braided configuration . design for 2-yr recurrence flood . proper slope, channel geometry, and bed and bank material . channel profile
Fish-habitat rehabilitation	. anadromous or resident fish .. adult and juvenile rearing .. spawning .. passage	. channel profile and configuration .. pools and riffles .. instream cover .. riparian vegetation . habitat parameters .. depth, velocity, substrate
Floodplain rehabilitation	. site grading . site revegetation	. active and inactive floodplains .. drainage control . terrace and bench .. erosion and sediment control . preferred locations for organics .. fish stream - riparian zone .. non-fish stream - riparian, settling ponds, catchment basins, wildlife corridors

patterns, stabilizing or cleaning settling ponds, and contouring steep slopes to control site erosion and siltation. Final slopes and contours are most important in the active floodplain, or riparian zone where it is critical that the stream remain in its designed channel for the first several years.

The stream rehabilitation section provides design details for preferred final slopes in the active floodplain. In the inactive floodplain and valley terrace, contouring should provide a series of connected depressions between graded tailing piles to act as high water drainages and silt catchment basins. If steep slopes have been disturbed on the valley wall, a series of side contour benches should be created to minimize erosion.

Following site grading, all stockpiled overburden, organics, and vegetative slash and trees should be placed in preferred locations for enhancement of site vegetation recovery. The preferred locations for enhancing revegetation will vary by site and are dependent upon stream configuration, presence of fish, and overall amount of site disturbance. Design recommendations are provided for selection of preferred locations. In all cases, the objective of the stockpile dispersement is to enhance the rapid development of shrub thickets dominated by willows, birch, and alder.

STREAM REHABILITATION

8.0 STREAM REHABILITATION

8.1 OBJECTIVES AND SCOPE

The objective of stream rehabilitation is to design a stream channel with natural stream patterns, cross-sectional geometry, longitudinal profile, and sediment-transport characteristics. Fish passage and, when appropriate, fish habitat should be provided in the rehabilitated stream. A channel so designed should require minimal self adjustment and thus should recover to its natural equilibrium condition rapidly. A combination of theoretical and empirical approaches is presented to meet this objective. Some elements of permanent stream rehabilitation design are also applicable to temporary stream diversions.

The first steps of stream rehabilitation are to assess the acceptable risks at the site, select a design flow recurrence interval for channel design, and compute the corresponding discharge. The risks at the site should be assessed for temporary structures by considering the value of the stream, the structures to be protected, and the extent of mining at the site. Important recurrence-interval design flows for permanent rehabilitation include the mean annual flow for evaluating fish passage, the 2-year flood for designing the bankfull channel, the 25-year flood for defining the lowest terrace level, and the 100-year flood to define the upper limit of the inactive floodplain.

Once the design-flood recurrence interval and discharge value are obtained, stream pattern and placement must be considered. Stream patterns selected for use in stream rehabilitation design are meandering, mountain, and braided. Recommendations are provided for selecting the stream pattern that would likely occur naturally in the valley being mined. Placement of the stream in the valley is important in both the horizontal and vertical directions. The horizontal or plan view placement within the valley may in part be dictated by the miner's plan of operation but must also consider alternatives that will enhance habitat development and recovery. The vertical placement of the stream in the valley is very important to the long-term stability of the stream.

The stream-channel design should be based on bankfull flow. Design considerations include channel geometry, hydraulics, stability, pattern, and profile. Design of meandering, mountain, and braided streams use different techniques. Meandering and braided streams are designed using the concept of regime-channel hydraulic geometry. With this method, the hydraulic geometry of numerous natural streams with the same pattern are used to develop equations for the hydraulic-geometry parameters of top width, mean depth, and mean velocity. These equations are used to size the rehabilitated stream. These streams will have a similar level of stability to natural streams with the same pattern. Mountain streams, which are generally armored and relatively stable, are designed using channel stability as the basis for design.

In addition to including channel stability as a general consideration in the design process, a separate section is provided that discusses specific techniques to maintain bed and bank stability. Bed and bank armoring and riprap protection are discussed and design recommendations are provided. This section is useful in the design of bed or bank protection at specific locations along the rehabilitated stream.

At mining sites where the stream is rehabilitated prior to the completion of mining at the site, areas of mining activity within the inactive floodplain of the stream should be protected with levees sufficient to satisfy the acceptable risks at the site. The levees should have maximum bank slopes of 3 to 1.

8.2 DESIGN FLOWS

Design flows consist of maximum and mean flows that may occur during the period of mine operation. Design-flow selection should be based on the acceptable risks at the site. Design flows must be evaluated for the design of temporary diversion channels and for final rehabilitation of a stream channel. Two characteristics of design flows are the recurrence interval and the discharge.

8.2.1 Risk Assessment and Recurrence-Interval Selection

The acceptable risks for the structure to be designed and the value of the stream should be assessed. Table 6 presents initial design values of acceptable risks for temporary structures which may be modified to meet agency management goals and site-specific conditions. The acceptable risk may be represented by the probability that a flood event will occur. A higher probability indicates a higher risk that the event will occur. Classification of the value of the stream is based on its value in providing fish habitat, as described in Section 9.1.

Table 6. Acceptable risks of flooding for streams.

	Value of Stream		
Structure	High	Medium	Low
Diversion Channel	30%	50%	50%
Settling Ponds	5%	10%	20%
Stockpiles	5%	10%	20%
Hazardous material and camp	<5%	<5%	<5%

Following the evaluation of the acceptable flood probability for the temporary structures, the number of years of operation at the site should be determined. The site plan, including consideration of the amount of reserves in the ground, should provide the basis to determine the duration of mining. The probability of occurrence of a certain event increases with the design life. A specific recurrence-interval flow is more likely to occur when more than 1 year is considered. For example, a 2-year recurrence-interval flood has a 50% probability of occurring in 1 year. If a mine is operated over 2 years, the probability that a 2-year recurrence-interval flood will occur increases to 75%.

The recurrence interval should then be selected from Table 7. The duration of mining (the project life) and the acceptable flood probability dictate the flood recurrence interval for design. The recurrence interval indicates the probability of the occurrence of a particular flow. For example, a 2-year recurrence-interval flood has a 50% probability of occurring in 1 year while a 10-year recurrence-interval flood has a 10% probability of occurring in 1 year.

Table 7. Recurrence interval (years) corresponding to acceptable risk and project life

Project	Acceptable Risk (%)													
Life	5	10	15	20	25	30	35	40	45	50	60	70	80	90	99+
1	20	10	7	5	4	3	3	2	2	2	1.7	1.4	1.25	1.1	1
2	40	19	13	9	7	6	5	4	4	3	3	2	2	1.5	1
3	59	29	19	14	11	9	7	6	6	5	4	3	2	2	1
4	78	38	25	18	14	12	10	8	7	6	5	4	3	2	1
5	98	48	31	23	18	15	12	10	9	8	6	5	4	3	1
8	156	76	50	36	28	23	19	16	14	12	9	7	5	4	1
10	195	95	62	45	35	29	24	20	17	15	11	9	7	5	1

Designing temporary structures for the acceptable risks presented in Table 6 involves interaction between the design considerations for the various structures; it can most effectively be accomplished through detailed site planning. As an example, assume that a miner will be operating 1 year at a site on a stream of medium value and wants to design his settling ponds. A direct application of the maximum risk criteria would mean that he should design his diversion channel for a 2-year flood (50% risk in one year of mining) and that his settling pond should be located or protected, or that his site be graded, such that waters spilling out of the diversion channel during a 10-year flood event (10% risk in one year) will not cause damage to the settling pond structure or wash silts out of the pond. An alternative to this approach may be to design the diversion ditch for a 5-year flood (20% risk in one year of mining) and design the settling pond for protection from the lesser quantity of water that would spill out of the diversion channel during the 10-year flood event. The miner should evaluate which approach would be most applicable for his particular situation.

The mean annual flow should be utilized as an index flow to assess the depth and velocity for fish passage and other habitat conditions (Section 9.3). The mean annual flow is approximately equal to the mean summer flow.

The design-flood recurrence interval for permanent stream channel rehabilitation is recommended on the basis of matching natural hydrologic and hydraulic processes. A natural gravel-bed stream channel generally adjusts its channel pattern, channel geometry, and longitudinal profile through a process of erosion and deposition. The controlling variables of the erosion and deposition process include stream discharge, sediment transport, bed and bank material, and valley slope (Hey 1982). Of these controlling variables, the bed and bank material and valley slope change slowly under natural conditions, while the stream discharge and sediment transport fluctuate widely each year.

Sediment transport processes, which are related to stream discharge, control the process of erosion and deposition. While rare flood events (e.g., 100-year flood) can transport large quantities of sediment, they occur infrequently and are not dominant in forming the channel shape. A smaller flood, but one which has significant sediment transport capability, would be the dominant flood. The frequently accepted flood for defining the channel cross section is the bankfull flood (Hey 1982, Parker 1979, Nixon 1959, Leopold and Wolman 1957). The recurrence interval of bankfull conditions was investigated by Emmett (1972) for streams in the Southcentral and Yukon regions of Alaska. The average value of bankfull frequency was about 1.5 years. Bray (1979) selected a 2-year flood to represent a relatively high in-bank flow on gravel-bed rivers in Alberta. A 2-year recurrence interval flood is recommended for bankfull discharge for stream channel design so that the rehabilitated stream flows at bankfull conditions as frequently as natural streams. Calculation of the 2-year flood discharge is described in Section 8.2.2.

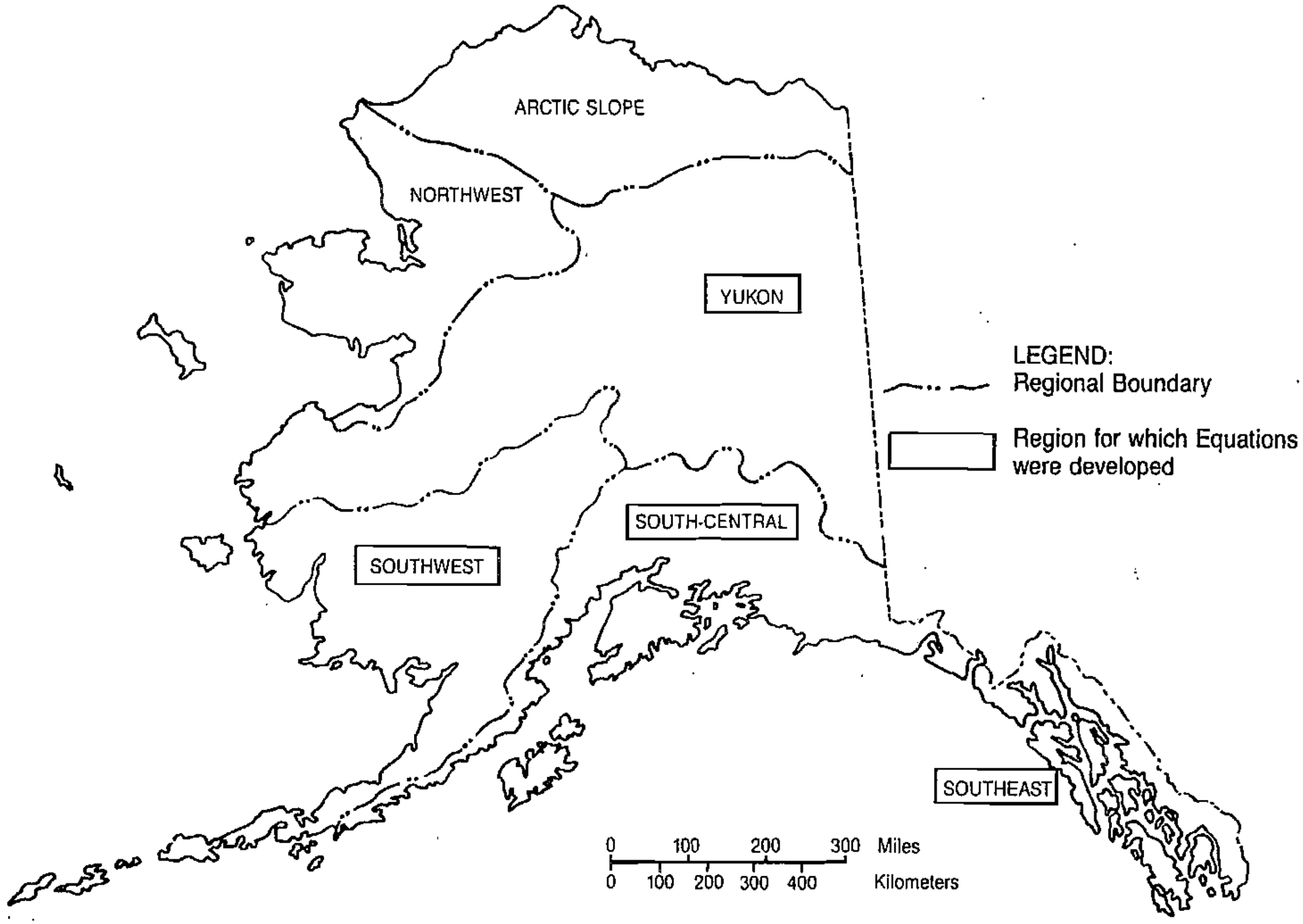
The 25-year and 100-year flood-recurrence intervals have been selected as reference floods for floodplain rehabilitation. The 25-year flood level should be selected as the minimum level below which the configuration is based primarily on flood conveyance and flood protection as described in Section 10.2. From this level up to the 100-year flood level, the rehabilitated topography can reflect other concerns, such as wildlife habitat in addition to the flooding concerns.

8.2.2 Design Flow Computation

After the acceptable recurrence intervals have been selected, corresponding discharges must be evaluated. If the site is located near a stream gaging station, the gage records should be used to assess potential high and low flows as described by the U.S. Water Resources Council (1981). Actual streamflow data are preferred when evaluating flows. The designer should contact the U.S. Geological Survey and the Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys to ask for flow data on his stream. When mining sites are not located in the vicinity of a stream gage, the high and mean annual flows must be estimated.

Parks and Madison (1985) have developed equations specific to Alaska for predicting high and mean annual flows of varying recurrence intervals given drainage area and mean annual precipitation. These equations represent the most current and extensive compilation of data collected by U.S. Geological Survey on Alaska streams. Equations for four regions of Alaska (Figure 12) were developed; for sites outside these four regions, the statewide equations should be used. Table 8 presents the equations and the standard error calculated for each equation.

The standard error of the equations should be considered when evaluating high and mean annual flows. The range within which the true value is expected to occur 67 percent of the time is approximately bounded by the values one standard error greater and less than the predicted value. Therefore, where equations are used to estimate the flows, the potential range of values should be considered. For high flow cases, the standard error should be added to the flow predicted by the equation. For mean annual flows, the standard error



Source: Parks and Madison 1985

REGIONAL BOUNDARIES OF EQUATIONS

ENTRIX | **Figure 12**

Table 8. Equations for evaluating high flows of varying recurrence intervals and mean annual flows.

$$Q = aA^{b1} P^{b2}$$

$$\log Q = \log a + b_1 \log A + b_2 \log P$$

Q = flow (cfs)
A = drainage area (mi^2)
P = mean annual precipitation (in)

	Statewide		Southeast Region		Southcentral Region		Southwest Region		Yukon Region	
	Parameters	Standard Error in log units	Parameters	Standard Error in log units	Parameters	Standard Error in log units	Parameters	Standard Error in log units	Parameters	Standard Error in log units
QA[1]	log a = -1.51 b_1 = +0.98 b_2 = +1.19	.15	log a = -0.46 b_1 = +1.01 b_2 = +0.68	.14	log a = -1.33 b_1 = +0.96 b_2 = +1.11	.16	log a = -1.38 b_1 = +0.98 b_2 = +1.13	.15	log a = -2.04 b_1 = +1.05 b_2 = +1.39	.10
Q_2[2]	log a = -0.41 b_1 = +0.88 b_2 = +1.20	.27	log a = +1.25 b_1 = +0.81 b_2 = +0.49	.19	log a = -0.69 b_1 = +0.87 b_2 = +1.31	.25	log a = +0.37 b_1 = +0.86 b_2 = +0.59	.18	log a = -0.20 b_1 = +0.91 b_2 = +1.02	.25
Q_5	log a = +0.10 b_1 = +0.84 b_2 = +1.04	.28	log a = +1.52 b_1 = +0.78 b_2 = +0.44	.20	log a = -0.25 b_1 = +0.83 b_2 = +1.19	.25	log a = +0.97 b_1 = +0.84 b_2 = +0.34	.16	log a = +0.39 b_1 = +0.85 b_2 = +0.85	.26
Q_{10}	log a = +0.39 b_1 = +0.82 b_2 = +0.95	.28	log a = +1.66 b_1 = +0.77 b_2 = +0.44	.21	log a = +0.03 b_1 = +0.81 b_2 = +0.13	.26	log a = +1.33 b_1 = +0.83 b_2 = +0.19	.15	log a = +0.73 b_1 = +0.82 b_2 = +0.74	.28
Q_{25}	log a = +0.73 b_1 = +0.79 b_2 = +0.84	.30	log a = +1.81 b_1 = +0.76 b_2 = +0.38	.22	log a = +0.25 b_1 = +0.79 b_2 = +1.05	.28	log a = +1.73 b_1 = +0.82 b_2 = +0.02	.15	log a = +1.13 b_1 = +0.78 b_2 = +0.62	.30
Q_{50}	log a = +0.97 b_1 = +0.77 b_2 = +0.76	.32	log a = +1.92 b_1 = +0.75 b_2 = +0.36	.23	log a = +0.44 b_1 = +0.77 b_2 = +0.99	.29	log a = +2.01 b_1 = +0.81 b_2 = -0.10	.15	log a = +1.39 b_1 = +0.76 b_2 = +0.54	.32
Q_{100}	log a = +1.20 b_1 = +0.75 b_2 = +0.69	.33	log a = +2.01 b_1 = +0.74 b_2 = +0.34	.24	log a = +0.63 b_1 = +0.75 b_2 = +0.94	.31	log a = +2.27 b_1 = +0.80 b_2 = -0.20	.16	log a = +1.64 b_1 = +0.73 b_2 = +0.47	.34

[1] QA = mean annual flow

[2] Q_2 = High flow of 2-year recurrence interval.

Note: Use statewide equation for regions without specified equations.

Source: Parks and Madison, 1985

should be subtracted from the flow predicted by the equation. The use of the standard error will decrease the uncertainties associated with using the generalized equations, especially in the case of small or high mountain basins.

Other methods of estimating high flows are available. Ashton and Carlson (1984) developed alternative equations for evaluating spring, summer, and fall high flows in southcentral and interior Alaska. These equations may be useful if flows during only one part of the mining season are of concern. High spring flows predicted by Ashton and Carlson (1984) appear to be similar to the annual high flows predicted by Parks and Madison (1985). The Alaska region of the U.S. Forest Service (1979) presented several graphs of high flows versus drainage area for streams in southeast Alaska.

High and mean annual flows may be evaluated from the easily measured variables of drainage area and mean annual precipitation. Although additional physical and climatic characteristics are known to influence streamflow, the reliability of the equations developed by Parks and Madison (1985) did not significantly increase when other variables were included.

The drainage area upstream of the mining site may be obtained from topographic maps of the region. The USGS topographic maps which depict the site in the greatest detail should be used. The drainage basin should be delineated and the area should be calculated. A planimeter or the grid-sampling method of determining drainage area may be used (Jones 1983).

Mean annual precipitation data for Alaska are presented in Appendix C (Lamke 1979). The data are generally from low-lying coastal and river valley areas and may not adequately predict precipitation at higher elevations. In portions of the Southcentral and Southeast regions, more accurate maps of mean annual precipitation adjusted for elevation have been prepared (Ott Water Engineers, Inc. 1979). Although the actual mean annual precipitation at a site is likely to be greater than the values obtained from Appendix C, the development of the flow-prediction equations was based on unadjusted mean annual precipitation values. If the equations developed by Parks and Madison (1985) are used, the maps in Appendix C should also be used. The use of unadjusted precipitation values should not cause a significant error in the flow prediction.

8.3 STREAM PATTERN AND PLACEMENT

8.3.1 Definitions

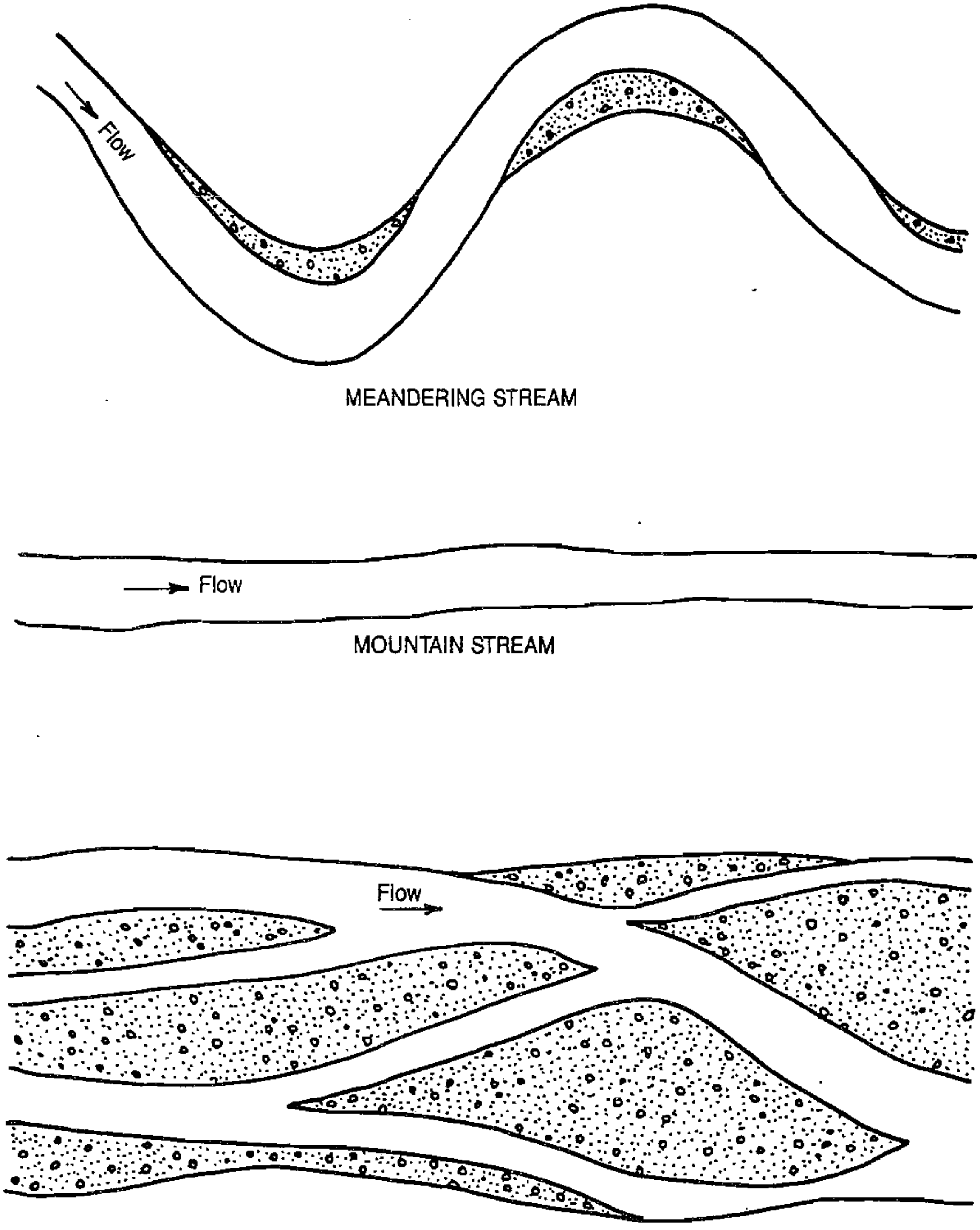
Stream pattern is the configuration of the stream as it is seen from the air. Natural streams may take any of a number of patterns depending on the slope of the valley through which the stream is flowing, the amount of flow in the stream channel at bankfull flow levels, and the amount of sediment carried by the stream. For the purposes of stream rehabilitation, streams will be classified into one of three types:

1. Meandering streams wind back and forth within the floodplain in a regular pattern and typically have gravel-bar deposits on the inside of each bend.

2. Mountain streams are high-gradient, single-channel systems carrying relatively low sediment loads.

3. Braided streams contain two or more interconnecting channels, separated by unvegetated gravel bars or sparsely vegetated islands, and transport large quantities of sediment during most summer flow levels.

Schematic diagrams of each are shown in Figure 13. Other stream patterns have been used in the past by various investigators (e.g. Leopold and Wolman 1957, Karaki, et al. 1974, Joyce et al. 1980). The categories selected for stream rehabilitation design include the other patterns as shown in Table 9.



PLAN VIEWS OF MEANDERING, MOUNTAIN AND BRAIDED STREAMS

ENTRIX | Figure 13

Table 9. Relationship between stream categories used for rehabilitation and those defined by various authors.

	Meandering	Braided	Mountain
Straight	X		
Sinuous	X		
Meandering	X		
Split	X		
Braided		X	
Alluvial Fan		X	
Mountain			X

For example, a stream that has been classified as sinuous should be rehabilitated using the BMP's for meandering streams.

8.3.2 Selection of Stream Pattern

The stream pattern for the rehabilitated stream channel should be selected to match the pattern that would likely occur naturally. Evaluating the natural pattern can be difficult since defining the channel-pattern categories requires selection of an indistinct boundary in a continuum of stream patterns. When uncertainties exist, the more stable meandering and mountain patterns should be selected.

The selection of a stream pattern should be based on actual data when available; theoretical data should be used only when actual data are unavailable. The type and amount of data which should be collected will depend on the previous amount of disturbance within the valley; three types of sites are defined in Table 10 and discussed further below.

Table 10. Type of data for selecting stream pattern category for three types of sites.

	Actual	Theoretical
Site not previously mined	X	
Site previously mined but upstream or downstream has not been mined	X	X
Entire valley has been mined		X

A. Site Not Mined

Actual stream observations and data should be used at sites which have not been previously mined and which have not been disturbed by upstream mining. This will enable the miner to design his rehabilitation plan to return the stream channel to a near-natural pattern. Data that should be collected and mapped to scale include:

1. stream channel course or position

2. number and length of pools and riffles

3. location of multiple-channel reaches and number of channels

These data can be collected from one or a combination of any of the following techniques, which are listed in order of decreasing accuracy:

1. field surveying measurements

2. aerial photographs with known scale

3. topographic maps

Field observations and estimates are helpful to support methods 2, 3, and 4.

The stream-rehabilitation plan should define a stream pattern that is similar to the natural pattern. The position within the floodplain may be different, but the length, number and degree of bends, and number and location of pools and riffles should be equivalent to those in the natural stream. Additional pools may be needed in mountain streams to increase stability. Multiple-channel reaches should be evaluated for stability and designed as meandering reaches if stable, or braided reaches if unstable. The stability can be evaluated by observing sediment-transport trends and channel shifting. Unstable braided streams typically transport suspended sediments and even bed load at flows less than those clearing flood events; many braided channels also shift frequently resulting in unvegetated floodplains. If the valley slope is nonuniform or unknown, then the design should be based on valley segments, with the relocated stream having the same characteristic as the natural stream within each segment.

B. Site Mined but Valley Not Mined

The valley slope should be surveyed in the field or measured on topographic maps for the site, as well as for similar lengths of undisturbed segments of the valley upstream or downstream of the site. If a valley segment upstream or downstream has a slope that is relatively uniform and nearly equal to the slope at the site, then the data collection recommended for unmined sites can be conducted at the undisturbed valley segment for application to the site. If the valley slope elsewhere is nonuniform or different from that at the site, then the theoretical approach presented below for mined valleys should be used to support measurements and observations of stream patterns elsewhere in the valley.

C. Valley Mined

Theoretical data must be used to evaluate an appropriate stream pattern in valleys which have been mined to the extent that natural stream patterns are not evident in the near vicinity of the site. Channel pattern was studied by Leopold and Wolmon (1957) based on field and laboratory data. They found that categorizing streams into braided, meandering, and straight patterns was difficult. Braided streams can change to meandering streams over a short distance, while individual channels of a braided stream may meander. They did observe that braided patterns could be differentiated from meandering patterns with certain combinations of channel slope, discharge, and width-to-depth ratio. A relation was developed between channel slope (S) and bankfull discharge (Q_{BF}) that separates meandering streams, which were taken to be those streams with a sinuosity greater than 1.5, from braided streams:

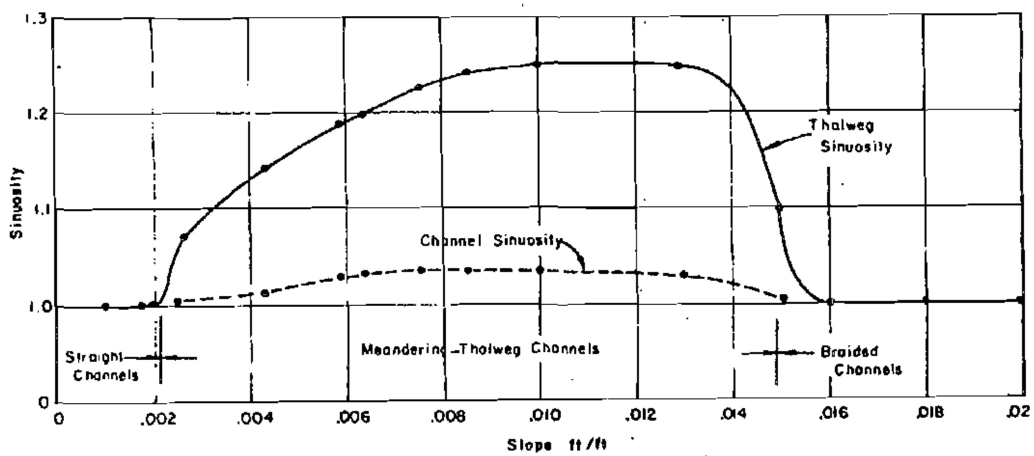
$$S = 0.06\ Q_{BF}^{-0.44}$$

For a given discharge, meandering streams would have channel slopes less than that calculated by the equation while slopes of braided channels would be greater. Straight channels did not follow this trend as they occurred throughout the range of slopes considered. Thus, other variables that may control the stream pattern are not considered. Bray (1982) plotted data from gravel-bed streams in Alberta on a graph relating channel slope (S) to the 2-year flood (Q_2). He found that many of his meandering gravel-bed streams had channel slopes greater than the slope indicated by the Leopold and Wolmon (1957) equation. He refined the equation to include most of his streams with sinuosities greater than 1.25:

$$S = 0.16\ Q_2^{-0.44}$$

Laboratory experiments by Schumm and Khan (1972) showed that there is a relationship between the slope on which the channel is formed, or the valley slope, and the sinuosity of the thalweg and channel (Figure 14). The thalweg is a fine line following the lowest or deepest part of the stream bed. Note that Figure 14 is illustrative of the effect of valley slope only, since discharge is not included as a variable.

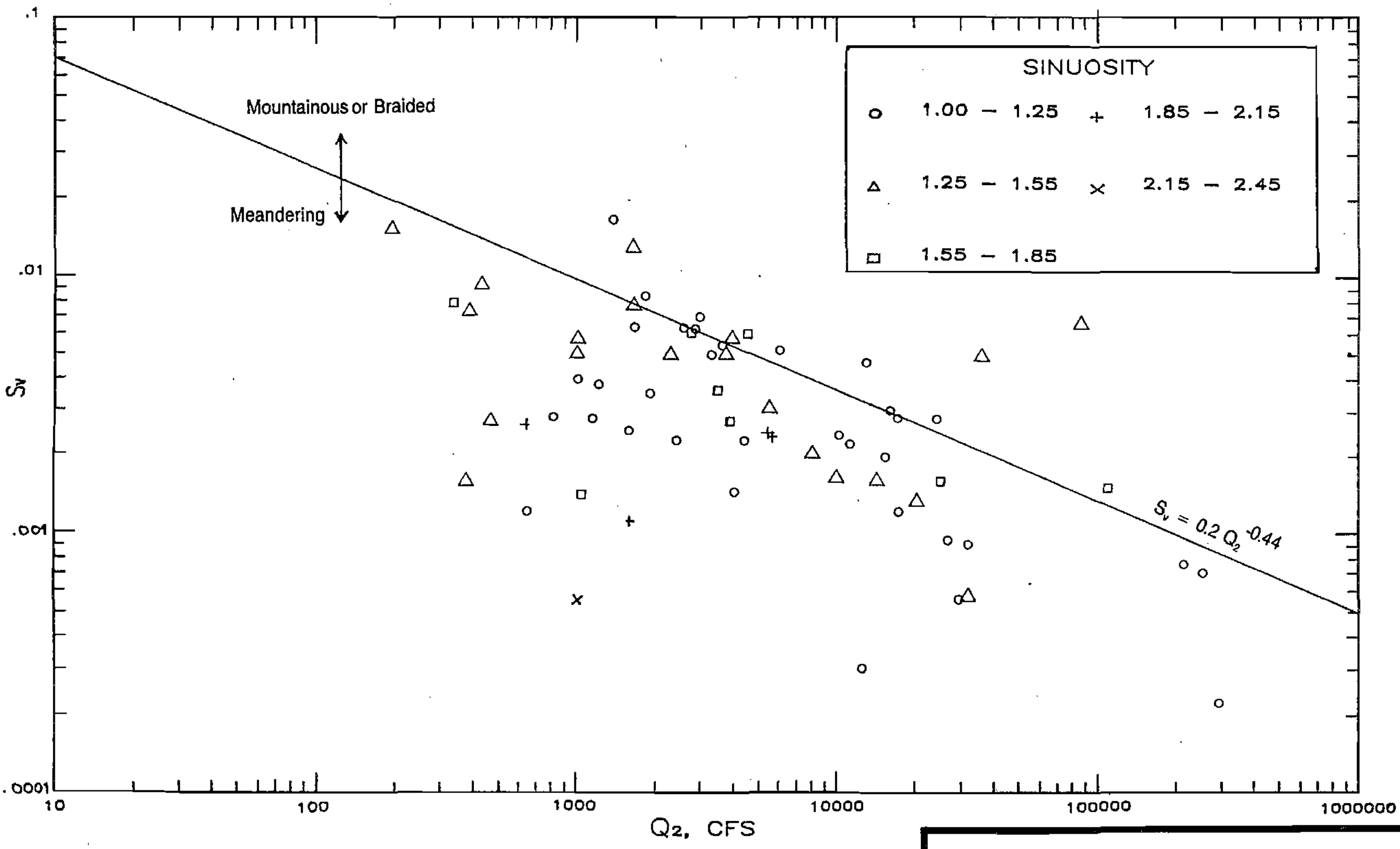
The studies discussed above illustrate that the causative factors for meandering and braided channel patterns as defined for these BMP's cannot be clearly differentiated. There are trends in stream pattern relating to channel and valley slopes, bankfull discharge, and possibly bed-material size. Using data on gravel-bed rivers in Alberta (Bray 1979), a graph was developed that relates channel pattern to valley slope and 2-year flood (Figure 15) for initial selection of stream pattern. The slope of the valley at the mine site



Source: Schumm and Khan 1972

RELATIONSHIP BETWEEN VALLEY SLOPE AND SINUOSITY

ENTRIX | **Figure 14**



NOTE: Line is modified from Bray's line for channel slope

Source: Modified from Bray 1982

GRAPH FOR INITIAL SELECTION OF STREAM PATTERN

ENTRIX

Figure 15

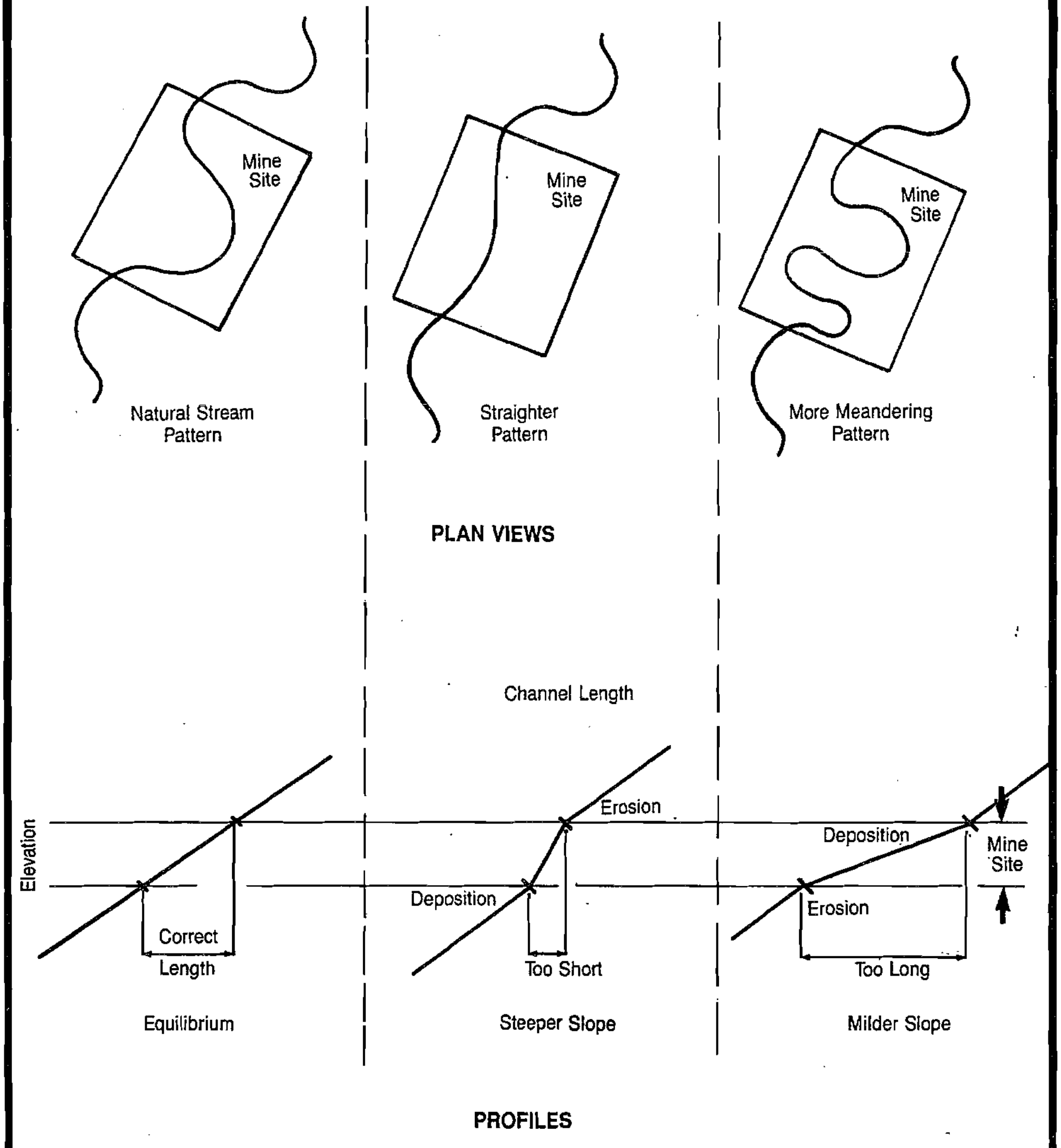
should be measured in the field or from topographic maps and the bankfull, or 2-year, discharge should be obtained as described in Section 8.2.2. These values should be used on Figure 15 to evaluate if the valley slope is mild enough to design a meandering stream. An equilibrium-slope technique can be used to estimate the value of sinuosity (Section 8.4.1). If the slope is too steep for a meandering stream, then in general, a mountain stream pattern should be selected. If the bed-load transport in the stream under natural conditions would be expected to be high during most summer flow levels, a braided pattern can be selected.

8.3.3 Stream Length

The stream pattern is important since it defines the length and consequently the slope of the stream channel. The length of the streambed is a critical element of stream rehabilitation. The length of the stream is related to the stream pattern and valley length (Figure 16). If the stream is shorter than the original stream length, then the slope will be steeper. The steeper slope can cause erosion at the upper end of the site; this material will typically be transported through the steep reach to downstream reaches where it will deposit (Bray and Cullen 1976). The opposite can occur if the stream is longer than natural through the site. Material will deposit in the upper end of the site and will erode in the upper end of downstream reaches. An equilibrium configuration without excessive aggradation or degradation can be achieved only if the stream bed is of proper length and slope. Thus, natural (unaffected by mining) stream lengths should be used for design. In cases where the natural stream length cannot be measured, the hydraulic design of the stream channel should be used to evaluate an appropriate length.

8.3.4 Placement of Stream Pattern

It is preferable to locate the stream adjacent to undisturbed vegetated areas whenever possible. This can often be accomplished by locating the stream along one valley wall. In wide valleys, this can allow final stream placement to be made on previously mined ground instead of using a temporary diversion while the other side of the floodplain is worked. This minimizes the number of times that a stream must be handled. It may also be advantageous to use



EFFECT OF CHANNEL LENGTH ON STREAM EQUILIBRIUM

ENTRIX | Figure 16

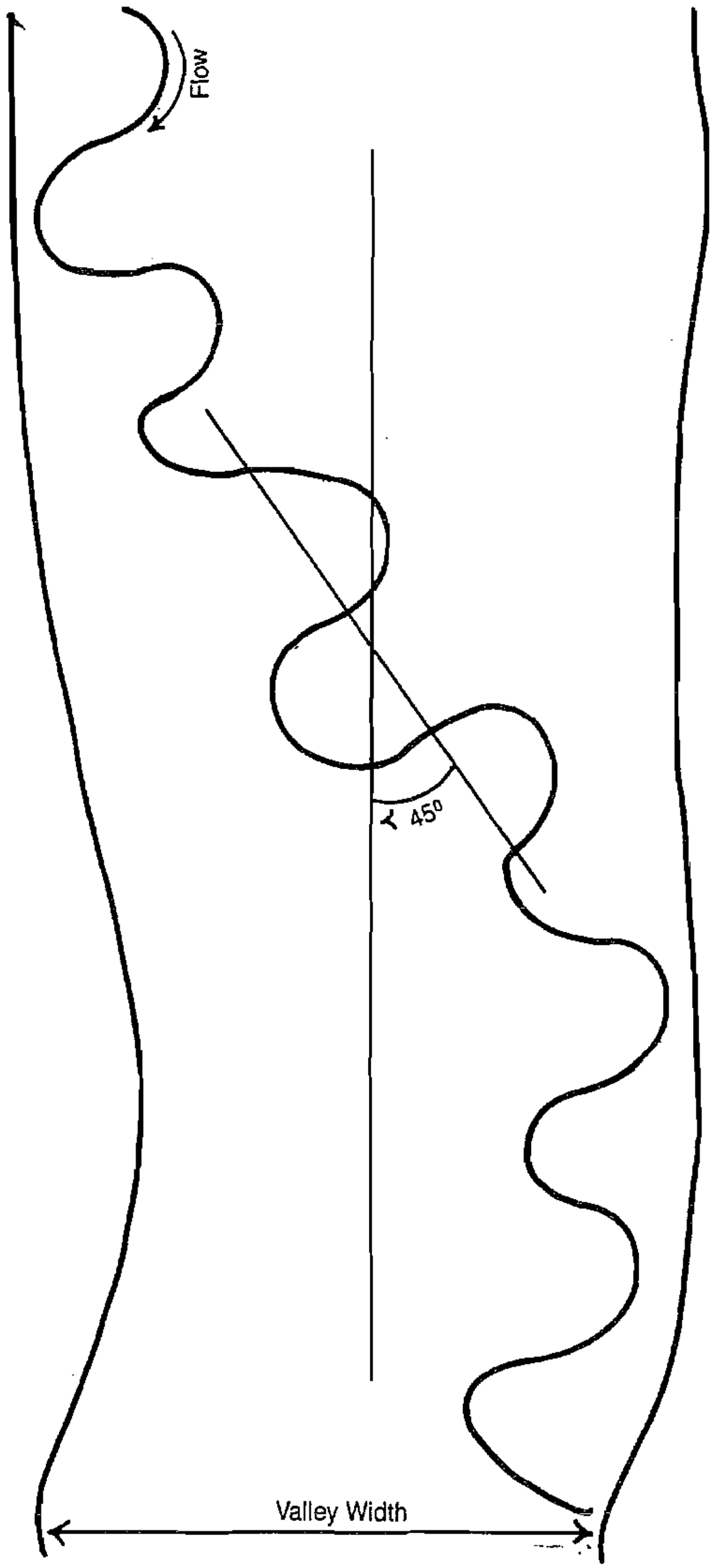
part of the diversion channel if final design is taken into account in the design of the diversion. Equipment should be confined to the excavated channel or previously disturbed areas to avoid disturbing vegetated banks. The stream can be placed so that it shifts from one side of the valley to the other, within the stream-length constraints placed by the stream pattern. The shift across the valley should be designed with a shallow angle between the stream-pattern axis and the valley axis (Figure 17).

The location of the settling pond system is an important consideration when relocating the stream pattern. Settling ponds within a stream channel should be avoided. Section 10.2 describes the rehabilitation of settling ponds which are not located within the stream channel. If site constraints necessitate the routing of a stream through an area containing an existing settling pond, extensive cleaning will be required. The pond must be cleaned of fine sediments as described in Section 4.2.5. The sediments should be stockpiled outside the active floodplain, contained, and protected to prevent the silty material from entering the stream. Section 10.2 describes the stockpiling and distribution of silty material from the settling pond. The settling-pond dam should also be rehabilitated to conform to the configuration of the rehabilitated stream.

8.3.5 Stream Bed Elevation

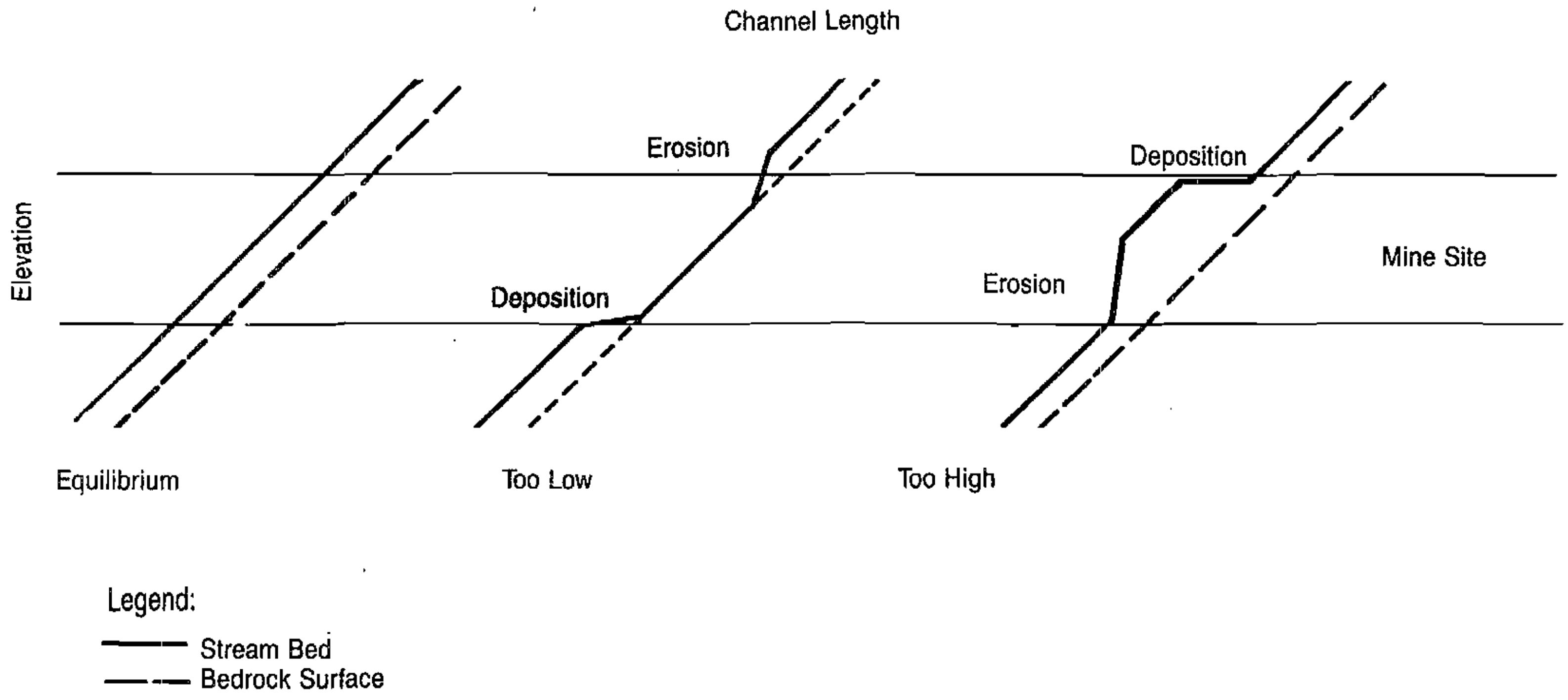
The level, or elevation, of the stream bed should be equivalent to that of the natural stream bed. The stream-bed level affects the local slope at the transition to the natural stream bed upstream and downstream of the mined site.

