Alaska Habitat Management Guide

Guidelines for the Protection of Fish and Their Habitat

Produced by
State of Alaska Department of Fish and Game
Division of Habitat

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Many individuals have been involved in the production of this volume. All narratives were reviewed first by project staff, then by staff within the Division of Habitat. Most sections were also reviewed by specialists within other divisions. The names of reviewers and other contributors are compiled in appendix A.

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The process of developing the initial plan and procedures for this project involved a number of individuals who are not otherwise listed as authors and contributors. These include many of the staff within the Division of Habitat, as well as planners and research and management coordinators of other divisions. This group also includes all project team members and all ADF&G regional supervisors. Special mention should be made of the support from Alvin G. Ott, Richard Reed, Lance Trasky, and Carl Yanagawa, Regional Supervisors of the Division of Habitat for Interior - Arctic, Southeast, Southwest and Southcentral regions, respectively. We would also like to acknowledge the many contributions of John A. Clark, who was Director of the Division of Habitat until his death in 1985.

General Introduction

OVERVIEW OF THE HABITAT MANAGEMENT GUIDES PROJECT

Background

Alaska is an immense and bountiful frontier, and until recently it was almost inconceivable that we would ever need to worry about its capacity to sustain the wealth of fish and wildlife resources for which it is renowned. But the impetus of progress has not abated, and the pressure to develop our lands and waters intensifies daily. Every year more lands in Alaska are being proposed for uses other than as wildlife habitat, especially around cities, towns, and villages. These proposed uses include logging, mining, agriculture, settlement, and geothermal, oil and gas, and hydroelectric projects, among others. As the number of proposals and plans for development continues to increase, so does the need to carefully and efficiently evaluate their possible effects upon species and habitats, and upon human use of species. Once these evaluations have been completed we can recommend viable managerial options to guarantee that our valuable fish and wildlife resources and habitats, and uses of these fish and wildlife resources are adequately protected and maintained. By using appropriate planning and managerial techniques most of the potential for damage to fish and wildlife resources and loss of human use of these resources can be avoided.

One of the responsibilities of the Alaska Department of Fish and Game (ADF&G) is to assist land managers by recommending to them the best ways and means, based upon the best available data, for protecting fish and wildlife resources and human use of these resources against impacts. Because many proposals and plans for development and land uses require a rapid response from the department, there may not be enough time for staff to actually study the specific area in which the proposed development is to occur. However, the department still needs to accumulate and assess a wide variety of information in order to prepare recommendations for managing habitat. Therefore, the department initiated the Alaska Habitat Management Guides (AHMG) project to prepare reports of the kinds of information upon which its recommendations must be founded in order to responsibly and rapidly address land and water use proposals made by land managers.

Purpose

The Alaska Habitat Management Guides (AHMG) present the best available information on selected fish and wildlife species: mapping and discussing their geographical distribution; assessing their relative abundance; describing their life functions and habitat requirements; identifying the human uses made of them; describing their role in the state's economy; determining the impacts of human land uses and developments on these species; and developing guidelines to avoid or minimize such impacts.

Essential to assessing what might happen to fish and wildlife if their habitats are altered is information about what impacts are typically associated with particular kinds of developmental activities. The habitat management guides therefore also provide summaries of these known impacts. This information, in conjunction with compiled species life history and distribution information, will allow those concerned to estimate to what degree fish and wildlife species and habitats are liable to be impacted and to develop recommendations for the avoidance or minimization of such impacts.

The completed guides coverage of fish and wildlife resources encompasses the Fish and Game Resource Management Regions established by the Joint Board of Fisheries and Game (map 1). These regions provide the most inclusive and consistent format for presenting information and fish and wildlife resources and relating it to management activities and data collection efforts within the department.