The level of the stream bed is important for the same reasons as the stream length. If the stream is located lower than its natural level, erosion or headcutting can occur at the upstream end (Figure 18). The channel bed will also be closer to the bedrock surface than the natural channel and thus more susceptible to aufeis formation. If the channel were placed too high, deposition would occur at the upper end, while headcutting would occur within the site (Figure 18).



SHIFTING A MEANDERING STREAM FROM ONE SIDE OF THE VALLEY TO THE OTHER

ENTRIX	Figure 17



EFFECT OF STREAMBED LEVEL ON CHANNEL EQUILIBRIUM

ENTRIX

Figure 18

Careful attention to the consistency of the materials at and below the streambed will help to minimize the loss of surface water to the underlying gravels. The channel should be formed in a mixture of the sand and small gravel tailings and some of the oversize materials consisting of large gravels and cobbles. A mixture of the sluice tailings and oversize material in the approximate proportions of the material at the site should be used. A layer of oversize material consisting of large gravels and cobbles should be placed above the finer material to form the bed and banks of the stream channel. Boulders and the remaining large gravels and cobbles should be retained for other uses (Section 8.5). The channel should either be excavated to the proper level and configuration in the existing materials, or appropriate materials should be backfilled onto bedrock to bring the streambed up to the desired level.

Erosion and deposition resulting from incorrect stream length or level are the natural processes through which the stream adjusts its channel shape and longitudinal profile to equilibrium conditions. If large adjustments are required, stream-recovery time is longer. Deposition can also reduce the channel's capacity to carry floods.

8.4 HYDRAULIC DESIGN

Hydraulic design of the bankfull channel includes the design of channel cross sections, stable bed slope, channel-pattern dimensions, and channel profile. Different design approaches are used for meandering, mountain, and braided stream patterns. The requirements for fish passage are incorporated into the stream design approaches.

8.4.1 Meandering-Stream Design

A number of parameters must be defined for the design of a meandering stream:

1. Channel geometry and bed stability
    a. Top width, W
    b. Mean depth, d

c. Mean velocity, V
d. Bed stability

2. Channel pattern
   a. Sinuosity, P
   b. Meander arc length, Z
   c. Position in floodplain

3. Pools and riffles
   a. Spacing and location
   b. Pool and riffle cross section and profile

In unmined sites or sites with nearly undisturbed floodplain, these parameters should be measured in the field and from aerial photographs. Lacking reliable data in the same stream valley, the approach outlined below should approximate a natural meandering stream for the valley.

A. Channel Geometry

An approach for evaluating the general hydraulic geometry of meandering streams is presented based on empirical studies by Bray (1982) and Emmett (1972). The concept of the approach is that rivers adjust their cross section and profile naturally to an equilibrium configuration based on a long-term average of the stream discharge at the site. Thus, top width, mean depth, and mean velocity can be predicted from the hydrology of the site: specifically, the bankfull discharge. Relations developed based on data from 70 gravel-bed river reaches are as follows (Bray 1982):

$$W = 2.38\ Q_2^{0.53} \quad (r^2=0.962,\ SE=0.076 \text{ log units})$$

$$d = 0.266\ Q_2^{0.33} \quad (r^2=0.871,\ SE=0.094 \text{ log units})$$

$$V = 1.58\ Q_2^{0.14} \quad (r^2=0.499,\ SE=0.102 \text{ log units})$$

Emmett (1972) obtained similar relations for streams in Alaska:

$$W = 2.39\ Q_{BF}^{\ 0.50}$$

$$d = 0.26\ Q_{BF}^{0.35}$$

$$V = 1.62\ Q_{BF}^{0.15}$$

These two sets of equations are very similar. The 2-year discharge calculated for the mine site should be used in Bray's equations to evaluate the general size and mean velocity of the channel.

B. Bed Stability

The slope of the rehabilitated stream should be compared to the equilibrium slope to identify the bed stability. The slope of the rehabilitated stream (S_c) can be obtained from the change in bed elevation between the upstream and downstream boundary of the site (H) divided by the channel length (L_c). If the natural channel length cannot be measured due to previous mining in the valley, the channel should be designed on the basis of the equilibrium slope. The condition of stability should be evaluated for a flow level equal to 3/4 of the bankfull flow level because this level has been found to represent the level at which median-sized bed material begins moving in meandering streams (Dunne and Leopold 1978). The equilibrium slope, or slope at which bed material is about to move for the given flow, geometry, and bed material size, is represented by the equation developed by Simons, Li and Associates (1982):

$$S_e = \frac{0.08\ D_{50}}{R}$$

where S_e = the equilibrium slope
D_{50} = the median size of the bed material (ft)
R = the hydraulic radius at 3/4 bankfull (ft)

The median size of the bed material (D_{50}) should be estimated through a visual inspection during a site visit or by a sieve analysis of a material sample collected during the site exploratory program. The design may need to be modified if the size of the available material is found to be significantly different from the estimated value. The hydraulic radius can be approximated by using the hydraulic depth if the stream is wide (W/d>10).

The channel bed is assumed to be stable if the channel slope is approximately equal to or less than the computed equilibrium slope. If the channel slope is greater than the equilibrium slope, the channel bed is likely to be unstable. Should a large discrepancy exist between the two slopes, the channel may require redesign by increasing the channel length; if the stream cannot be lengthened, the channel bed can be armored by increasing the median size of the bed material. Although a layer of coarser material placed on the stream bed would stabilize the channel, this may not be desirable when restoring spawning fish habitat (Section 9.0).

C. Channel Pattern

The channel pattern of a meandering stream can be defined by the sinuosity and the meander arc length (Hey 1983). The sinuosity is the ratio of the channel length to the valley-axis length (Figure 19):

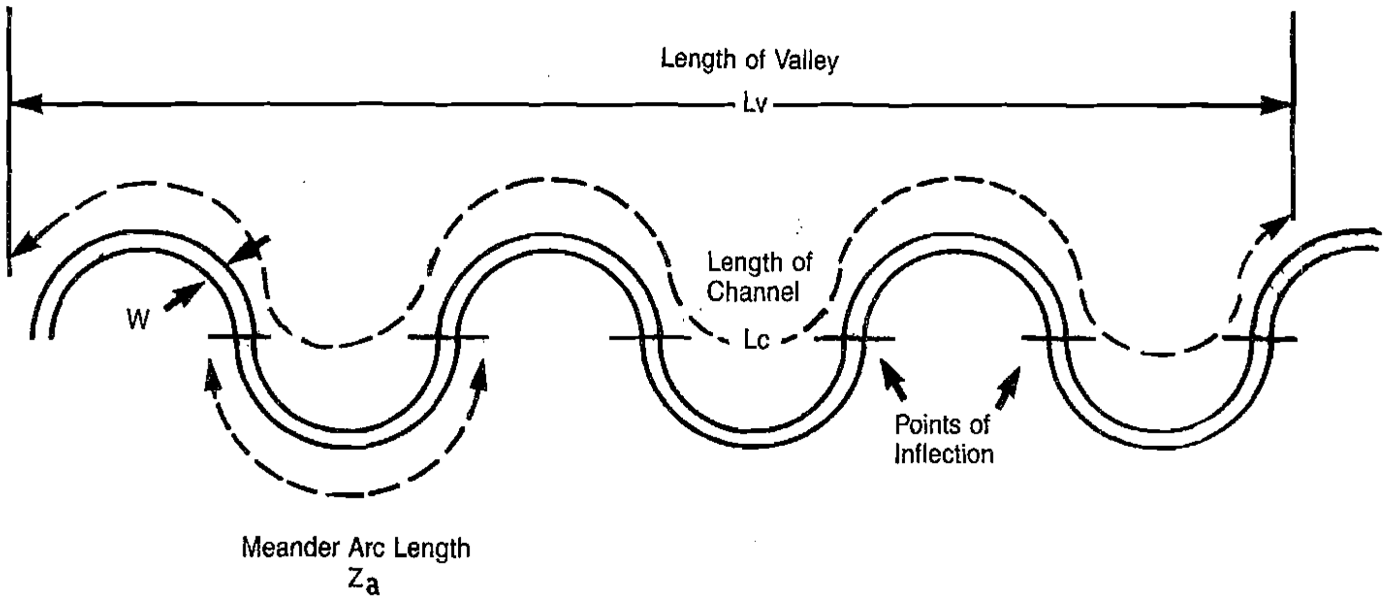
$$P = \frac{L_c}{L_v}$$

or

$$P = \frac{S_v}{S_c}$$

where P = sinuosity
L_c = channel length
L_v = valley length
S_c = channel slope
S_v = valley slope

The stable channel slope developed in the previous section should be used with the valley slope to evaluate the sinuosity of the meandering stream. If the equilibrium slope was used to evaluate the slope or length of the channel, a check of the reasonableness of the results is warranted. The sinuosity should be between 1.3 and 2.5, a common range of sinuosities for meandering streams.



Meander Arc Length, $\bar{Z} = 6.28W$

Sinuosity, $P = \frac{Lc}{Lv}$

DEFINITION SKETCH OF MEANDERING CHANNEL PATTERN DESCRIPTORS

ENTRIX | **Figure 19**

If the calculated sinuosity is less than this range, the stream should be designed for a sinuosity of 1.3 in order to maintain a meandering stream pattern; such a sinuosity will be more stable than the equilibrium condition. If the sinuosity is calculated to be greater than 2.5, consideration should be given to whether the valley physical constraints allow a greater sinuosity and/or whether drop structures could be used to reduce channel slope, and thus sinuosity.

The meander arc length is the channel distance between two points of inflection (Figure 19). The relation for meander arc length is given by Hey (1983) as follows:

$$Z_a = 6.28\ W$$

Since bankfull channel width (W), sinuosity (P), and the length of the site (L_v) are known, the number of meander arcs (N_a) in the site can be calculated by:

$$N_a = \frac{L_c}{Z_a}$$

$$= \frac{PL_v}{6.28W}$$

A meander arc is half of a full meander sequence, so the number of meander sequences is:

$$N_m = N_a/2$$

$$= \frac{PL_v}{12.56W}$$

The length of the site should be subdivided into N_m segments, each of which will have a similar design. Partial segments should be split between the upstream and downstream ends for use as transition segments. Each segment should be further designed as described in the next section.

The segments must also be linked into a somewhat regular sequence of meanders through the site. While it is likely and preferable that the entire sequence of meanders will follow one valley wall through the site, conditions may necessitate shifting from one side of the valley to the other.

D. Pools and Riffles

Pools and riffles are characteristic of most streams, but are most prevalent in meandering streams. The spacing of the pools and riffles is related to the meander arc length discussed in the previous section. Generally, pools are spaced 5 to 7 channel widths apart, as are riffles (Leopold, Wolman, and Miller 1964). In an unmined site, the lengths of pools and riffles and the distance between riffles should be measured at a relatively low flow.

Pools and riffles are formed by an undulating streambed. At low flows, the water surface is nearly flat in the pools and steep on the riffles (Figure 20). As flows increase, the water surface in the pool increases while the riffle water surface decreases its steepness. At about three-fourths bankfull, the riffles are drowned out and the water surface is relatively uniform (Dunne and Leopold 1978).

The shape of the channel through pools and riffles continuously changes from deep, asymmetric pool cross sections to more shallow, nearly symmetric riffles or crossings (Figure 21). Several characteristics can be summarized from these cross sections:

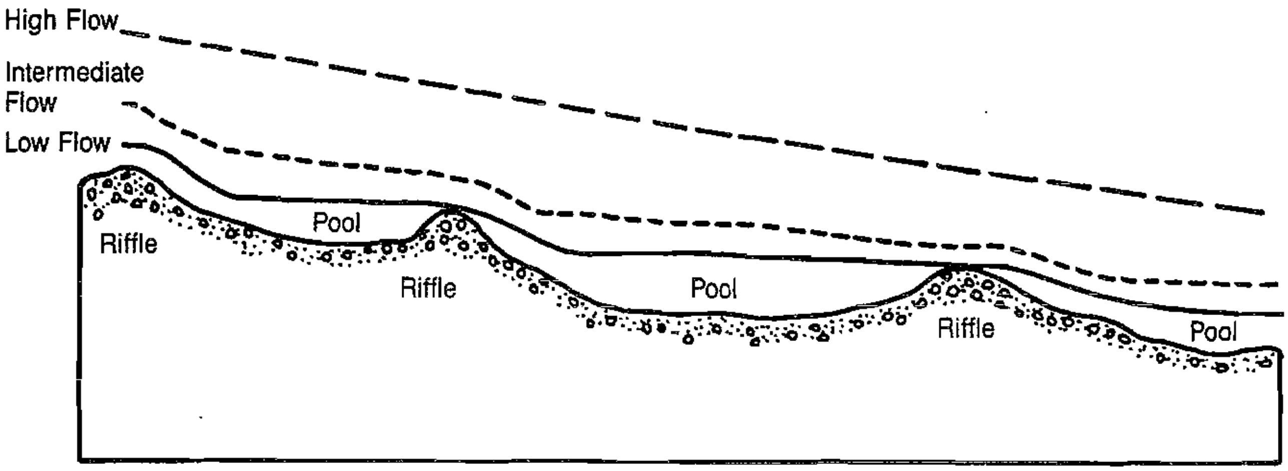
1. Pool (bend) cross sections are deepest in the apex of the bend

2. Pool cross sections have a steep outer bank

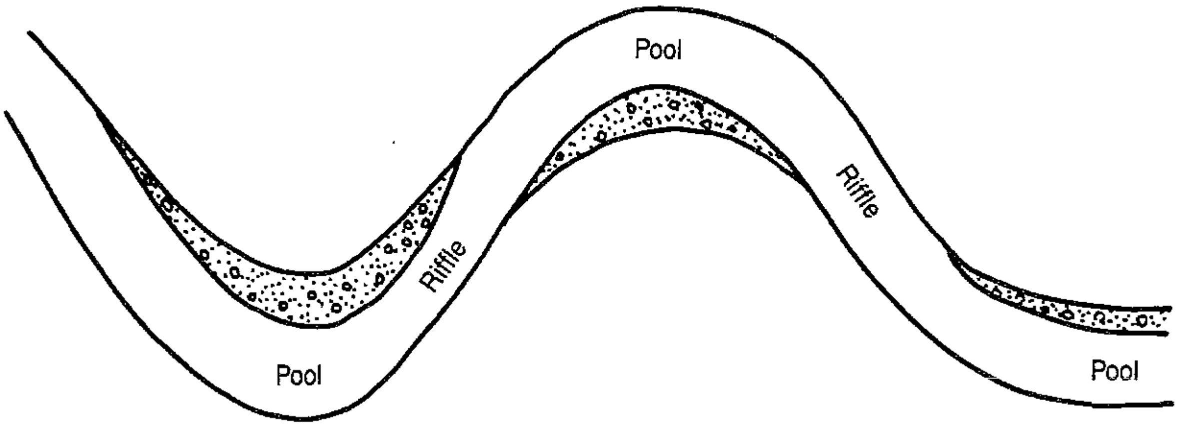
3. Pool cross sections rise slightly less steeply on the inside of the bend than the outside

4. Pool cross sections level off significantly on the point bar

5. Pool cross sections sometimes have a small depression on the inside edge of the channel



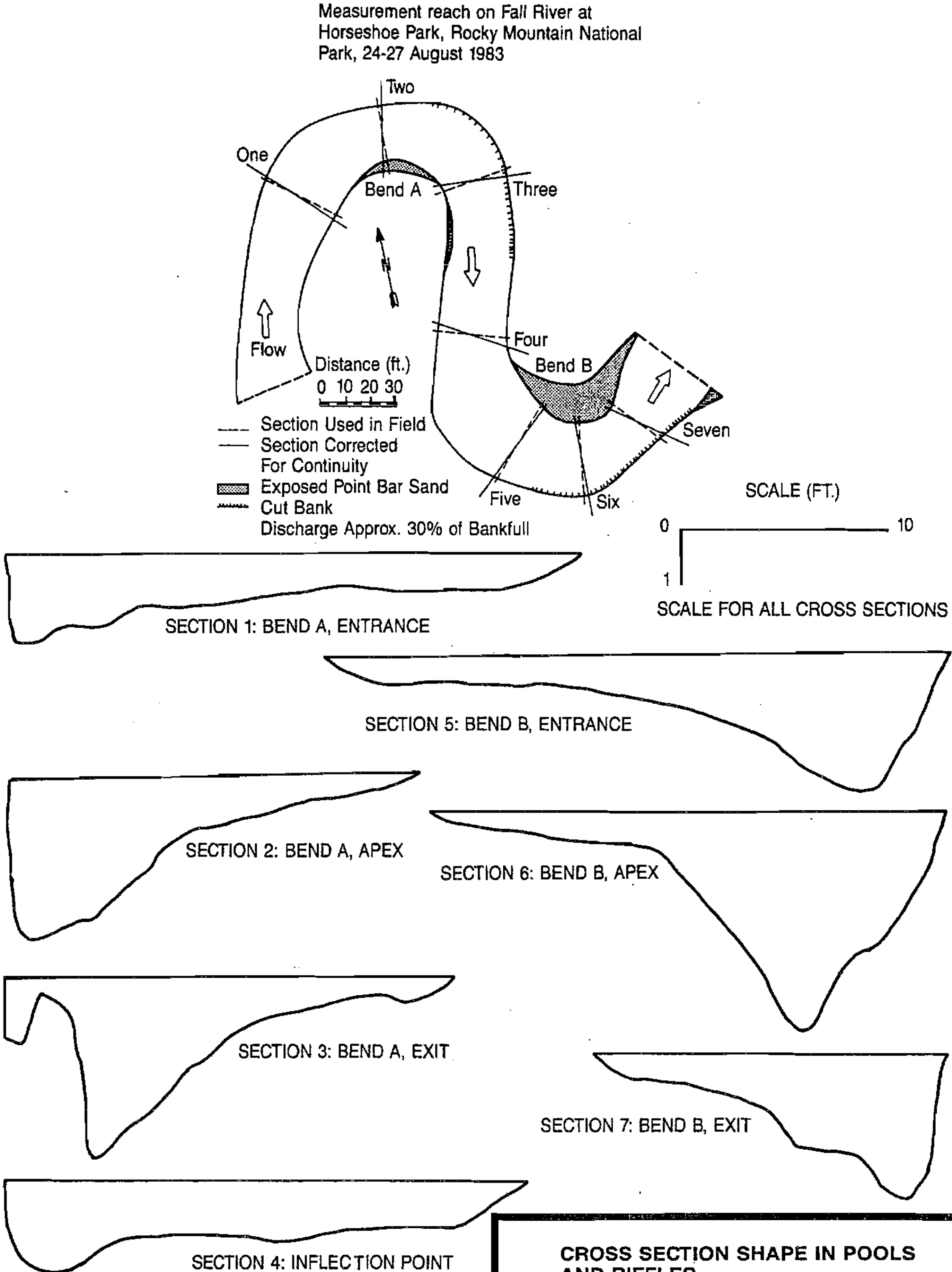
SIDE VIEW



PLAN VIEW

SIDE VIEW AND PLAN VIEW OF A POOL-RIFFLE SEQUENCE

ENTRIX | **Figure 20**



Source: Thorne and Rais 1983

CROSS SECTION SHAPE IN POOLS AND RIFFLES

ENTRIX | **Figure 21**

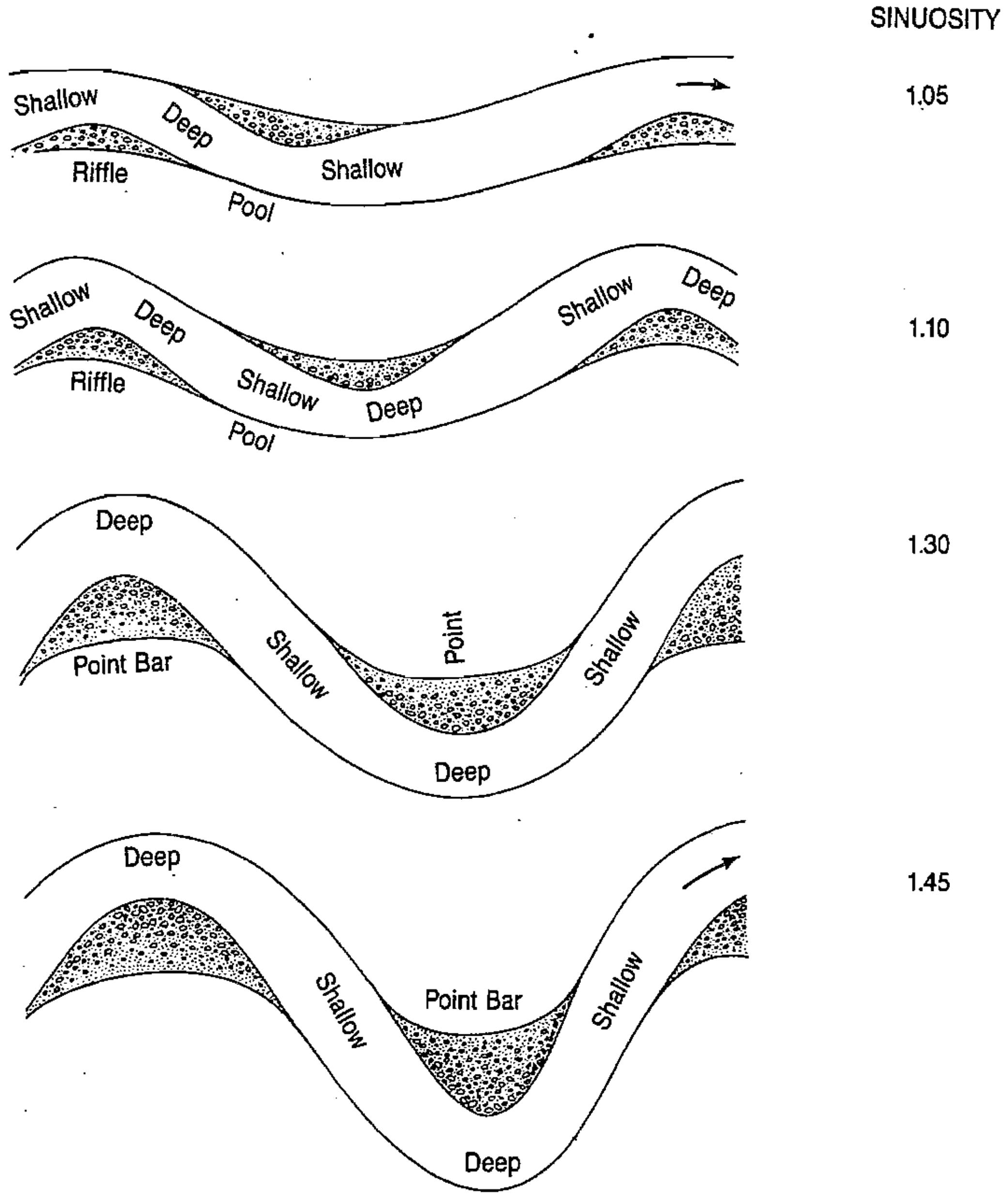
6. Riffle cross sections (inflection points) are slightly asymmetric

The locations of pools and riffles vary somewhat as a function of sinuosity, as shown in Figure 22. The depth and length of a pool is dependent upon the radius of curvature of the bend, sediment load, and stream size (Karaki et al. 1974). Sharp bends are normally deeper and have larger bars than long-radius bends (Figure 23). The shape of a cross section in a bend is developed theoretically by Bridge (1975) (Figure 24). A simple approach was taken to develop a meandering channel out of a previously channelized stream in North Carolina; an asymmetric channel was developed by cutting a 2 to 1 slope on one bank and a 3 to 1 slope on the other bank with the bed undisturbed (Keller 1976). Following construction, point bars formed on the 3 to 1 slope as planned. A simple approach illustrated in Figure 25 is recommended for use as a guide establishing cross sections during stream rehabilitation. The grades and channel-width proportions provided in Figure 25 are general guidelines for obtaining appropriate cross-section shapes for a meandering stream. These guidelines should be used for the initial design but can be modified slightly in the final design to simplify construction. Abrupt changes in cross-section shapes should be avoided. Bank configuration above the bankfull level is considered in Section 10.2.

8.4.2 Mountain-Stream Design

A mountain stream is characterized by narrow valley walls and/or steep gradients. The stream may be confined by the narrow valley. The steep gradient contributes to a relatively straight, single channel with rapid flow.

Stability within the stream channel is the predominant hydraulic-design parameter. High channel velocities would erode small materials on the stream bed and banks. In addition, flow will tend to cascade around rocks creating uplifting forces rather than flowing over the rocks (Simons, Li and Associates 1982). Therefore, large rocks should be used to armor the channel. Details of stream-bed armoring are provided in Section 8.5.1.



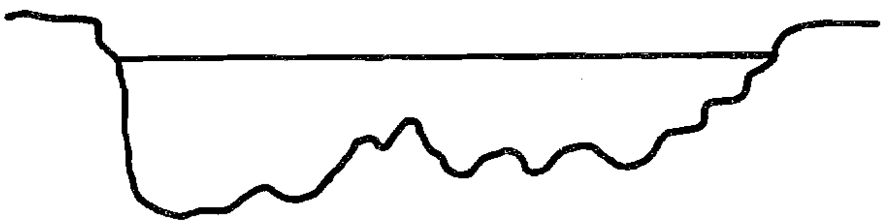
Source: Dunne and Leopold, 1978.

LOCATIONS OF SHALLOW AND DEEP ZONES IN CHANNELS OF DIFFERENT SINUOSITY

ENTRIX | **Figure 22**

Sharp Bend

Optimum Bend



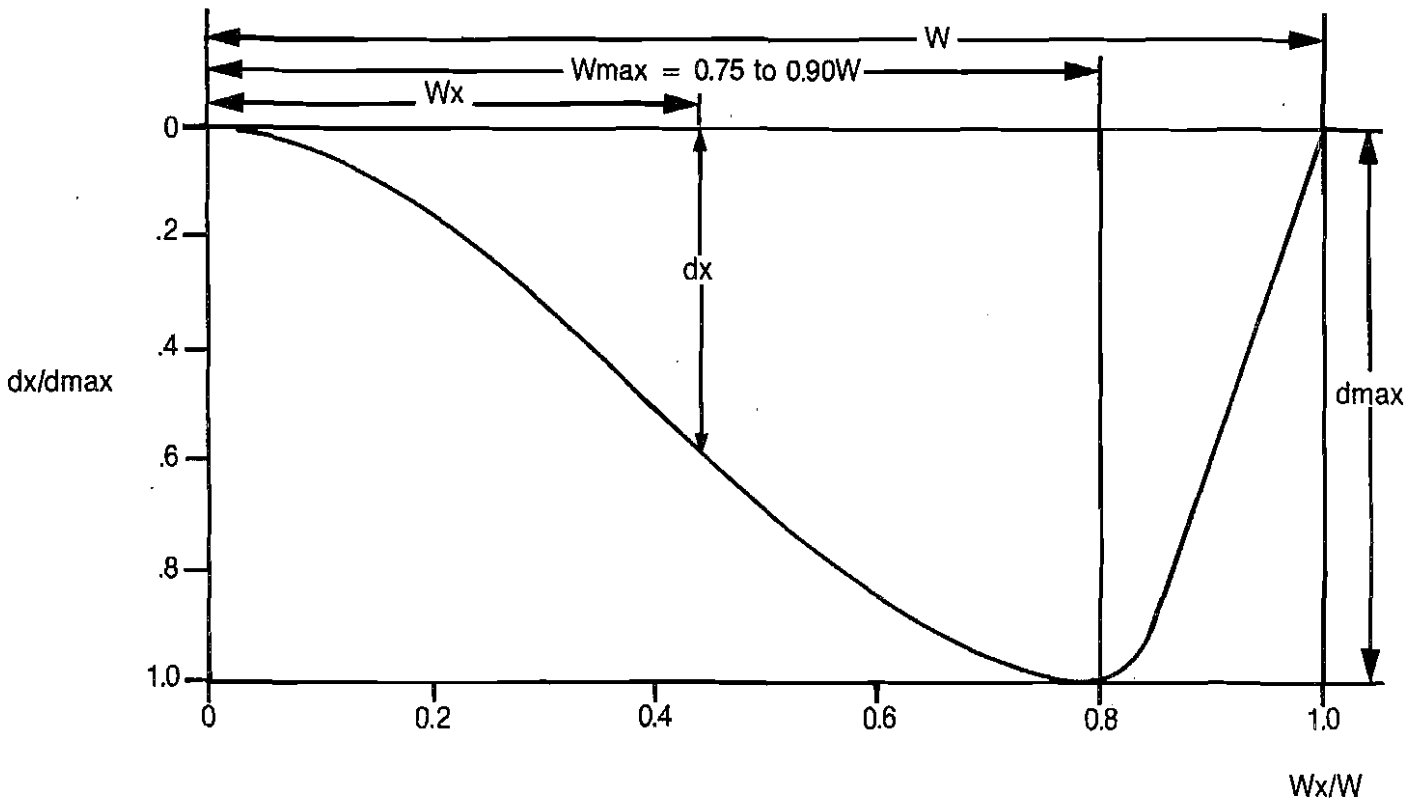
Flat (Long-Radius) Bend

TYPICAL CHANNEL CROSS SECTIONS

Source: Vanoni 1975

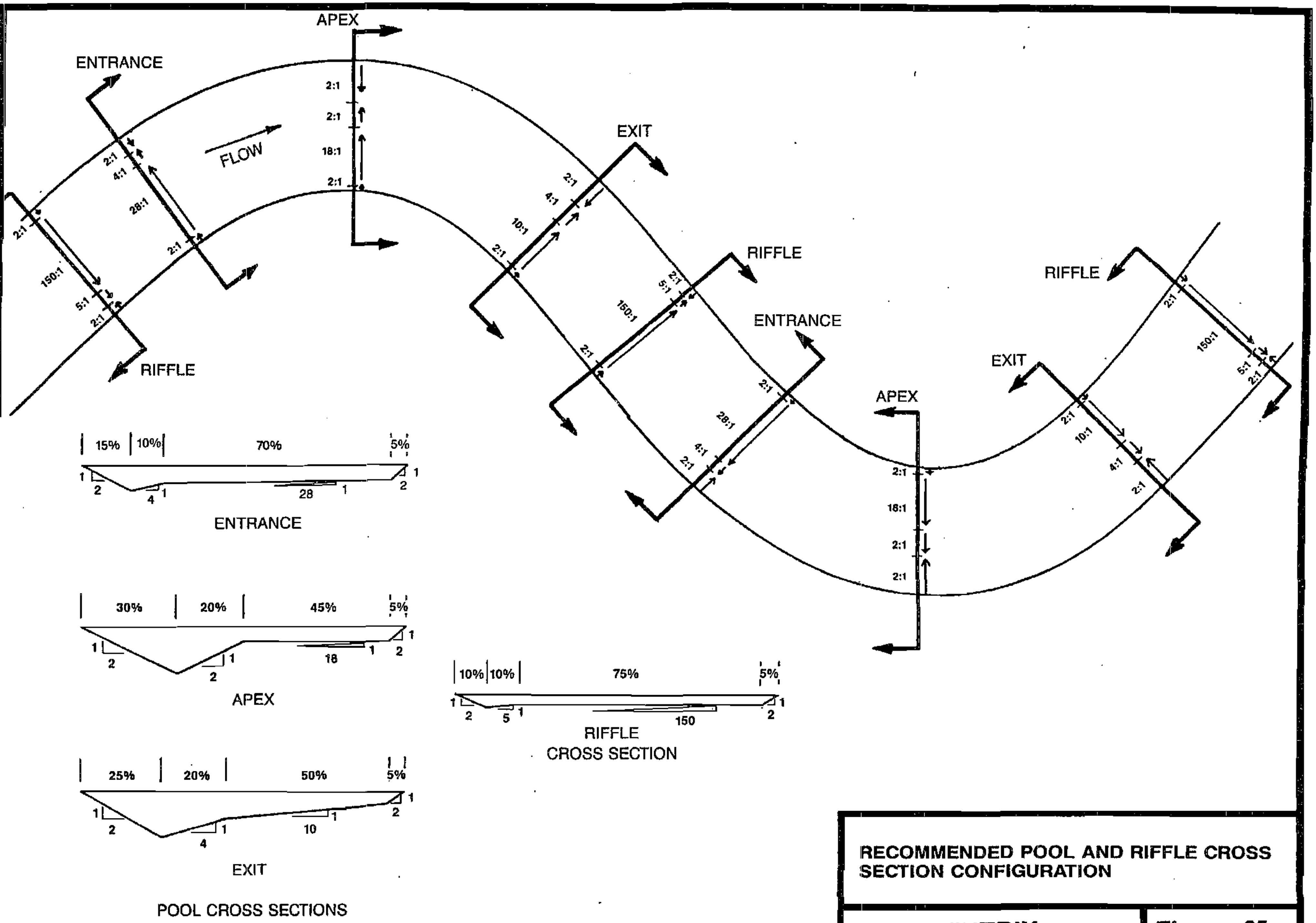
ENTRIX

Figure 23



THEORETICAL GEOMETRY OF POOL CROSS SECTION

ENTRIX | **Figure 24**



NOTE: Cross sections are symmetrical depending on the direction of the bend.

RECOMMENDED POOL AND RIFFLE CROSS SECTION CONFIGURATION

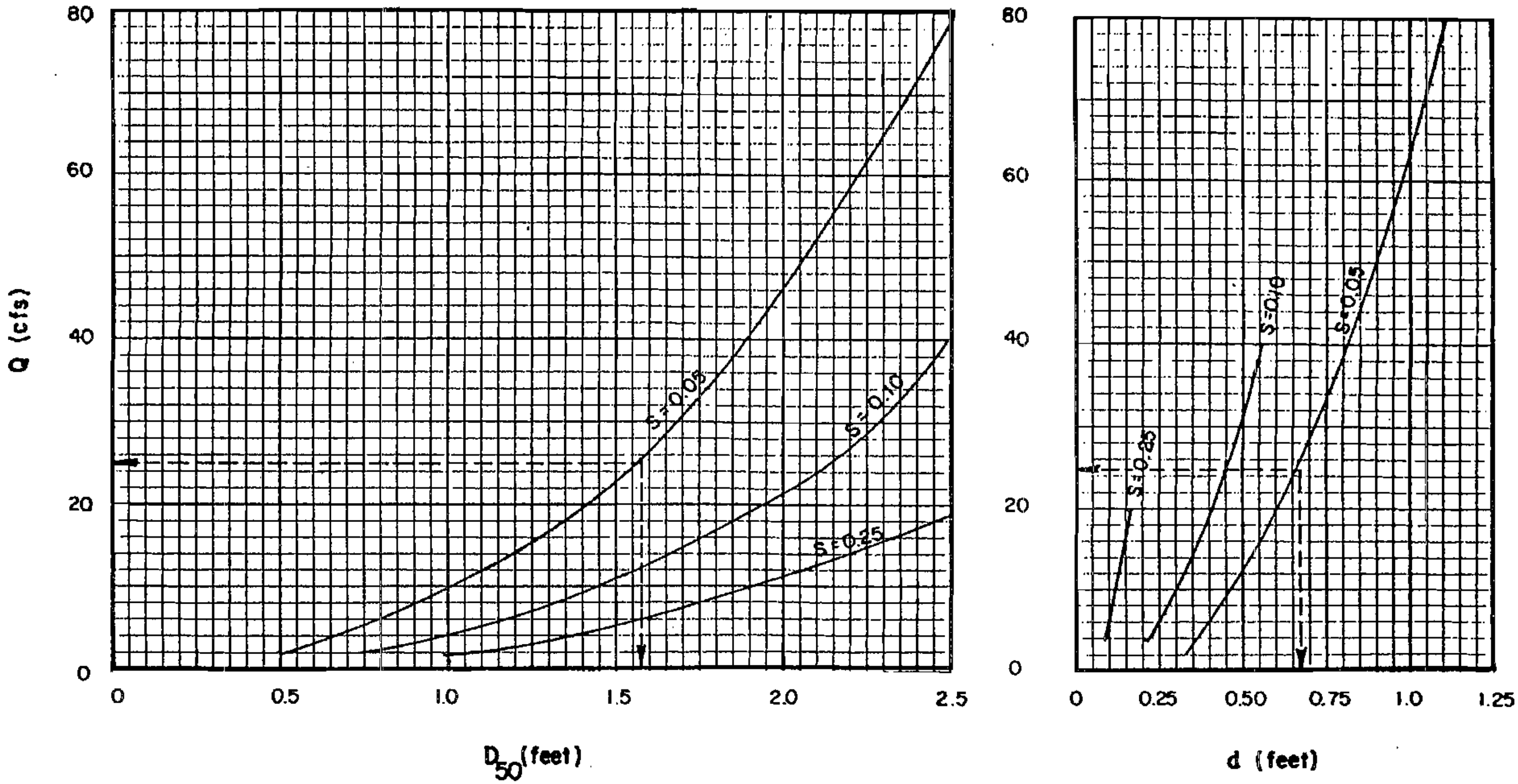
ENTRIX | **Figure 25**

A. Channel Geometry and Bed Stability

The shape of the stream channel should be evaluated from the bankfull (2-year recurrence interval) discharge (Section 8.2) and the riprap sizes available to the miner. The median size of the riprap (D_{50}) may be estimated through visual inspection (Simons, Li and Associates 1982). The large material which is separated during mining is expected to be similar in size or larger than the naturally occurring armor layer. Bathurst et al. (1979) derived relationships between the velocities in steep mountain streams and the channel roughness. Simons, Li and Associates (1982) used these relationships to develop design curves relating channel geometry, discharge, and depth of flow. Figures 26 through 30 present these curves for trapezoidal channels of varying widths. Channel banks should not be steeper than 2 to 1 for all steep-slope channels (Simons, Li and Associates 1982).

An iterative process will be required to assess the optimum channel shape given the site parameters. The 2-year high flow (Q_2), the median riprap size (D_{50}), and the channel slope (S_c) should be evaluated. The slope of the channel should be measured in the field or estimated from topographic maps. Figures 26 through 30 should be used to assess the optimum channel shape. If the actual channel slope is greater than the slope predicted by the design curve, a different curve should be used. When a width that fits the slope criteria is obtained, the depth of flow (d) may be evaluated from the same figure. At bankfull conditions, the depth of the channel should be equal to the depth of flow.

If the channel slope is too steep to yield a reasonable width or depth, channel drop structures (Figure 31) may be used to reduce the slope. The desired channel slope can be obtained using the equilibrium slope approach (Section 8.4.1.B) for bankfull conditions. Although vertical drops may be used, sloped drops are recommended (Simons, Li and Associates 1982). The drop structure should be located within a reasonably straight channel section without channel bends within 100 to 200 ft of the structure. The amount of drop through the drop structure should be evaluated from the site topography, with greater drops being required in steeper valleys. A maximum drop of 3 ft should be used to avoid erosive velocities (Simons, Li and Associates 1982).

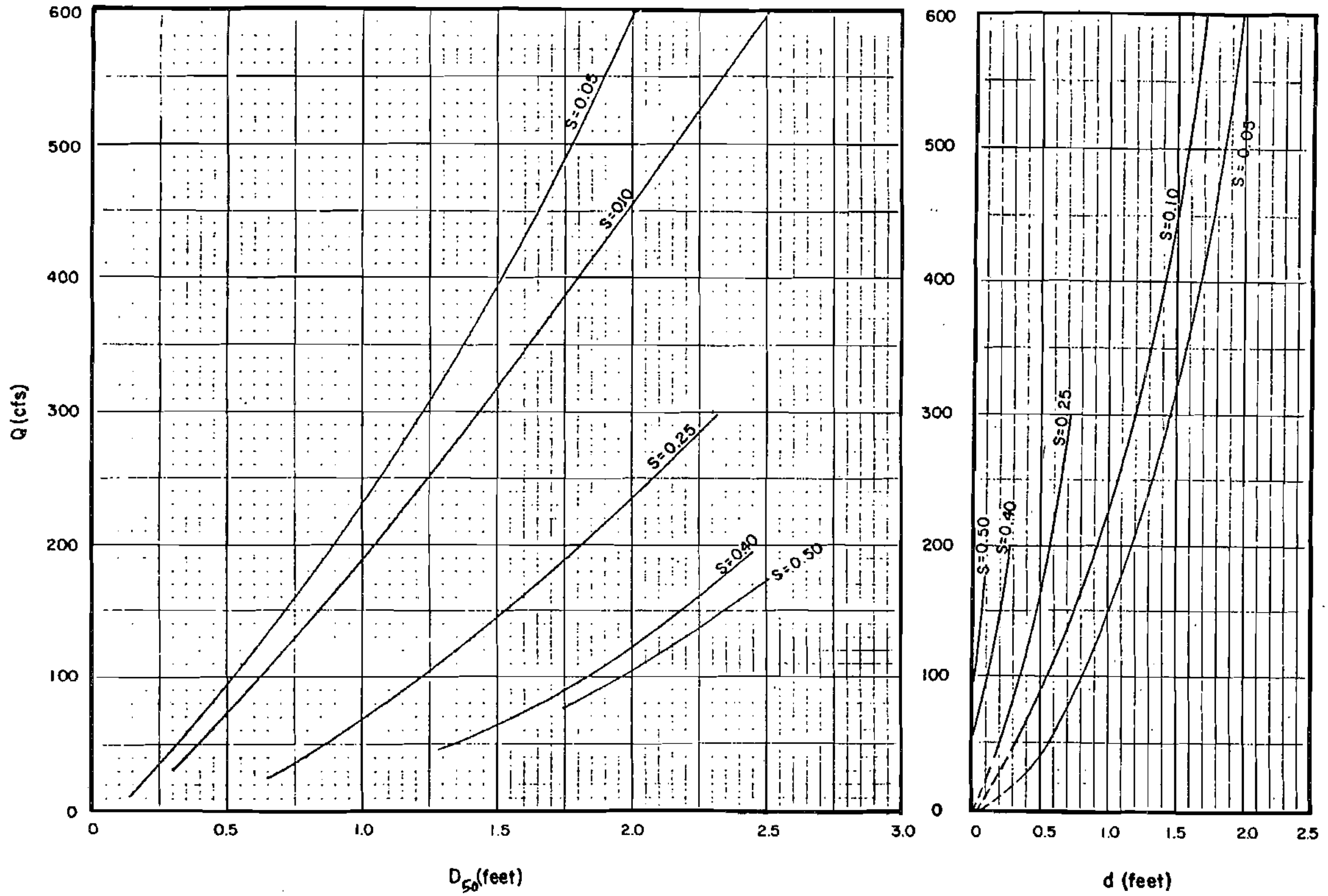


S = Slope of Channel
Q = Peak Flow
D_{50} = Median Size of Material
d = Depth of Flow

Source: Simons, Li and Associates 1982

MOUNTAIN STREAM DESIGN, TRIANGULAR CHANNEL, 2:1 SIDESLOPES

ENTRIX | **Figure 26**

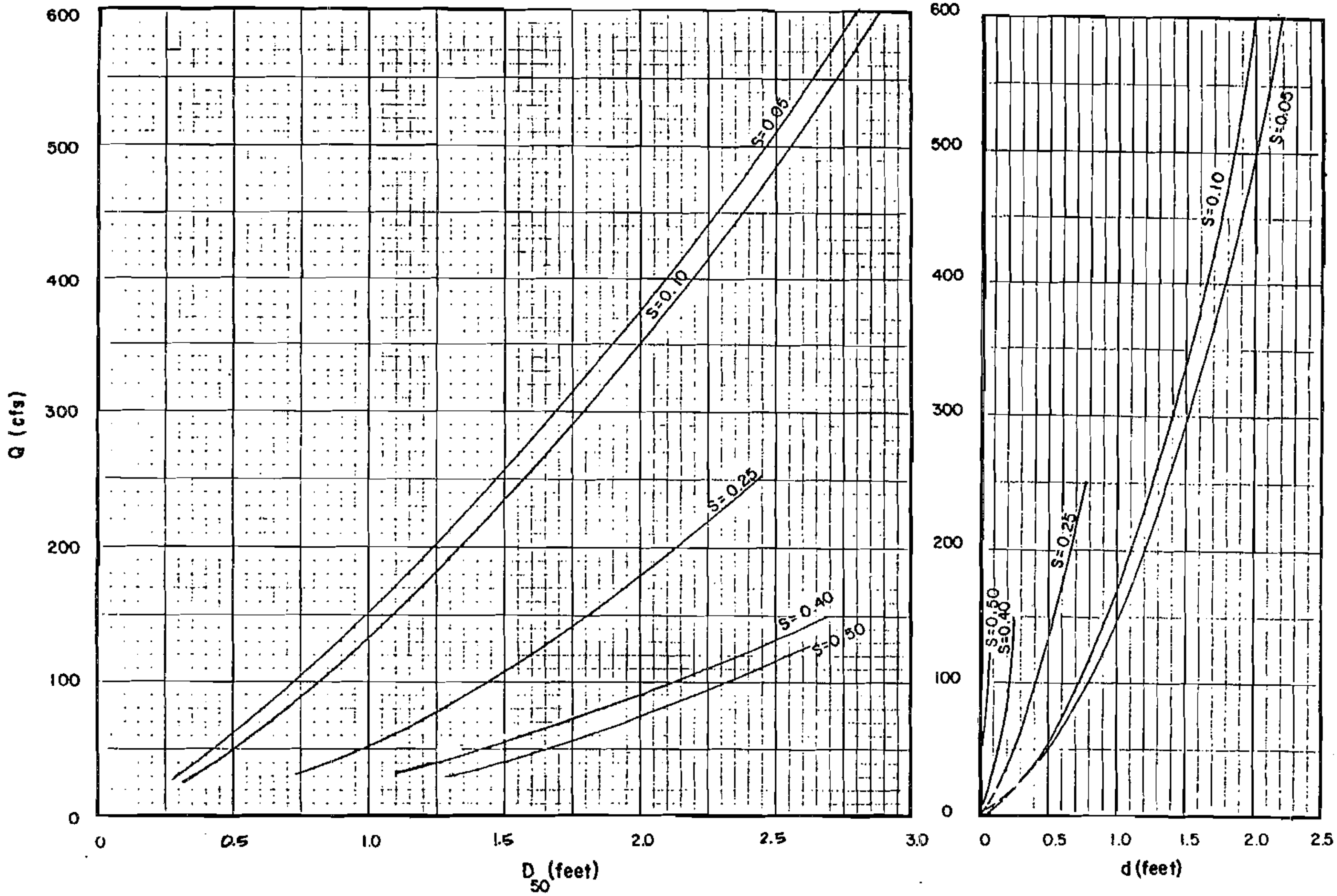


S = Slope of Channel
Q = Peak Flow
D_{50} = Median Size of Material
d = Depth of Flow

Source: Simons, Li and Associates 1982

MOUNTAIN STREAM DESIGN, TRAPEZOIDAL CHANNEL, 2:1 SIDESLOPES, 6 FT BASE WIDTH

ENTRIX | **Figure 27**



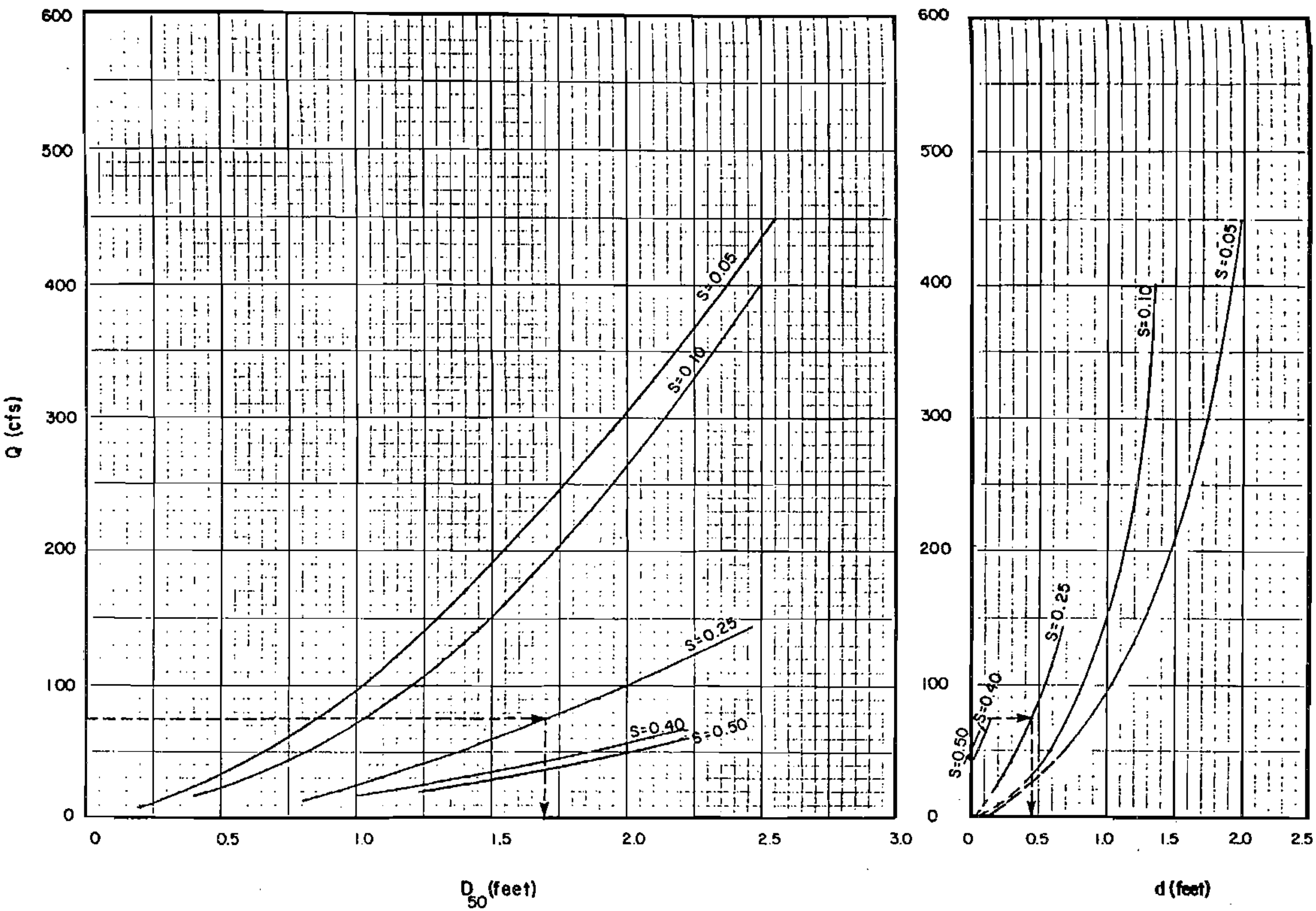
S = Slope of Channel
Q = Peak Flow
D_{50} = Median Size of Material
d = Depth of Flow

Source: Simons, Li and Associates 1982

MOUNTAIN STREAM DESIGN, TRAPEZOIDAL CHANNEL, 2:1 SIDESLOPES, 10 FT BASE WIDTH

ENTRIX

Figure 28



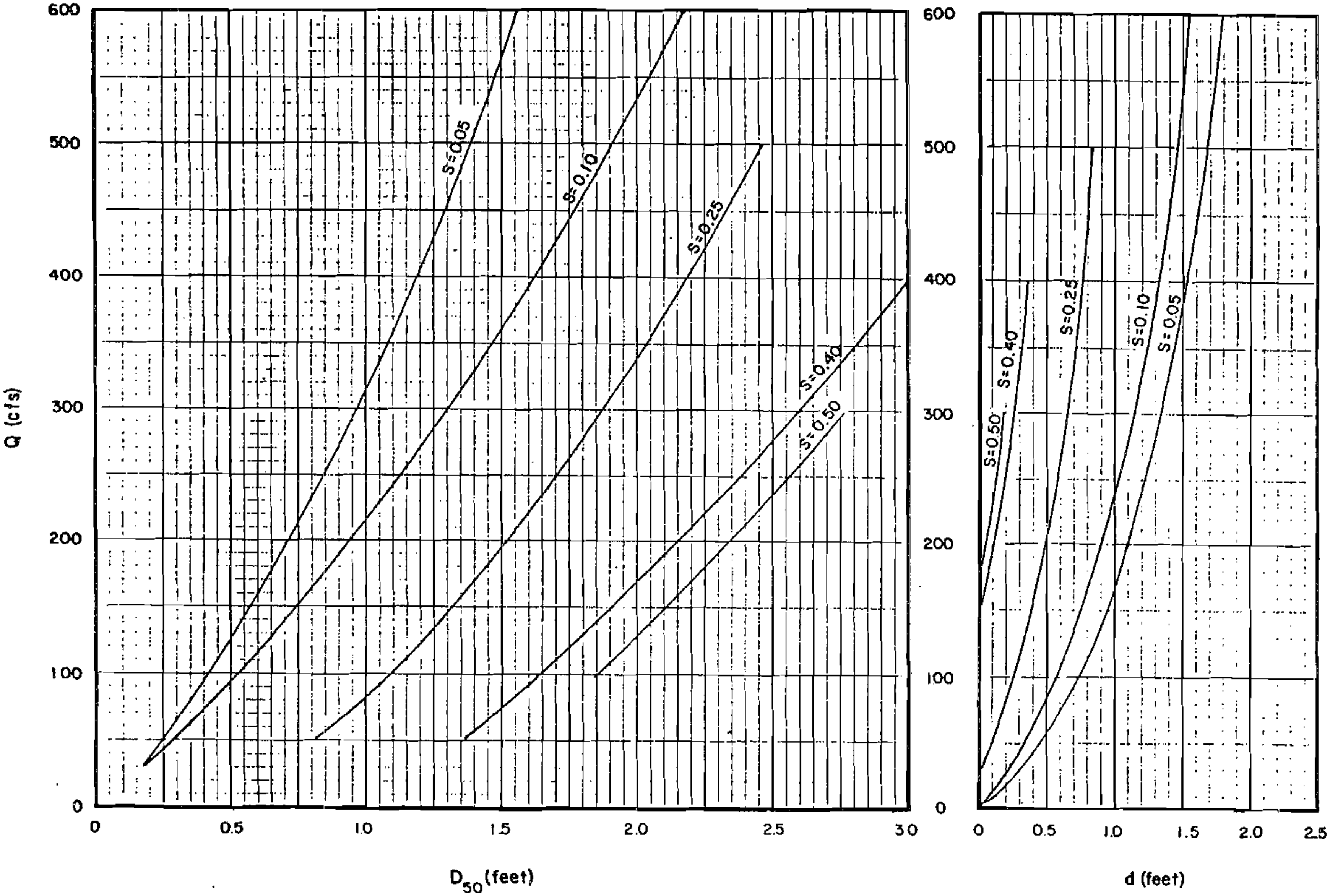
S = Slope of Channel
Q = Peak Flow
D_{50} = Median Size of Material
d = Depth of Flow

Source: Simons, Li and Associates 1982

MOUNTAIN STREAM DESIGN, TRAPEZOIDAL CHANNEL, 2:1 SIDESLOPES, 14 FT. BASE WIDTH

ENTRIX

Figure 29

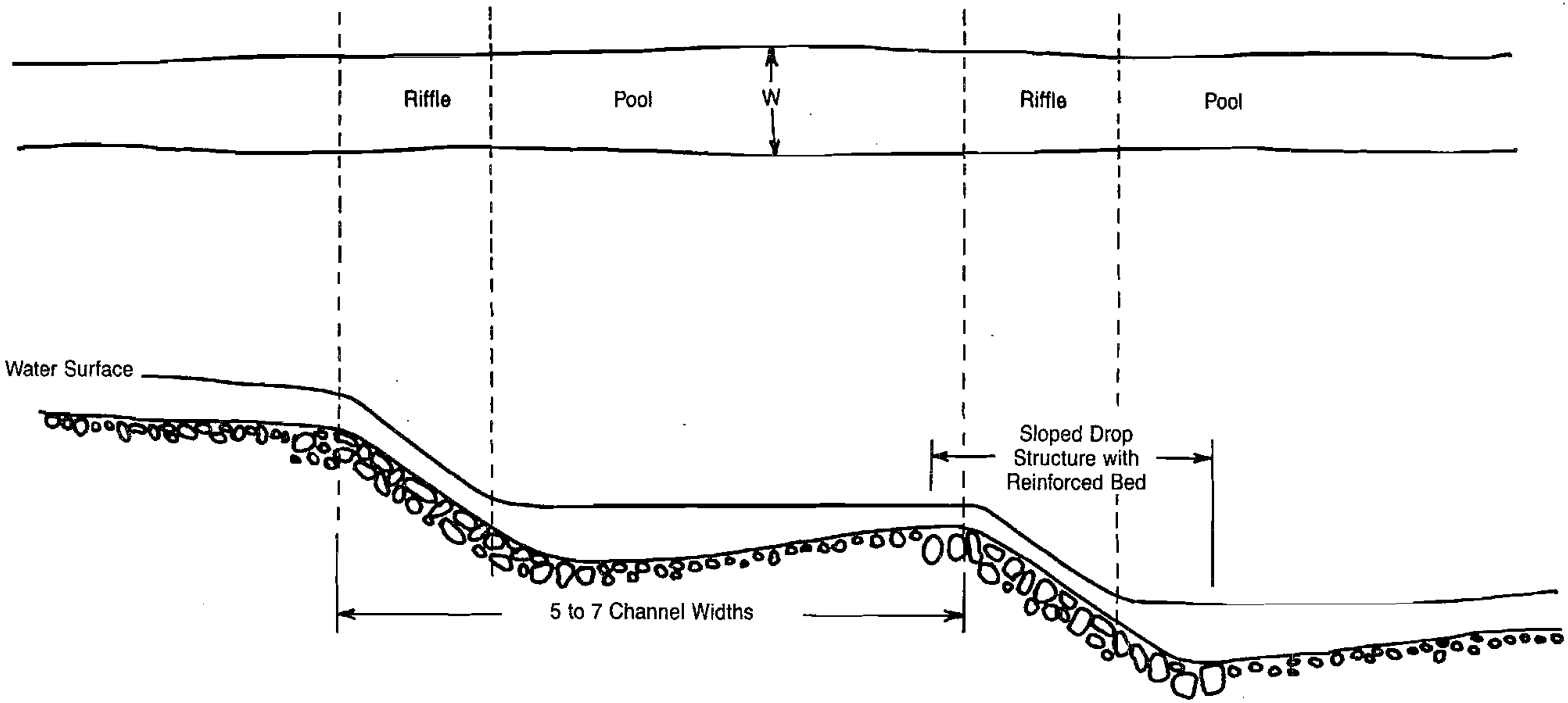


S = Slope of Channel
Q = Peak Flow
D_{50} = Median Size of Material
d = Depth of Flow

Source: Simons, Li and Associates 1982

MOUNTAIN STREAM DESIGN, TRAPEZOIDAL CHANNEL, 2:1 SIDESLOPES, 20 FT. BASE WIDTH

ENTRIX | **Figure 30**



SLOPED DROP STRUCTURE

ENTRIX | **Figure 31**

Large riprap should be used to reinforce the channel bed at the sloped drop structure (Figure 31). The width of the channel at the structure should match the widths selected during channel design. Additional information on the design of drop structures is available (Simons, Li and Associates 1982).

To maintain fish passage, a narrow trench 0.5 ft deep should be provided in the bottom of the stream channel. The trench will concentrate flow to permit fish passage at low flows.

B. Channel Pattern and Profile

The channel pattern and profile of a mountain stream is expressed by pools and riffles located within a steep, straight channel. In natural mountain-stream systems, the pool and riffle sequence repeats approximately every 5 to 7 bankfull-channel widths.

Alternating flatter sections and shorter, steeper sections throughout the length of the channel will create a pool and riffle sequence. Sloped drop structures can be used to create a riffle as shown in Figure 31. In mountain streams with relatively less steep slopes, pools 1 to 3 ft in depth or deeper in fish streams should be excavated every 5 to 7 channel widths along the channel. The average slope should be used to design the channel geometry.

8.4.3 Braided-Stream Design

Braided channels are unstable channels that frequently adjust their position in the floodplain. Because of this unstable character, their initial design configuration is less critical than that for other stream patterns. Design parameters include:

1. Channel geometry
    a. Top width, W
    b. Mean depth, d
    c. Mean velocity, V

2. Channel pattern

3. Channel profile

In unmined sites or sites with nearby undisturbed floodplain, these parameters should be measured in the field and from aerial photographs. Lacking reliable data in the same stream valley, the approach outlined below should form a starting point for the braided stream to evolve from.

A. General Hydraulic Geometry

The approach to developing a braided channel pattern is to design the main channel to carry the bankfull discharge and to excavate high-water channels to concentrate overbank flow. Drage and Carlson (1977) developed channel-geometry relationships with bankfull discharge for 69 rivers in the eastern Brooks Range in northern Alaska. Bankfull discharge is the dominant discharge for braided rivers; it is characterized by water levels to the top of the bar between channels such that an increase in water level will cause flooding of the floodplain. The equations that were developed by Drage and Carlson (1977) follow a format similar to those for meandering systems:

$$W = 4.66\ Q_{BF}^{0.47} \qquad (r^2 = 0.54)$$

$$d = 0.13\ Q_{BF}^{0.38} \qquad (r^2 = 0.63)$$

$$V = 1.65\ Q_{BF}^{0.15} \qquad (r^2 = 0.29)$$

Using a 2-year recurrence-interval flood in these equations will give an approximate channel geometry for the main channel of a rehabilitated braided stream. A trapezoidal channel with 2 to 1 side slopes is an appropriate configuration. The stream will adjust as part of the normal unstable character of braided streams.

An evaluation of the bed stability of a braided stream is not necessary. Braided streams are characterized by unstable beds, with transportation of bed material expected to occur at relatively low flows.

A comparison of the above equations for braided streams with the equations in Section 8.4.1 for meandering streams shows that the braided channels are typically wider and shallower than meandering streams. This is a common characteristic of braided streams (Leopold and Wolman, 1957).

B. Channel Pattern

The pattern of the braided stream should have a main channel that carries most of the flow and several high-water channels that carry some flow, even at flows less than bankfull. Although the main channel should have some variation in its alignment, straight channels would be acceptable. High-water channels are discussed further in the floodplain-rehabilitation section (Section 9.2).

C. Channel Profile

Braided streams, like meandering and mountain streams, have non-uniform bed profiles. While the pattern of deep and shallow channel sections is less defined and more variable than in meandering streams, it is recommended that depressions of 1 to 3 ft be excavated below average bed level at intervals of about 5 to 7 bankfull-channel widths along the channel.

8.5 CHANNEL STABILITY

Channel stability should be evaluated to assure that stream rehabilitation measures will not be damaged or destroyed during subsequent high-flow events. Unstable stream channels will erode causing the transport of material from the bed and banks, and possible failure of the channel. The lateral movement of the channel into a recently rehabilitated riparian zone (Section 10.2) should be avoided.

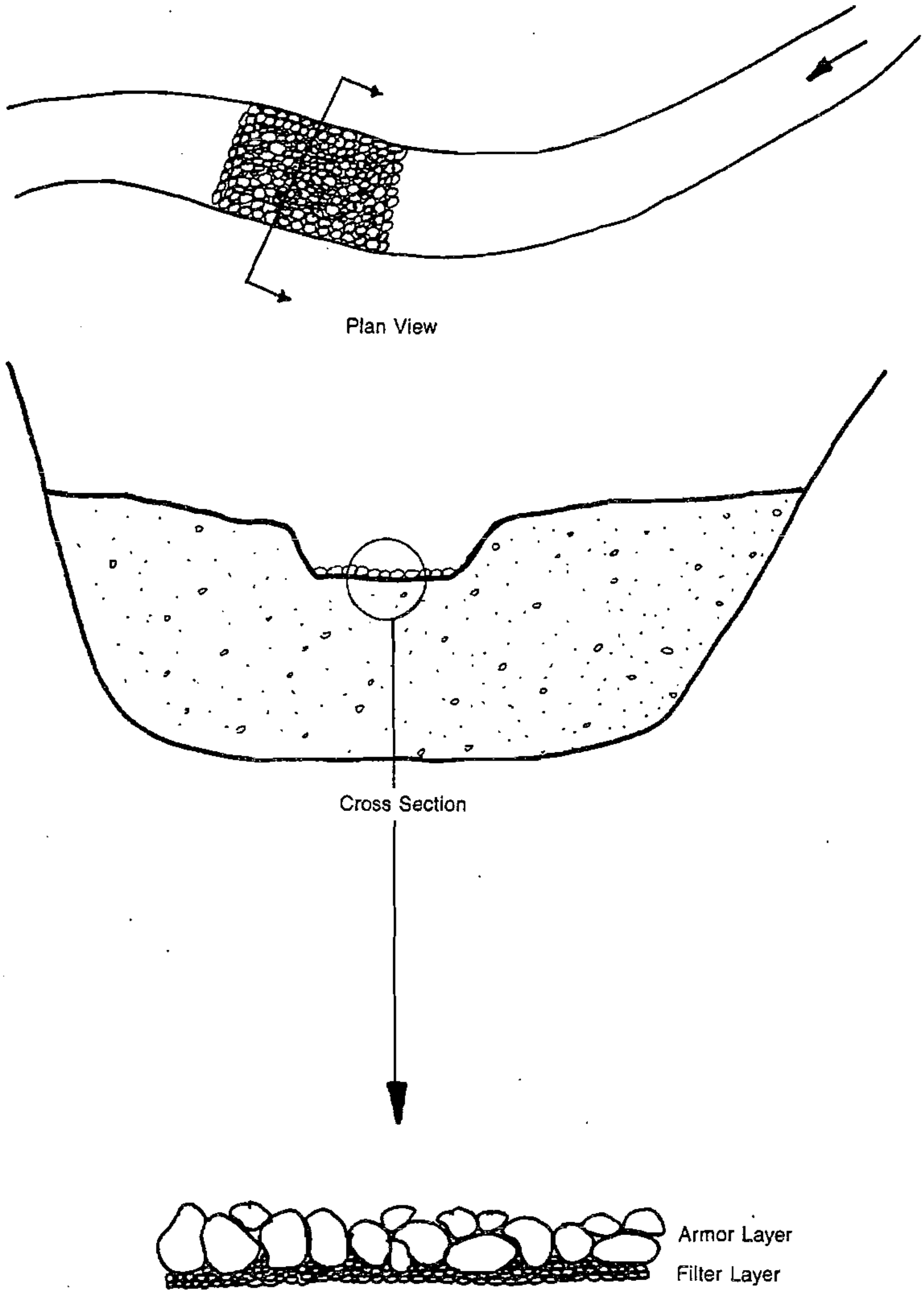
8.5.1 Bed Stability

The bed stability of the rehabilitated stream should be similar to the stability of a natural stream with the same stream pattern. A meandering stream is expected to have a stable bed until bed motion occurs at about three-fourths bankfull (Dunne and Leopold 1978). A mountain stream should have low sediment transport and a stable channel at bankfull conditions. A braided stream has an unstable configuration and is likely to transport bed material at relatively low flows. If slightly greater bed stability is desired, an armor layer can be developed or the armor-layer sizes can be increased.

Bed armoring occurs in many natural mountain and meandering streams. High velocities at bankfull conditions transport smaller-sized material until an armor layer develops. The armor layer will be composed of the larger bed materials which remain after the smaller material has been transported downstream (Figure 32). The system thus reaches an equilibrium condition with relatively little sediment transport occurring except during large flood events.

In designing a bed armor layer, several layers of different sized material should be used to form the stream channel. A gravel layer with an optimum size range from 0.2 in. to 3.5 in. should be placed first (Joyce et al. 1980). This layer should be at least 6 in. in depth. In low velocity streams, a second layer of material consisting of large cobbles and small boulders should be placed above the gravel-sized material to armor the channel bed. If further bed stability is required in higher velocity streams, riprap may be placed on the stream bed in areas where scour should be avoided. The minimum thickness of this larger layer should be greater than the longest dimension of the largest rock used in the layer (Joyce et al. 1980). Figure 32 illustrates a rehabilitated stream channel with a filter layer of gravel material and an armor layer placed on the stream bed.

The gravel material will resist movement and stabilize the armor layer (Simons, Li and Associates 1982). In the absence of a gravel filter layer, cavities in the underlying material may be formed by turbulent eddies and jets penetrating the armor layer or by water flow at the interface of the layer (Simons, Li and Associates 1982). Large cavities beneath the armor layer which could result in the failure of the stream bed and/or banks will be minimized by the presence of a gravel filter layer.



BED STABILITY

ENTRIX | FIGURE 32

8.5.2 Bank Stability

Erosion of channel banks may be avoided by protecting the bank with revetment. Revetment will preclude vegetative development on the banks, however. Revetment on stream banks will prevent the lateral movement of the channel (Jackson and Van Haveren 1984). Figure 33 illustrates several types of revetment.

Riprap of large rocks, rubble, or quarry stone is generally the most reliable and economical revetment (U.S. Army Corps of Engineers 1981). Proper riprap gradation and sizing (Section 8.5.3) is important. Filter layers of finer materials should be placed beneath the riprap layer (Section 8.5.3).

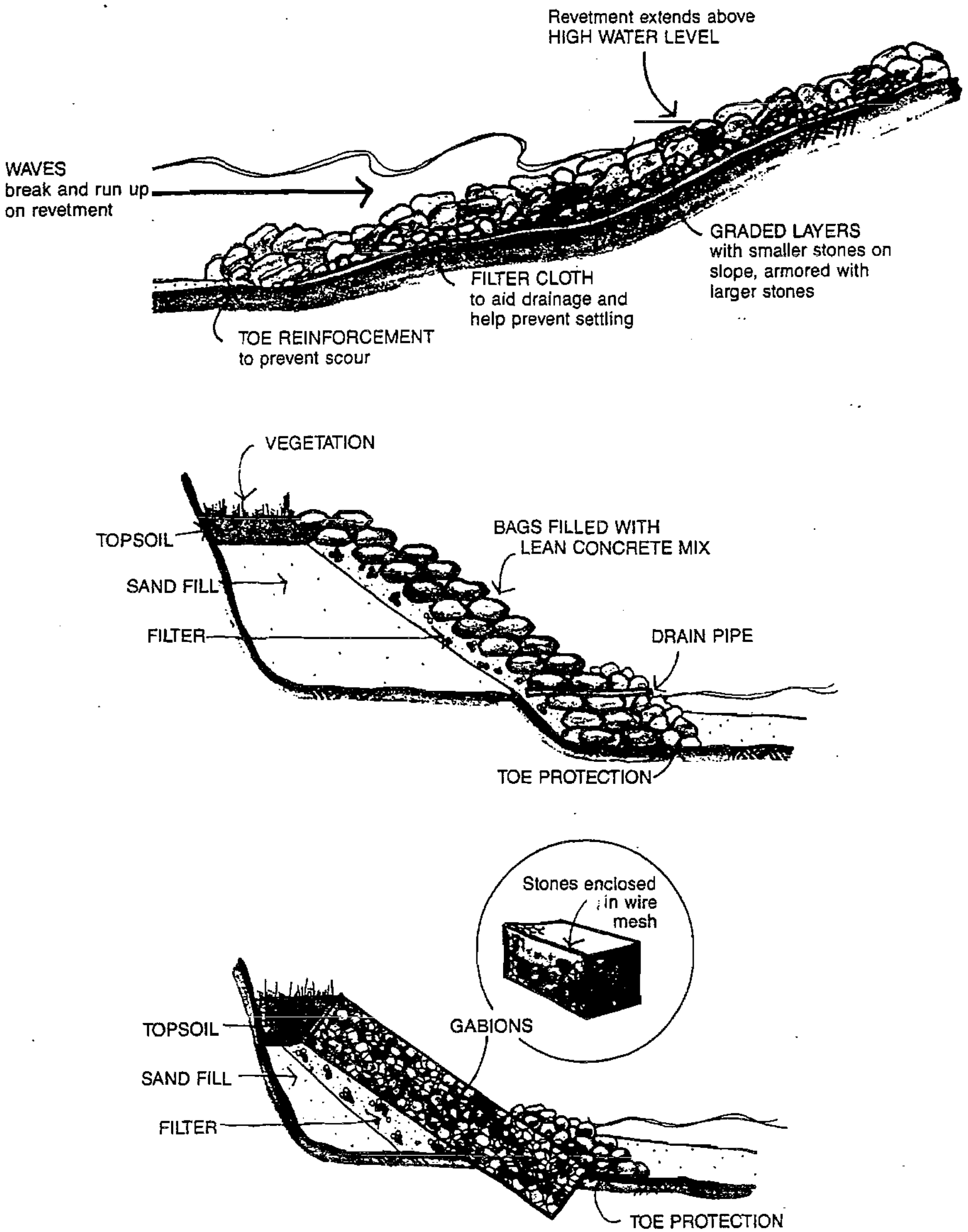
In the absence of properly sized and graded riprap, stone-filled wire baskets (gabions) can be used as revetment. The baskets must be solidly filled with stones large enough to prevent loss through the gabion mesh. Stones are typically at least 4 inches in diameter (U.S. Army Corps of Engineers 1981). Gabions may require maintenance.

Burlap bags filled with sand or lean concrete mix may also be used as revetment. Bags filled with set sand-cement mixture may be piled two-deep on the face of the slope. These bags will interlock slightly and resist removal or displacement.

8.5.3 Riprap Design

Several factors are important in the design of rock riprap (Joyce et al. 1980):

- shape, size, and gradation of the rock
- density and durability of the rock
- velocity and depth of flow near the rock
- steepness of the slope being protected
- thickness of the riprap layer
- filter layer presence and design
- end and toe protection



SOURCE: U.S. Army Corps of Engineers 1981

BANK STABILITY

ENTRIX | **Figure 33**

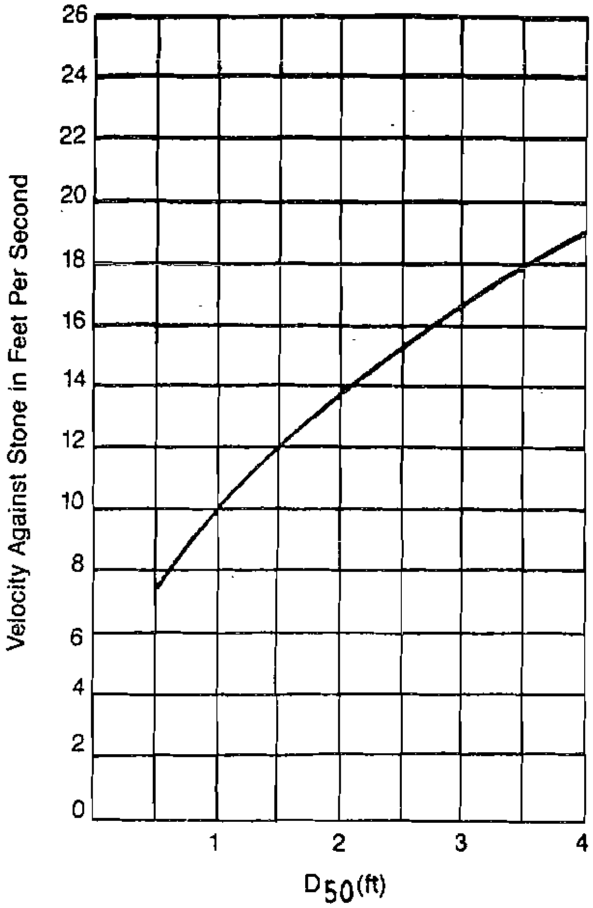
The shape, size, and gradation of the rock riprap are the primary properties in resisting erosion. The shape should be angular to provide an interlocking of the rocks. The size of a rock is generally determined from its middle dimension; large rock should be used as large rock is more erosion resistant than small rock and the rock size should be selected for the velocity expected in the channel as shown in Figure 34. Well-graded material improves the interlocking of the rock and reduces spaces between rocks; a recommended gradation is shown in Figure 34.

The rock used for riprap should be hard, dense, and durable to withstand cycles of wetting and drying, and freezing and thawing. These cycles can cause cracking of the rock, resulting in reduction of size and erosion resistance. Density and durability are generally determined by laboratory tests.

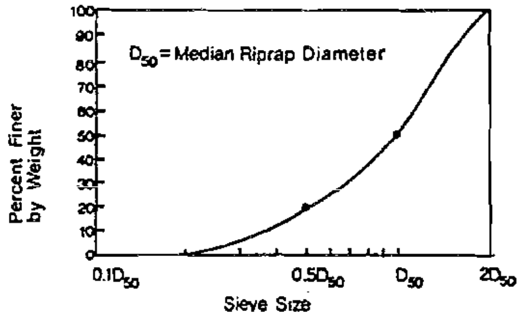
A primary factor influencing erosion is the local velocity of the flow. Direct flow measurements are recommended, but these may be difficult to obtain during flood events. In the absence of measured data, the velocity against a slope should be evaluated as two-thirds of the average velocity in straight reaches or four-thirds of the average velocity in severe bends (Joyce et al. 1980). Rock size should increase with increasing depth as the shear stress on the rock riprap is proportional to the depth of flow above the riprap.

The stability of riprap decreases with increasing steepness of slope. Riprap should be placed on slopes with a maximum steepness of 2 to 1 (Simons, Li and Associates 1982).

The thickness of the riprap should be sufficient to provide the desired protection of the slope. The minimum thickness should be equal to the longest dimension of the largest rock or be 50 percent larger than the median rock size (D_{50}), whichever is larger (Joyce et al. 1980). This minimum thickness should be increased by 50 percent if wave action is possible, the gradation is not as recommended, the riprap is to be placed in flowing water, or if a filter is not used when recommended (Joyce et al. 1980).



Reference: Neil 1973



Suggested Gradation for Riprap

Reference: Karaki et al 1974

RIPRAP DESIGN

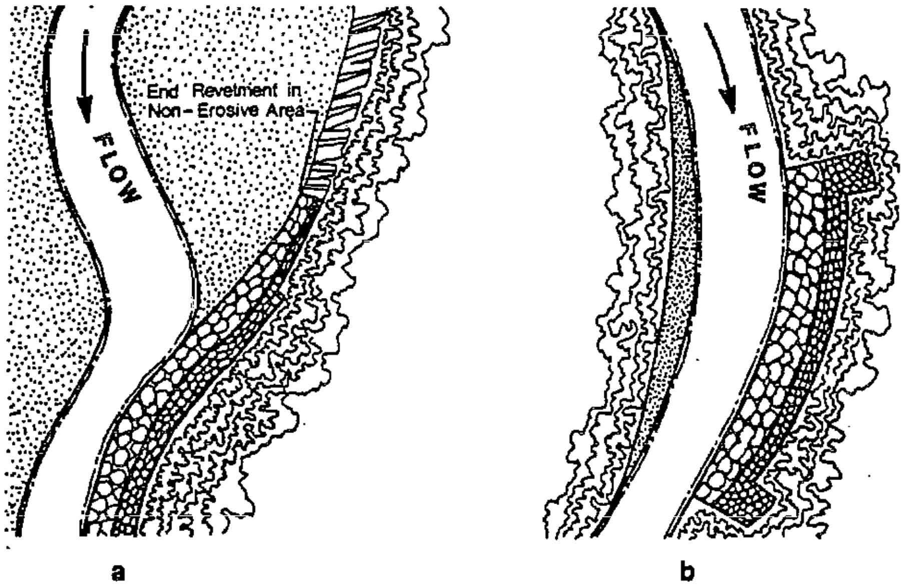
ENTRIX

FIGURE 34

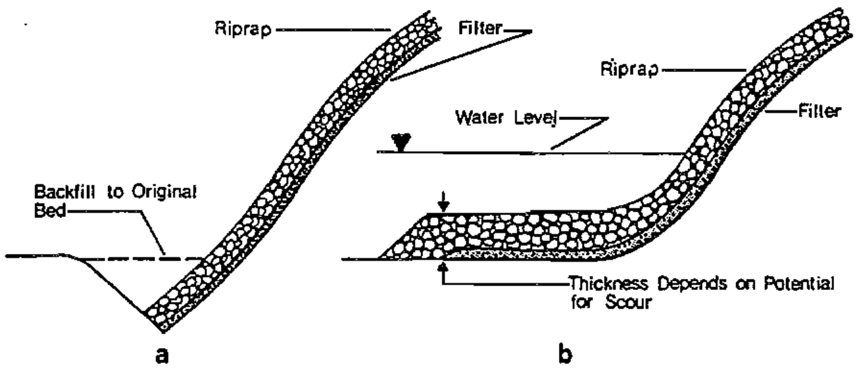
A filter layer may be recommended for placement beneath the rock riprap layer to prevent the loss of bank material through the voids in riprap. If the bank material will be easily eroded, a filter layer is recommended. Poor riprap gradation is also a reason to recommend a filter.

Gravel filters should use gravels ranging from about 0.2 in. to 3.5 in. Depending on the classification sizes obtained during washing, material from the sluice tailrace should be mixed with a larger classified size from the screening plant to provide an optimum filter layer. The filter thickness should be no less than 6 in. A filter thickness equal to half the riprap thickness is recommended (Joyce et al. 1980).

The ends and base of the riprap along the channel may be subject to erosion and should be protected. Riprap should be extended to areas along the channel not having erosive velocities (Figure 35). If this is not possible, the thickness of the riprap layer at the end should be increased to twice that otherwise needed by excavating a recess in the bank and backfilling with gravel (Joyce et al. 1980). The riprap layer should be extended below the level of the bed to the expected depth of scour to avoid undercut of the riprap. If this is not possible, the thickness of the riprap layer at the toe should be increased to twice that otherwise needed (Joyce et al. 1980).



Schematic showing plan view of end protection configurations: a) extension out of the zone of erosion with a potential reduction in thickness, and b) increasing the thickness at the ends of the revetment.



Schematic showing cross section of toe protection configurations: a) extension of the riprap below the dry bed and backfilling, and b) placement of extra material along the bed to launch itself into developing scour holes.

SOURCE: JOYCE ET AL 1980

RIPRAP PROTECTION OF END AND TOE SECTIONS

ENTRIX | **Figure 35**

FISH-HABITAT REHABILITATION

9.0

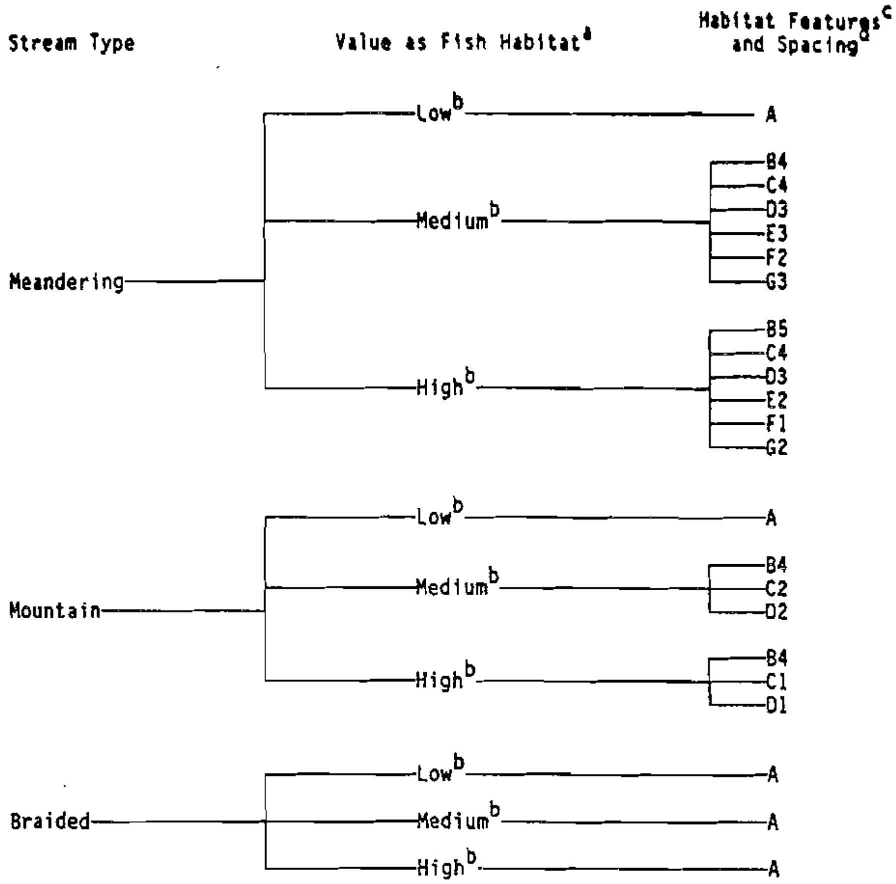
FISH-HABITAT REHABILITATION

9.1 OBJECTIVES AND SCOPE

Since much of the placer-mining activity takes place in active floodplains and may affect fish resources of the streams, fish-habitat concerns are central to the stream rehabilitation. Reconstructing fish habitat is a complex task that requires an understanding of the major physical and biological components of the stream environments, their interactions, and the habitat requirements of fish. The objectives of this section are to identify the major stream-habitat components and fish-habitat requirements and to present stream reconstruction and rehabilitation techniques that modify various habitat components to better meet fish-habitat requirements.

There is a relationship between the amount and quality of habitat and the size of fish populations; therefore, mitigation measures for stream-altering activities usually focus on habitat rehabilitation. Stream alterations resulting from placer mining can reduce habitat quality resulting in similar reductions to associated fish populations. In some cases, rehabilitation may result in improved habitat conditions, as the reconstructed stream channel can be designed to compensate for natural deficiencies.

Desirable habitat features must be included in the rehabilitation plan to ensure that fish utilize the rehabilitated mine site. The selection and spacing of these habitat features for the restoration of fish habitat in a mined stream depends on several factors: stream type, value of the stream as fish habitat prior to mining, and the degree of habitat alteration or degradation resulting from mining. The decision-making flow chart for selecting and spacing habitat features (Figure 36) was developed with the assumption that mining had significantly altered and degraded fish habitat in



[a]Value prior to mining an unmined stream or assessment of value in previously mined stream

[b]Low = no significant fish populations, Medium = moderate resident and/or anadromous fish populations, High = significant resident and/or anadromous fish populations

[c]Habitat Features Codes:
- A = no habitat features needed, design for hydraulic parameters
- B = rock island
- C = boulder grouping
- D = submerged rock weir
- E = tree cover
- F = wing deflector
- G = overhanging bank cover

[d]Spacing Codes:
- 1 = one every two pool/riffle sequences (P/R)
- 2 = one every three P/R
- 3 = one every four P/R
- 4 = three every two P/R
- 5 = three every one P/R

(Note: one pool/riffle sequence = approximately six stream widths)

FLOW CHART FOR SELECTING AND SPACING HABITAT FEATURES

ENTRIX | FIGURE 36

the mined stream. The suggested spacings of habitat features in a restored stream are general guidelines that can be modified to site-specific conditions.

The instream habitat features for rehabilitating a stream create habitat diversity by altering local stream hydraulics (depth, velocity, and stream width) and structure (substrate, cover). The change in local stream hydraulics will cause minor bed scour, bank erosion, or deposition in the vicinity of the habitat feature as the stream readjusts its configuration. These readjustments in the bed are part of habitat rehabilitation and are incorporated in the design of the habitat feature. Habitat features used in areas with bed or bank protection should be carefully designed since desired readjustment in the cross section may be prevented.

To rehabilitate a stream for fish, the types of fish occurring within and adjacent to the mine site should be determined and their seasonal habitat utilization patterns evaluated. In some cases previous mining activities may have eliminated fish species from the stream reach. If this has occurred, habitat features should be included during stream rehabilitation to prepare the stream for recolonization by displaced fish species.

Fish can be divided into two major categories: anadromous and resident. These two categories of fish have different habitat requirements. Important anadromous species in Alaska streams generally include salmon, Dolly Varden/Arctic charr, steelhead, and some whitefishes. Important resident fish generally include Arctic grayling, rainbow trout, Dolly Varden/Arctic charr, northern pike, burbot, and other whitefishes. Salmon are selected as the anadromous evaluation species while Arctic grayling is selected as the resident evaluation species. Habitat requirements vary with species and life stage.

In the stream environment, physical and biological factors combine to create fish habitat. Generally, fish do not occupy all portions of a stream but select specific areas that have conditions meeting their habitat requirements. Understanding these requirements is important for successful stream rehabilitation. Physical characteristics determine the amount and quality of habitat available to the fish. Biological factors such as food availability, predation, or harvest are important factors in controlling fish population size.

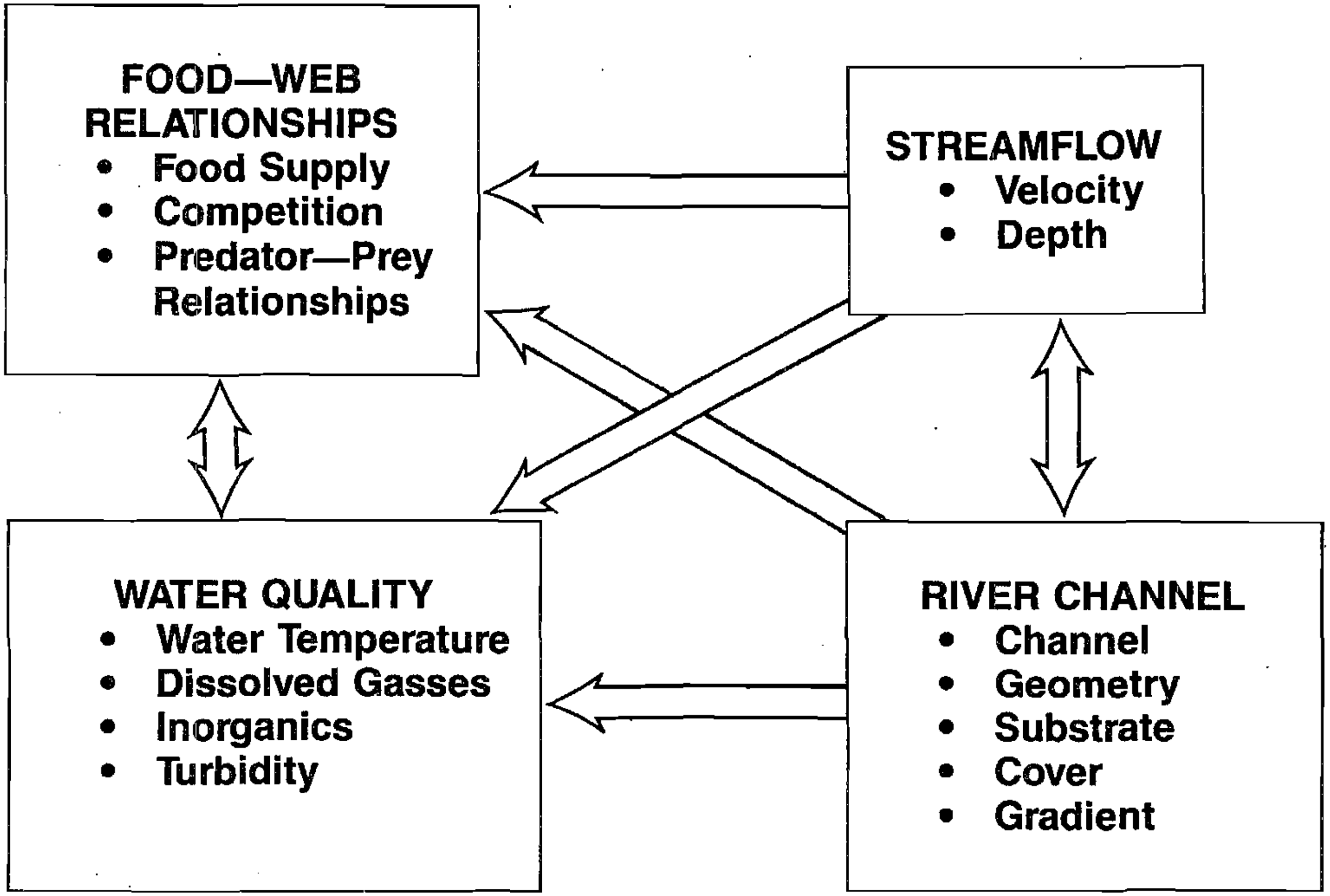
9.2 FISH HABITAT COMPONENTS

Fish habitat consists of several interdependent physical and biological components including: channel structure, streamflow, water quality, and food-web relationships (Figure 37). The channel structure component includes factors such as channel geometry, substrate or streambed materials, and instream objects used as cover by fish. Each of these factors contributes to habitat quality. Streamflow, the second major component, determines instream hydraulics. In a given channel structure, the depth and velocity of flow are a function of stream discharge. Water quality also influences habitat quality. Turbidity and dissolved solids are two water-quality parameters commonly altered by placer-mining operations. Placer mining typically also alters channel structure. In addition to the physical components, a biological component, food-web relationships, is an important habitat determinant for resident and young anadromous fish.

The four major habitat components are interrelated and each can influence the factors of other components. For example, changes in channel geometry will alter depth and velocities of a given discharge. High streamflow can change the substrate compositions of particular areas by removing or depositing smaller particles. Increased turbidity can reduce light penetration and, in turn, food production. Reducing the amount of fine particles in the substrate can enhance production of aquatic insects and other food organisms. Since changes in one component of fish habitat can affect the factors of other components, the four major habitat components must be evaluated in concert to develop sound rehabilitation plans.

9.3 HABITAT REQUIREMENTS

Fish occupy areas that have habitat factors within their tolerance limits. Within specific tolerance limits, a narrow range of values provides optimal or preferred habitat. Fish production is assumed to be best under optimal



MAJOR COMPONENTS OF RIVERINE FISH HABITAT

ENTRIX

Figure 37

habitat conditions. For habitat to be usable, each factor must be within an acceptable range. If the value of one factor is beyond the tolerance range, then its associated area becomes unusable regardless of the suitability of other factors. For example, if the substrate is too large for spawning then no spawning will occur, even though optimal depths and velocities are provided.

In order to establish self-sustaining fish populations, the habitat requirements for all species and life stages present must be considered. To accommodate the divergent habitat preferences, a diversity of habitat characteristics is necessary for successful stream rehabilitation.

Since different life stages use different types of habitat and habitat is available in varying amounts, there is often a limiting habitat that controls the size of the population. In Alaskan streams, limiting habitat is often related to severe environmental conditions encountered during winter. Other habitats often limiting fish populations include spawning or rearing areas. Limiting habitats vary based on physical characteristics of the stream and habitat requirements of different life stages.