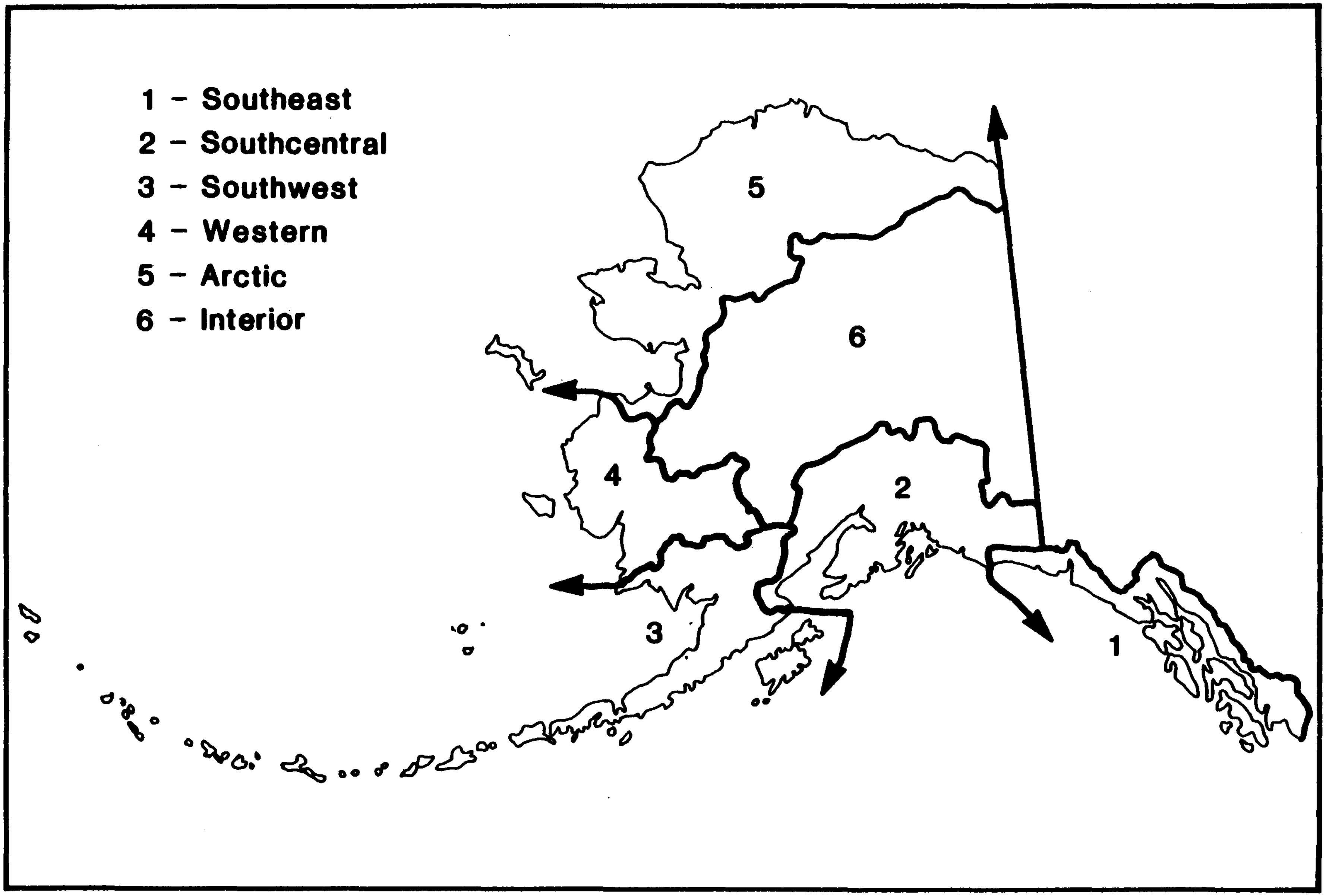
Applications

The choice of the term "guides" rather than "plans" for the reports is consistent with the largely advisory role of the department with respect to land management issues. The guides will provide the department as well as other state, federal, and private land managers with information necessary for the development of land and water use plans. Thus, the guides themselves are not land management plans, and neither do they provide for the allocation or enhancement of fish and wildlife populations. Information included in the guides will be used by the department's staff during their involvement in the land use planning endeavors of various land managers. For specific land use planning efforts, the department joins with other agencies to recommend particular uses of Alaska's lands and waters, as, for example, in plans by the Department of Natural Resources (Susitna Area Plan, Tanana Basin Area Plan, Southeast Tidelands Area Plan). The public, by means of the public review that is an integral part of land management agencies' planning processes, then has an opportunity to evaluate any recommendations made by the ADF&G that are incorporated by the land management agency.

The guides have been designed to provide users with interrelated subject areas that can be applied to specific questions regarding habitat management. Each type of data will be presented in a separate volume, as indicated in figure 1. Material from the project's database can be used, for example, to correlate information on species' seasonal and geographic habitat use with the written and mapped information on known distribution and abundance. The narratives and maps regarding human uses of fish and wildlife can be compared with abundance and distribution information to obtain an indication of the overall regional patterns of distribution, abundance, and human use for the species of interest. The specific information on habitat requirements also relates directly to the information on impacts associated with land and water use. This in turn forms the basis for the preparation of habitat management guidelines.

An additional purpose of this project is to identify gaps in the information available on species, human uses, and associated impacts. A particular species, for example, may be known to use certain habitats during certain seasons; yet information on the timing of these use patterns may be inadequate. In general, there is little documentation of impacts from land and water uses on species' habitats and on the human use of those species, or on the economic values associated with the use of fish and wildlife resources.

To maintain their usefulness these habitat management guides are designed to be periodically updated as new research and habitat management options are reported to fill data gaps. However, users of these guides are advised to consult with the appropriate species experts and area biologists to check on the availability of more recent information.



Map 1. The six regions of the Alaska Habitat Management Guides.