Habitat requirements differ from species to species and change from life stage to life stage. For example, the range of velocities that a fish is able to use increases with fish size and swimming capabilities. Since fry are small and have limited swimming capabilities, they occupy a narrow range of low velocities. Larger juveniles can use a broader range of velocities, while spawning adults have different velocity requirements than either juveniles or fry. Hence, fish with different habitat preferences will occupy different areas of the stream.

9.3.1 Anadromous Fish

A. Passage

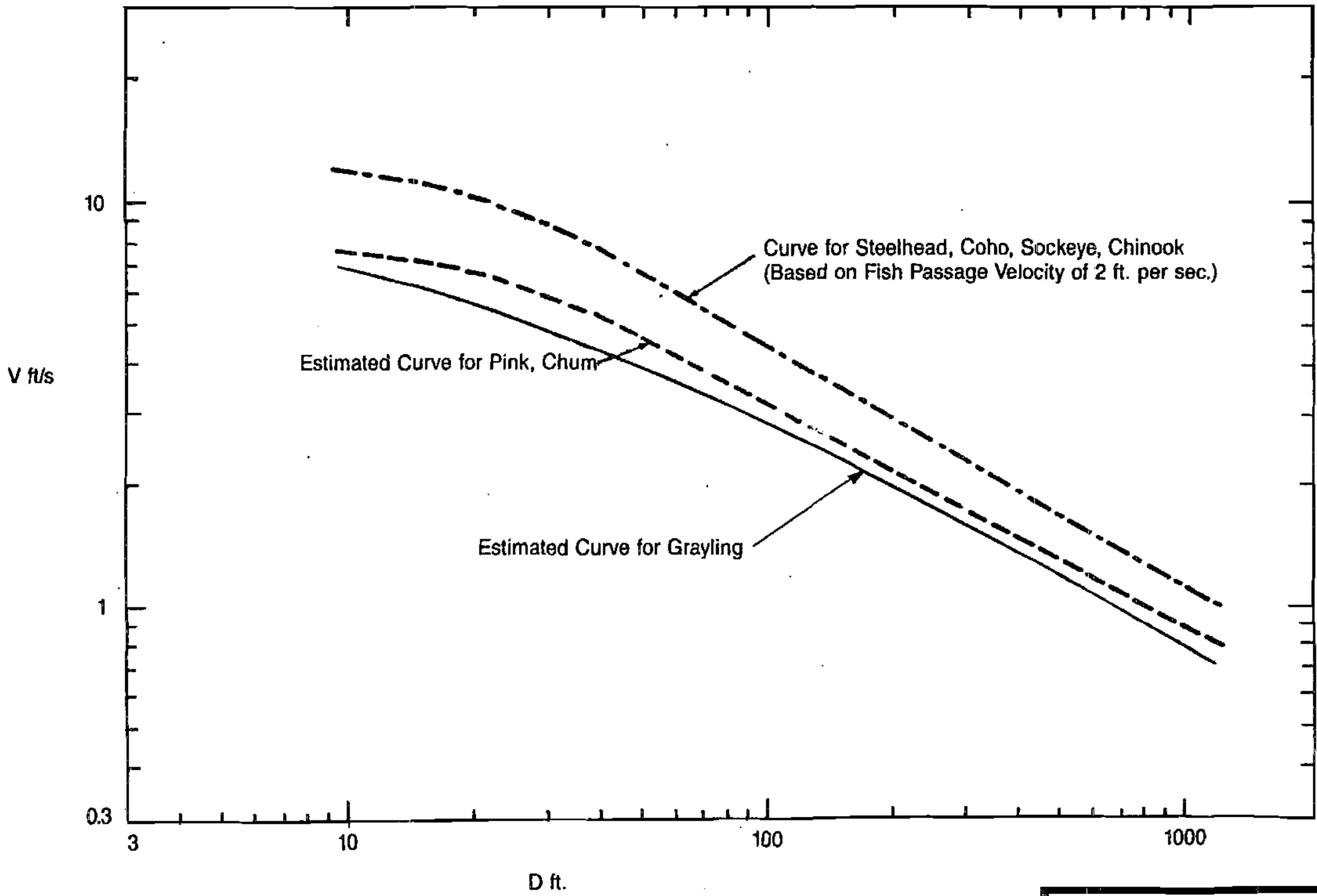
Adult salmon, as with other anadromous fish, return to their natal stream for spawning. Timing of spawning migration is species, drainage, and site specific but generally occurs in summer and fall. Thus, when evaluating fish passage and designing the hydraulics of a restored stream channel (Chapter 8.0), the mean annual flow, which approximates the mean summer flow, can be used. Adult fish swim upstream, holding occasionally for short periods in pools or backwater areas. Passage requirements usually consider only hydraulic conditions, depth, and velocity, although resting areas formed by pools, backwaters, and substrate roughness are important considerations. Suitable hydraulic conditions depend of the size and swimming capability of the fish (Bell 1973).

For adult salmon, depths of 0.5 ft or greater allow easy passage (Thompson 1972, Blakely et al. 1985). Adult salmon can move upstream through shallower depths for short distances. Passage studies completed on the Susitna Hydroelectric Project indicate that adult chum salmon were able to pass 80-ft reaches with thalweg depths of 0.3 ft (Blakely et al. 1985).

Velocity is also a major factor in passage requirements. High velocities inhibit passage (Bell 1973, Thompson 1972). Passage criteria are generally based on swimming performance of the fish. Swimming performance is generally divided into three categories: bursting (darting), sustained (prolonged) and cruising. Bursting speed is defined as the speed which a fish can maintain for a short time (5 to 10 minutes). Sustained speed is the speed that a fish can maintain for a prolonged period but would ultimately result in fatigue. Cruising speed, the third category, can be maintained for an extended period of time without fatigue. For passage requirements, sustained speed is used as the upper limit for velocity. Figure 38 presents the relationship between horizontal distance traversed and maximum velocity for common anadromous and resident fish. Salmon can pass velocities of 8-11 fps for short distances (10 ft) and velocities of 5-8 fps for longer distances (50 ft) (Ziemar 1961). Smaller fish can pass through shallower depths but require lower velocities.

B. Spawning

When salmon reach their spawning areas they select habitat with specific attributes. Salmon-spawning habitat is generally composed of definable ranges of depth, velocity, substrate, and intragravel flow. Several recent Alaskan studies have identified microhabitat conditions for spawning salmon (Estes and



Source: Fisheries and Oceans 1980
Adapted from Ziemer, G.L. 1961

SWIMMING CAPABILITY OF SELECTED ANADROMOUS AND RESIDENT FISH

ENTRIX | Figure 38

Vincent-Lang ed. 1984, Estes et al. 1981, Wilson et al. 1981, Woodward-Clyde 1983, and Burger et al. 1983). Earlier studies also addressed habitat requirements for spawning (Burner 1951, Thompson 1972, Smith 1973, Sams and Pearson 1963, Collings 1974) and most of these are summarized by Wesche and Rechard (1980).

Spawning salmon use a wide variety of depths. Minimum depths appear to be most restrictive to spawning. Depths suitable for salmon spawning range from 0.3 ft to 10.0 ft. The optimal range appears to be 1.0 to 3.0 ft, although the lower end of the range is more critical than the upper range. Spawning salmon are also sensitive to velocity. Mean-column velocities associated with salmon spawning range from 0.2 to 4.5 fps. The optimal range for velocity is between 1.0 and 2.5 fps.

Substrate requirements for spawning salmon are described by dominant particle size and percent fines. Suitable particle sizes range from small gravels to cobbles with larger fish being able to use larger substrates. Salmon generally prefer particle sizes ranging from 1.5 to 3 in. gravels. Recommended content of fines (less than 0.084 mm diameter) is 5 percent or less, although successful embryo development has occurred with 20 percent fines (McNeil and Ahnell 1964, Tagart 1976). The percentage of fines generally affects incubation. Developing embryos depend on intragravel flow to bring in oxygen and carry away metabolic wastes. Substrates with high percentages of fines have reduced porosity and less intragravel flow (McNeil and Ahnell 1964).

The most successful spawning areas have strong intragravel flow. Upwelling has also been identified as an important feature of spawning areas for some species, particularly chum salmon (Wilson et al. 1981, Estes and Vincent-Lang ed. 1984).

Creation of successful spawning habitat is a complex task. The design must incorporate species and site-specific features that require the combined efforts of both biologists and engineers skilled in habitat rehabilitation.

C. Incubation

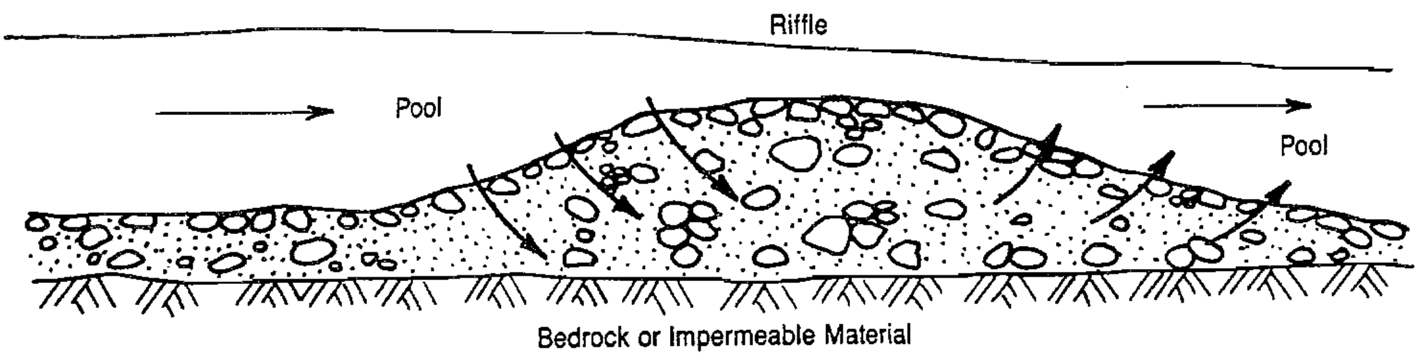
After fertilization, salmon embryos undergo a 4- to 6-week period during which they are sensitive to disturbance. Once embryos reach the eyed stage, habitat disruptions (e.g., reduced streamflows or temperatures) are not as critical. The embryos develop in the gravels throughout the winter and hatch in February or March. Development rate is dependent on temperature. After hatching, the alevins remain in the gravel until yolk absorption, and they then become free-swimming fry.

During incubation, successful embryo development is subject to the environmental conditions surrounding them. Even as alevins, fish have limited mobility. If the spawning area dewaters, freezes, or has insufficient intragravel flow, embryo mortality will result. Habitat requirements for incubation center on preventing spawning areas from dewatering and maintaining intragravel flows. Water depths of 0.1 ft are suitable for incubation if ice does not freeze to the streambed. Mean-column velocities of 0.5 to 1.0 fps have been required (Bovee 1978). However, the hydraulic connection between surface and intragravel flows that influences the rate of percolation is site specific.

Pool-riffle sequences provide good spawning and incubation habitat. Velocities in the tail of the pool and riffles are generally high enough to prevent the deposition of silts and debris that may clog the interstices of streambed gravels. In unaltered streams, the pool-riffle sequence usually enhances intragravel flow. The undulation of the streambed longitudinally through the pool-riffle sequence causes downwelling at the tail of the pool (Figure 39). However, in a mined stream the streambed materials are often cemented with fine particles, which Bjerklie and La Perriere (1985) have shown to reduce or cut off the interchange between groundwater and streamflow.

D. Juvenile Rearing

Each of the salmon species has different juvenile rearing patterns (Morrow 1980). Emergence from the gravels takes place in the spring (March to June) following spawning. Upon fry emergence, juvenile pink salmon and chum salmon



WATER INTERCHANGE BETWEEN STREAM AND GRAVEL IN A RIFFLE

Source: Fisheries and Oceans 1980
Adapted from Vaux 1968

ENTRIX

Figure 39

outmigrate immediately to the ocean during or after the spring breakup. In some rivers, chum salmon fry may spend 1 to 3 months rearing in freshwater. Juvenile chinook salmon usually remain in rivers and streams for 1 or 2 years before moving to sea. Most juvenile coho in Alaska rear for one to 2 years in rivers and streams. Sockeye salmon juveniles usually move from streams into lakes where they spend 1 to 2 years. In rivers without connecting lakes, juvenile sockeye remain in stream habitats.

Habitat requirements for juvenile fish include many interrelated factors and change on a seasonal basis. Factors usually evaluated to assess juvenile rearing habitat include depth, velocity, substrate, cover, food availability, and water quality. Several Alaskan studies have characterized juvenile salmon habitat (Burger et al. 1983, Wilson et al. 1981, Schmidt et al. 1984). Fry (0+ fish) habitat is generally separated from that of older juveniles (1+ fish). After emergence, fry occupy areas with low velocities (less than 0.5 fps) and shallow depths (less than 1.0 ft). Most fry are associated with backwater areas and stream margins. Cover is important for all juveniles. Log debris, overhanging vegetation, undercut banks, and substrate (> 1 in. diameter) are commonly used cover objects. Juvenile fish use cover to escape from predators and as a barrier from high velocities.

As the fish grow, they move from early nursery areas into less sheltered rearing habitats in the stream channel. Juvenile fish utilize depths ranging from 0.2 ft to 10 ft, but are most commonly associated with depths of 0.5 to 4.0 ft. Juvenile fish are more sensitive to velocities than depths. They use mean-column velocities ranging from 0.0 to 2.5 fps. Preferred velocities change from species to species but are generally between 0.0 and 1.5 fps. Juvenile chinook salmon prefer faster water than coho, sockeye, or chum juveniles.

E. Overwintering

Chinook, coho, and sockeye juveniles usually overwinter in freshwater be moving into the ocean. Overwintering habitat has not been fully define streams, adequate depths (>3.0 ft) to maintain living space and veloci maintain sufficient dissolved oxygen concentrations are required. Ve less than 1.0 fps are usually preferred, so that overwintering juveniles can maintain their positions in the stream. Substrate (>5 in. diameter) can provide important resting places for overwintering fish.

9.3.2 Resident Fish

A. Passage

Arctic grayling spawn during spring just after breakup (Morrow 1980). It is suspected that grayling, similar to salmon, return to natal streams for spawning. Prior to spawning, there is a migration from overwintering areas to spawning areas. Passage requirements for grayling are primarily a function of water depth and velocity, although blockages due to ice jams may temporarily occur because of the timing of the spawning migration relative to spring breakup.

Grayling can maintain sustained swimming speeds for prolonged periods, thus sustained swimming tolerances are used as the upper range of velocities suitable for passage. Bell (1973) and Dane (1978) reported that sustained swimming speeds for an average adult grayling range from 2.6 to 7.2 fps, while MacPhee and Watts (1975) found that 15-inch (38-cm) grayling could maintain sustained swimming speeds ranging from 5.9 to 7.5 fps. Grayling have a lower maximum velocity criterion than salmon, but because of their size, grayling are not as restricted by depths. Thus, the 0.5-ft-depth criterion for salmon passage exceeds that which is needed for the upstream passage of grayling and other resident species. Wesche and Rechard (1980) suggest a minimum depth of 0.4 ft for trout less than 20 inches. This criterion should approximate, or exceed, the minimum depth requirement for adult grayling.

Smaller grayling can migrate through shallower reaches of rivers, but, due to slower sustained swimming speeds, require lower current velocities. Arctic Hydrologic Consultants (1985) has developed passage criteria for grayling negotiating culverts. A regression equation was developed that allows estimating the average velocity required for successful passage under a variety of conditions. One important variable in the equation is fish length.

Evaluation of passage requirements generally focuses on maintaining sufficient water depths. Since grayling migrate during higher flows associated with breakup, attention is focused on high stream velocities that may occur during floods. Although high velocities are associated with flood flows, the roughness of the bed in natural channels is generally sufficient to create turbulance and eddies with low velocities near the streambed. Grayling and other fish often take advantage of low velocities near the bottom for migration. Unless associated with extensive rapids or cascades, velocities in natural channels rarely create passage barriers.

B. Spawning

Once grayling reach their spawning sites they select areas with suitable spawning habitat. Depth, velocity, and substrate are generally the important factors defining grayling-spawning habitat.

Grayling have been observed spawning in depths ranging from 0.2 to 3.0 ft (Krueger 1981). An optimal depth may be about 1.0 ft, as Tack (1980) reported that this was the mean value for 22 observations. Mean-column velocities ranging from 0.5 to 4.8 fps have been measured at grayling-spawning sites (Krueger 1981). However, an optimal range of velocity is likely between 0.5 and 2.0 fps. The range of substrate size used by spawning grayling is from silt to gravels of 1.5 in. diameter (Krueger 1981). Grayling do not excavate a redd. Instead, they spawn over the substrate and their eggs sink to the bottom, adhering to the substrate. Embryos are usually covered by a thin layer of substrate (up to 2 in.), as a result of spawning action and water velocity.

The percentage of fines is generally not considered when evaluating grayling spawning substrate. Grayling embryos are not deposited as deep in the substrate as salmon embryos (2 in. or less versus 9 to 12 in.) and therefore are less dependent on strong upwelling or intragravel flows to maintain development. Additionally, grayling occasionally spawn over silt substrates. Thus, for grayling it appears that larger substrate is more restrictive than smaller substrate, since material larger than 1.5 in. is not used for spawning

(Krueger 1981). The optimal substrate size for grayling spawning appears to be pea-size gravel.

C. Incubation

The incubation period for grayling normally lasts from 2 to 3 weeks (Morrow 1980), during which time the developing embryos are susceptible to habitat disruptions. Flooding, associated with spring breakup, may wash embryos downstream since the embryos are covered by only a thin layer of substrate. Velocities that cause bedload movement would likely be sufficient to dislodge embryos downstream.

The siltation of grayling spawning areas during embryo incubation should be prevented. A heavy silt layer (greater than 2 in.) covering incubating embryos can cause mortalities due to reduction in the supply of oxygen to the embryos and reduction in the removal of metabolic wastes.

D. Juvenile and Adult Rearing

Habitat characteristics for juvenile and adult grayling in Alaska have been addressed by Krueger (1981) and Aquatic Environments Incorporated (1984).

After fry emergence, young-of-the-year grayling seek out areas of low velocities along the stream margins and in backwater areas. As young-of-the-year fish grow larger and become stronger swimmers, they move into slightly higher velocities where food availability from drifting aquatic organisms is higher. Juvenile grayling use velocities ranging from 0.0 to 2.0 fps. Preferred velocities are probably less than 1.0 fps.

Juvenile grayling utilize a wide range of depths, from 0.2 to 10 ft, and are more commonly associated with depths between 0.5 and 4.0 ft. Newly emergent fry typically are found in shallow, low-velocity areas along stream margins and in backwater areas. Larger juvenile grayling tend to occupy slightly deeper, higher-velocity areas.

Juvenile and adult grayling are sight-feeding fish, primarily on aquatic and terrestrial insects. Therefore, they are dependent on clear water for active feeding and growth. While grayling are known to migrate in turbid rivers, they normally do not remain in these rivers. Instead, grayling are generally found in clearwater or tannin-stained streams where aquatic insect production and sight-feeding responses are improved.

Cover is an important component of rearing habitat for juvenile and adult grayling. Log debris, overhanging riparian vegetation, undercut banks, and substrate (>1 in. diameter) are commonly used cover objects. Cover functions in two important ways for grayling: to protect fish from predators and, in the case of substrate and debris, provide resting places from high velocities. In some instances, overhanging riparian vegetation becomes an important source of terrestrial insects.

E. Overwintering

Grayling overwinter in the deeper pools of rivers and in lakes. In smaller tributaries, there is usually a fall migration from small streams into larger rivers and lakes. Thus, passage requirements should be considered for a fall migration to overwintering areas as well as a spring-spawning migration.

Overwintering habitat has not been fully defined. In streams, adequate depths (>3.0 ft) to maintain living space under an ice cover and velocities to maintain sufficient dissolved oxygen concentrations are required. Velocities less than 1.0 fps are usually preferred, so that overwintering fish can maintain their positions in the stream. Substrate (>5 in. diameter) can provide important resting places for overwintering fish.

9.4 HABITAT DESIGN FOR FISH STREAMS

Rehabilitation of streams containing fish should be undertaken with adequate care and forethought to produce the desired effect of replacing lost fish habitat. Although stream rehabilitation follows the cessation of the mining operation, proper planning before and during mining will insure that rehabilitation will be accomplished in a cost-efficient, effective manner.

For example, materials to be used during rehabilitation should be properly stockpiled and located during the mining operation (Chapter 6.0). This will minimize the amount of material handling during rehabilitation.

Stream rehabilitation focuses on the habitat components that the miner can control or strongly influence: channel structure and water quality (refer to Figure 37). Habitat rehabilitation is achieved through designing or modifying the factors associated with the river-channel component. Habitat designs discussed below for each stream pattern recommend modifications of channel structure to create specific desirable habitat features. Channel-structure modification creates habitat features such as pool-riffle sequences, cover, spawning substrates, and resting areas. Channel structure provides fish passage and rearing habitat.

Placer mining influences the water quality component through introduction of sediments, toxic metals, and potentially through the introduction of fuels (Bjerklie and La Perriere 1985, La Perriere et al. 1985). With respect to this habitat component, rehabilitation focuses on avoiding habitat degradation. Beyond these 3 factors, the miner has little ability to alter the water quality characteristics of a basin. By following the recommendation for control of nonpoint-source pollution (Chapter 3.0), and careful handling of fuel and other toxic materials including pond sediments containing adsorbed metals (Section 2.2.1), water quality should be similar to pre-mined conditions.

Design of channel structure (Chapter 8.0) is used to influence depth and velocity, factors associated with the streamflow component of habitat. Since the cross-sectional area and slope of the channel dictate the distribution of depths and velocities for a given flow, channel design is used to increase the diversity of depths and velocities in the rehabilitated stream. Depth and velocity change with stream discharge and the stream discharge will vary seasonally in response to climatic and precipitation patterns. Even though the miner has no influence over the stream discharge, the channel can be designed to function at both high and low flows. By designing for diversity, suitable habitat conditions are present over a variety of flows.

Channel structure can also influence biological factors, particularly food production. The diversity and abundance of fish food organisms, aquatic and terrestrial invertebrates, is influenced by channel structure and vegetation, as well as water quality. Constructing riffles from gravels or cobbles with low levels of fine particles will encourage aquatic food production. Promoting streamside riparian vegetation will increase the number of terrestrial insects available to fish. Areas near pools are the first priority for revegetation in fish streams (see Section 10.3). Although channel structure and erosion control can influence food availability, they do not directly influence the presence or absence of competitors and predators. The development of adequate cover can increase fish survival by reducing the effectiveness of predation. The creation of habitat diversity may promote coexistance of competing species by allowing alternate habitat selection.

Habitat diversity is a key element in successful rehabilitation and often a notable failing in mined streams without habitat restoration. After being mined to bedrock, the stream channel usually lacks substrates suitable for food production, cover, or spawning. The steep-gradient, high-velocity environment normally left affords little opportunity for rearing. Providing a diversity of habitat conditions is accomplished through construction of an undulating streambed with a variety of substrate types. Adding stream-stabilization structures to enhance the perpetuation of pools and presence of cover are the major elements of habitat rehabilitation.

Rehabilitation for fish use should focus initially on fish passage since it provides fish access to habitats within and upstream from the stream reach of the mine site. Passage requirements for fish are based primarily on depth and velocity criteria (Section 9.3). These should be considered in the hydraulic design of the restructured channel at a mean annual flow (Section 8.2).

Once passage conditions have been addressed, various channel structures or modifications to promote rearing habitat should be evaluated. Channel structures and modifications should be selected based on the stream type (meandering, mountain, or braided) and specific site conditions. The goal in rearing-habitat restoration is to provide good water quality (low turbidity and suspended-sediment levels) and a diversity of pool, riffle, and run habitats that encompass a variety of depths, velocities, and substrates.

Fish cover should also be incorporated in the design. The rehabilitation of rearing habitat usually requires a higher degree of complexity in channel design compared to simply providing passage conditions, and will necessitate more time and care. Various channel structures and modifications that promote rearing are presented in the sections on habitat design by river type.

The restoration of spawning habitat, particularly for salmon, is a complex undertaking that may require considerable biological and hydraulic engineering. Spawning may occur in the rehabilitated stream reach if the channel is rebuilt with a variety of riffle, run, and pool habitats that have suitable depths, velocities, and substrates (see spawning criteria in Sections 9.3.1 and 9.3.2).

Stream systems are dynamic, changing with fluctuating streamflows. Hence, channel modifications and structures should be designed and operable for a range of hydraulic conditions, including both flood and low flows. Even where structures and modifications have been implemented with changing streamflows in mind, the habitats created will be somewhat transitory over the range of natural streamflows, resulting in a range and diversity of habitats.

9.4.1 Meandering Streams

In the rehabilitation of a meandering stream, it is desirable to maintain or promote the original channel sinuosity (meander pattern) to maintain habitat diversity (Hardy Associates, Ltd. 1982). The channel design of an altered meandering stream was described in detail in Section 8.4.

Passage requirements for fish (Sections 9.3.1 and 9.3.2) should be evaluated in the rehabilitation of an altered channel at a mean annual flow (Section 8.2). Depths and velocities must be within an acceptable range so that fish can utilize habitats available within the mine site, and upstream of the mine. Thus, passage requirements should be included during the channel-design phase of stream rehabilitation.

Once the stream channel has been designed for fish passage, stream modifications can be added to promote rearing habitat in a meandering stream. Wing deflectors are designed to enlarge pools on the opposite bank in the river (Fisheries and Oceans 1980, U.S. Department of Transportation 1979). These structures are often constructed in sequence down a river channel to maintain the normal meander pattern. Because the wing deflector guides and concentrates the flow, pools and banks on bends will become deeper and more steep, respectively. This will create more rearing habitat in the stream for fish. A wing deflector is considered to be one of the best all-around devices for improving fish habitat (White and Brynildson 1967). A typical wing deflector is shown in plan view and cross-section profile in Figure 40.

Fisheries and Oceans (1980) recommend the following guidelines for using wing deflectors:

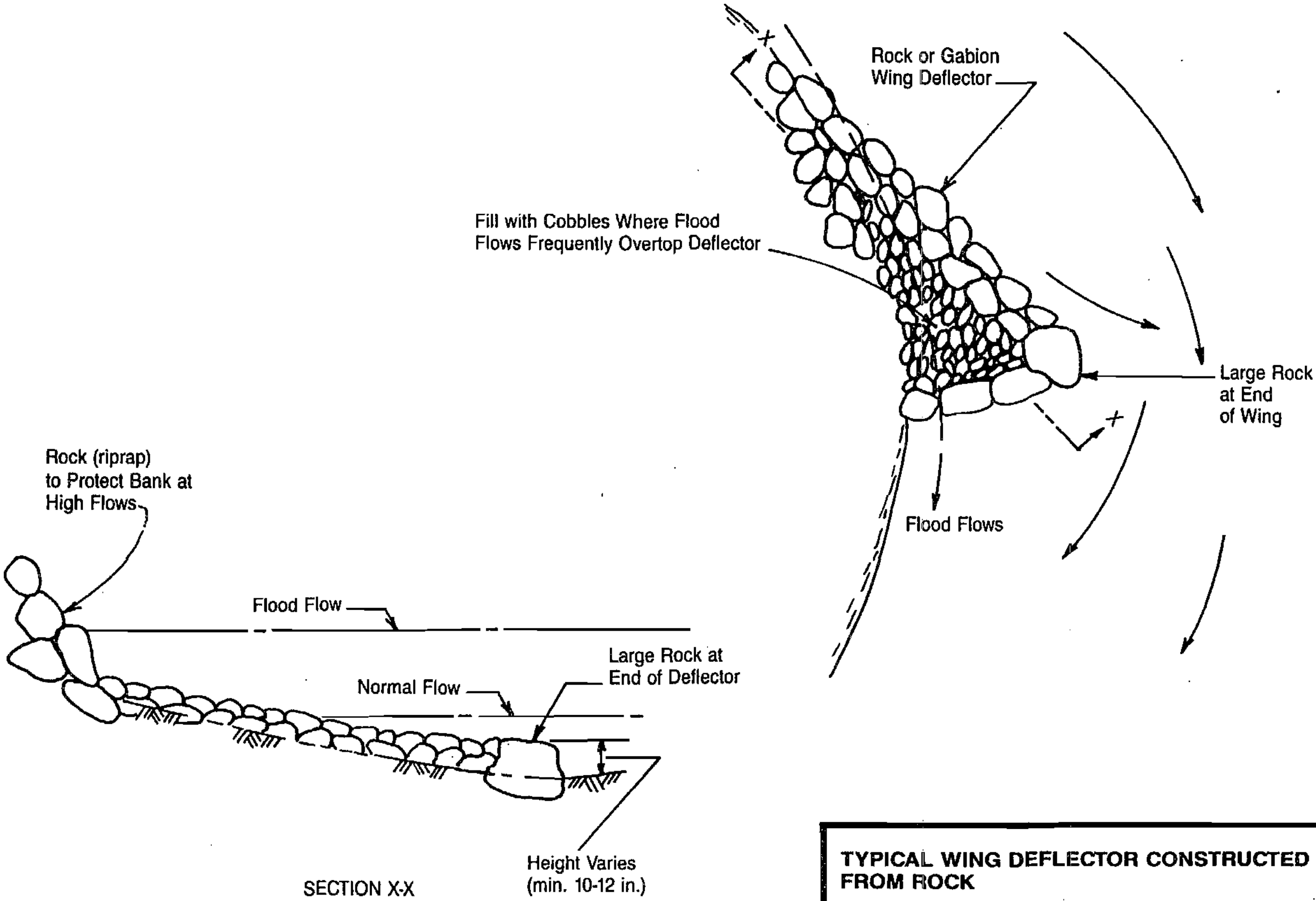
(1) Boulders are the best material to use for the construction of wing deflectors. Rocks should normally be larger than 2 ft in diameter, but size depends on site-specific characteristics. Rocks should be of sufficient size to avoid downstream displacement during normal flood flows.

(2) The point of connection, where the wing deflector is attached to the river bank, must be protected with riprap (Section 8.5.3) of sufficient height to prevent erosion around the end of the deflector (Figure 40).

(3) Locate the deflector toward the lower end of a riffle, so that it will not impound water upstream.

(4) Deflectors should be positioned at an angle of 45° or less in relation to the stream bank.

(5) The height of the deflector should be set so that the deflector slopes downward into the channel and is sufficiently low to pass logs and debris during flood flows (Figure 40).



Source: Fisheries and Oceans 1980

TYPICAL WING DEFLECTOR CONSTRUCTED FROM ROCK

ENTRIX	**Figure 40**

(6) To minimize undermining at the base of the deflector, use two rows of rocks with the joints staggered. The second row should be set into the river bed so that the top of the second row is lower than the first.

(7) The deflector should be triangular in shape (Figure 40).

(8) The bank opposite the deflector should be protected with riprap to prevent erosion.

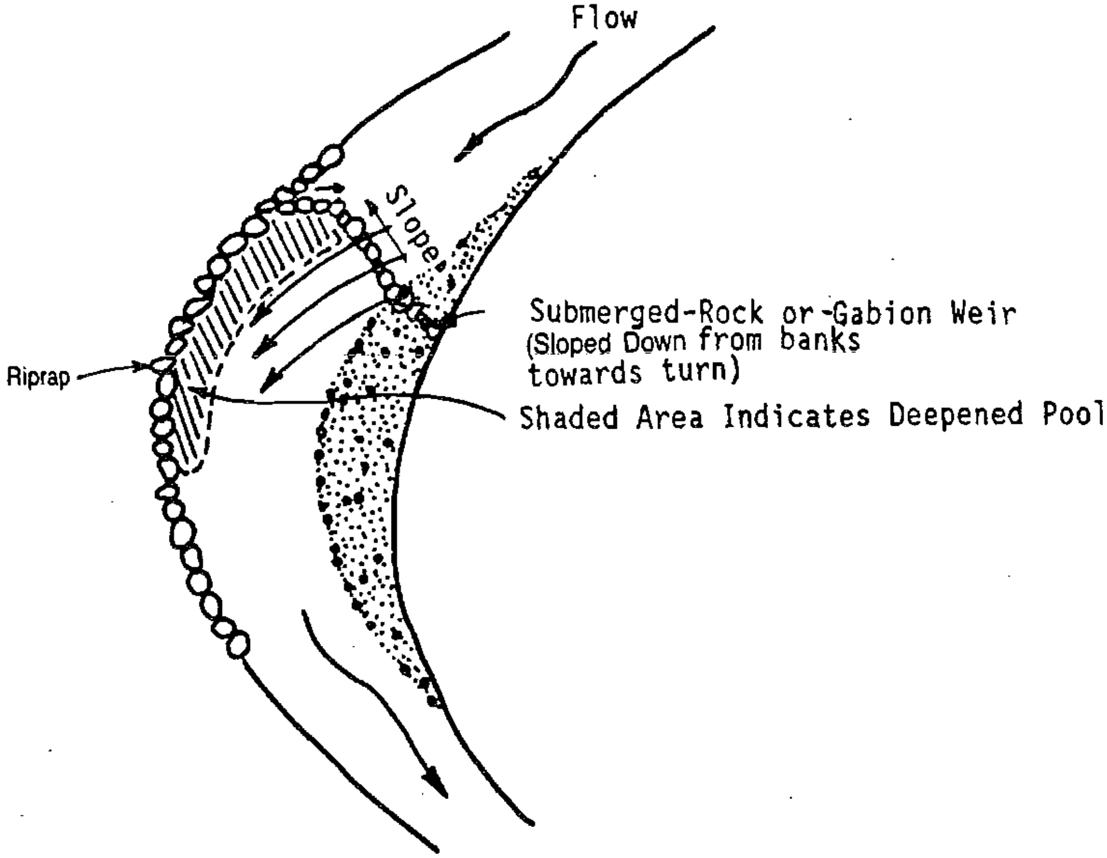
(9) Pre-excavation of the intended pool or run is required to help the natural erosion process.

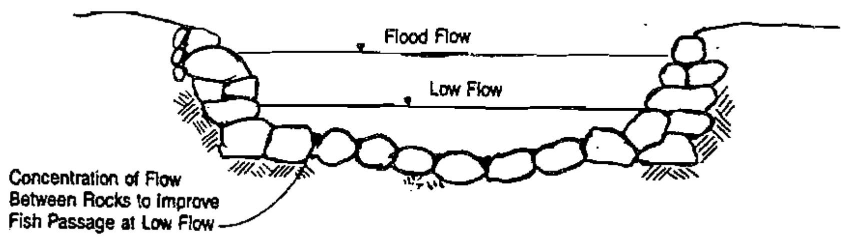
In some situations an inclined submerged-rock weir may be preferable to the wing deflector. The submerged-rock weir functions similarly to the wing deflector. It concentrates and guides the streamflow to deepen runs or pools (Figure 41). The inclined submerged-rock weir is often used in steep-gradient, high-velocity streams (Fisheries and Oceans 1980) (see discussion under mountain stream, Section 9.4.2).

Like wing deflectors, submerged-rock weirs are constructed of boulders and are located at the lower end of a riffle or run. The weir can be either straight across the stream, angled, or bent depending on local conditions and desired scour pattern. The weir is sloped down toward the deep part of the cross section or toward the outside bank to direct flow in that direction.

Fish cover is an important component of rearing habitat (Section 9.3). In many situations, the natural stream cover (riparian vegetation, debris, deadfalls, boulders) is removed during the mining operation. Thus, during stream rehabilitation the provision for fish cover will need to be evaluated on a site-specific basis.

There are various methods to provide fish cover during stream rehabilitation. A log and riprap structure is one way to create overhanging bank cover (Figure 42). Submerged logs are lashed together and carefully held in place by rocks,





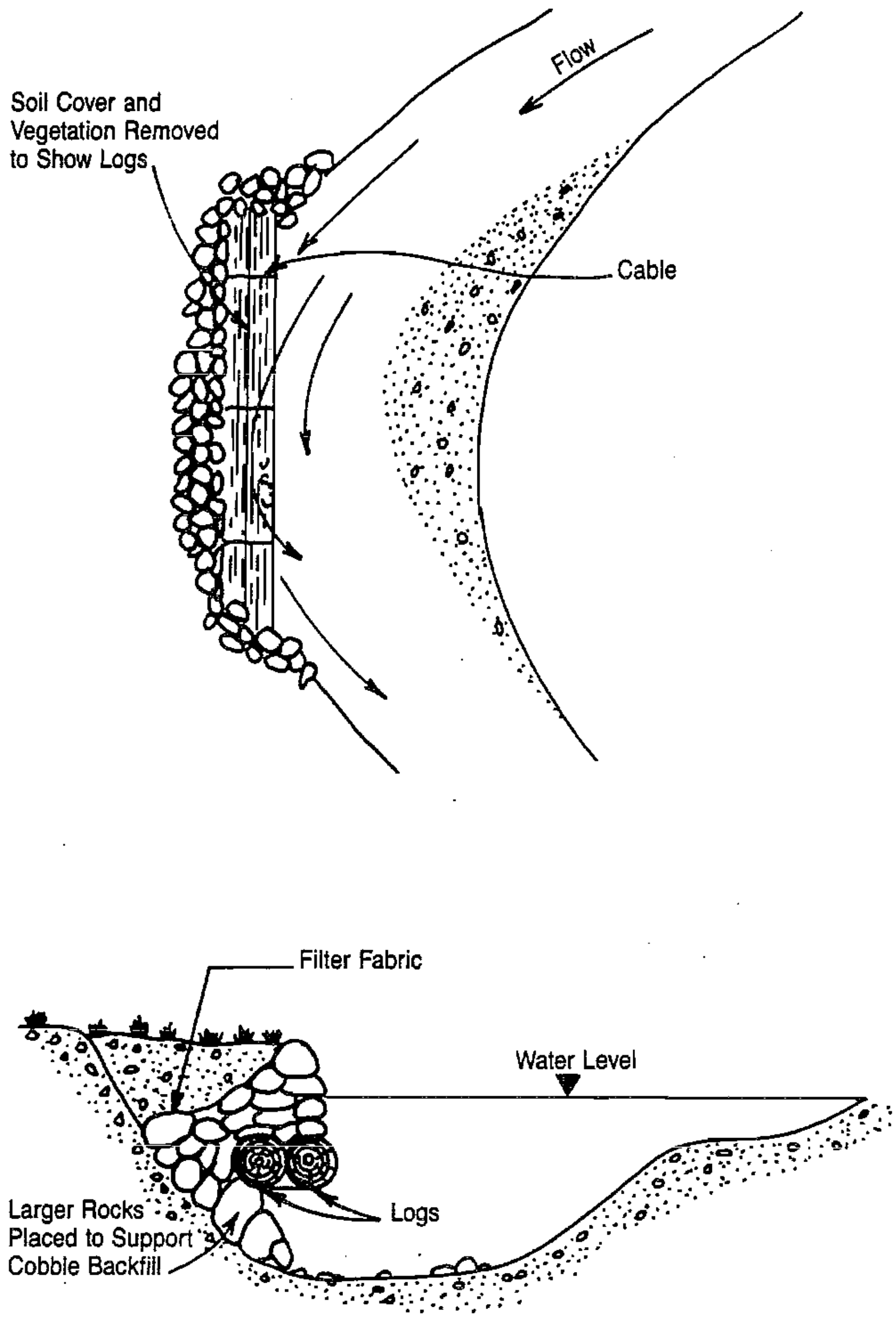
CROSS SECTION OF
STREAM CHANNEL
(looking upstream)

Adapted from Fisheries and Oceans, 1980.

SUBMERGED-ROCK WEIR

ENTRIX

Figure 41



BANK OVERHANG COVER FOR A SHARP BEND IN A STREAM

Source: Fisheries and Oceans 1980

ENTRIX

Figure 42

cobbles, and vegetation. This will create rearing habitat on a sharp bend in a river.

Another method of providing cover to improve rearing habitat is to anchor trees, large branches, or root wads to the stream bank (Figure 43). The following guidelines will aid in developing functional cover for fish from trees (Fisheries and Oceans 1980):

(1) Cover should be incorporated with other stream modifications such as boulder groupings, overhanging bank cover, riprap opposite wing deflectors, and other structures.

(2) Anchor trees to avoid damming the flow (Figure 43). Trees can be anchored with cable to a stake or to buried logs.

(3) When anchoring root wads, approximately 10 ft of the butt should be buried in the stream bank and positioned so that the root wad angles downstream.

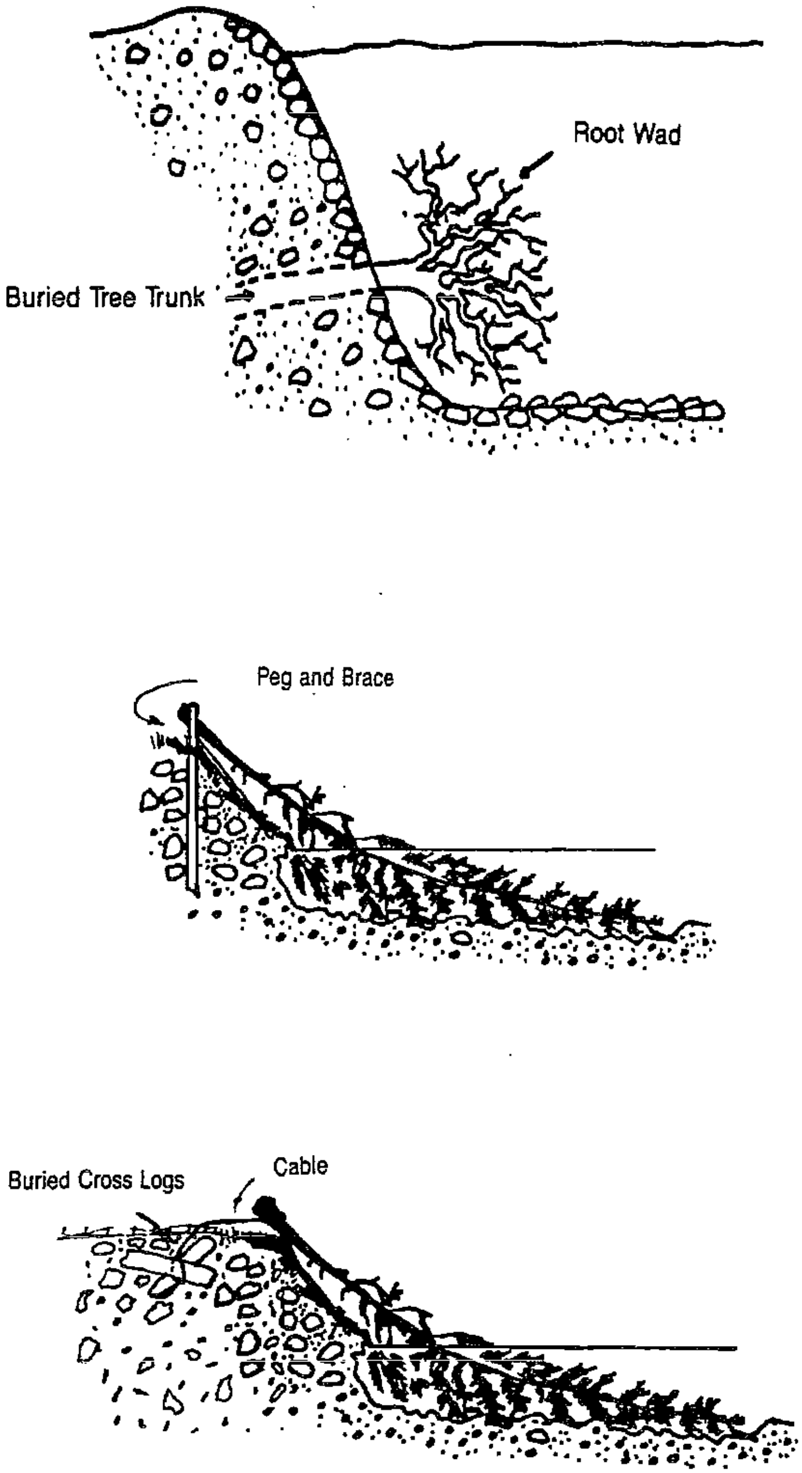
(4) To avoid snagging debris on anchoring systems, anchor tree butts above the high water line (Figure 43).

(5) When entire trees are used, branches should trail downstream with the tree butt anchored to the stream bank.

(6) Trees, large branches, and floating logs anchored along the stream bank must drag parallel to the flow (Figure 43).

(7) Cut trees, branches and floating logs have limited life due to decay and physical damage. In Alaska, birch or spruce is preferred. Alder, cottonwood and aspen should be avoided.

Fish cover can be created by carefully placing a large rock or boulder in the stream (Figure 44). This is one of the most simple and effective means of improving rearing habitat. A pool is usually scoured out on the downstream side of the boulder during high streamflows when water spills over the



Adapted from White and Brynildson 1967

TREES AND ROOT WAD

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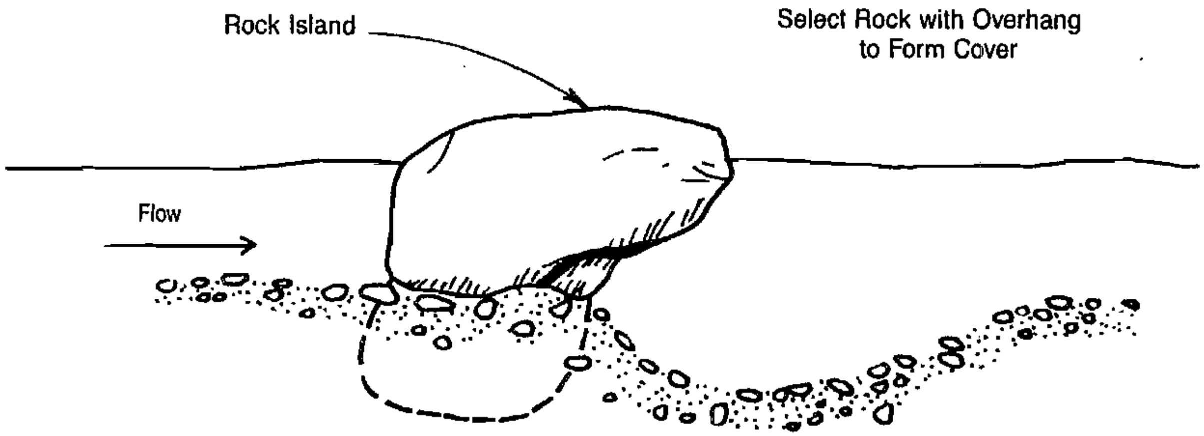
FIGURE 43



Source: Fisheries and Oceans 1980

A LARGE ROCK ISLAND FORMING A POOL WITH COVER

ENTRIX | **Figure 44**

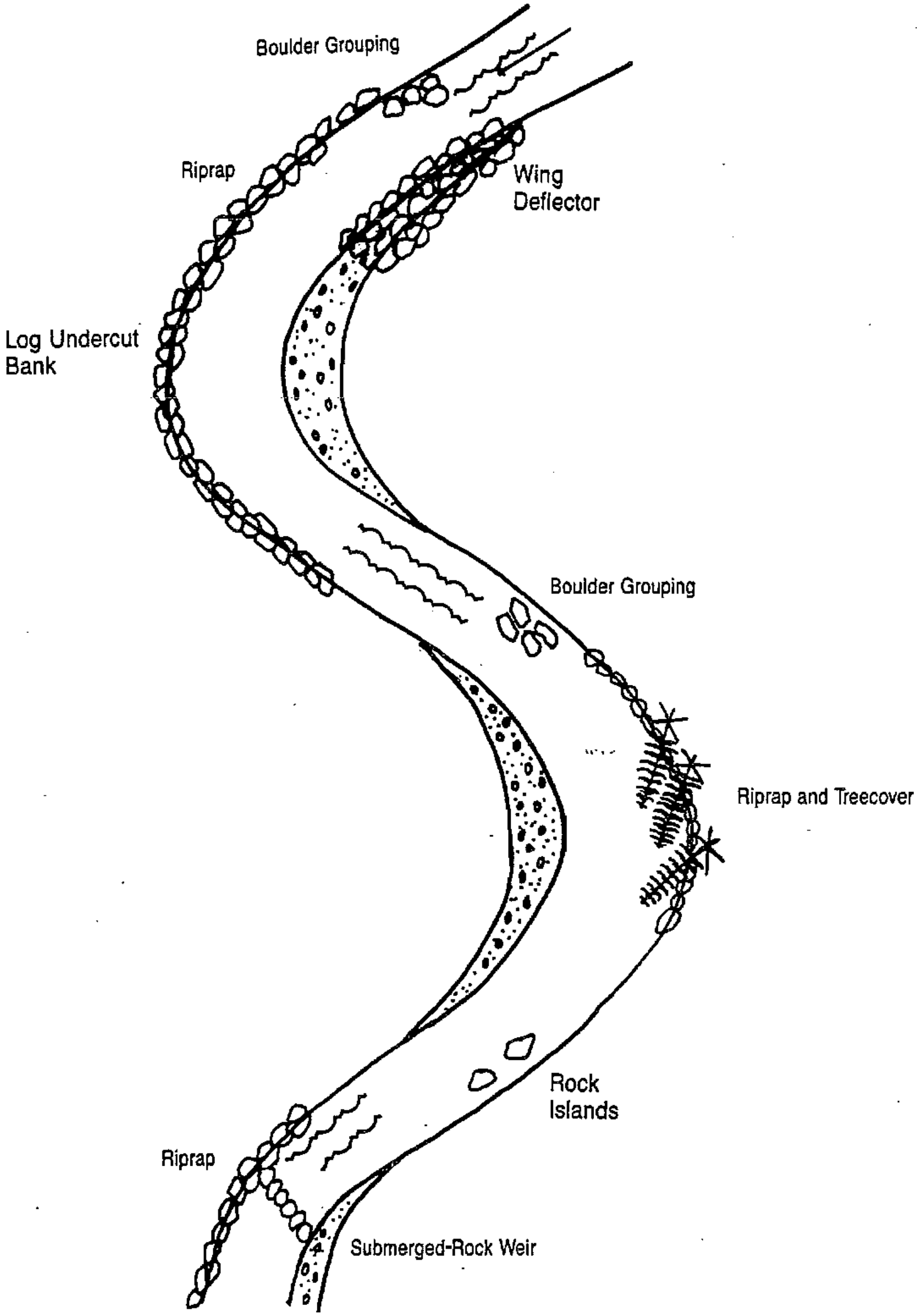
boulder. The scour pool provides a resting place for fish and protection from predators. Boulders screened during mining can be used to create rock islands. A 3- to 4-ft diameter boulder, or the largest available, should be used. While the overhanging rock depicted in Figure 44 is desirable, rocks with no overhang are also effective. The boulder should be set into the river bed with the overhang positioned downstream. Boulders are most effective when placed near the upstream end of a shallow pool or run, or in the middle and downstream portions of riffles (Fisheries and Oceans 1980, U.S. Department of Transportation 1979). Careful pre-exacavation of the intended scour pool will speed the natural erosion process.

After stream modifications and structures similar to the ones described above are in place, the restored stream reach will provide improved rearing habitat for fish. Figure 45 shows some of the suggested habitat features in a rehabilitated meandering stream. Guidelines for spacing habitat features were presented in Section 9.1.

If a stream reach is designed and implemented with care, incorporating recommended pool/riffle ratios (Section 8.4.1), spawning may occur within the reach of rehabilitated stream at the downstream ends of riffles and upstream ends of pools. The placement of small to large gravels (1 to 5 in. diameter) at these locations will provide suitable spawning substrate for salmon, while smaller sized gravels and sands (0.1 to 1.5 in. diameter) should be provided for grayling (Sections 9.3.1 and 9.3.2). The normal split in classification of screened materials by a washplant occurs at 0.5 to 0.75 in. The smaller materials should be used for grayling spawning while the larger sizes should be used in salmon spawning areas. Some larger material (up to 10-in. diameter) will not greatly diminish the usefulness of the substrate for spawning. However, substrates that contain predominantly large materials (10-in. diameter or greater) should be avoided in areas where spawning is desired.

9.4.2 Mountain Streams

Mountain streams are high-gradient streams that usually have straight channels with little meandering or channel sinuosity. Because of the steep gradient



Adapted from Fisheries and Oceans, 1980.

STREAM-HABITAT FEATURES FOR REHABILITATION OF A MEANDERING STREAM

ENTRIX

Figure 45

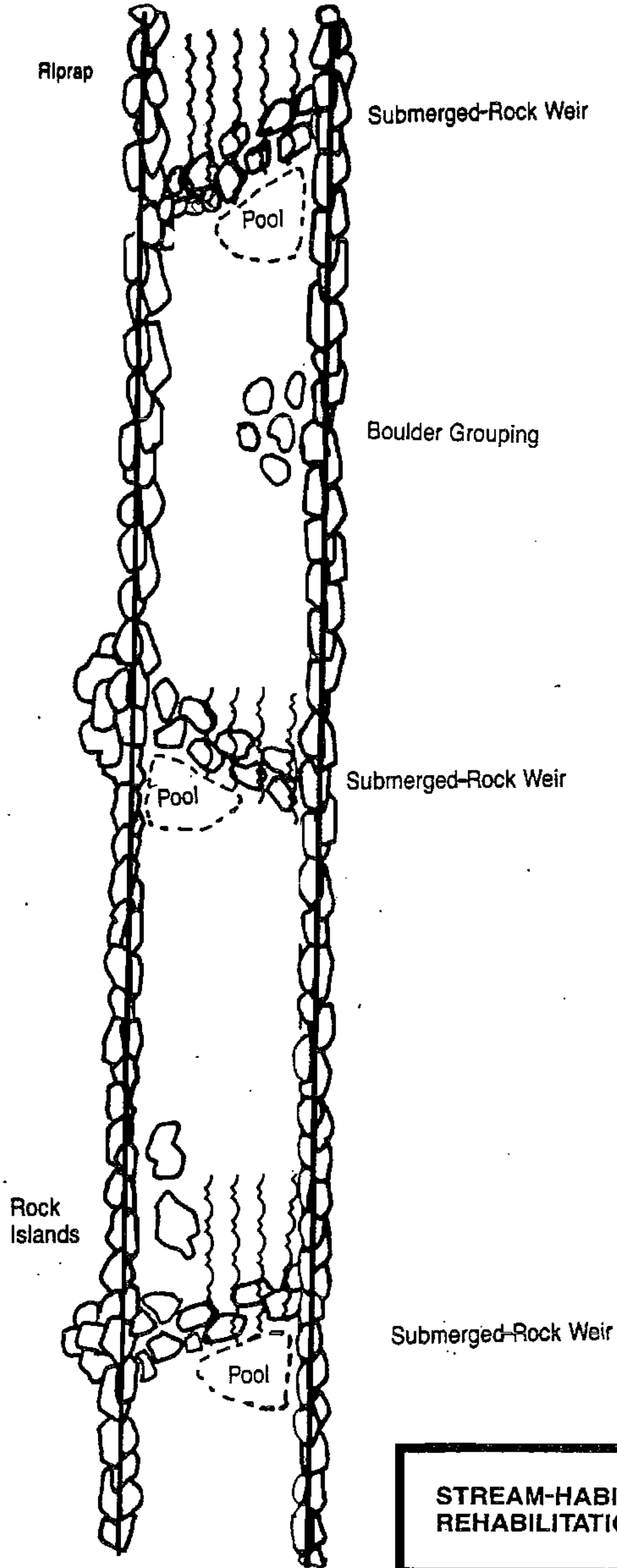
and relatively straight channel, velocities in mountain streams tend to be high. Riffles and runs are the dominant habitats, while pool habitat is often scarce. Thus, the goal of stream restoration for fish use in mountain streams is to avoid a uniform, straight-channel stream that has little or no structural diversity (i.e., boulders, pool/riffle configuration) and resembles a drainage ditch. Instead, channel structures and modifications that create habitat diversity should be emphasized (Hardy Associates, Ltd. 1982).

As previously mentioned, fish-passage requirements should be evaluated at a mean annual flow during the hydraulic design phase of the stream rehabilitation (Section 8.2). In mountain streams, care must be taken to avoid waterfalls or cascades that will prevent the upstream movement of fish.

After passage requirements have been incorporated in the stream design, rearing habitat should be evaluated. Two relatively simple channel modifications can greatly add to the habitat diversity and provide rearing habitat for fish in mountain streams. They are the boulder grouping or rock island and the submerged-rock weir.

If properly sized and placed, boulders can provide cover and velocity breaks (small pockets or pools) important for juvenile anadromous and juvenile and adult resident fish. Boulders can be placed either singly or in carefully spaced groupings. In general, boulders should be 3 to 4 ft in diameter. Another method of sizing is to use the larger boulders that were separated during the mining operation. This will insure that boulders are not washed downstream by flood events.

Boulders are best placed near the upstream end of a shallow pool or run, or in the middle and downstream portions of riffles (Fisheries and Oceans 1980, U.S. Department of Transportation 1979). If boulders are placed in groupings of 2, 3, or 4, they should normally be positioned 5 to 10 ft apart to avoid deposition of bedload materials or debris in between the boulders. However in steep-gradient streams, where deposition is less likely due to high velocities, they can be grouped closer. Boulder groupings can be repeated down the length of riffles in larger streams. Figure 46 shows a boulder placement, with a pool forming on the downstream side of the rock island.



STREAM-HABITAT FEATURES FOR REHABILITATION OF A MOUNTAIN STREAM

ENTRIX | FIGURE 46

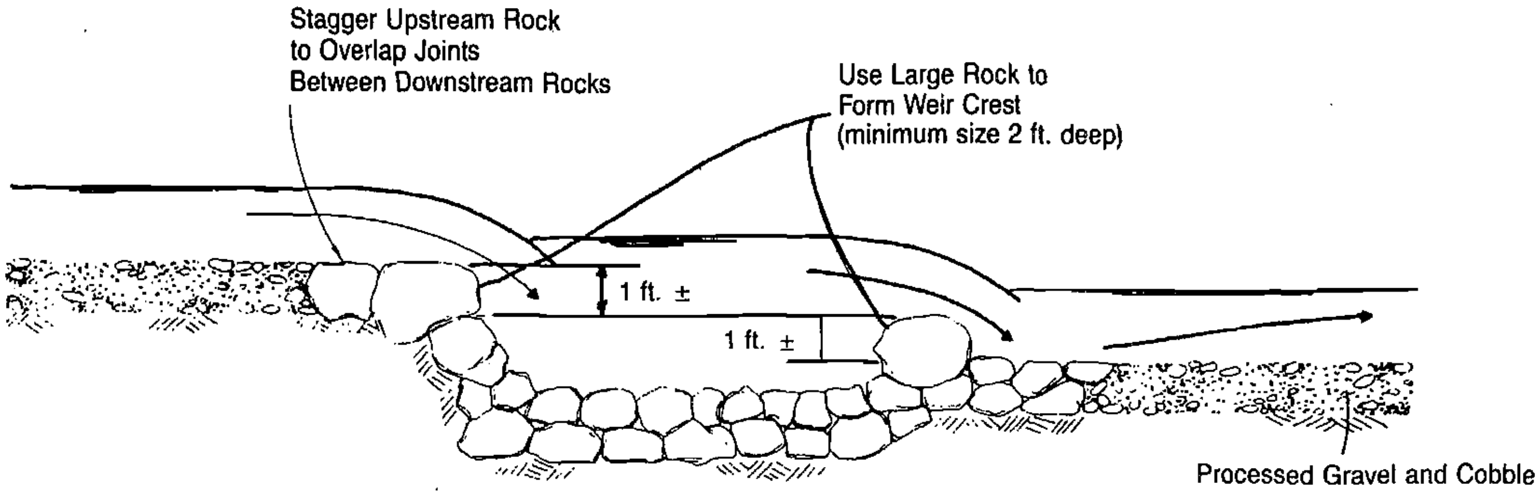
The double-step submerged-rock weir is an effective modification for steep-gradient, high-velocity streams (Fisheries and Oceans 1980; White and Brynildson 1967). This structure is designed to reduce velocities and increase depths by creating small plunge pools on the downstream side of the weir. Reduced velocities and more pool habitat will increase the amount of rearing habitat in mountain streams. Fish passage is maintained where the streamflow is concentrated between rocks.

The ends of the rock weir that abut the stream bank must be riprapped (Section 8.5.3) to a sufficient height to prevent flood flows from eroding around the ends of the weir. A height of 2 ft above the high water mark should suffice. The rocks chosen for the weir should be flat or slightly rounded on their top sides so that the crest of the weir is relatively flat. Rocks should be sized using the bed- and bank-stabilization criteria (Section 9.5) so that they will not wash downstream at high flows. Spacing of the rocks must be sufficient to allow fish passage at low flows. A cross-section of a rock weir in Figure 47 illustrates these concepts. Where the stream gradient is particularly steep, a double-step rock weir can be used (Figure 47). Weirs can be placed straight across a stream channel, or angled downstream as shown in Figure 46.

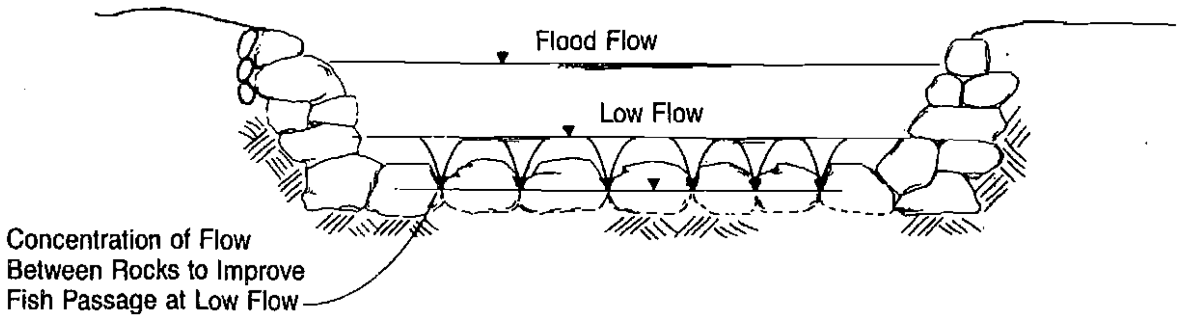
Spawning may occur if gravels of suitable size are placed in the downstream end of riffles and at the head end of pools. Sections 9.3.1 and 9.3.2 discuss the range of substrate preferred by spawning fish. In general, small to large gravel (1- to 5-in. diameter) will suffice for spawning substrate. Refer to previous section for further details (Section 9.4.1).

9.4.3 Braided Streams

Braided streams often have unstable stream channels that shift within the floodplain over short time intervals. Stream modifications and structures used to enhance fish habitat are generally not recommended for this river type since the dynamic nature of the stream most likely will result in frequently altered channel locations and shapes (U.S. Department of Transportation 1979). Therefore, when rehabilitating a braided stream for fish use, it is best to design for fish passage, and avoid stream modifications for rearing or spawning that may quickly become ineffective.



PROFILE OF DOUBLE-STEP WEIR



CROSS SECTION OF
STREAM CHANNEL
(looking upstream)

Source: Fisheries and Oceans 1980

ROCK USED TO CONTROL GRADE IN A CHANNEL

ENTRIX | **Figure 47**

Fish passage criteria for resident and anadromous fish were presented in Sections 9.3.1 and 9.3.2. Depth and velocity are usually the two important factors to consider when providing fish passage. If the stream channel affected by mining is restored to a gradient and channel structure with a configuration similar to pre-mined conditions, passage requirements will usually be met. However, passage requirements should be considered in the hydraulic design of an altered stream channel to ensure that fish will continue to have access to upstream habitats and will have free movement in the river (Section 8.2).

FLOODPLAIN REHABILITATION

10.0
FLOODPLAIN REHABILITATION

10.1 OBJECTIVES AND SCOPE

Floodplain rehabilitation is the final phase of placer-mine site closure. The primary goal of rehabilitation is to return the floodplain to a condition that promotes rapid recovery to pre-development conditions (Berry 1974). This process is begun through stabilization of floodplain materials, the establishment of natural vegetative communities, and the enhancement of vegetative recovery (Dick 1974). Complete short-term rehabilitation of the floodplain is not expected to be accomplished by performing the procedures outlined in the following sections. Instead, these techniques are designed to enhance natural recovery. Without enhancement, a floodplain may not be fully recovered even after 100 years (Hardy Associates 1978; Crocker and Dickson 1957). Use of the prescribed rehabilitation techniques can accelerate recovery so that the floodplain is returned to pre-disturbance condition in 20 to 50 years with significant vegetative recovery often noted within the first 5 to 10 years (Joyce 1980, Johnson 1981).

Wildlife species adapted to early and mid-successional stages of floodplain vegetation are those most likely to receive short-term benefits from terrestrial rehabilitation. The big game species that will benefit most frequently is the moose. Terrestrial furbearers are usually associated with mature forests and thus would not benefit from rehabilitation in the near term. Beaver might benefit from intermediate successional stages at rehabilitated sites. For most sites, elaborate manipulation of invading vegetative communities will not be indicated. Rehabilitated floodplains and uplands can be expected to support different fauna at each successional stage. At sites where specific migitation of habitat loss to benefit specific species is required by a resource management agency, it is recommended that more detailed references be examined and species experts be consulted during plan preparation.

Rehabilitation of the floodplain should be conducted in three phases: site grading, stockpile dispersement, and revegetation (Keller and Leroy 1975). Site grading is performed over the entire disturbed area, including adjacent to stream channels (riparian zone), in the inactive floodplain, on the valley terraces, and on the valley benches. Specific recommendations for slope, contour, and methods of stabilization vary for each of these zones. The second phase of floodplain rehabilitation is stockpile dispersement. Since organic stockpiled material may be present in insufficient quantities to cover the entire disturbed area, specific areas in each zone should be selected to receive organic material. At sites where organic material is not available, and large stockpiles of fine organic material (loess) or settling pond deposits are present, these inorganics may be used in place of the organics. The selection of these sites is based on providing maximum habitat value for fish and wildlife (Morrison 1982). The third phase of rehabilitation is revegetation. Techniques described for revegetation are designed to enhance and expedite natural recovery of floodplain species. This can be accomplished by several methods, including broadcasting woody debris, planting viable portions of live shrubs (sprigging), transplanting live vegetation from areas adjacent to the disturbed area, and seeding (Dabbs et al. 1974, Johnson and Van Cleve 1976, Billings 1974, Saville 1972, Joyce 1980).

In addition to establishing vegetation, other techniques of wildlife habitat enhancement should be conducted. These include creating log piles by placing large, woody vegetation in strategically located sites to attract small birds and mammals, placement of tree trunks in the riparian zone to provide habitat for birds, and constructing small rock piles that are occasionally used by small mammals (Herricks 1982, Szafoni 1982).

10.2 SITE GRADING

The first task of floodplain rehabilitation is to grade the tailings piles to final slopes and contours. Much of this grading should have been done during operation of the site. The goal of site grading is to modify the topography of the site to reduce the potential for nonpoint-source pollution and prepare the floodplain materials for later revegetation (Leroy 1973). Although the goal is the same for all areas of the floodplain, different techniques should be employed in different zones of disturbance. Dimensions provided within these best management practices are guidelines that may need to be adjusted for the available quantity of materials.

Settling ponds should also be rehabilitated during site grading. Settling ponds in the active floodplain must have all sediments removed. Settling ponds in the inactive floodplain may be rehabilitated by excavation for use as fish habitat or if the sediments are required for revegetation. Settling ponds may also be stabilized by placing oversize material over the fine sediments and grading level with the surrounding topography.

10.2.1 Riparian Zone

The riparian zone is defined as the area within the active floodplain adjacent to active stream channels. The final grade of materials in the riparian zone is dictated by hydrologic and engineering constraints as well as the type of stream channel that has been designed. Sediments must be removed from all settling ponds located in the riparian zone. The settling-pond depression must be graded to conform to the surrounding topography.

The hydrologic and engineering constraints are controlled by the stream type within the site. Chapter 8.0 describes the reestablishment of an appropriate channel within the site. The channel should be located to avoid settling ponds if possible. If settling ponds are located within the riparian zone, special rehabilitation measures will be required as described in Sections 4.2 and 8.3.4. Following the design and selection of the stream-channel location, the remainder of the floodplain should be graded. The features that are developed by site grading are specific to the type of stream that has been established. However, all slopes should be graded to 3 horizontal to 1 vertical or less.

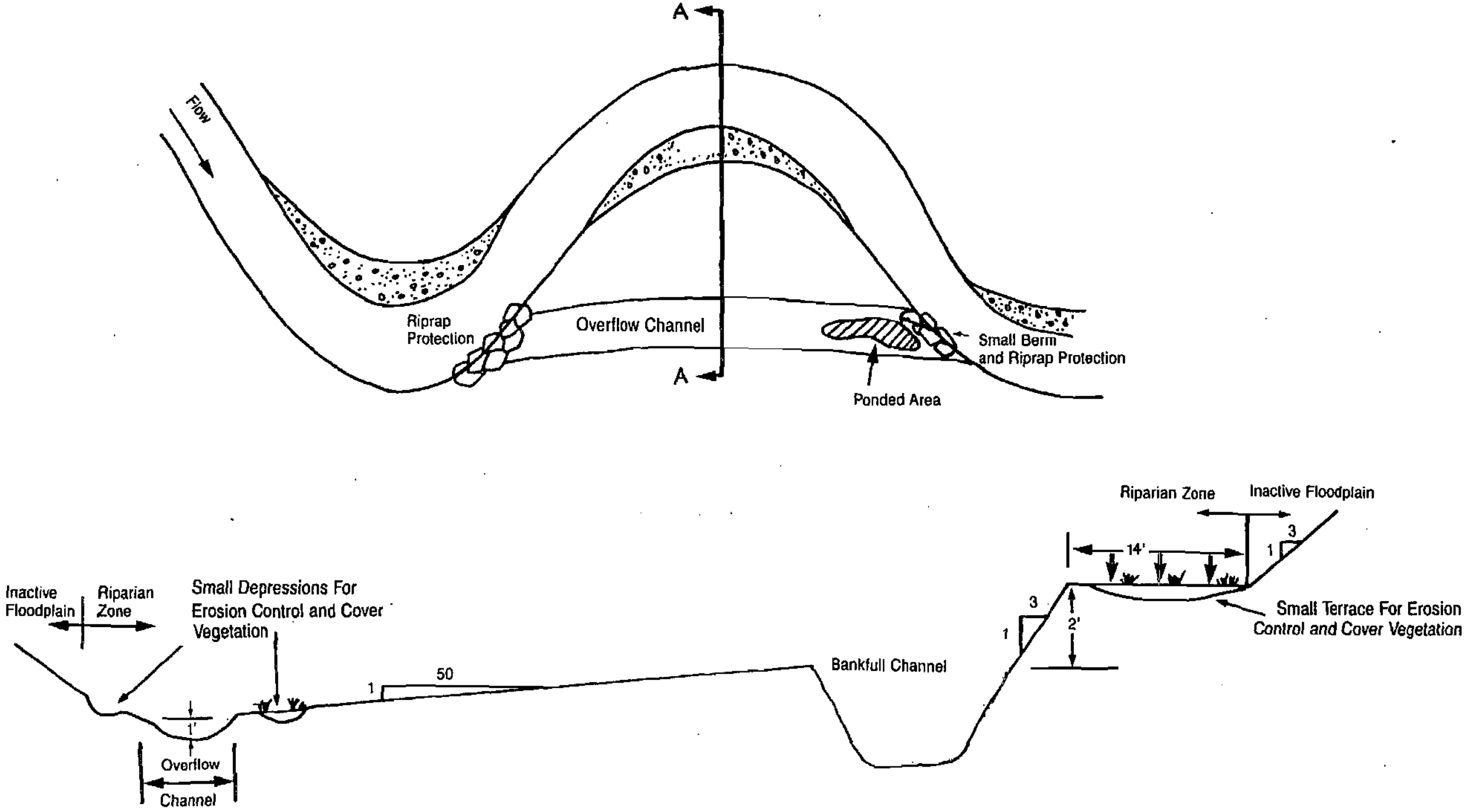
The final elevations of the floodplain materials to be established within a meandering stream should conform to the elevations established by the stream channel. For a meandering stream, the bankfull elevation may be used as a reference. On the inside of meanders, a grade of 50 to 1 (ADEC 1979), sloping away from the stream should be provided from the bankfull stream channel toward the valley wall. Although a grade of 50 to 1 is recommended, site constraints may require the use of a slope with maximum steepness of 10 to 1. The grade should commence at the bankfull elevation at the stream margin (Figure 48).

An overflow channel may be provided within a meander to carry flows greater than bankfull. Overflow channels would not be needed at each meander bend. The overflow channel must be designed and constructed with caution to minimize the potential for the channel to develop into a permanent cutoff. The overflow channel should connect the outside stream margins of the previous and subsequent meanders (Figure 48). The overflow channel should consist of a depression approximately 1 ft in depth and with a width of 12 ft or larger. Small depressions on either side of the overflow channel may be required if riparian vegetation is to be established at the channel margins. Riprap should be placed on a small berm at the upstream junction of the overflow channel to a level slightly less than the adjacent bank height.

A small berm should also be constructed at the downstream end of the overflow channel. The berm should be riprapped and have a total height slightly less than the adjacent bank. The berm will likely pond water within the overflow area (Figure 48). Natural overflow channels often contain ponded water in the downstream areas. The pond may encourage silt deposition and raise the groundwater table, which would promote revegetation.

On the outside of the meander, slopes should be graded to a maximum steepness of 3 to 1. A terrace should be provided at least 2 ft above the bankfull elevation on the outside bend to minimize runoff entering the stream and to promote development of riparian vegetation (Figure 48). The terrace should be at least 14 ft wide with a depression between 1 and 2 ft deep.

In a mountain stream, the size of the valley and the amount of tailing pile material to be graded will govern the final site topography. Terraces at bankfull level should be sloped away from the stream channel (Figure 49) to

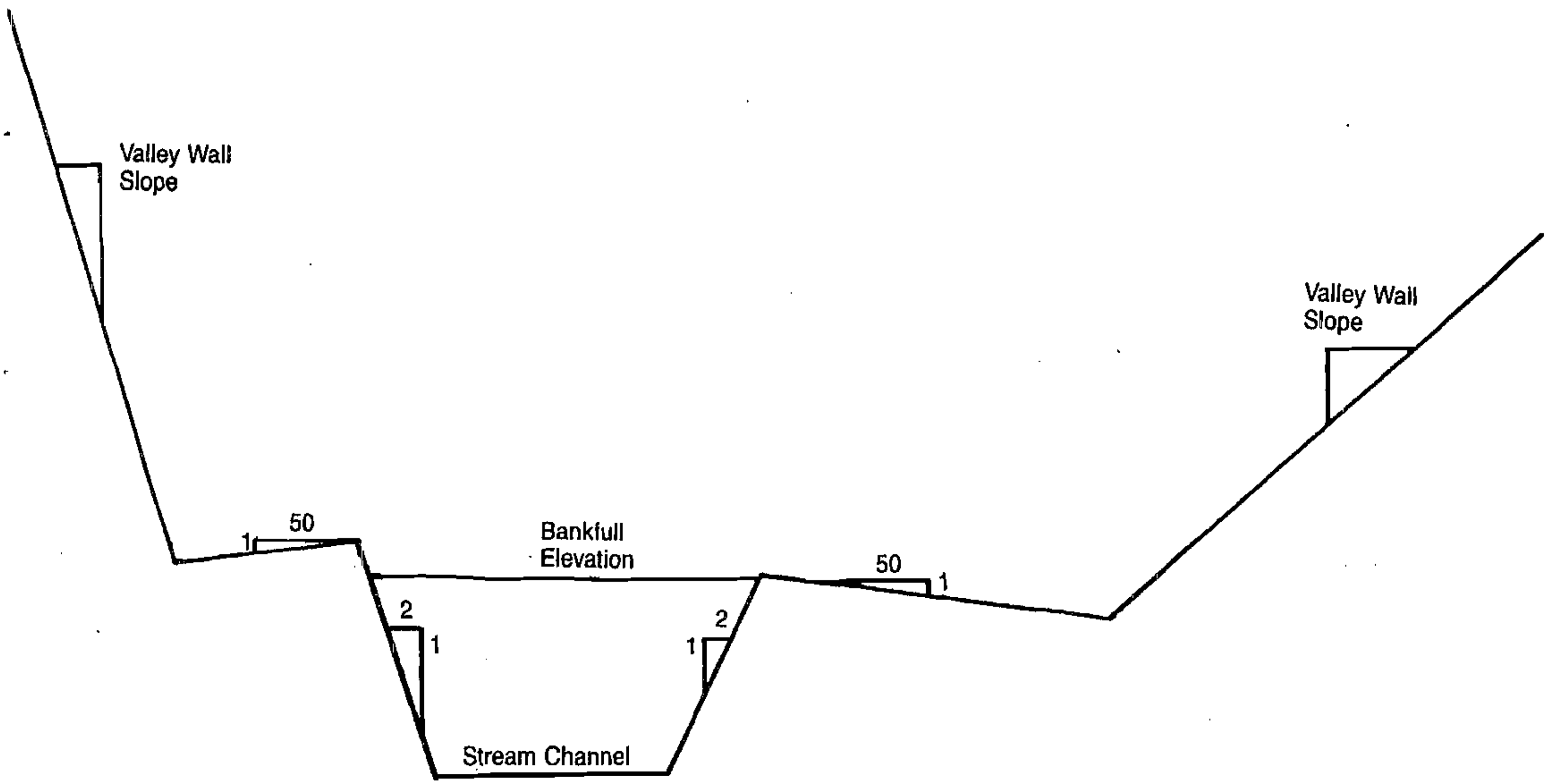


SECTION A-A

VERTICAL SCALE IS EXAGGERATED FOR ILLUSTRATIVE PURPOSES

OVERFLOW CHANNEL IN A MEANDERING STREAM

ENTRIX | **Figure 48**



VERTICAL SCALE IS EXAGGERATED FOR ILLUSTRATIVE PURPOSES

MOUNTAIN STREAM

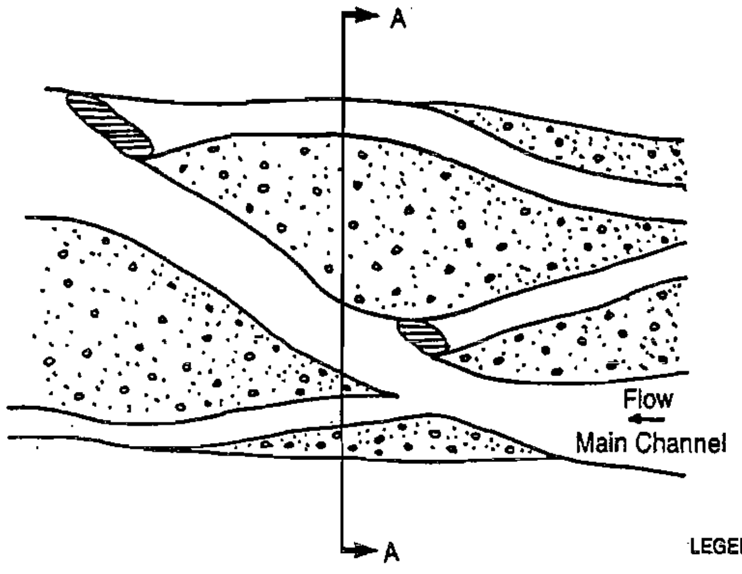
ENTRIX | **Figure 49**

control nonpoint-source pollution by collecting sediments. Terrace slopes should range between 10 to 1 and 50 to 1 (ADEC 1979). Terraces function as high-water channels for flows above bankfull.

The main channel in a braided stream should be designed to contain the bankfull flow with highwater channels available to discharge higher flows (Section 7.4.3). The highwater channels should be graded with undulating beds approximately 1 to 2 ft in depth and widths of 12 ft or more (Joyce et al. 1980). The channels should wind through the floodplain, occasionally rejoining the main channel. At the downstream junctions, small berms should be left in the highwater channels to slow water velocities (Figure 50).

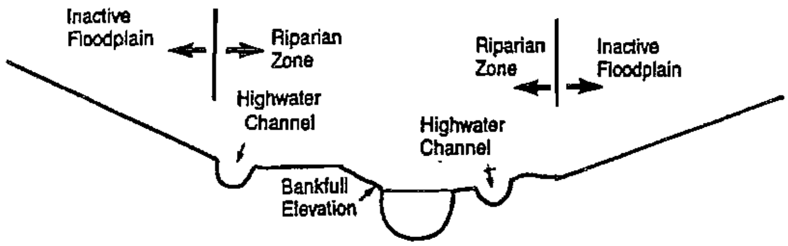
After the slopes and elevations of the riparian zone have been established for hydraulic design, additional grading may be necessary for areas where organic or inorganic material is to be placed. At some placer mining sites, the quantity of organic material available for distribution is limited. At these sites, organic material should be placed in areas that will provide the greatest benefit to fish and wildlife, whereas fine-inorganic material, when available, should be used in areas of lower priority. Placing organic material in the riparian zone puts the material at risk. A single high flow event could wash the material away before vegetation has a chance to become established. However, the potential benefits of riparian vegetation to fish and wildlife communities make the risk acceptable with proper hydraulic design.

To minimize the chances of organic material being removed during a high flow event, protective devices should be installed in the riparian zone at all locations where organic material is to be placed. Protective devices can be any object or material capable of remaining in place when subjected to moderate flows. Materials could include tree stumps, tree trunks, and large rocks. The material should be placed in the riparian zone, perpendicular to the flow and downstream of the site where organic material is to be placed. These devices will reduce the amount of material lost if a moderate flow event occurs. Under more extreme flood conditions, it is likely that the barriers and the organic material may be lost; however, as stated, the value of a newly created vegetated riparian zone to fish and wildlife is worth the potential

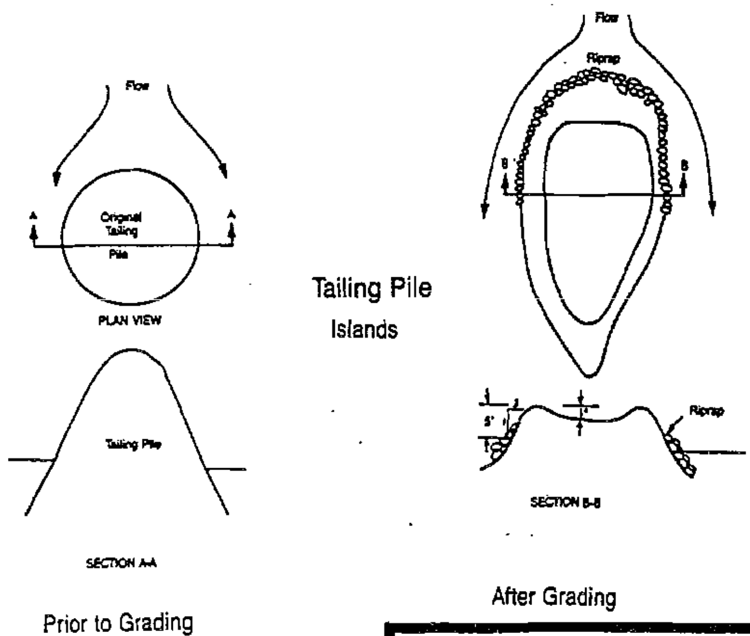


LEGEND:

Small Berms at Downstream Junction with Main Channel



SECTION A-A



VERTICAL SCALE IS EXAGGERATED FOR ILLUSTRATIVE PURPOSES

BRAIDED STREAM

ENTRIX | **Figure 50**

risk. As described in other sections, creating a new riparian zone adjacent to active channels is probably more desirable at sites where fish occur in the stream.

In braided floodplains riparian zones can also be constructed on large islands. These islands would consist of graded tailings piles between active channels. Due to the dynamic nature of braided channels, a special design is required to maintain the integrity of the island. Organic material should be placed in the centers of the islands to encourage colonization by vegetation.

Tailing piles within the active floodplain of a braided river should be graded and stabilized to conform with the stream pattern. The tailing piles should be graded primarily parallel to the river flow; this grading will elongate the piles into a shape similar to braided gravel bars. The graded tailing piles should have a maximum elevation of about 5 ft above bankfull conditions with a maximum slope of 3 to 1. The maximum elevation of the piles will be on the outer margins, as a depression should be scraped in the middle of the pile to a depth of about 1 ft as shown in Figure 50. A berm along the edge of the island should be maintained between the scraped center and the active channel. Upstream, the berm should be increased in width to protect against overtopping. The upstream end of the island should be stabilized by placing riprap to minimize erosion. Riprap will also reduce wave runup and assist in preventing berm breaching.

10.2.2 Inactive Floodplain

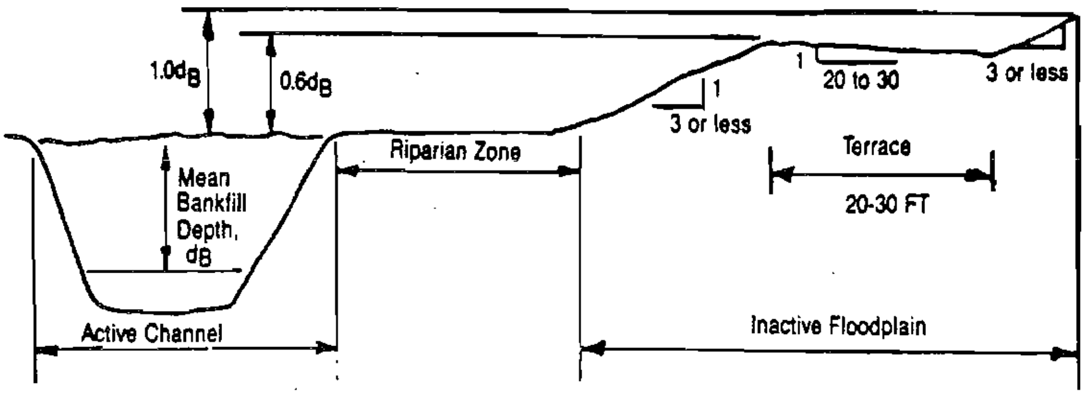
The inactive floodplain is defined as the area between the riparian zone and the 100-year floodplain (Figure 11). It is likely that this portion of the mine site will contain settling ponds and numerous tailings piles. As in the riparian zone, the final topography of the inactive floodplain is dictated by hydrologic and engineering constraints.

The physical configuration of the site and the stream channel location and pattern may constrain the grading of the inactive floodplain. The inactive floodplain should be shaped to allow floods in excess of bankfull to spread out as shallow flow on the floodplain while maintaining some degree of containment. From the riparian zone, a 3 to 1 slope or less should be provided. This slope should continue until an elevation gain of 0.6 times the mean bankfull depth at bankfull stage has been exceeded (Figure 51). This elevation represents the depth of about the 25-year recurrence-interval flood in many natural systems (Emmett 1972). A terrace should be provided at this elevation, and should be sloped away from the active channel at a slope between 30 to 1 and 20 to 1 (Stoecker 1982). Further up the bank, a slope of 3 to 1 or less should be maintained until an elevation of 2 times the mean depth at bankfull is reached (Figure 51). This depth corresponds to about the 100-year recurrence-interval flood event in many natural systems (Emmett 1972).

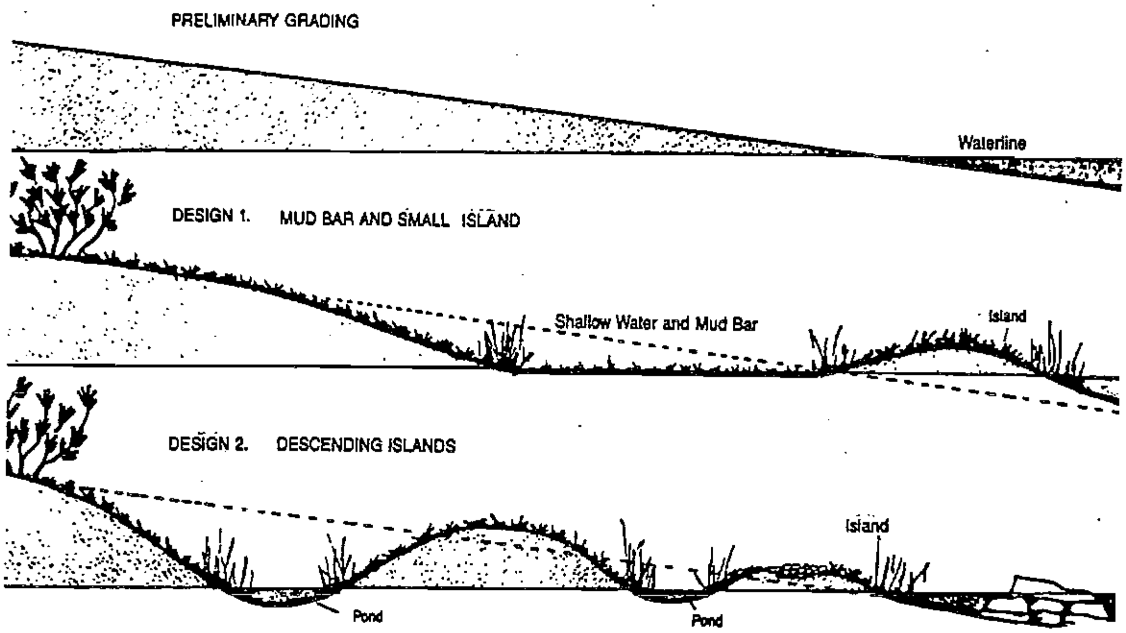
The final topography of the inactive floodplain should include appropriate grading for wildlife habitat (Figure 51) (Stoecker 1982). Ponds should be created by modifying the final shoreline configuration of the settling ponds, removing the majority of the accumulated sediments from the ponds, and, if necessary, improving the integrity of retaining walls, dikes, and dams (Stoecker 1982). Pond modification should create high habitat diversity and provide feeding and nesting areas for waterfowl, shorebirds, and passerines by developing a diverse shoreline configuration, islands, and variable water depths. A stabilizing layer of riprap, if available, should be placed along the dikes or berms nearest the active channel to prevent breaching. Armoring the section of the structure where the largest velocities are expected should have the highest priority when distributing riprap (Section 8.5.3).

If necessary, most accumulated sediments should be removed from the settling ponds during final site grading for use in revegetation. These sediments should be placed in a depression located on an elevated area on the opposite side of the settling ponds from the active channel. In addition to the depression (of at least 1 ft) a berm may be required to contain the sediments and prevent them from returning to the pond. This will allow the sediments to dry and will reduce the potential for the sediments to be carried into the active channel.

As sediments are being removed from the pond, the shoreline configuration should be made more complex (Figure 52). Bays, spits, and peninsulas can be



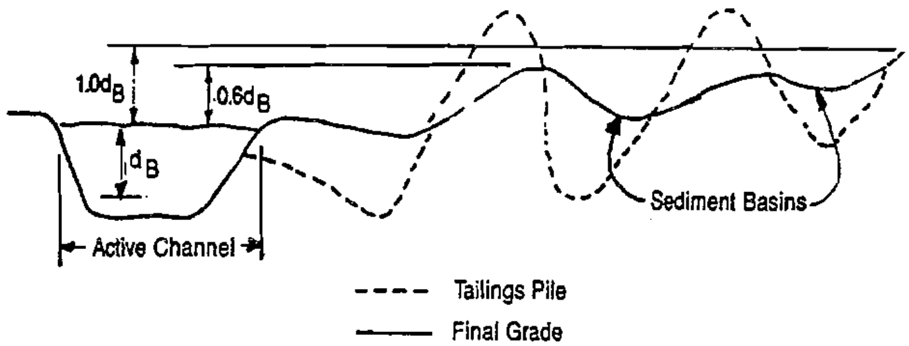
CROSS SECTION



Source: Stoecker 1982

FLOODPLAIN GRADED TO CREATE WILDLIFE HABITAT

ENTRIX **Figure 51**



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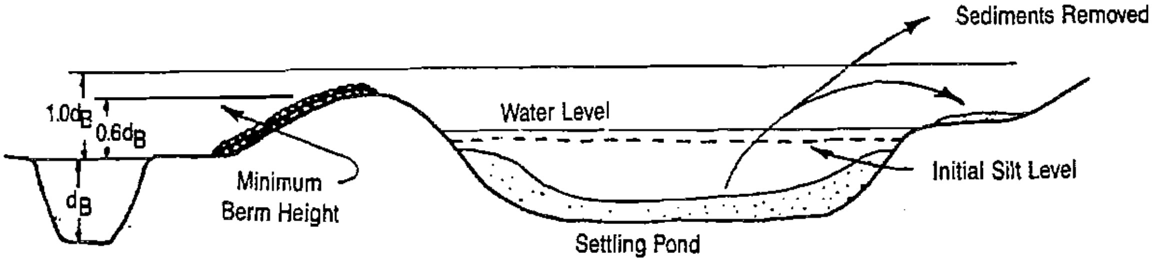

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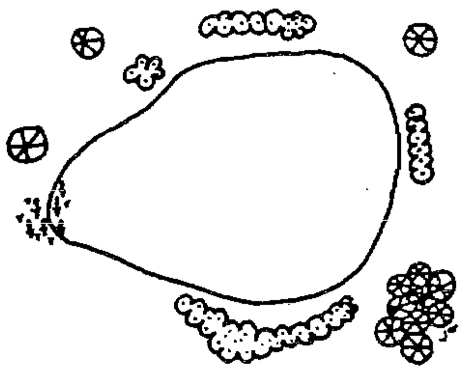


Settling Pond Before Grading

Settling Pond After Grading

Source: Herricks 1982

SITE GRADING IN INACTIVE FLOODPLAIN

ENTRIX

FIGURE 52

added to the pond (Herricks 1982). In addition, the bottom profile of the pond can be modified to create deep water areas near the center (2 to 4 feet deep) and shallow littoral zones near the shore (1 to 2 feet deep) (Joyce et al. 1980). Connecting a series of small ponds will create the same effect.

Settling ponds can also be modified to create fish habitat. The shoreline configuration of the ponds still should be modified to include bays, spits, peninsulas, and islands. The bottom profile of the ponds should be modified to create deep-water areas near the center (8 to 10 feet deep) and shallow littoral zones near the shore (1 to 2 feet deep); a mean depth of 8 feet is required to insure winter survival of fish. Shoreline and bottom modifications should be done in conjunction with the removal or stabilization of settling-pond sediments. All fine sediments should be removed from the pond or covered with coarse tailings to prevent the fines from washing into the stream channel. Large boulders, tree roots, or logs may be placed in the ponds to provide cover for the fish. The outlet channel connecting the ponds to the active channel should be excavated deep enough to allow fish passage during low flow conditions. An outlet channel should be connected to the active channel at a downstream angle in a non-depositional area of the stream.

Catchment basins (sediment basins) can be excavated in any area on the inactive floodplain. Settling ponds that have been rehabilitated by cleaning out or by being covered with coarse tailings may function as catchment basins with no excavation required. The purpose of the basins is to collect surface runoff and to retain water that enters the inactive floodplain during high flow events. Since water that enters the basins will likely contain suspended sediments, these basins will reduce nonpoint-source pollution and the accumulated sediments will enhance natural revegetation.

The basins should be designed to conform to the valley topography. Basins should be large enough to intercept overland flow with maximum depths of about 2 ft. The slopes around the basins should be fairly shallow and graded towards the depression.

Final sloping and contouring of the inactive floodplain should allow for the placement of organic material to create shrub thickets to be used as wildlife-migration corridors. The purpose of the corridors is to provide a meandering strip of vegetation between the undisturbed vegetation adjacent to the mine site and settling ponds, active channels, or catchment basins in the disturbed area (Figure 53). The corridor should be graded so that the elevations of material at the ends of the corridor are the same elevation as the shore of the waterbody and the ground layer in the undisturbed zone. The corridor should be relatively flat, about 10 to 20 feet wide, and should be slightly lower (shallow depression) than the surrounding grade of the inactive floodplain. This design will encourage natural revegetation in the corridor since runoff, sediments, and wind-borne seeds will accumulate in this area.

10.2.3 Valley Terrace

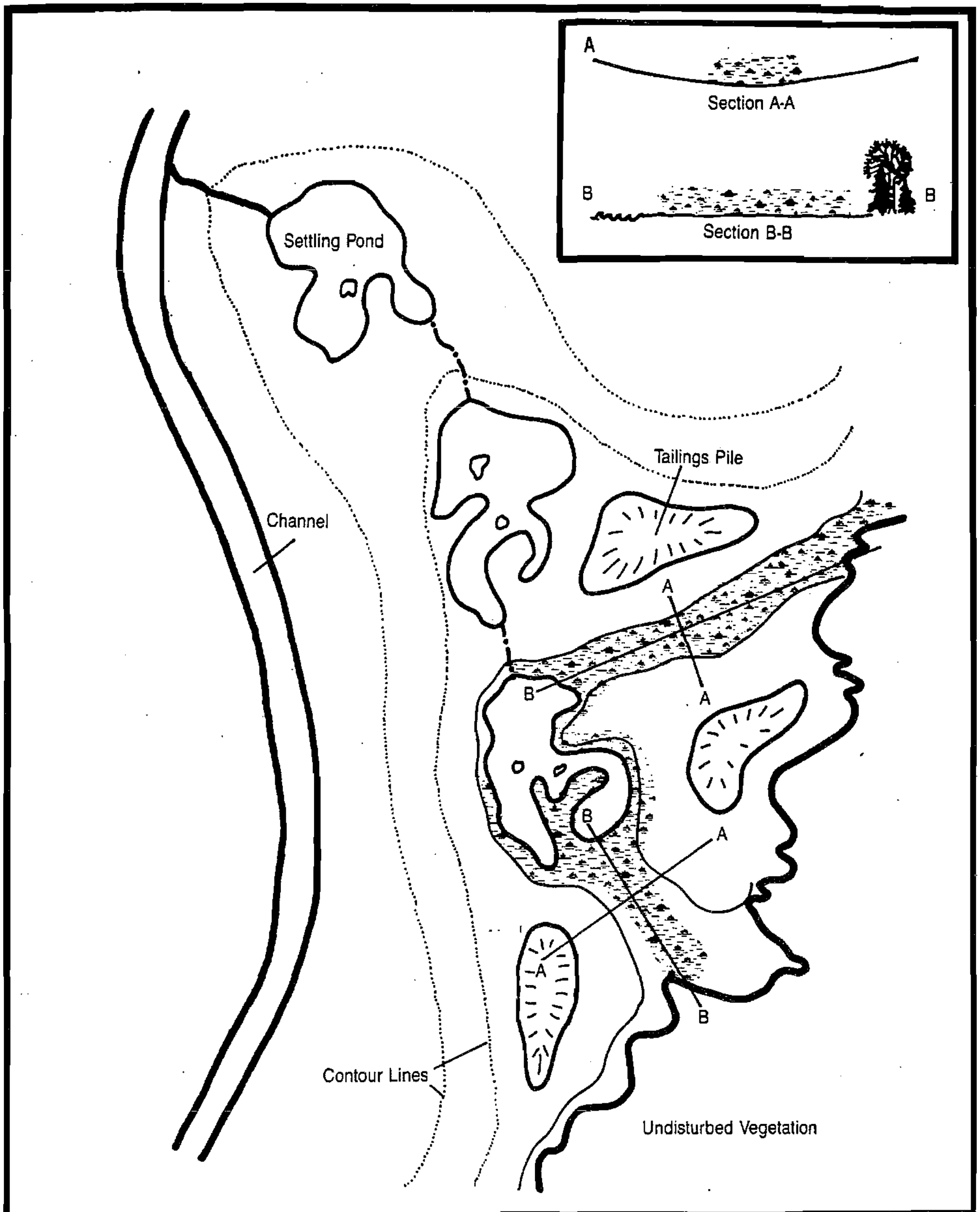
The valley terrace is the section of the floodplain outside of the 100-year floodplain, yet on relatively level ground (Figure 11). After mining has been completed, this area will likely contain settling ponds and tailings piles similar to those found on the inactive floodplain (Section 10.2.2).

The goals of final grading on the valley terrace are to return the area to its approximate pre-development topography and to mitigate loss of wildlife habitat. Specific features that can enhance natural revegetation and create wildlife habitat are similar to the features described for the inactive floodplain. These include ponds with complex shorelines and diverse bottom profiles, catchment basins, and wildlife-migration corridors.

10.2.4 Valley Bench

The valley bench is a relatively flat and narrow area located on the steep slopes of the valley side wall. Frequently the placer gravels located on these benches are mined and processed in place, resulting in all mining operations, including tailing piles and settling ponds, being located on the bench. Since these operations are usually confined to these narrow benches, extensive site grading is not always required.

The goal of site grading on a valley bench is to return the site to the pre-development slopes and control erosion (Berry 1974). On steep valley



PLAN AND CROSS-SECTION DIAGRAM OF TOPOGRAPHY FOR WILDLIFE MIGRATION CORRIDORS

ENTRIX	Figure 53

walls, terraces and catchment basins may need to be constructed to trap sediments originating on the bench (Doyle 1976).

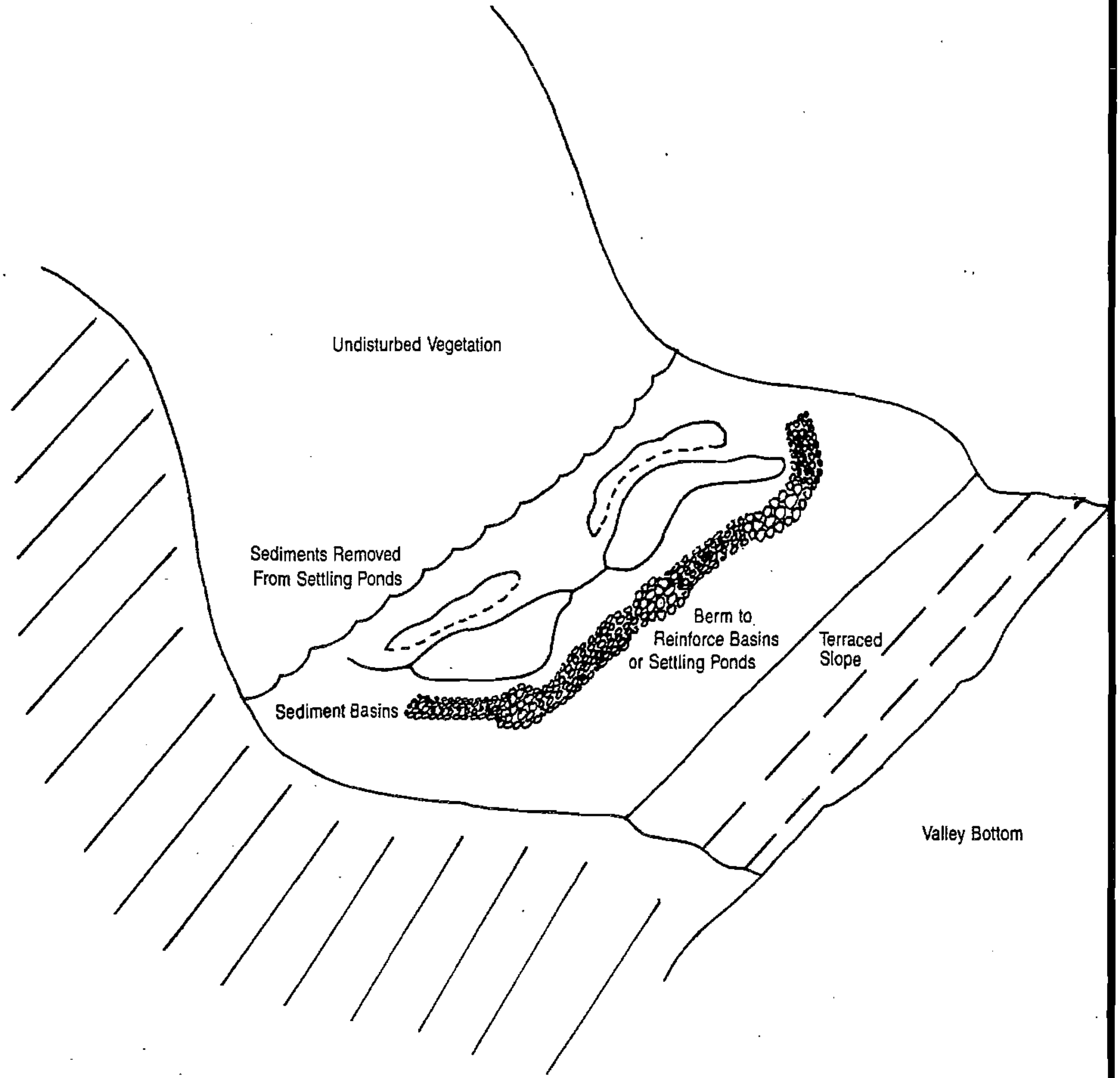
Settling ponds should be rehabilitated by burial or by removing sediments, or be reinforced to ensure the long-term integrity of the structures (Figure 54). Removal of sediments from the settling ponds can provide habitat for wildlife; they should be removed as described for the inactive floodplain (Section 10.2.2). Since these sediments may be on a slope, additional containment structures may need to be constructed. Materials that could be used include tree stumps, tree trunks, and large rocks.

10.3 STOCKPILE DISPERSEMENT

The amount of organic material available for distribution will vary for each placer-mining site. Some sites that were recently opened may have an abundance of organic material. Other sites, including large braided floodplains may have few, if any, organic materials to distribute. Due to the normally limited quantity of organic material available, a list of priorities has been established so that placement of the available organic material provides maximum habitat value for fish and wildlife. At those sites where organics are not available, but large quantities of inorganic fines are available (from settling ponds or loess stockpiles), these inorganics may be used in lieu of organic material.

The first criteria for deciding where to place organic material is whether the stream supports fish or is being rehabilitated to provide fish habitat. In this instance, the highest priority location in all stream types is to place the material in the riparian zone. If excess material remains after placement in the riparian zone or if fish are not present in the stream, the objective is to create wildlife habitat over as much of the disturbed area as possible. At those sites that contain an over-abundance of organic material, only the material necessary for rehabilitation should be distributed.

The goal of creating wildlife habitat will be best achieved by rehabilitating the floodplain to pre-development conditions. In this way, species of birds and mammals that utilized the floodplain prior to commencement of mining will



GRADING ON VALLEY BENCH

ENTRIX

Figure 54

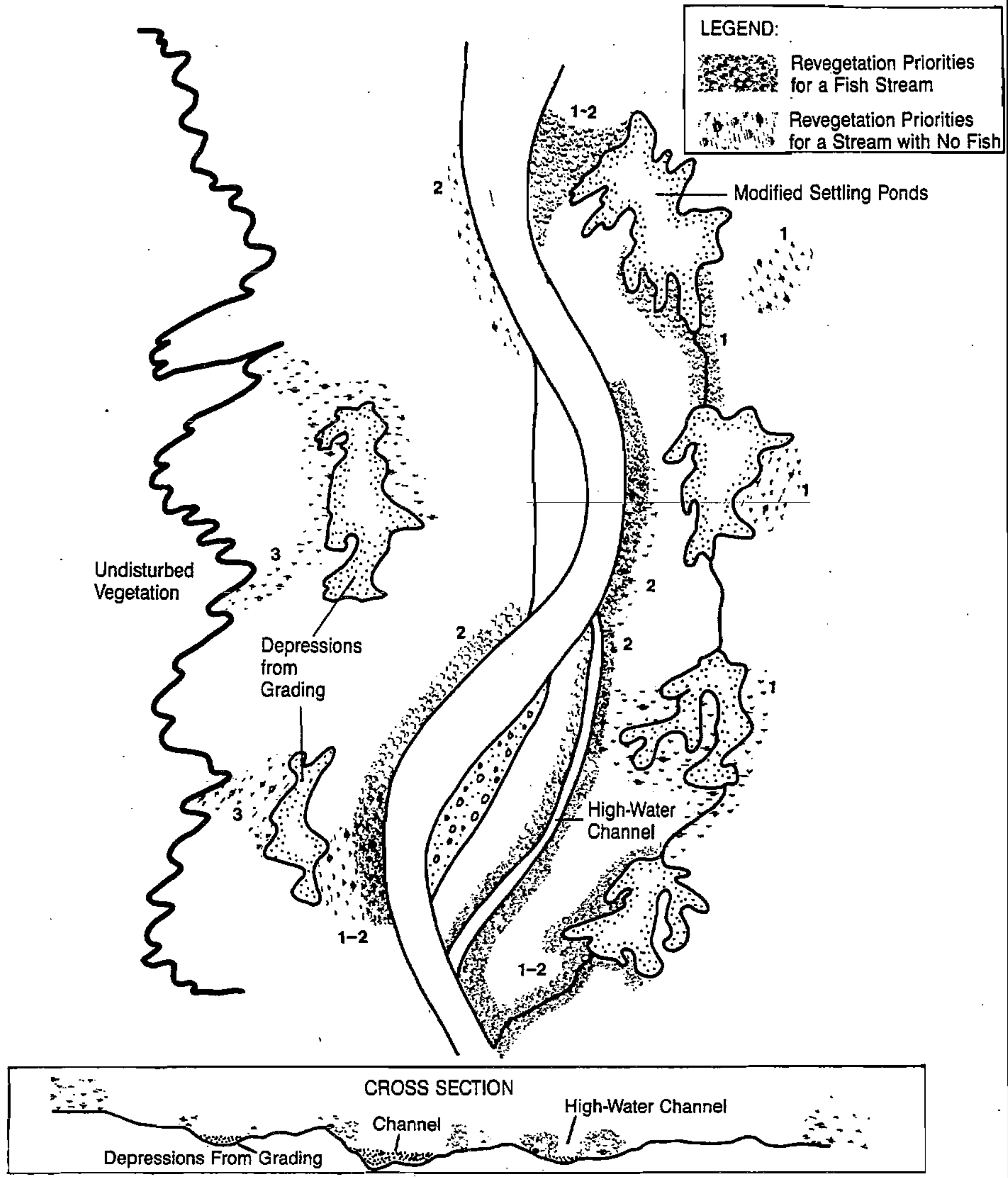
have that habitat replaced. Specialized habitats designed for particular wildlife species need not be created, unless they existed prior to development.

Priority locations for the placement of organic material in the three types of floodplains (meandering, mountain, and braided), as well as valley terraces and valley benches, are depicted in Figures 55, 56, 57, and 58. In general, vegetation should be established in three areas: adjacent to ponds and catchment basins, in the riparian zone, and in the wildlife migration corridors created during final site grading. Note that if settling ponds are connected to the active channels, the fine sediments in the ponds must be removed or stabilized prior to making the connection to prevent fines from entering the stream.

The greatest impediment to natural revegetation is the lack of moisture in the organic material (Berry 1970; Johnson et al. 1981). Typically, organic material is mixed with, or placed on top of tailings piles consisting of coarse, porous gravels. Water that enters the organic layer rapidly percolates through the gravels and is lost. At sites where moisture can be retained in the organic material, natural revegetation is accelerated (Berry 1970).

Before materials from the organic stockpiles are distributed, a leveling layer of material should be dispersed. Optimally, this material can be obtained from the stockpile containing the shallow soils removed when the site was opened. This material serves as a moisture retention layer since it consists of fine sediments, sand, and fine-textured organic material. If the shallow soils are not available, settling pond sediments, loess overburden, or sand can be used.

After the leveling layer has been applied, the organic stockpile containing the top layer of soil, root systems, and shrubs can be dispersed over the site. This layer generally should be applied at a lightly compacted thickness of 6 to 8 inches, although actual depth will depend upon the availability of organic material at each site. Large stumps and trees that were stockpiled

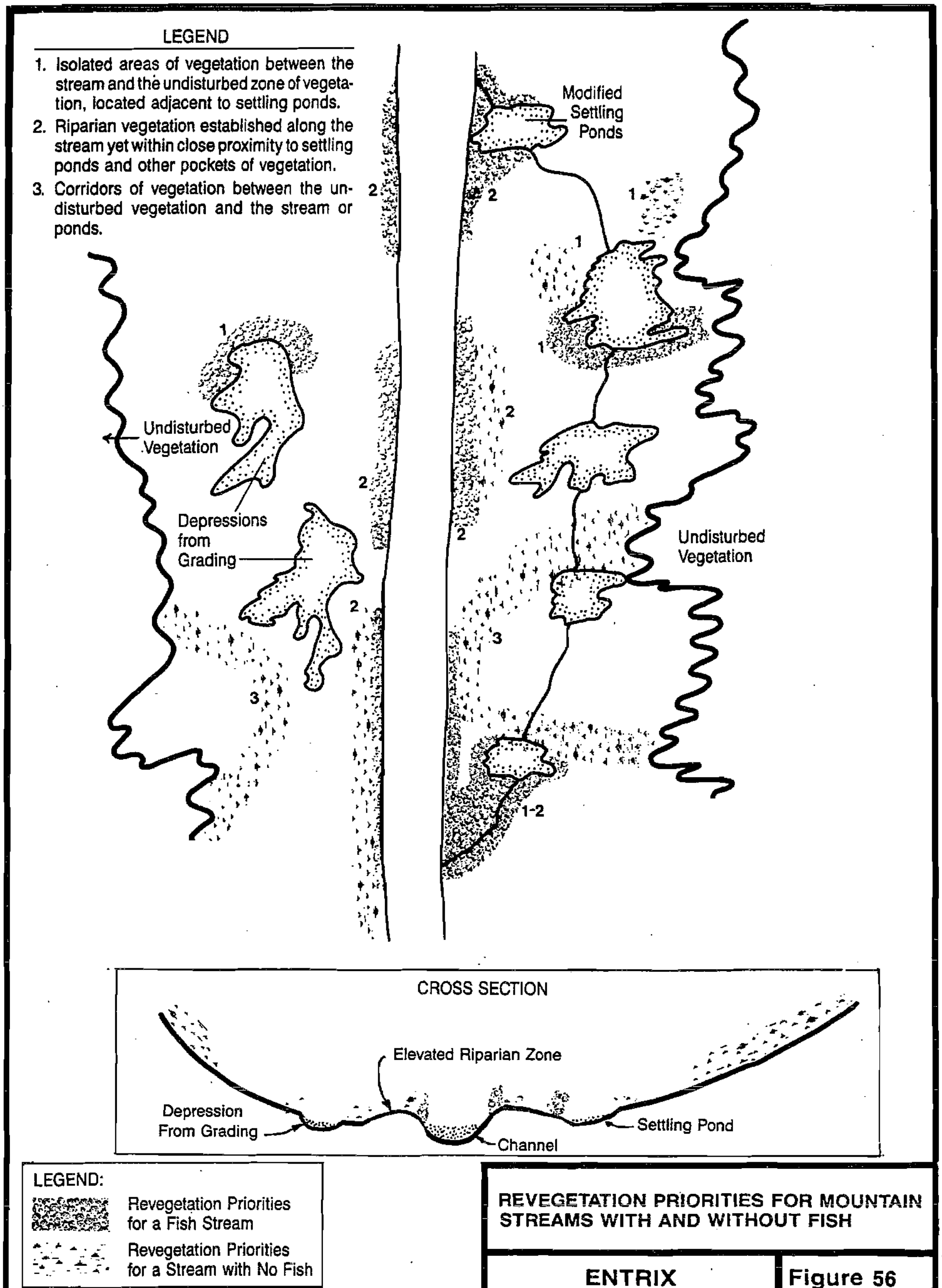


LEGEND

1. Isolated areas of vegetation between the stream and the undisturbed zone of vegetation, located adjacent to settling ponds.
2. Riparian vegetation established along the stream yet within close proximity to settling ponds and other pockets of vegetation.
3. Corridors of vegetation between the undisturbed vegetation and the stream or ponds.

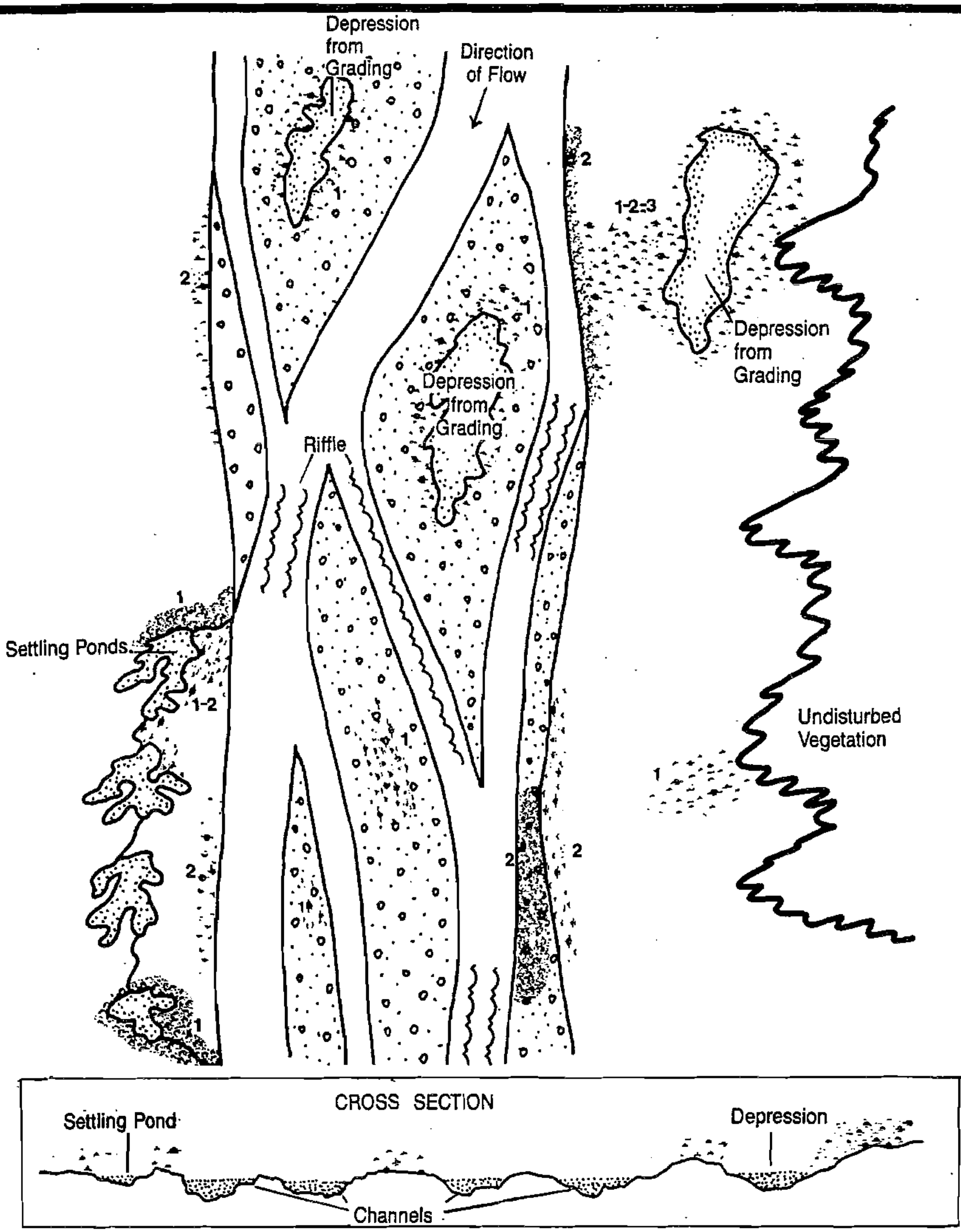
REVEGETATION PRIORITIES FOR MEANDERING STREAMS WITH AND WITHOUT FISH

ENTRIX | **Figure 55**



REVEGETATION PRIORITIES FOR MOUNTAIN STREAMS WITH AND WITHOUT FISH

ENTRIX | **Figure 56**



LEGEND:

Revegetation Priorities for a Fish Stream

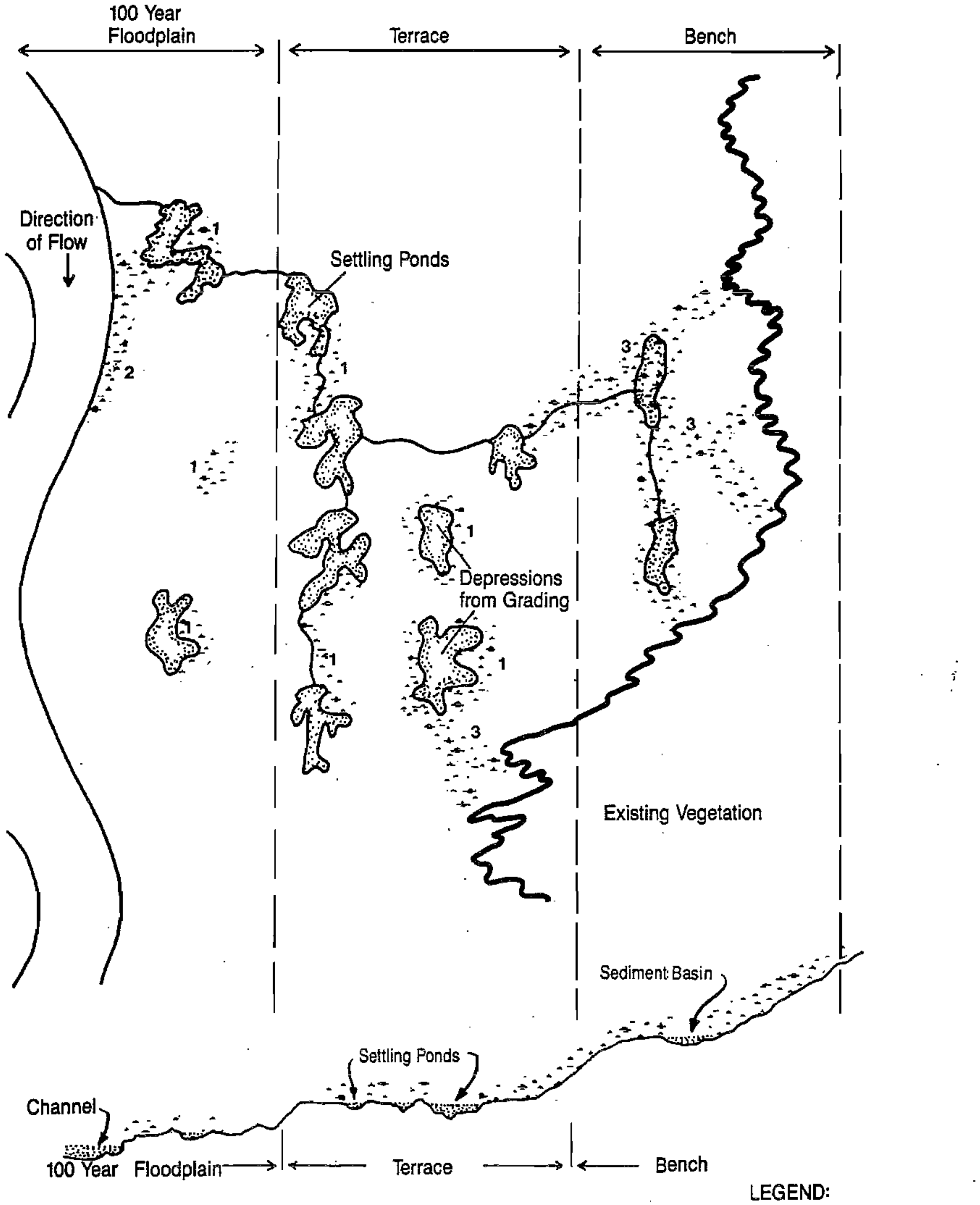
Revegetation Priorities for a Stream with No Fish

LEGEND

1. Isolated areas of vegetation between the stream and the undisturbed zone of vegetation, located adjacent to settling ponds.
2. Riparian vegetation established along the the stream yet within close proximity to settling ponds and other pockets of vegelation.
3. Corridors of vegetation between the undisturbed vegetation and the stream or ponds.

REVEGETATION PRIORITIES FOR BRAIDED RIVERS WITH AND WITHOUT FISH

ENTRIX | **Figure 57**



LEGEND

1. Isolated areas of vegetation between the stream and the undisturbed zone of vegetation, located adjacent to settling ponds.
2. Riparian vegetation established along the stream yet within close proximity to settling ponds and other pockets of vegetation.
3. Corridors of vegetation between the undisturbed vegetation and the stream or ponds.

LEGEND:

Revegetation Priorities for a Fish Stream

Revegetation Priorities for a Stream with No Fish

REVEGETATION PRIORITIES FOR VALLEY TERRACES AND VALLEY BENCHES

ENTRIX | **Figure 58**

during site clearing can also be dispersed to create wildlife habitat (Figure 59). As stated, the optimal location for these materials is adjacent to ponds or in the riparian zone (Szafoni 1982).

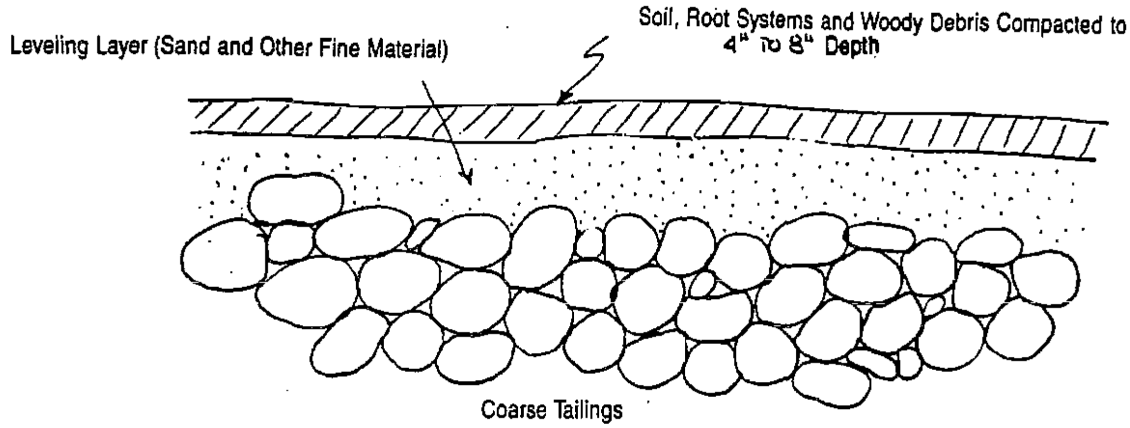
10.4 REVEGETATION

The goal of the revegetation program is to enhance recovery by native species, particularly woody shrubs, and to mitigate wildlife habitat losses by maximizing development of riparian shrub thickets. By encouraging revegetation, nonpoint-source pollution can be reduced and wildlife habitat is created (Dick 1974).

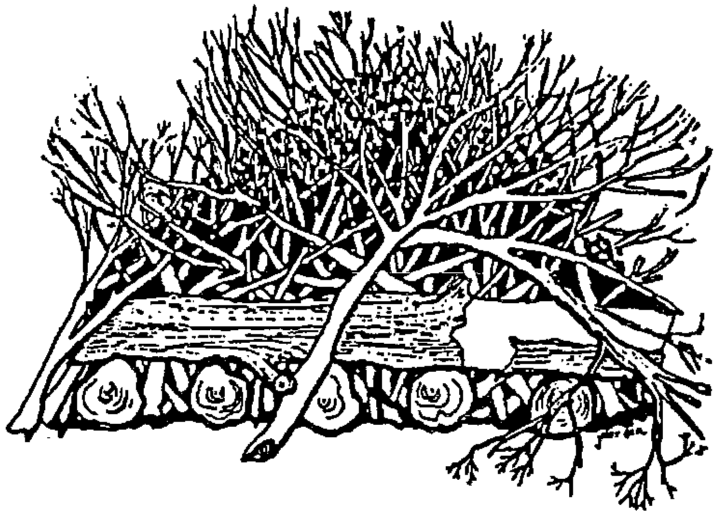
Rates of revegetation vary for different geographic locations and for different areas of the floodplain. Hardy Assoc. (1978) found that without enhancement, shrub communities formed at placer-mining sites in the Klondike within 20 years. Full recovery to coniferous forest required 80 to 100 years (Hardy Assoc. 1978). Revegetation can be accelerated by planting viable stem or branch cuttings, or roots of shrubs that are native to the area, broadcasting woody debris over organic soil, or transplanting intact sections of tundra mats. Using these techniques, shrub thickets can often be produced in less than 10 years.

The rate of revegetation can be slowed by several factors. Planting non-native grasses impedes the invasion of the area by woody plants (Dabbs et al. 1974; Johnson et al. 1981). Excessive application of fertilizers, lime, and other chemicals can alter the soil chemistry, thus also impeding natural revegetation. Attempting to grow vegetation in soil contaminated by gasoline, diesel fuel, and other petroleum products is usually unsuccessful (Johnson 1981).

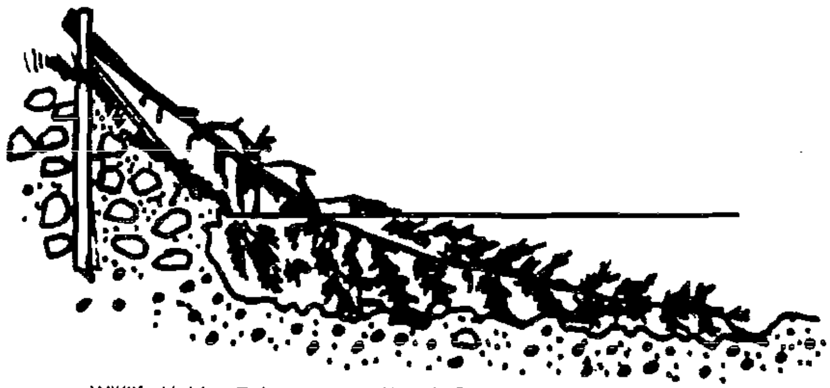
The two techniques that have had the highest success in enhancing natural revegetation are surface broadcast of organic material containing woody debris with viable willow and alder stems and rootstocks, and large-scale transplanting (Figure 60) (Joyce 1980; Dick 1974; Lowenberger 1973; Zasada and Epps 1976). Surface broadcasting of organics is a technique where live branches, roots, and trunks of small to medium size shrubs are spread across the top layers of organic soil (Joyce 1980). With adequate moisture retention



Application of Leveling Layer and Organic Material



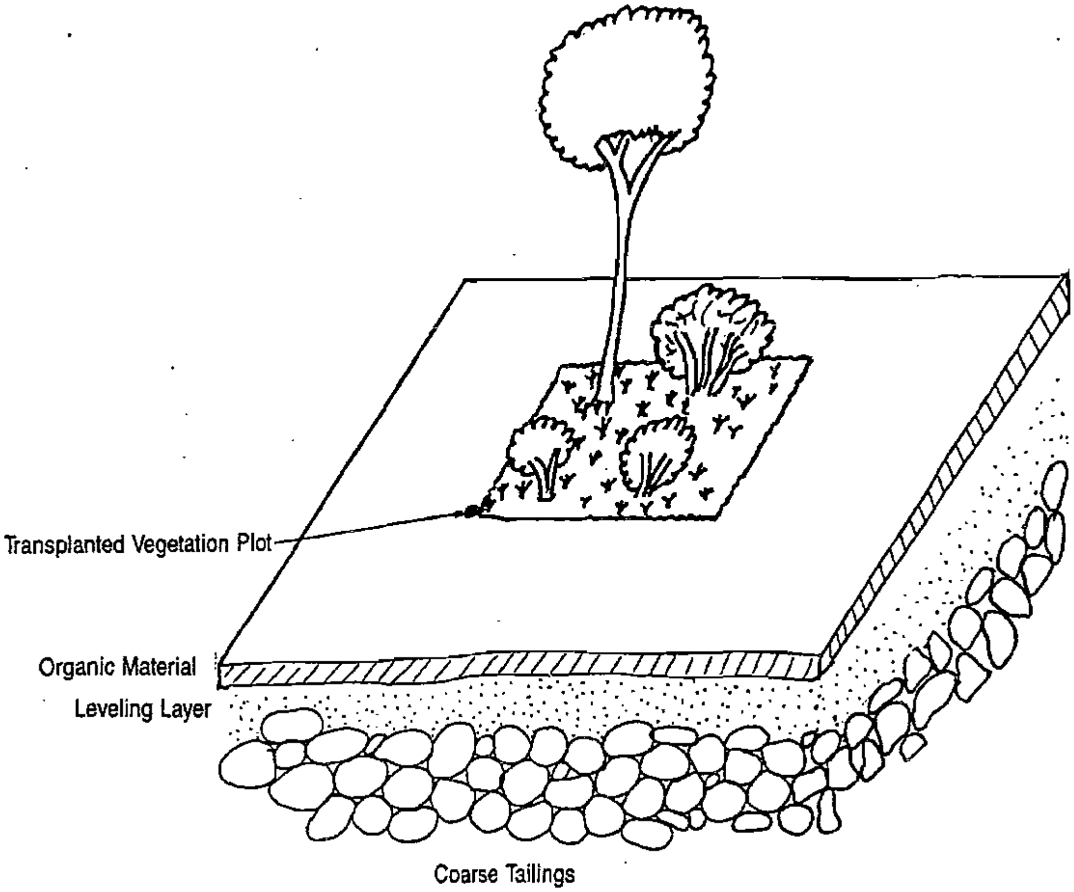
Wildlife Habitat Enhancement - Slash Pile for Small Mammals and Birds



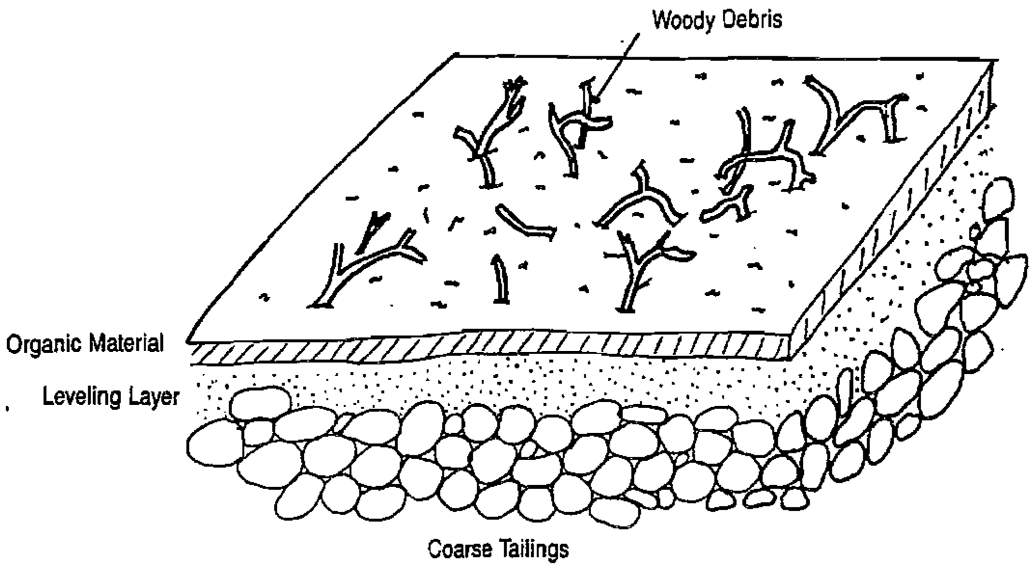
Wilflife Habitat Enhancement - Woody Debris in Riparian Zone

DISTRIBUTION OF STOCKPILE MATERIALS

ENTRIX | **FIGURE 59**



Large-Scale Transplanting



Surface Broad Casting of Woody Debris

REVEGETATION TECHNIQUES

ENTRIX | Figure 60

in the soil, these woody plant parts will sprout stems and roots. This technique can accelerate vegetative recovery by eliminating primary successional stages (grasses) and beginning with mid-range successional species (shrubs) (Viereck 1970).

When stockpiling organics and woody slash for use in rehabilitation it is important to minimize the time these materials are stockpiled. Although little data are available, roots and buried seeds may die quickly when stockpiled, particularly when they are not kept moist. Thus, if possible these materials should be placed directly on areas that have been final graded and are ready for revegetation, or used within one year of stockpiling.

The second technique that has proven to be successful in enhancing natural revegetation is large-scale transplanting (Lowenberger 1973). This technique involves using a piece of heavy equipment, such as a front-end loader, to scoop up soil and vegetation from an undisturbed location, and place the entire mass of material in a single location. For this method to be most successful, 12 to 18 inches of soil, as well as the above-ground vegetation must be moved intact (Zasada and Epps 1976), and the transplant should be placed in an area that will retain ground moisture. If the vegetation is scarred or broken, or if the soil and root mass is broken, survival of the vegetation will be reduced. There is no optimal size for the piece of soil and vegetation that is to be moved; however, the survival rate is higher when large plots are moved.

Sections of undisturbed soil and vegetation can be acquired from two types of sites. The first option is to collect soil and vegetation plots from the undisturbed edges of the floodplain where mining activity will not be occurring. This option should only be used if revegetation of the mine site is essential due to fish and wildlife habitat considerations and if no other organic material is available at the site. Plots should be removed from scattered locations so that a large, disturbed site is not created.

The most efficient means of obtaining plots of soil and vegetation is to collect material that is being cleared for future mine operations. Even if the operator is not yet ready to revegetate a portion of the mine site, the soil and vegetation plots can be stored in temporary locations until they are needed. Recommendations concerning plot storage are the same as for organic stockpile placement. This includes protecting the material from surface runoff and high streamflow, but choosing a location where the material will collect and retain moisture.

At sites where organic material is unavailable and fine-grained inorganic material (such as settling-pond fines or loess overburden) has been used in its place, it may be appropriate to use light applications of fertilizer if nutrients are thought to be limiting.

Although seeding is known to impede natural revegetation, it may be necessary to complement site sloping and contouring by seeding annual grasses on steep slopes with exposed erodible materials. Seeding should be conducted only if it is judged that substantial material would likely enter adjacent streams. If available, native grass seed should be used. If soil nutrients are thought to be limiting, the area can be lightly fertilized. If seeding and fertilizing are conducted, the seed and fertilizer should be "raked" into the upper several inches of soil. This will increase germination and decrease loss of seed and fertilizer. Raking can be accomplished by dragging a section of chain-link fence behind a truck or dozer. The methods used to seed an area should be consistent with Miller et al. (1983).

In addition to the above uses of light applications of fertilizer, carefully designed fertilization programs may be used on a site-specific basis to speed the revegetation process.

The time of year that revegetation occurs can affect the success of the effort by influencing the survival rate of the vegetation. Grading and distribution of the leveling layer of material can be conducted during any time of the year. Broadcasting organic material, planting live portions of shrubs, and transplanting plots of soil and vegetation should occur during the late spring to early summer, or during freeze-up. Schwendiman (1973) found the highest survival of vegetation occurred when planting occurred immediately after the surface soils were free of ice. Johnson and Van Cleve (1976) had reduced survival rates when planting in late August. Higher survival is achieved by early planting since the vegetation has the opportunity to sprout roots before winter, and thus reduce winter-kill. If seeding is necessary, it also should be completed by mid-summer, although if site work does not allow seeding until late summer, it should be delayed until freeze-up. If seed is sowed too early prior to freeze-up, the seeds will sprout but not mature prior to snowfall and then will winter kill.

APPENDIX A
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APPENDIX B
GLOSSARY

active channel -- That portion of the channel or channels that transports the 2-year recurrence interval flood.

active floodplain -- That portion of the floodplain that contains the active channel or channels and adjacent riparian strips: same as riparian zone.

anadromous -- Aquatic organism migrating from marine waters to freshwater for reproduction.

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. A frequent source of the water is shallow groundwater flow forced to the surface by a constriction in the flow area. Also referred to as icings, glaciation, and naleds.

bank -- A comparatively steep side of a channel or floodplain formed by an erosional process; its top is often vegetated.

bankfull discharge -- Discharge corresponding to the 2-year recurrence interval flood.

bar -- An alluvial deposit or bank of sand, gravel, or other material in the stream channel.

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, stream -- The bottom of a stream below the low summer flow.

bench -- A relatively flat area occurring on the valley walls.

BMP -- Best Management Practice.

braided stream -- 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, 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: same as pattern.

contour -- A line of equal elevation above a specified datum.

cover, fish -- Areas of shelter in a stream channel that provide fish 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, e.g., pools, boulders, water depths, surface turbulence, undercut banks, overhanging vegetation, accumulated debris, and others.

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).

cut -- Excavated area.

dbh -- Diameter of a tree at breast height.

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 or cfs.

dragline -- A type of excavating equipment that uses a bucket and a boom. It is capable of the removal of underwater material.

detention time -- Period of time that water remains in a settling pond and equals the flow rate divided by the volume of the pond.

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.

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 -- process of sediment removal by wind or water.

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 bankfull capacity of a stream or channel and flows out on the floodplain; greater than bankfull 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.

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, low -- The lowest discharge recorded over a specified period of time.

flow, low summer -- The lowest flow during a typical open-water season.

flow, mean -- See mean flow.

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.

freeboard -- The vertical distance from the top of the channel to the water surface at the design condition.

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.

grizzlies -- Iron or steel bars used to sort or separate large rocks from placer bearing materials.

habitat -- The place where a population of animals live 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.

hydraulicing -- A soil loosening operation which uses water at high pressures to move earth downgrade. It can be used to thaw frozen material.

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 lies between the riparian zone and the 100-year recurrence interval flood boundary.

island -- A sediment deposit located between two channels.

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

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

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 column velocity -- The water velocity measured at 0.6 of the depth or the average of the velocities as measured at 0.2 and 0.8 of the depth.

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.

meander wave length -- The average downvalley distance of two meanders.

meandering stream -- A stream 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 deposits typically are found on the point bars at the insides of meanders.

mid-channel bar -- An unvegetated or lightly vegetated sediment deposit located between two channels.

mountain stream -- A single channel, high gradient stream.

nonpoint-source pollution -- all turbidity, suspended sediment, and sedimentation resulting from soil erosion caused by human activity and emanating from a widespread area.

overburden -- Any organic or inorganic material lying on top of placer gravels.

overflow rate -- rate of flow through a settling pond divided by the surface area of the settling pond.

parameter -- A variable in a mathematical function which, for each of its particular values, defines other variables in the function.

permafrost -- Perennially frozen ground.

point bar -- An unvegetated sediment deposit located adjacent to the inside edge of a channel in a meander bend.

point-source pollution -- Pollution which originates at a single entry point into a body of water.

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 against 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.

resident fish -- remaining in freshwater for entire life cycle.

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 the banks of a stream or other body of water.

riparian vegetation -- Vegetation bordering floodplains and occurring within the active floodplain.

riparian zone -- Area within the active floodplain adjacent to active stream channels.

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.

root stock -- Any root or lower stem mass from woody shrubs and small trees.

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.

screen -- Device used to separate material into size classifications.

settling ponds -- Artificial structures designed to prevent downstream pollution by trapping and removing sediment from waters draining the mining operation.

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.

sinuosity -- 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.

sluicing -- A general term applied to many forms of placer mining. A sluice is an inclined channel or trough through which gravel is carried by a stream of water with the intent to separate gold and heavy metals.

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.

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 tpyically are stable and floodplains are usually narrow. These river systems are considered to be an unusual configuration in transition to some other configuration.

substrate -- Stream bottom materials including silts, sands, gravels, cobbles, boulder and bedrock.

suspended sediment -- 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.

tailing piles -- Material processed through a placer mining operation.

terrace -- An elevated 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.

top width -- The width of the effective area of flow across a stream channel.

turbidity -- An expression of the optical property that causes light to be scattered and adsorbed rather than transmitted in straight lines through a water sample. Turbidity in water is caused by the presence of suspended matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms.

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.

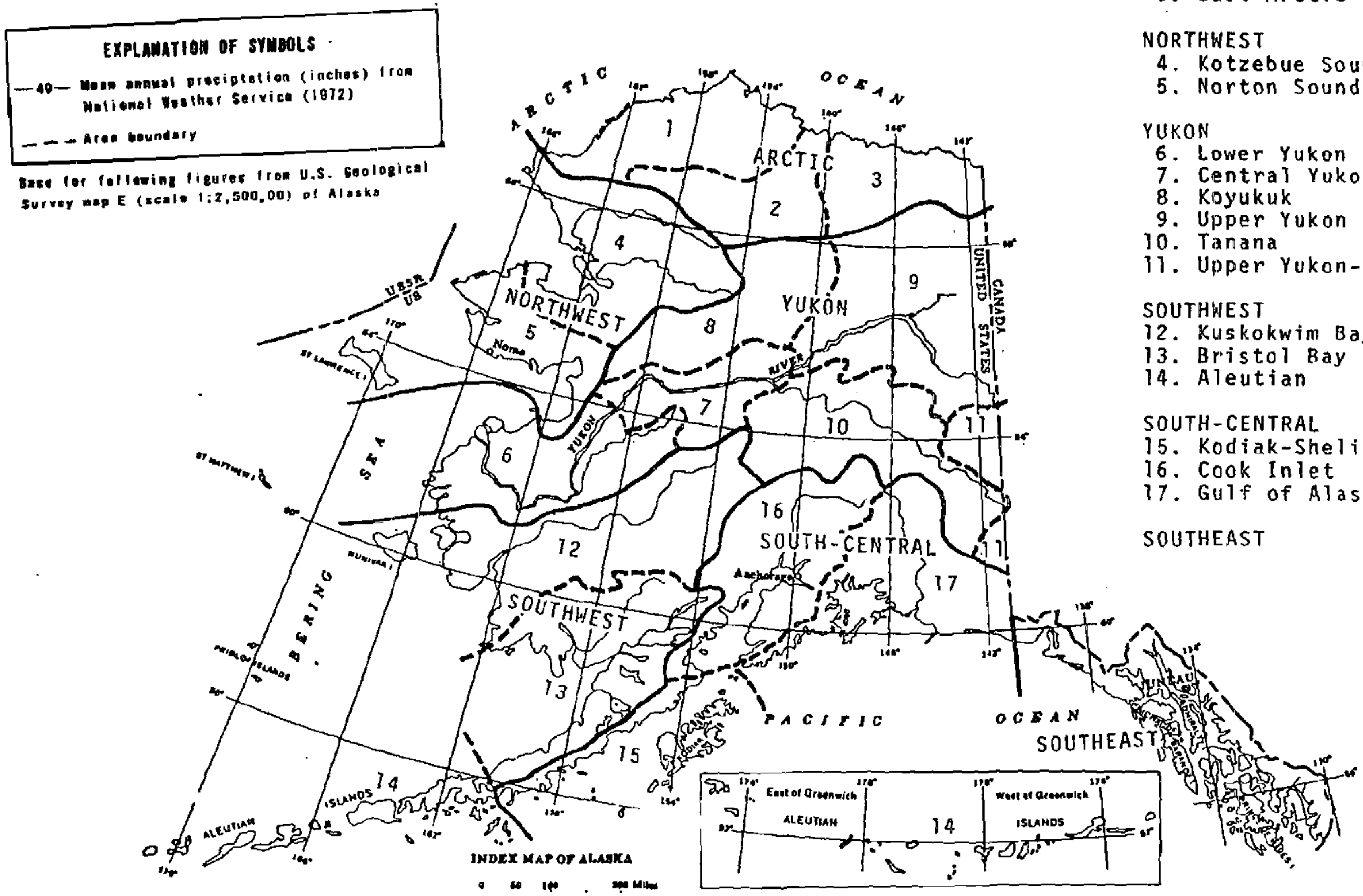
water quality -- A term used to describe the chemical, physical, and biological characteristics of water in reference to its suitability for a particular use.

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.

APPENDIX C
MAPS OF
MEAN ANNUAL PRECIPITATION

MAPS OF MEAN
ANNUAL PRECIPITATION

Maps of mean annual precipitation (Lamke 1979) are presented in this appendix. During the rehabilitation of stream channels (Chapter 7.0), mean annual precipitation values are used to evaluate design flows (Section 7.2). Mean minimum January temperatures are also presented (Lamke 1979) although not used within this report.



MAP INDEX

ARCTIC
1. West Arctic
2. Colville
3. East Arctic

NORTHWEST
4. Kotzebue Sound
5. Norton Sound

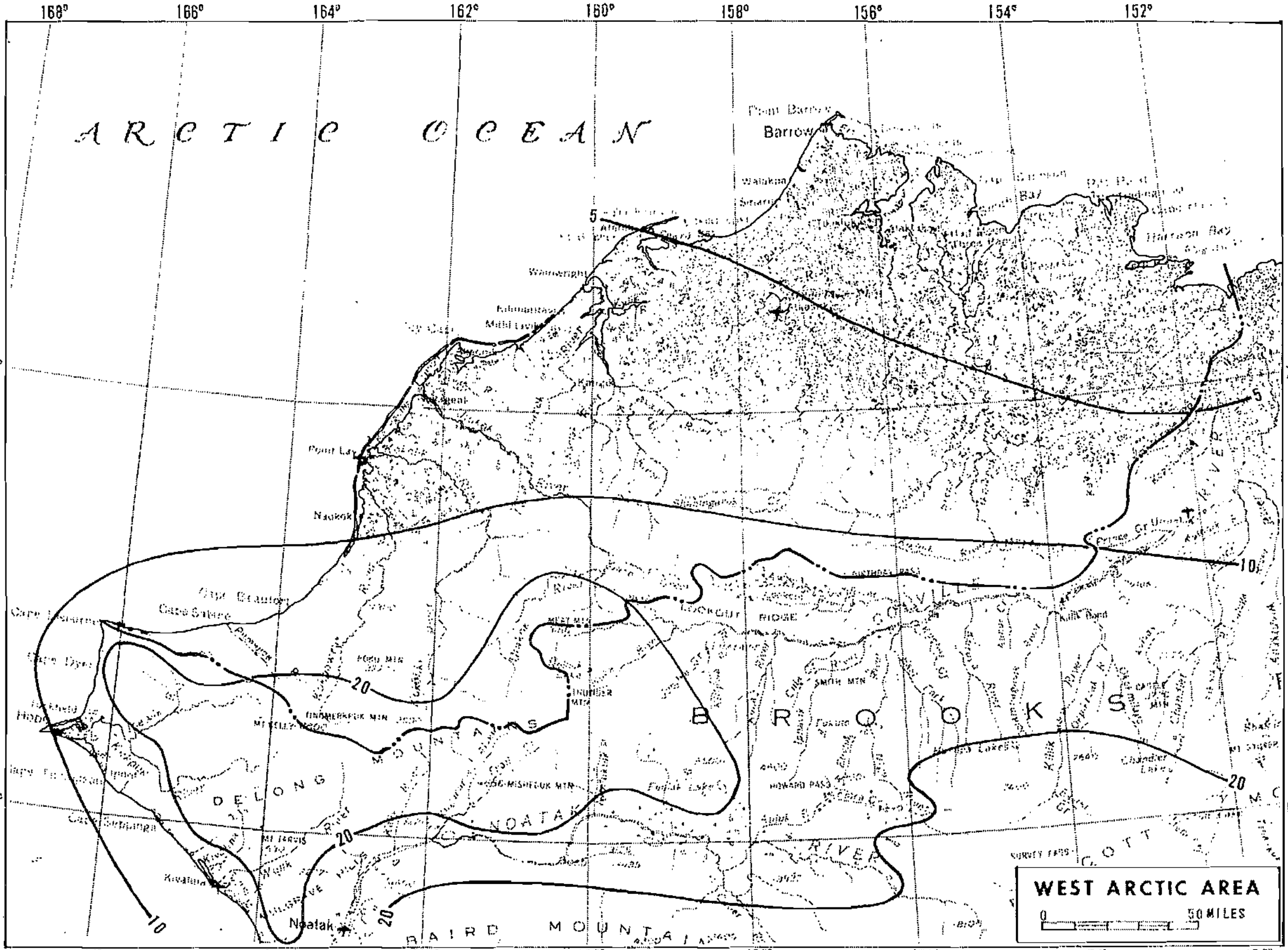
YUKON
6. Lower Yukon
7. Central Yukon
8. Koyukuk
9. Upper Yukon
10. Tanana
11. Upper Yukon-Canada

SOUTHWEST
12. Kuskokwim Bay
13. Bristol Bay
14. Aleutian

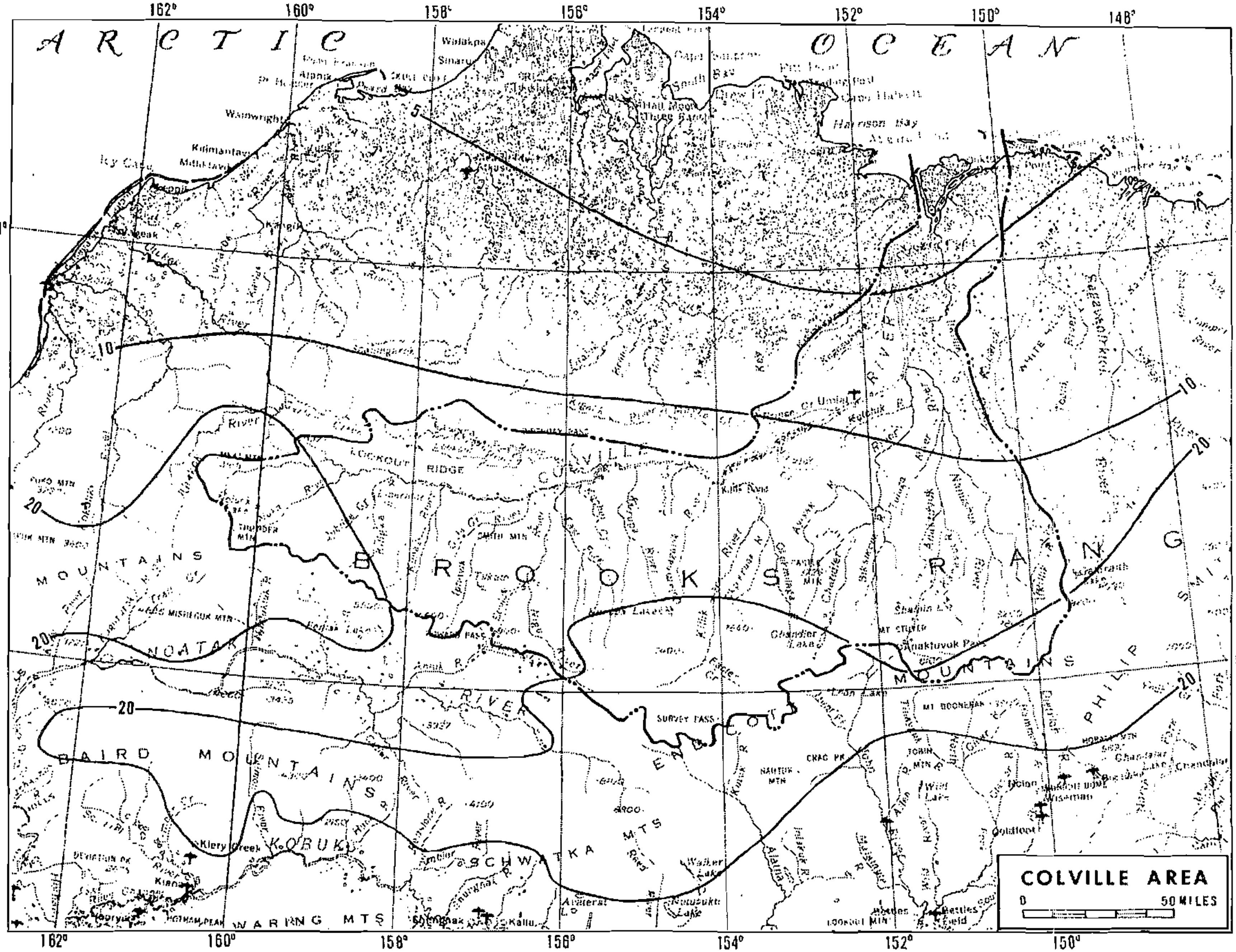
SOUTH-CENTRAL
15. Kodiak-Shelikof
16. Cook Inlet
17. Gulf of Alaska

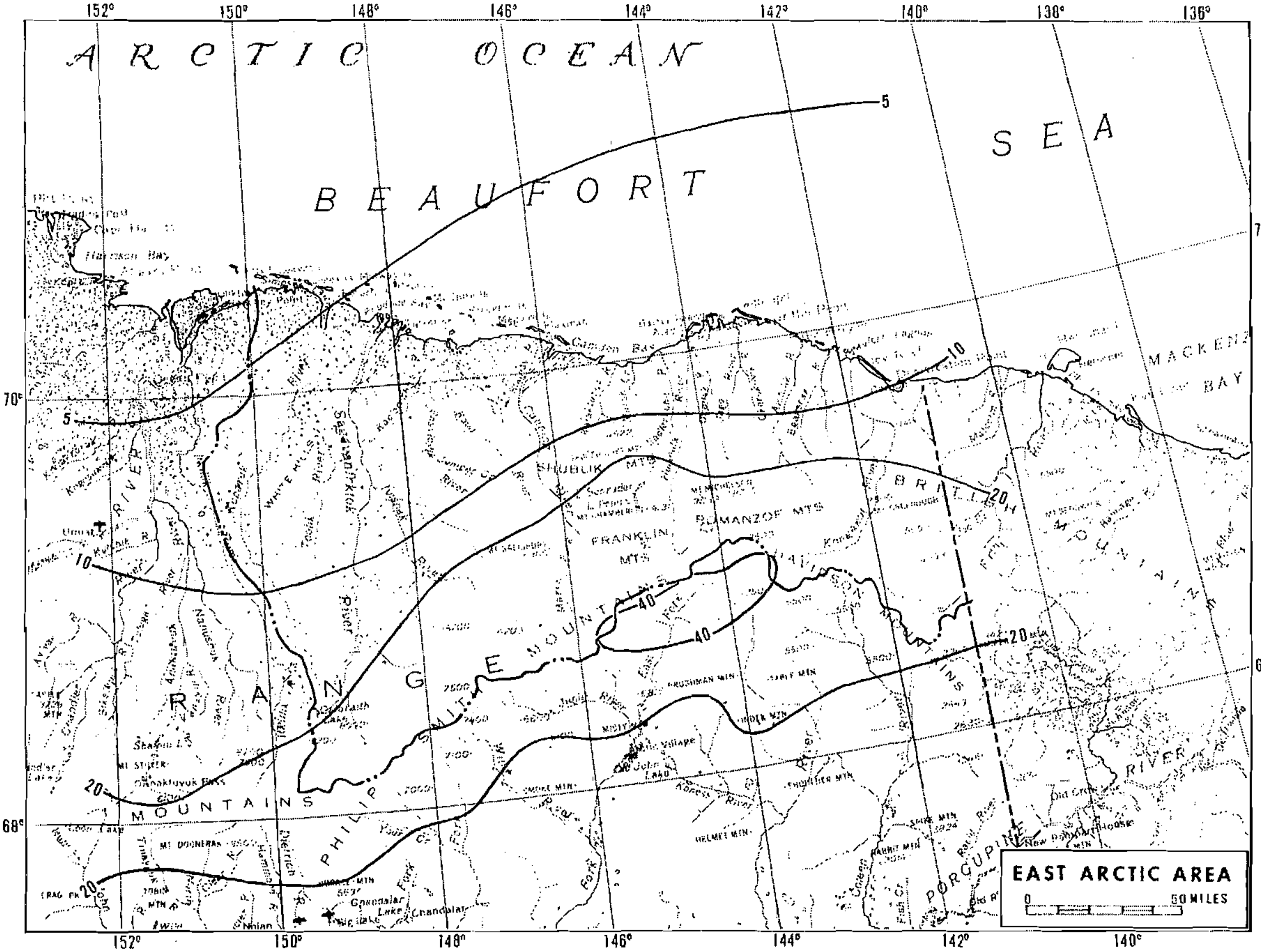
SOUTHEAST

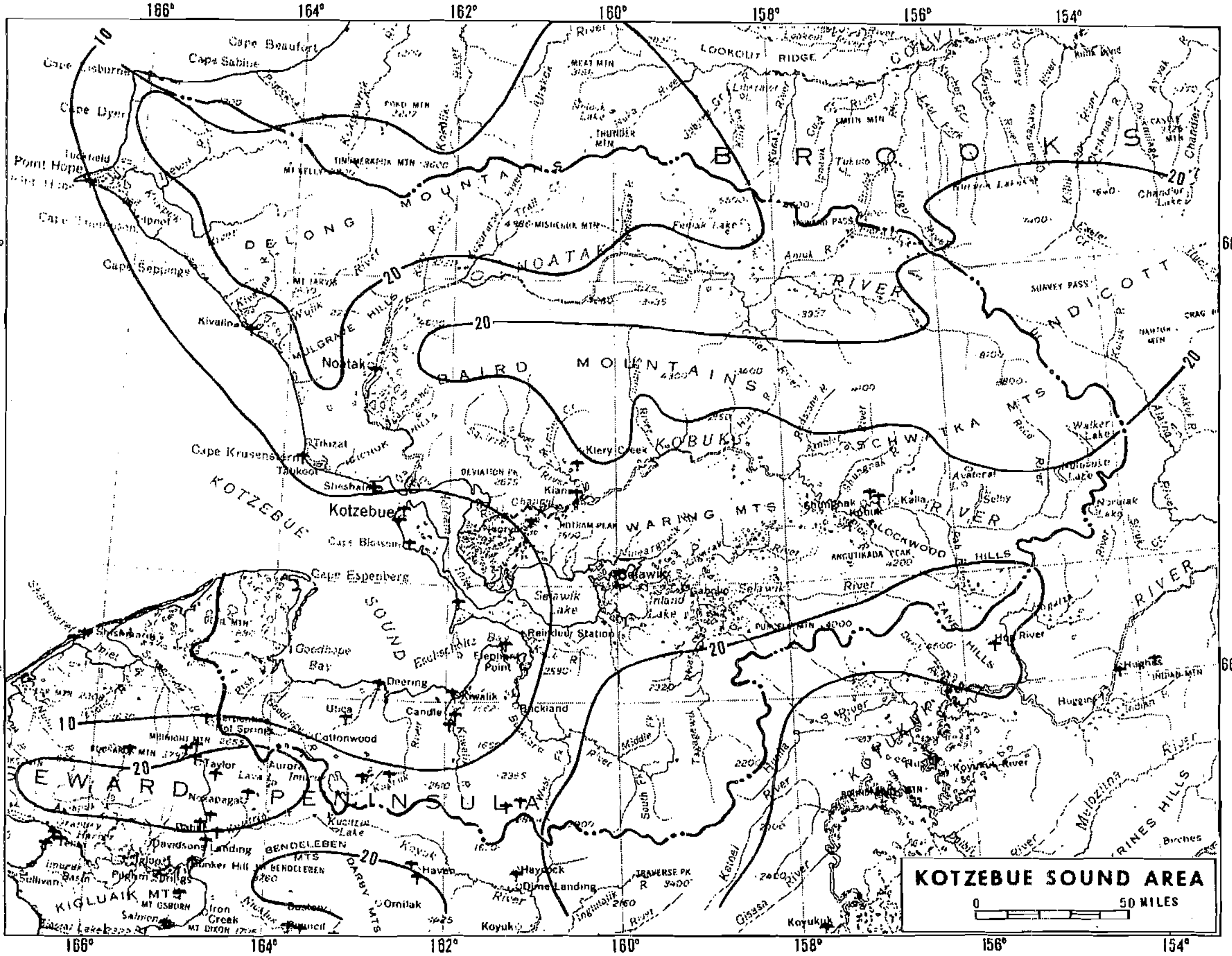
MAP INDEX AND SYMBOLS USED IN APPENDIX C

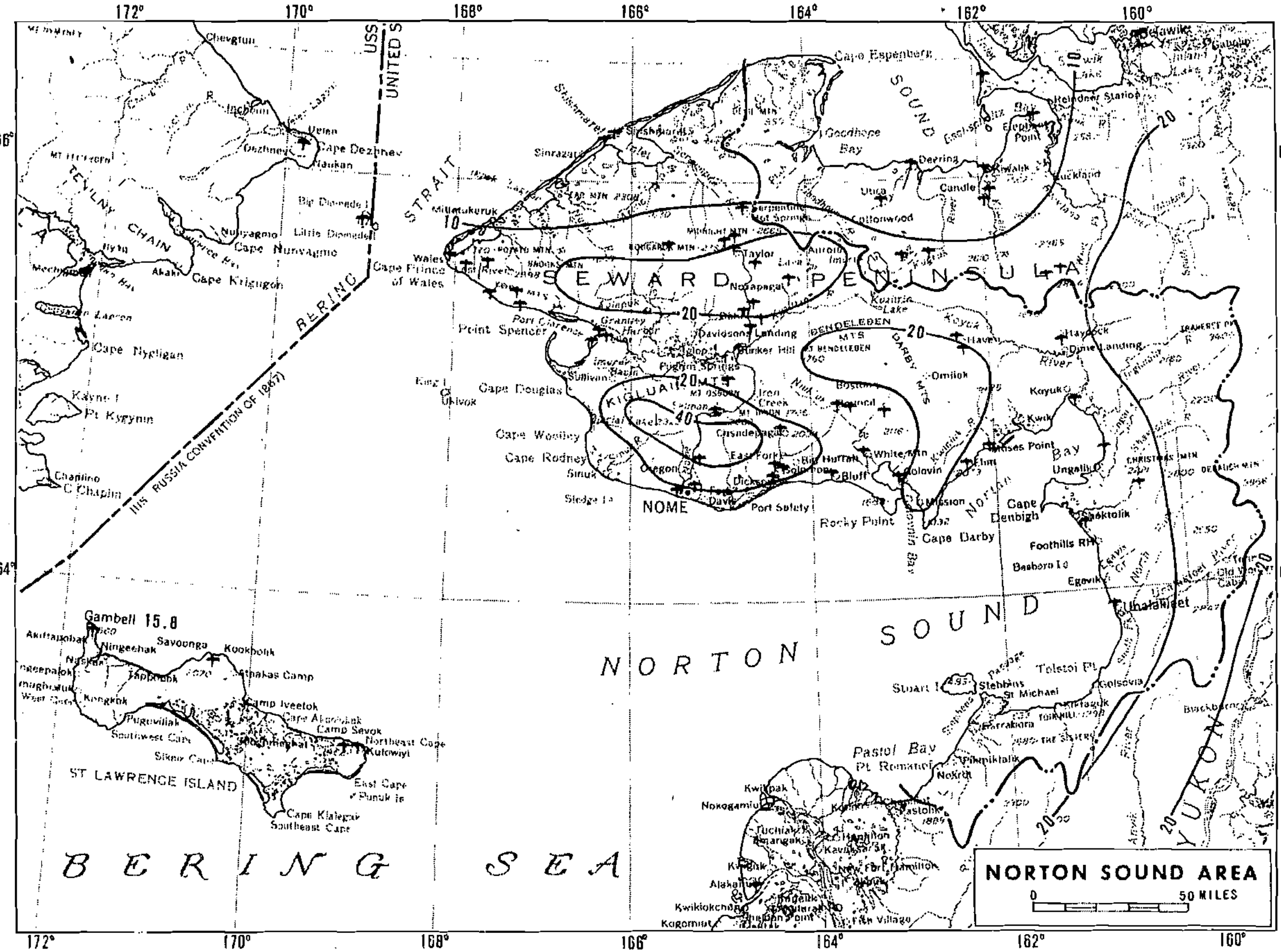


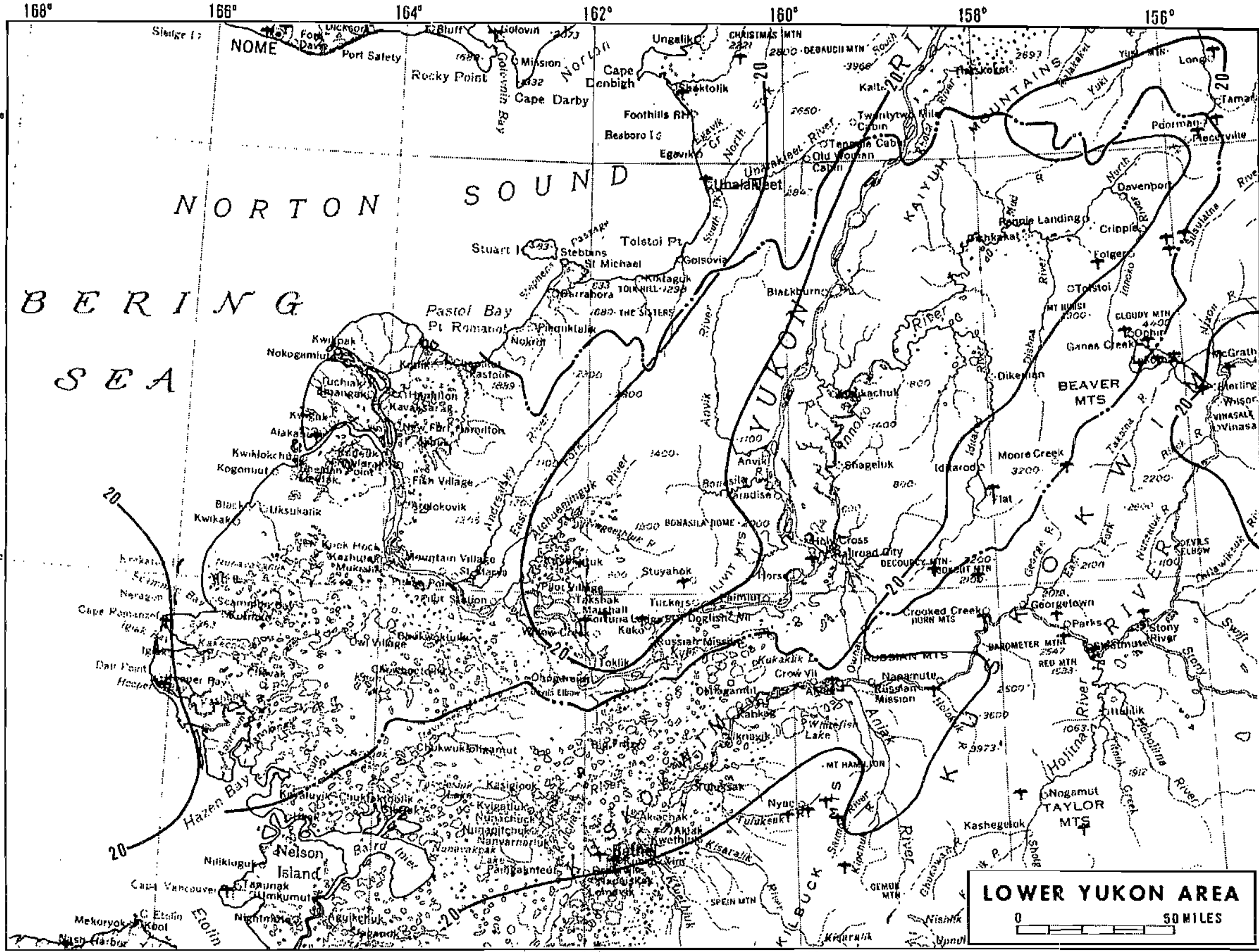
ARCTIC OCEAN
WEST ARCTIC AREA
0
50 MILES
168°
166°
164°
162°
160°
158°
156°
154°
152°
70°
68°
Barrow
Point Lay
Noatak
B R O O K S
D E L O N G
M O U N T A I N S
N O A T A K
R I V E R
B A I R D
M O U N T A I N S
5
10
20

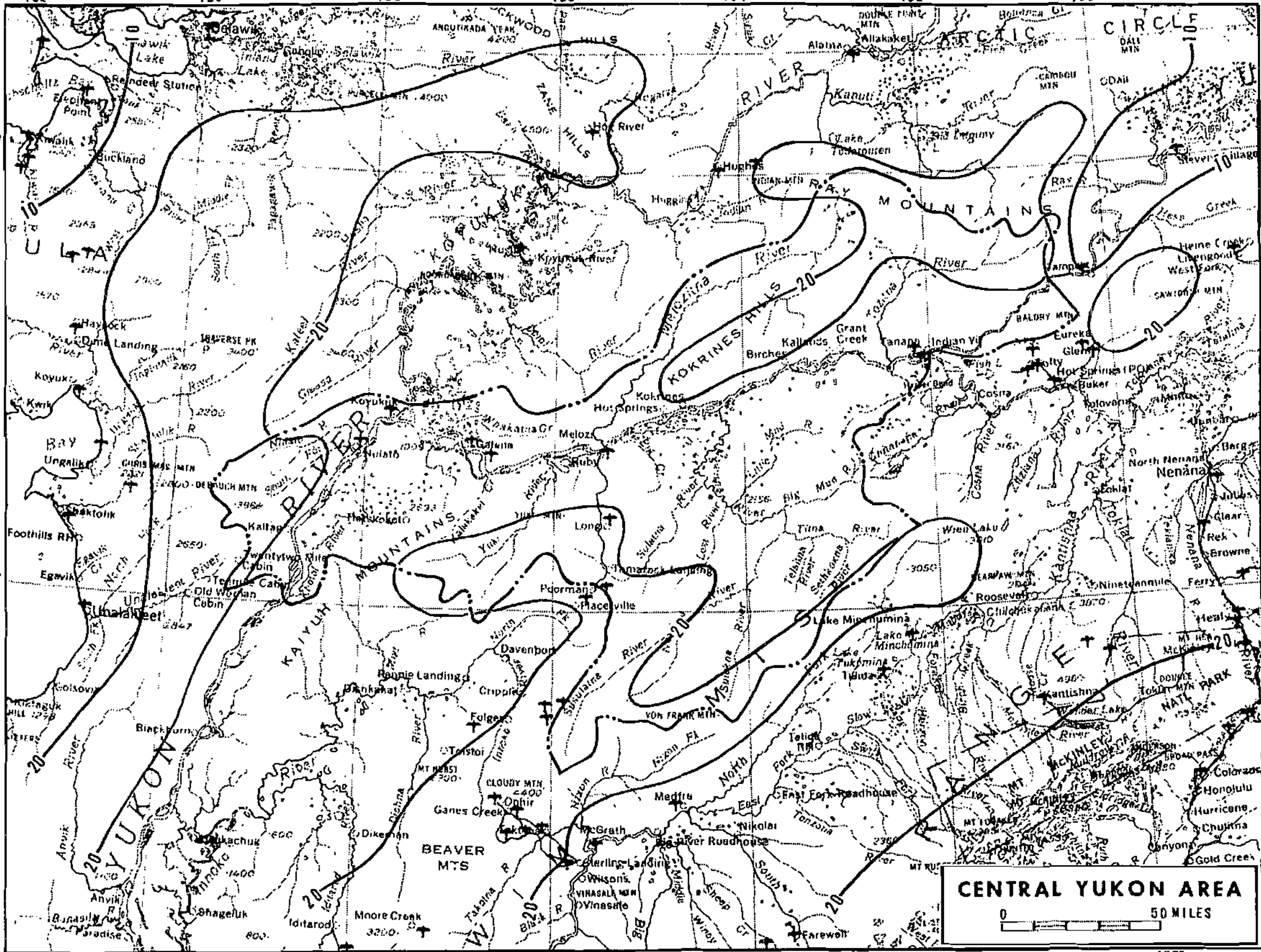

ARCTIC OCEAN
COLVILLE AREA
0 50 MILES
BROOKS RANGE
COLVILLE RIVER
NOATAK RIVER
BAIRD MOUNTAINS
KOBUK
SCHWATKA MTS
WARING MTS
ENDICOTT MOUNTAINS
PHILIP SMITH MOUNTAINS
DE LONG MOUNTAINS
LOOKOUT RIDGE
Harrison Bay
Wainwright
Icy Cape
Point Lay
Anaktuvuk Pass
Chandler Lake
Survey Pass
Wiseman
Coldfoot
Bettles Field
Shungnak
Kiana
70°
68°
162°
160°
158°
156°
154°
152°
150°
148°
5
10
20

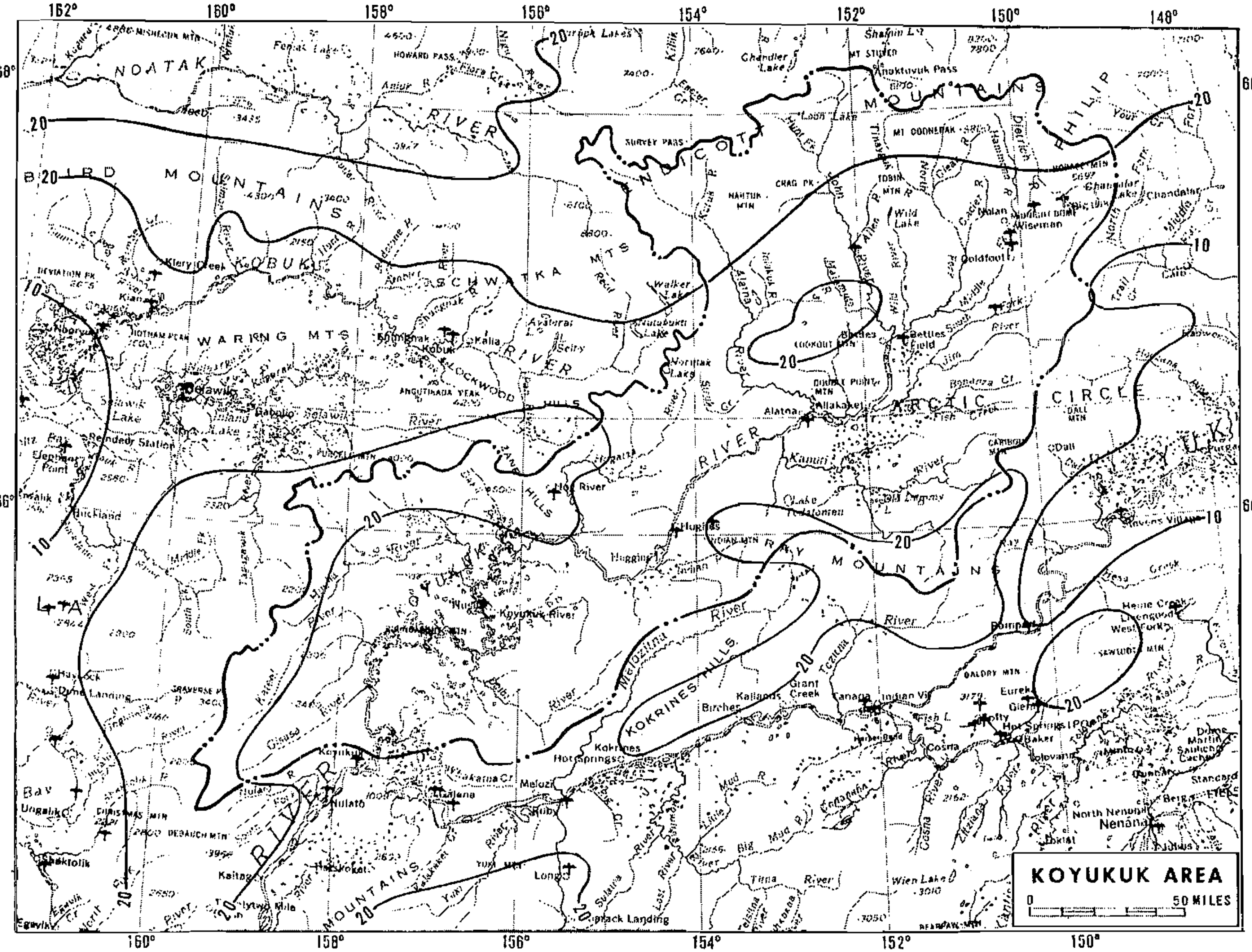

ARCTIC OCEAN
BEAUFORT SEA
MACKENZIE BAY
SHUBLIK MTS
ROMANZOF MTS
FRANKLIN MTS
DAVIDSON MOUNTAINS
BRITISH MOUNTAINS
PHILIP SMITH MOUNTAINS
RANGE
MOUNTAINS
PORCUPINE RIVER
5
10
20
40
152°
150°
148°
146°
144°
142°
140°
138°
136°
70°
68°
EAST ARCTIC AREA
0 50 MILES

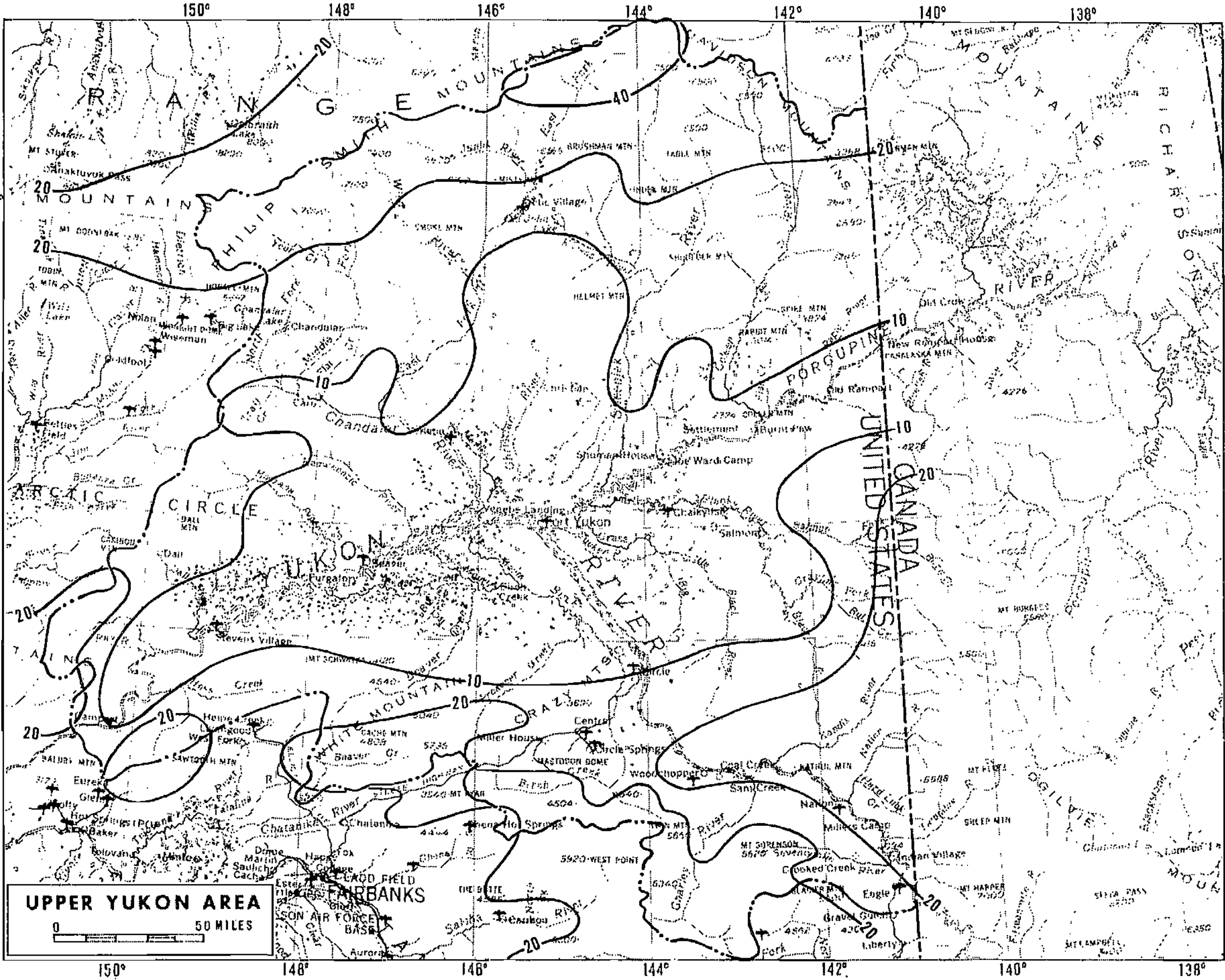

KOTZEBUE SOUND AREA
0
50 MILES
186°
164°
162°
160°
158°
156°
154°
166°
68°
66°
BROOKS
MOUNTAINS
DELONG
NOATAK
RIVER
ENDICOTT
BAIRD
MOUNTAINS
SCHWATKA MTS
KOBUK
RIVER
WARING MTS
LOCKWOOD HILLS
KOTZEBUE
SOUND
SEWARD PENINSULA
KOYUKUK
NULATO HILLS
KIGLUAIK MTS
BENDELEBEN MTS
DARBY MTS
ZANE HILLS
LOOKOUT RIDGE
MULGRAVE HILLS
Cape Beaufort
Cape Sabine
Cape Lisburne
Cape Dyer
Point Hope
Cape Thompson
Cape Seppings
Kivalina
Noatak
Cape Krusenstern
Tikizat
Sheshalik
Kotzebue
Cape Blossom
Cape Espenberg
Goodhope Bay
Eschscholtz Bay
Elephant Point
Deering
Kiwalik
Candle
Buckland
Utica
Cottonwood
Taylor
Aurora
Noxapaga
Davidsons Landing
Bunker Hill
Haven
Haycock
Dime Landing
Omilak
Koyuk
Council
Solomon
Iron Creek
Pilgrim Springs
Teller
Shishmaref
Inlet
Selawik
Selawik Lake
Inland Lake
Reindeer Station
Kiana
Klery Creek
Shungnak
Kobuk
Kalla
Selby
Walker Lake
Nutuvuk Lake
Norutak Lake
Hog River
Hughes
Indian
Huggins
Koyukuk River
Koyukuk
Birches
Chandler Lake
Feniak Lake
Meat Mtn
Thunder Mtn
Tinmerkpuk Mtn
Mt Kelly
Mt Osborn
Mt Dixon
Deviation PK
Angutikada Peak
Traverse PK
Shaviovik Pass
Howard Pass
10
20

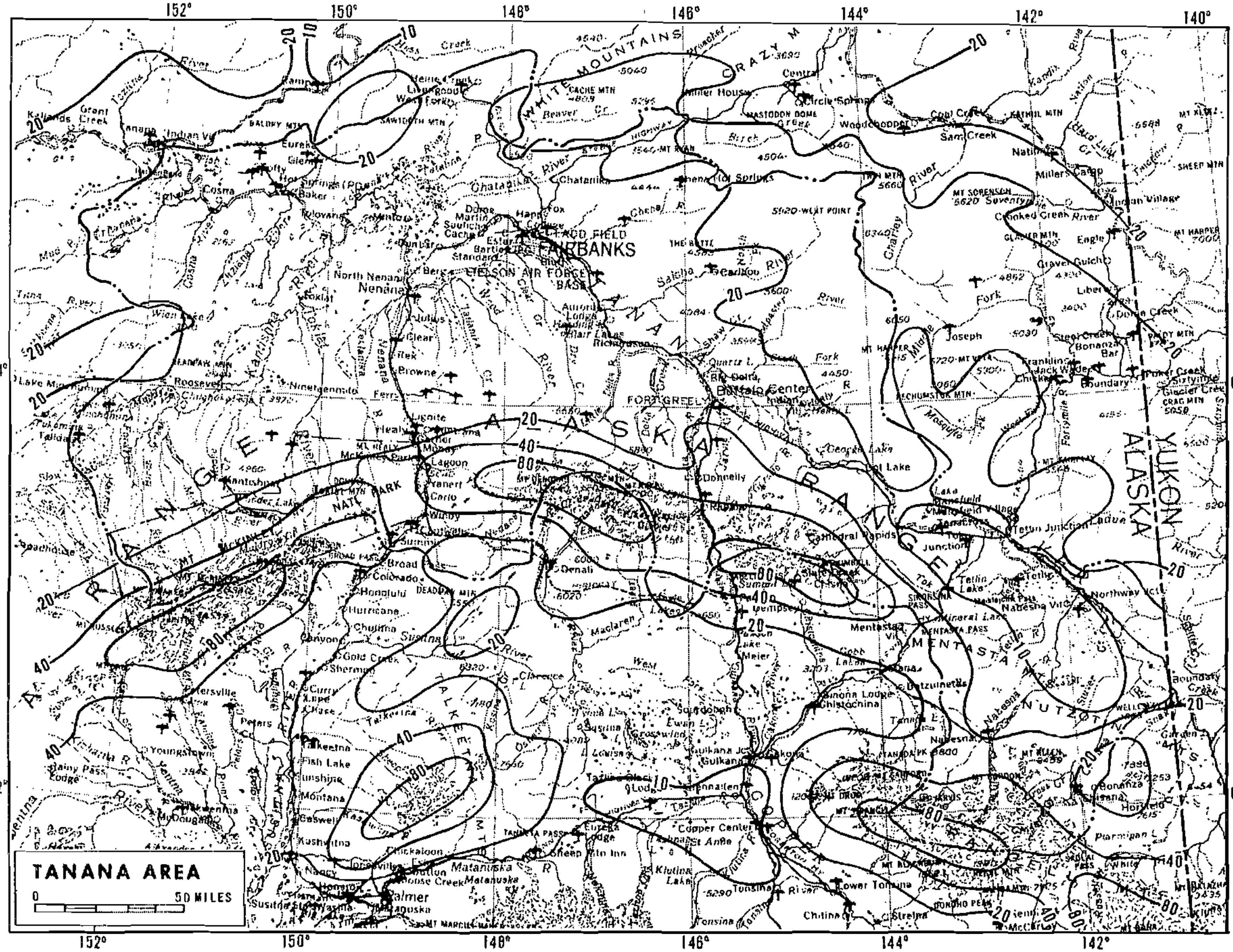

NORTON SOUND AREA
0
50 MILES
BERING SEA
NORTON SOUND
SEWARD PENINSULA
BERING STRAIT
KIGLUAIK MTS
BENDELEBEN MTS
DARBY MTS
ST LAWRENCE ISLAND
Gambell 15.8
NOME
Cape Prince of Wales
Cape Espenberg
Goodhope Bay
Point Spencer
Cape Douglas
Cape Woolley
Cape Rodney
Cape Darby
Cape Denbigh
Rocky Point
Port Safety
Unalakleet
Stuart I
St Michael
Pastol Bay
Pt Romanof
Cape Dezhnev
Cape Nunyagmo
Cape Krigugon
Cape Nygligan
Little Diomede
Big Diomede I
US RUSSIA CONVENTION OF 1867
USSR
UNITED S
YUKON
172°
170°
168°
166°
164°
162°
160°
66°
64°

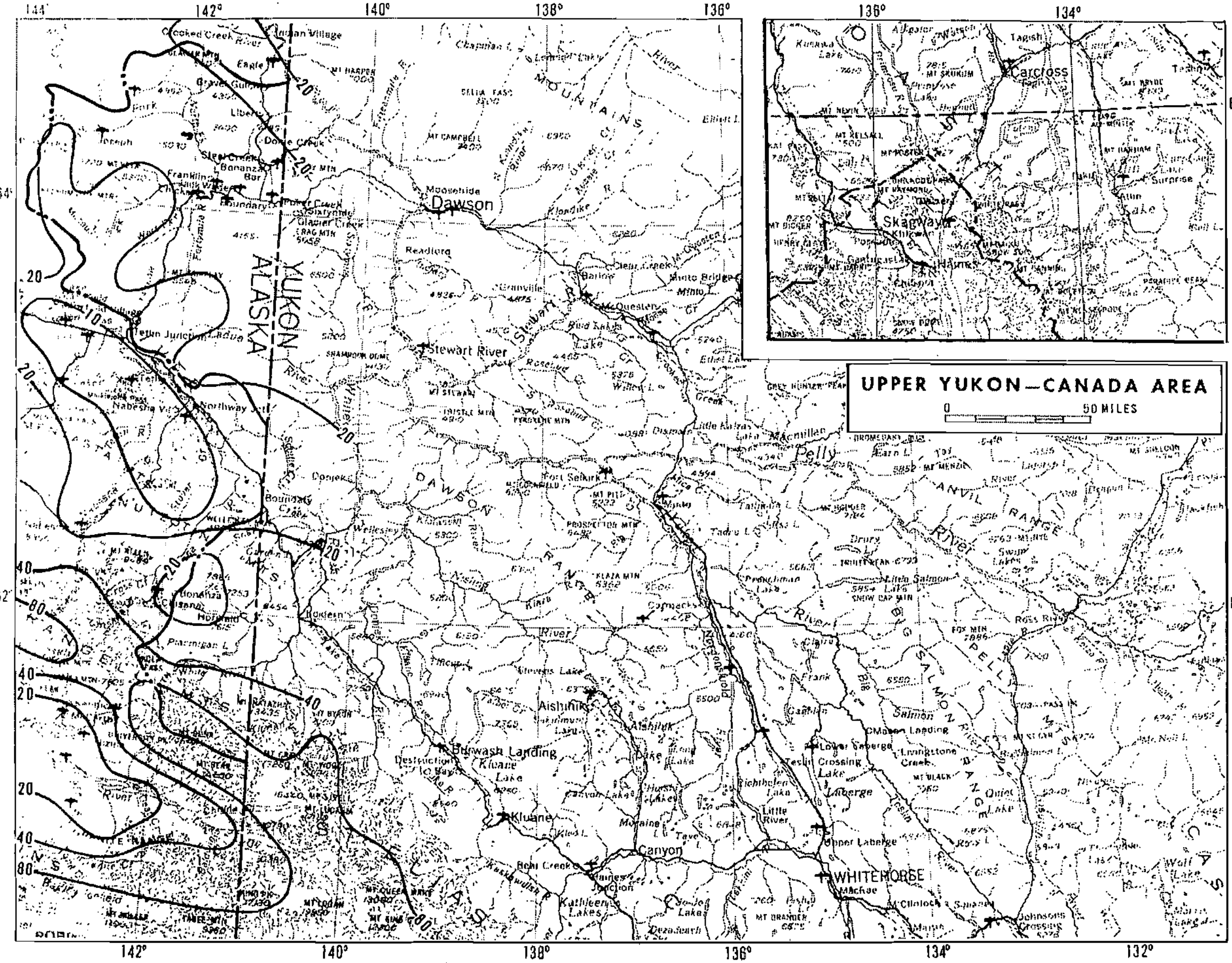

LOWER YUKON AREA
0 50 MILES
NORTON SOUND
BERING SEA
NOME
Norton Bay
Cape Denbigh
Stuart I.
St Michael
Tolstoi Pt.
Unalakleet
Pastol Bay
Pt Romanof
KAIYUH MOUNTAINS
YUKON RIVER
KUSKOKWIM RIVER
BEAVER MTS
TAYLOR MTS
KILBUCK MTS
RUSSIAN MTS
Nelson Island
Baird Inlet
Hazen Bay
Bethel
McGrath
Holy Cross
Russian Mission
Anvik
Shageluk
Crooked Creek
Georgetown
Sleetmute
Stony River
Flat
Iditarod
Ophir
Takotna
Kaltag
Cape Romanzof
Cape Vancouver
Nunivak
168°
166°
164°
162°
160°
158°
156°
64°
62°
20

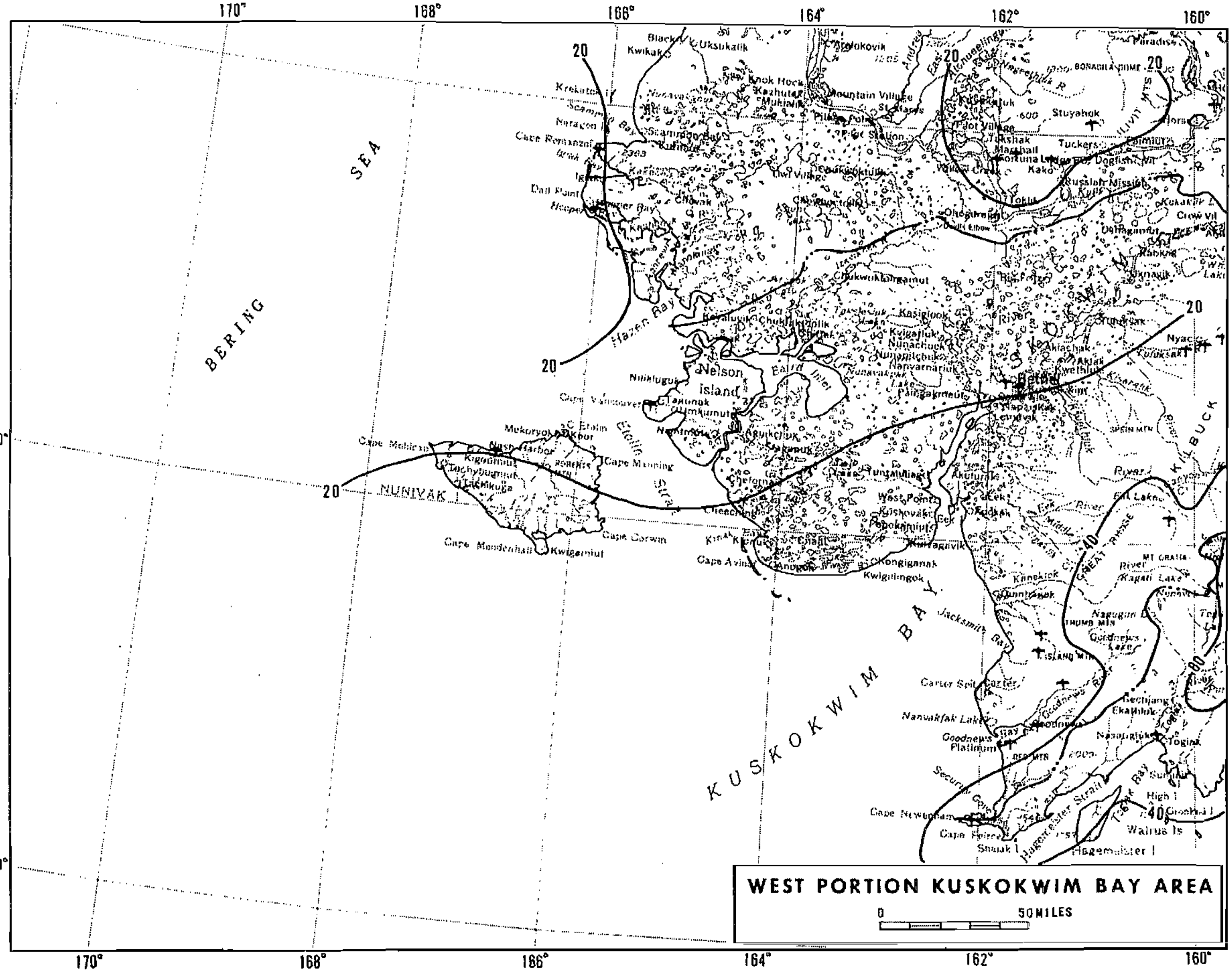

CENTRAL YUKON AREA
0
50 MILES
162°
160°
158°
156°
154°
152°
150°
66°
64°
ARCTIC CIRCLE
RAY MOUNTAINS
KOKRINES HILLS
KAIYUH MOUNTAINS
BEAVER MTS
YUKON RIVER
MT McKINLEY NAT'L PARK
Galena
Ruby
Nulato
Koyukuk
Tanana
Unalakleet
Hughes
McGrath
Nenana
Lake Minchumina
Kaltag
Poorman
Placerville
Takotna
Ophir
Moore Creek
Iditarod
Farewell
Medfra
Nikolai
Kantishna
Colorado
Honolulu
Hurricane
Hot Springs
Kokrines
Melozi
Long
Tanana
Hot Springs
Manley
Eureka
Nenana
Shageluk
Anvik
Holy Cross
Paradise
Kotlik
Alatna
Allakaket
Bettles
Selawik
Buckland
Koyuk
Golsovia
Egavik
Foothills RHC
Hay Rock
Dime Landing
Dikeman
Ganes Creek
Cloudy MTN
Folger
Cripple
Davenport
Ruby
Tolstoi
Gold Creek
Cantwell
Chulitna
Canyon
Rex
Browne
Ferry
Healy
Roosevelt
Wien Lake
Sterling Landing
Vinasale
Big River Roadhouse
East Fork Roadhouse
Telida
Tokotna
Cosna
Tolovana


KOYUKUK AREA
0 50 MILES
NOATAK
BAIRD MOUNTAINS
KOBUK
SCHWATKA MTS
WARING MTS
ENDICOTT MOUNTAINS
PHILIP SMITH
ARCTIC CIRCLE
RAY MOUNTAINS
KOKRINES HILLS
ZANE HILLS
KOYUKUK RIVER
YUKON
Anaktuvuk Pass
Chandler Lake
Walker Lake
Wild Lake
Wiseman
Nolan
Coldfoot
Bettles Field
Allakaket
Alatna
Hughes
Huslia
Koyukuk
Nulato
Galena
Ruby
Kokrines
Melozi Hot Springs
Tanana
Rampart
Stevens Village
Manley Hot Springs
Minto
Nenana
Kiana
Selawik
Buckland
Kaltag
Unalakleet
Shaktolik
Hot Springs
Long
Black Landing
Wien Lake
Lookout MTN
Hogatza
Indian River
Purcell MTN
Dall MTN
Caribou MTN
Tobin MTN
Nahtuk MTN
Survey Pass
Howard Pass
Mt Ooonerak
Mt Stuver
Chandalar Lake
Chandalar
162°
160°
158°
156°
154°
152°
150°
148°
68°
66°
10
20


UPPER YUKON AREA
0
50 MILES
150°
148°
146°
144°
142°
140°
138°
68°
66°
BROOKS RANGE
PHILIP SMITH MOUNTAINS
DAVIDSON MOUNTAINS
RICHARDSON MOUNTAINS
ARCTIC CIRCLE
YUKON
YUKON RIVER
PORCUPINE RIVER
WHITE MOUNTAINS
CRAZY MTS
OGILVIE MOUNTAINS
UNITED STATES
CANADA
Fort Yukon
Circle
Circle Springs
Central
Eagle
FAIRBANKS
LADD FIELD
EIELSON AIR FORCE BASE
Old Crow
Chandalar
Wiseman
Stevens Village
Beaver
Livengood
Chena Hot Springs
Woodchopper
Coal Creek
Chalkyitsik
Venetie Landing
Miller House
Anaktuvuk Pass
10
20
40

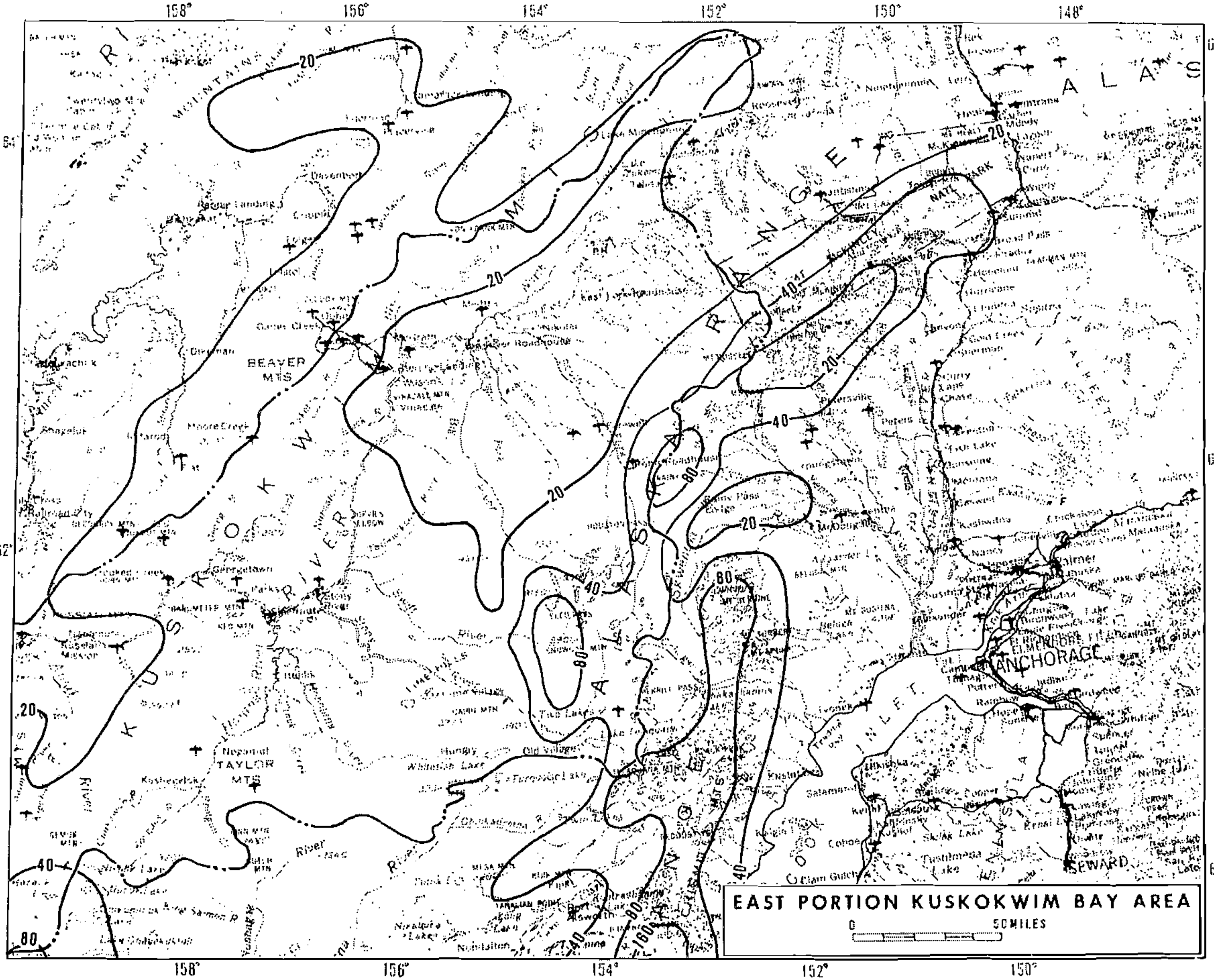

TANANA AREA
0
50 MILES
FAIRBANKS
WHITE MOUNTAINS
CRAZY M
ALASKA RANGE
MENTASTA
NUTZOTIN MTS
TALKEETNA MTS
COPPER R
YUKON
ALASKA
FORT GREELY
LADD FIELD
EIELSON AIR FORCE BASE
Nenana
Palmer
Matanuska
Copper Center
Tok Junction
Northway
152°
150°
148°
146°
144°
142°
140°
64°
62°

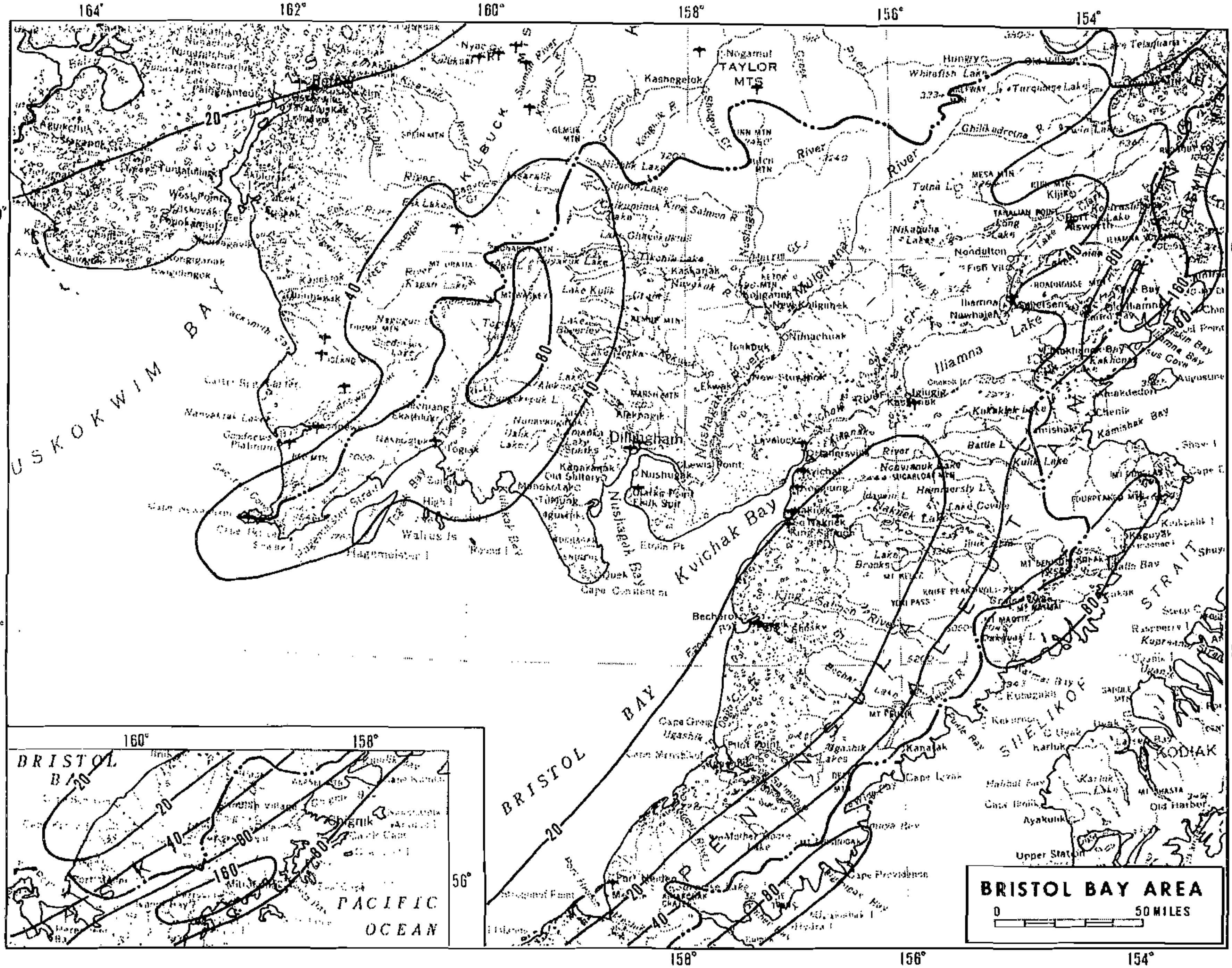

UPPER YUKON—CANADA AREA
0 50 MILES
YUKON
ALASKA
144°
142°
140°
138°
136°
134°
132°
64°
62°
60°
Dawson
Moosehide
Stewart River
Fort Selkirk
Carmacks
Aishihik
Burwash Landing
Kluane
Kluane Lake
Canyon
WHITEHORSE
Carcross
Skagway
Haines
Tagish
Pelly
MOUNTAINS
DAWSON RANGE
ANVIL RANGE
Northway
Tetlin Junction
Boundary
Eagle
Chicken
Readford
Granville
McQuesten
Mayo
Little River
Upper Laberge
Laberge
Lower Laberge
Teslin Crossing
Johnsons Crossing
Big Salmon
Ross River
Kathleen Lakes
Haines Junction
20
40
80

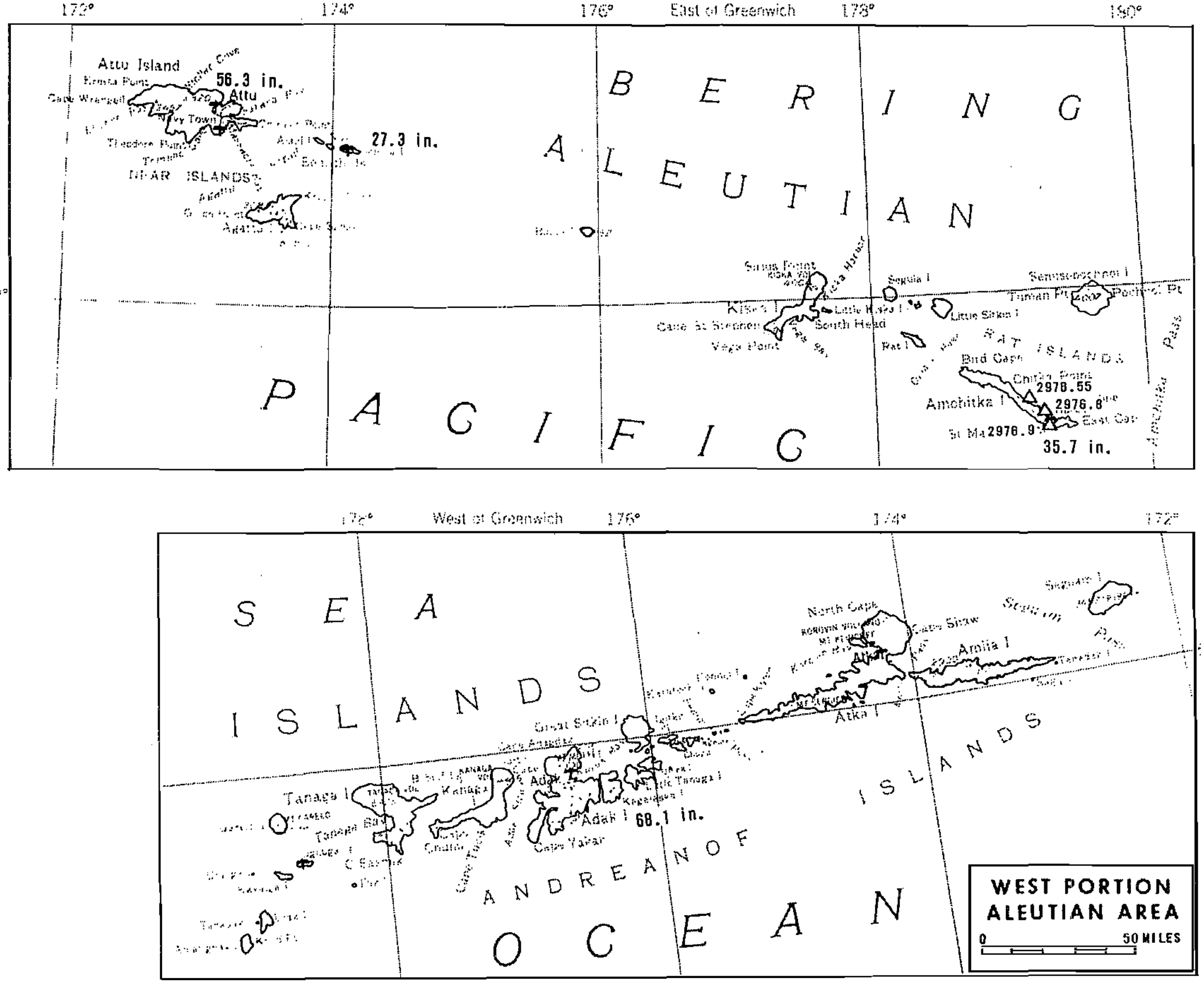


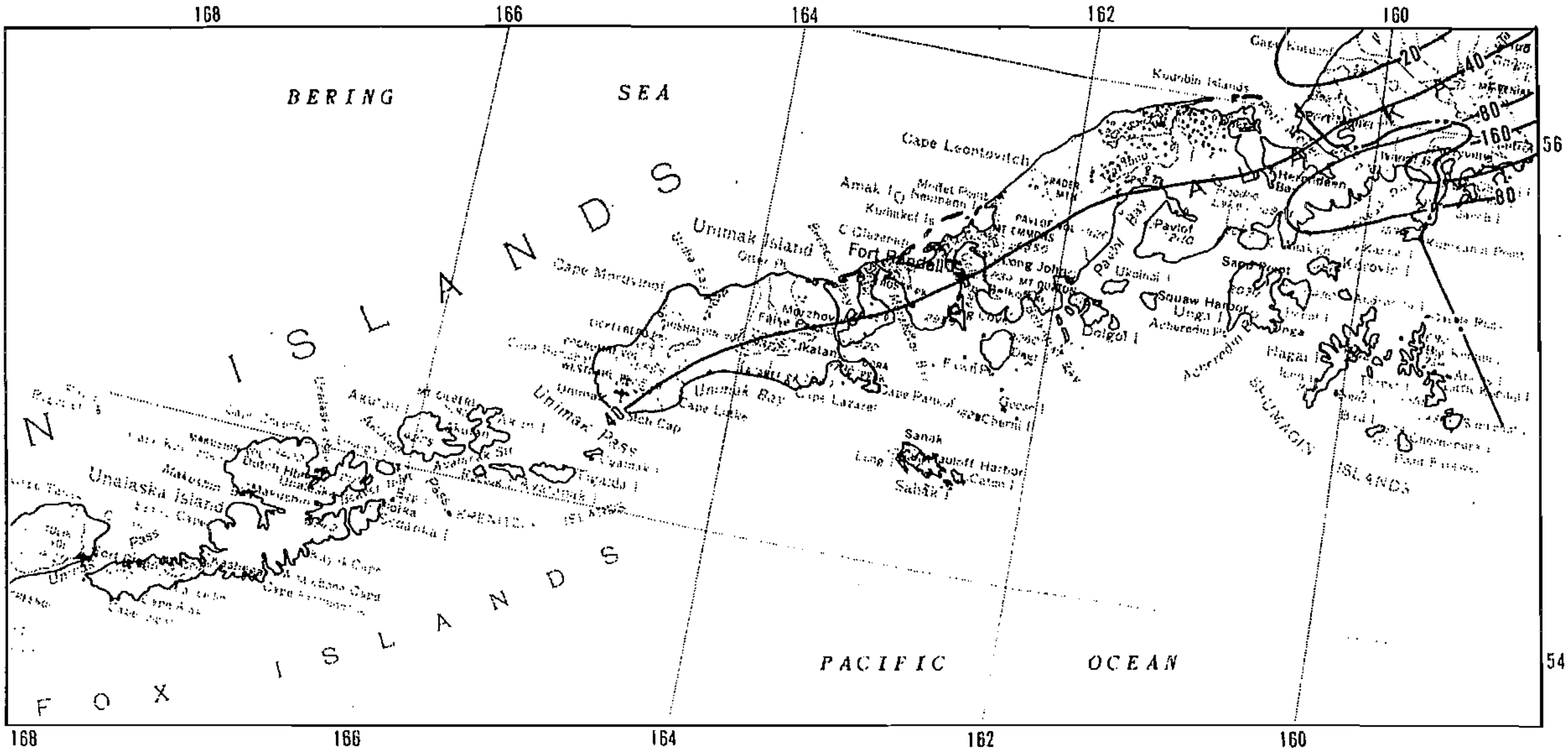
WEST PORTION KUSKOKWIM BAY AREA

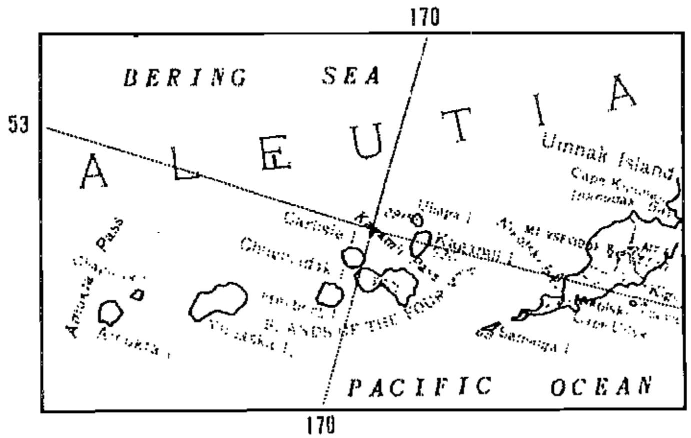
0 50 MILES

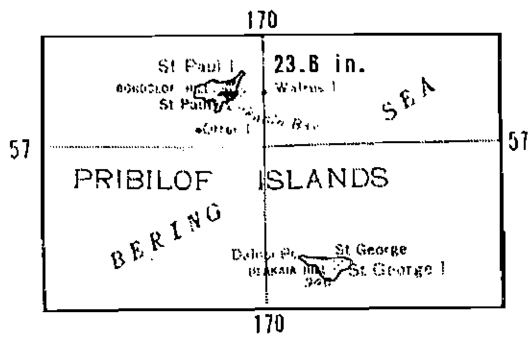

EAST PORTION KUSKOKWIM BAY AREA
0 50 MILES
158°
156°
154°
152°
150°
148°
64°
62°
60°
ANCHORAGE
SEWARD
BEAVER MTS
TAYLOR MTS
KUSKOKWIM RIVER
ALASKA RANGE
INLET
Palmer
20
40
80
160


BRISTOL BAY AREA
0
50 MILES
164°
162°
160°
158°
156°
154°
60°
58°
56°
TAYLOR MTS
KILBUCK
KUSKOKWIM BAY
BRISTOL BAY
Kvichak Bay
Dillingham
Iliamna Lake
Nushagak Bay
Walrus Is
Hagemeister I
SHELIKOF STRAIT
KODIAK
PACIFIC OCEAN
BRISTOL
Chignik
Upper Station
Old Harbor
Cape Providence
20
40
80
160


East of Greenwich
172°
174°
176°
178°
180°
BERING
ALEUTIAN
PACIFIC
Attu Island
56.3 in.
Attu
Navy Town
Theodore Point
NEAR ISLANDS
27.3 in.
Kiska I
Cape St Stephen
Vega Point
South Head
Little Kiska I
Segula I
Little Sitkin I
Rat I
RAT ISLANDS
Bird Cape
Amchitka I
2978.55
2976.8
2976.9
35.7 in.
East Cape
Tuman Pt
West of Greenwich
176°
174°
172°
SEA
ISLANDS
OCEAN
North Cape
Cape Shaw
Amlia I
Atka
Atka I
Great Sitkin I
Tanaga I
Tanaga Bay
Kanaga I
Adak
Adak I
68.1 in.
Cape Yakak
Kagalaska I
Little Tanaga I
ANDREANOF
ISLANDS
WEST PORTION
ALEUTIAN AREA
0
50 MILES

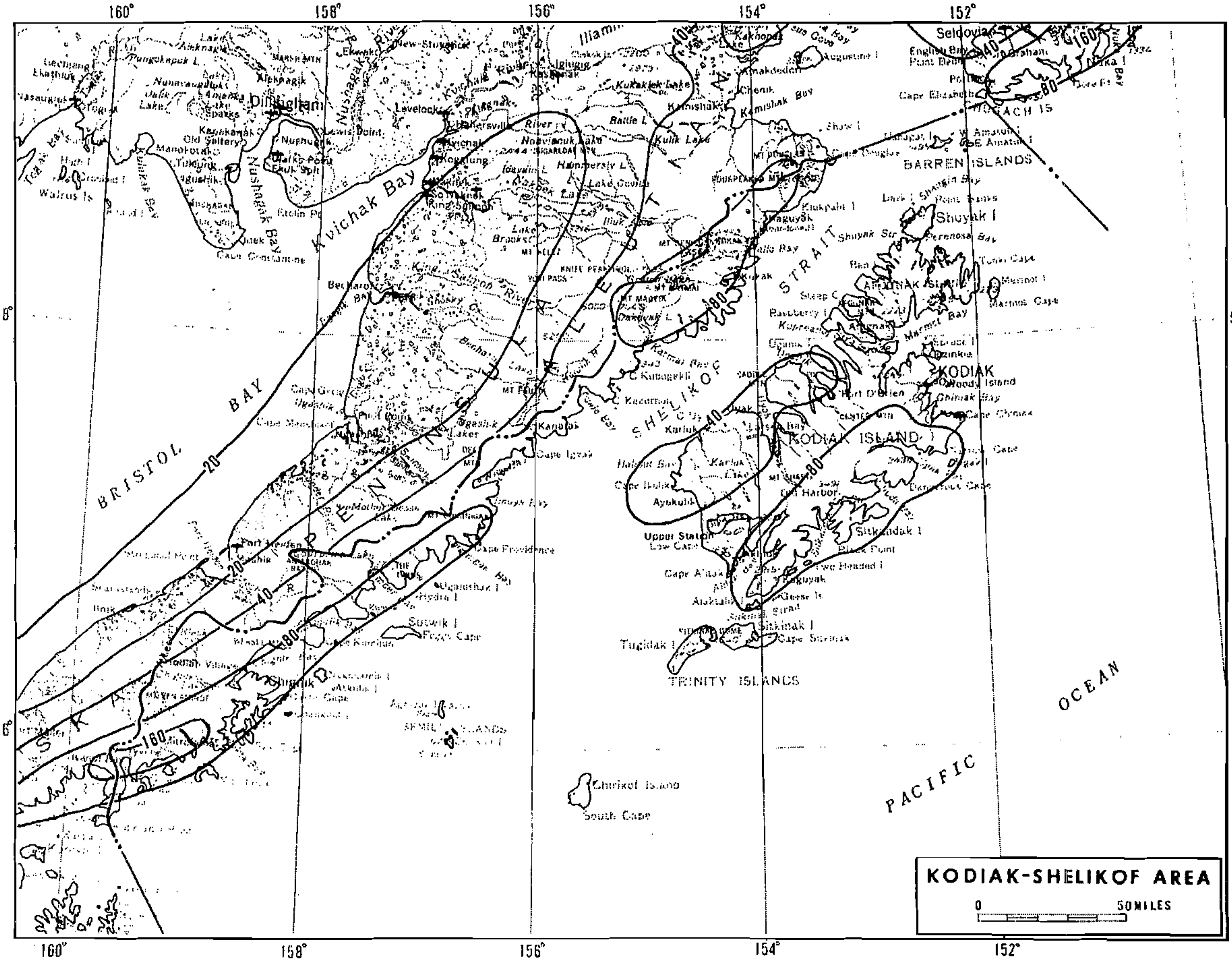




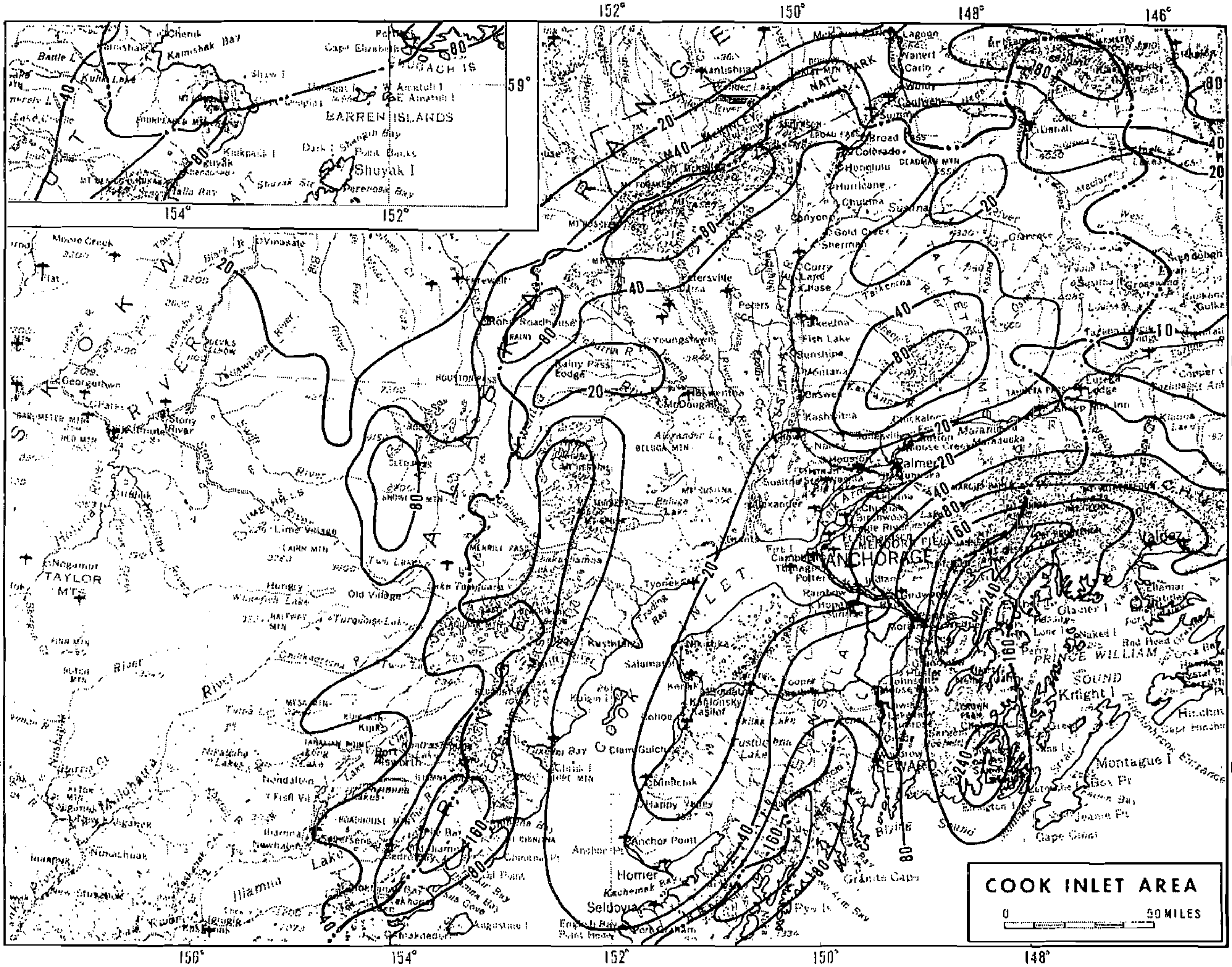


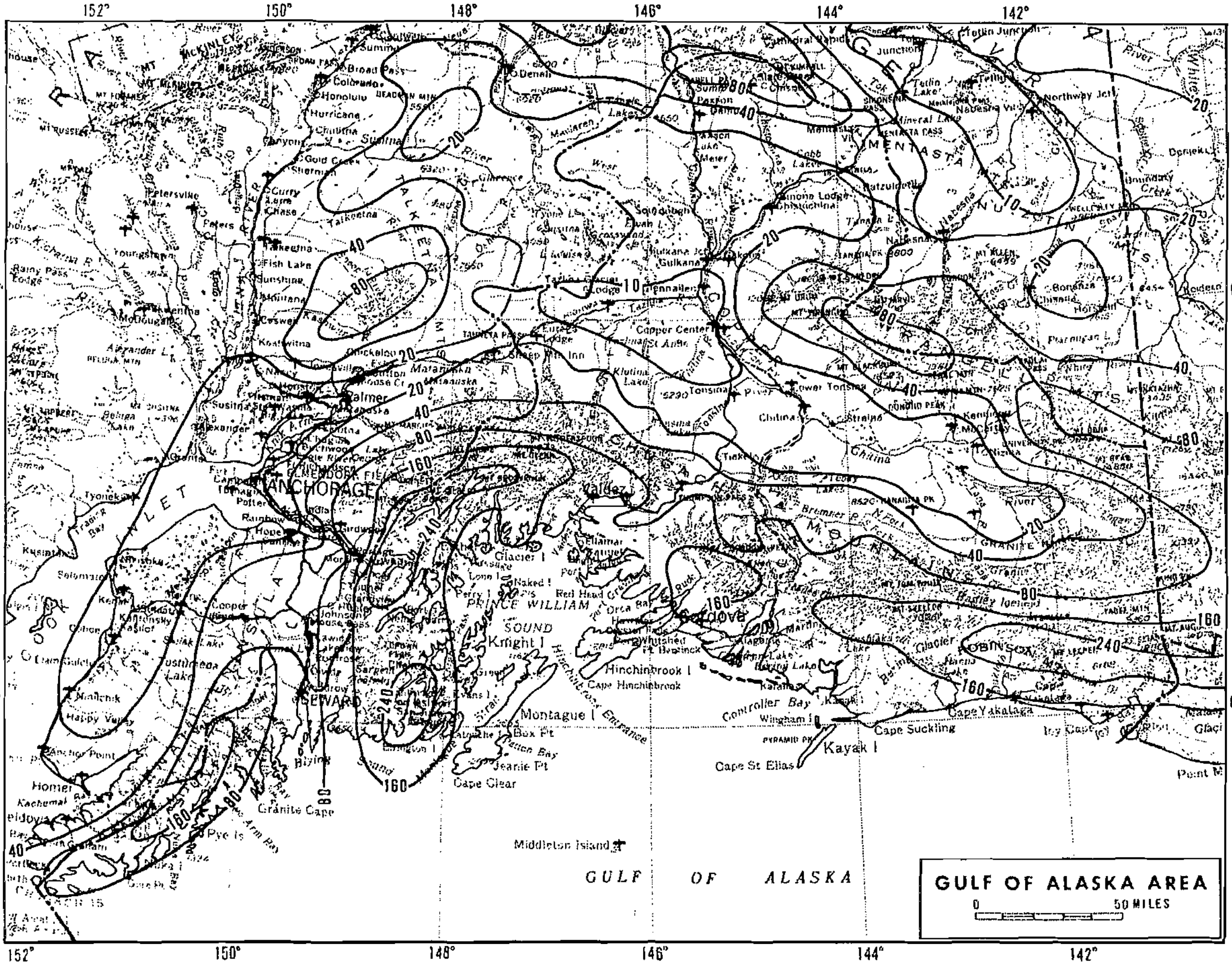
**EAST PORTION
ALEUTIAN AREA**

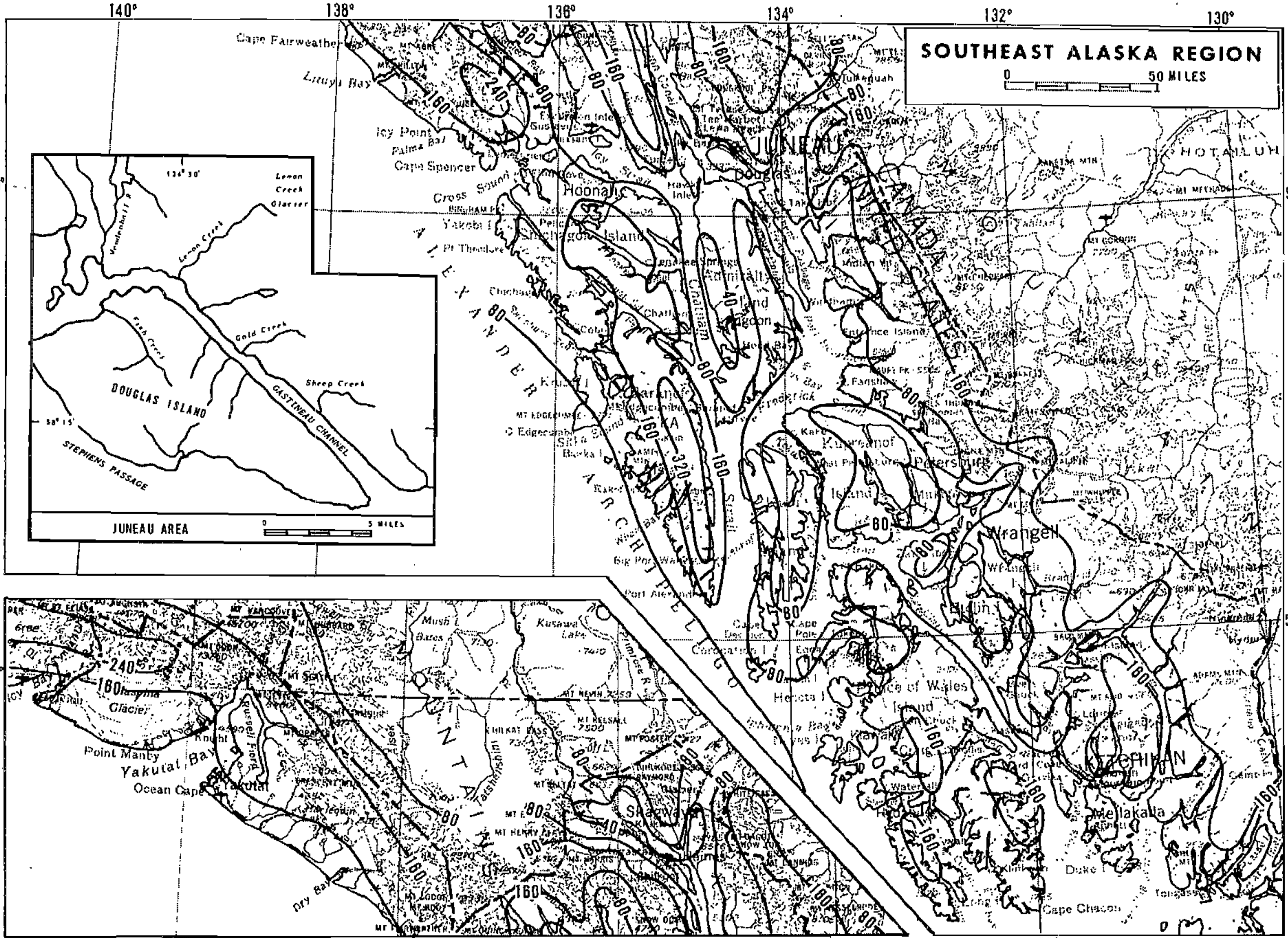
0 50 MILES



KODIAK-SHELIKOF AREA
0
50 MILES
160°
158°
156°
154°
152°
58°
56°
BRISTOL BAY
Kvichak Bay
SHELIKOF STRAIT
KODIAK ISLAND
KODIAK
TRINITY ISLANDS
BARREN ISLANDS
PACIFIC OCEAN
Dillingham
Seldovia
Shuyak I
Tugidak I
Chirikof Island
South Cape
Sitkinak I
Sitkalidak I
Afognak
Naknek
Port Heiden
Cape Providence
Ugashik
Kulik Lake
Iliamna
Kamishak
Kamishak Bay
Nushagak Bay
Walrus Is
Upper Station
Karluk
Ayakulik
Old Harbor
Woody Island
Chiniak Bay
Cape Chiniak
Alitak
20
40
80
160
180


COOK INLET AREA
0
50 MILES
152°
150°
148°
146°
154°
156°
59°
62°
60°
BARREN ISLANDS
Shuyak I
ANCHORAGE
Palmer
Valdez
Homer
Seldovia
Anchor Point
PRINCE WILLIAM
SOUND
Knight I
Montague I
Iliamna
TAYLOR
MTS
INLET
Cape Elizabeth
Kamishak Bay
Hinchinbrook Entrance


GULF OF ALASKA AREA
0 50 MILES
GULF OF ALASKA
PRINCE WILLIAM SOUND
ANCHORAGE
Valdez
Cordova
SEWARD
Palmer
Knight I
Montague I
Hinchinbrook I
Kayak I
Middleton Island
Cape St Elias
Cape Suckling
Cape Yakataga
Controller Bay
Homer
Granite Cape
Cape Clear
152°
150°
148°
146°
144°
142°
62°
60°


SOUTHEAST ALASKA REGION
0
50 MILES
JUNEAU AREA
0
5 MILES
DOUGLAS ISLAND
GASTINEAU CHANNEL
STEPHENS PASSAGE
Lemon Creek Glacier
Lemon Creek
Gold Creek
Sheep Creek
Fish Creek
ALEXANDER ARCHIPELAGO
Cape Fairweather
Lituya Bay
Icy Point
Cape Spencer
Cross Sound
Hoonah
Yakobi I
Chichagof Island
Pt Theodore
Admiralty Island
Juneau
Douglas
Kuiu I
Kupreanof Island
Petersburg
Wrangell
Prince of Wales Island
Ketchikan
Metlakatla
Duke I
Cape Chacon
Port Alexander
Coronation I
Heceta I
Point Manby
Yakutat Bay
Yakutat
Ocean Cape
Dry Bay
Glacier
Russell Fiord
Mush L
Kusawa Lake
Skagway
140°
138°
136°
134°
132°
130°
58°
56°
60°
240
160
80
40
320