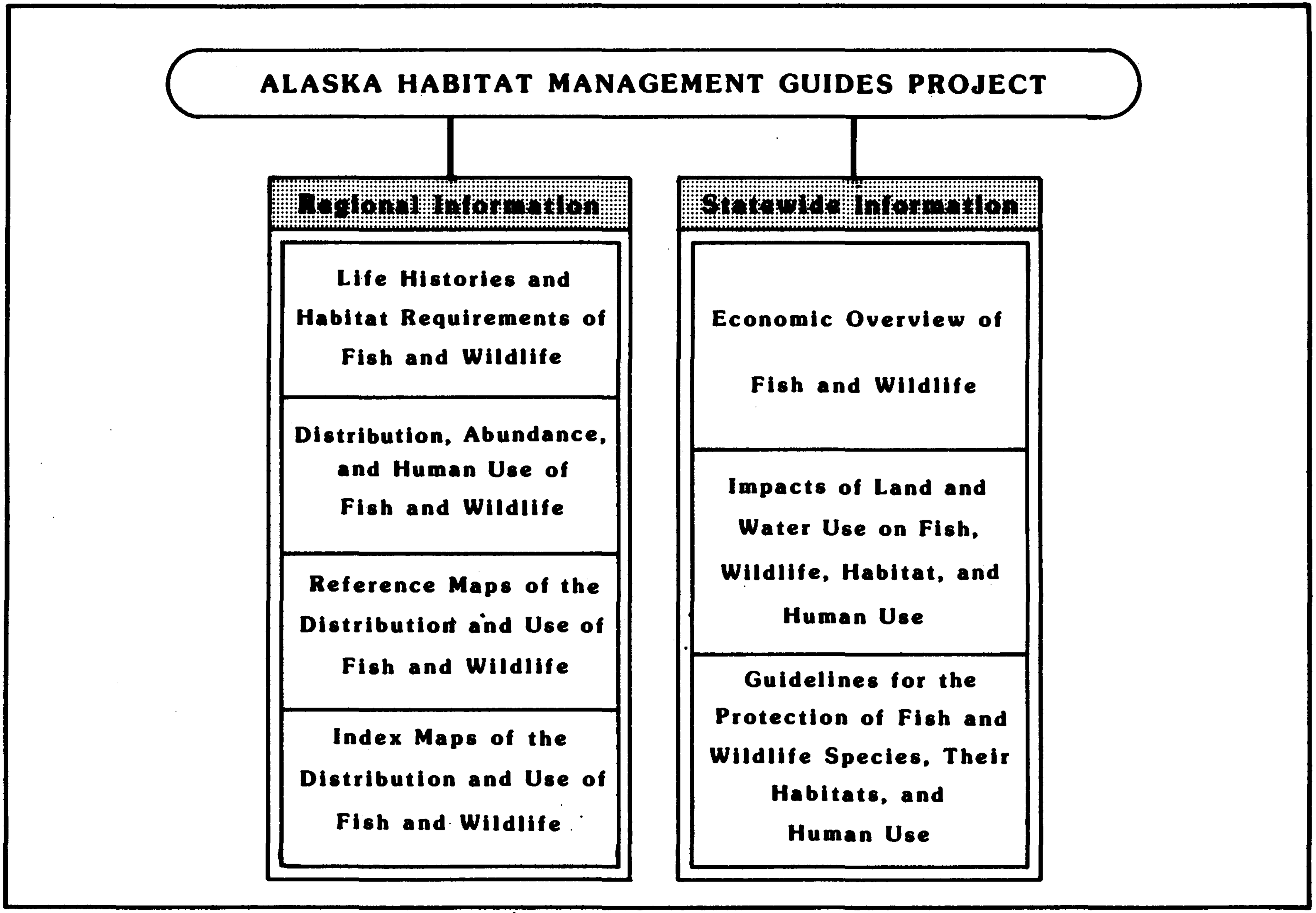


Figure 1. Types of narratives and maps produced by the Alaska Habitat Management Guides Project.

INTRODUCTION TO THIS VOLUME

Purpose

A primary purpose of the Alaska Habitat Management Guides is to provide information that is useful in preparing land management recommendations or requirements that will mitigate the impacts of land and water uses and types of development on fish and wildlife species and their habitats and on human use of those species. Toward that end, this volume contains options that have been developed to maximize the protection of aquatic resources (biota and their habitats). The basis for the options is found in the department's 1982 Statement of Policy on Mitigation of Fish and Game Habitat Disruptions. This document states that "the overall goal of the Department of Fish and Game is to maintain or establish an ecosystem with the project in place that is as nearly desirable as the ecosystem that would have been there in the absence of the project."

It should be emphasized that the managerial alternatives presented here do not exist in isolation from the other products of the Alaska Habitat Management Guides project. On the contrary, these options should be considered in context of the body of information compiled in the volumes of narratives and maps covering the life histories and habitat requirements, distribution, and relative abundance of species, the human uses made of them, and --- especially --- the survey of documented impacts. These data should be used in conjunction with existing guidelines and the managerial options provided in this volume to generate appropriate recommendations applicable to a specific proposal, such as a land management plan or a permit for a development project. In sum, then, although these alternatives have undergone numerous technical reviews within the department (see appendix A) they are not to be regarded as in themselves statements of department policy. The department may, however, elect to incorporate one or another of them into specific policy statements in response to a given land use issue.

In order to effectively formulate habitat management options, the source documentation must be objective and reliable. Accordingly, for the purpose of this document, literature sources were limited to studies that specifically document at least one impact to the aquatic biota and/or their habitat resulting from some form of human development. In some instances, review articles were used as a means of reducing unnecessary duplication of effort if they were judged to be objective reviews of documented impacts literature. Literature relating only to potential impacts was not included.

For each developmental activity for which habitat management options were written, there was an attempt to translate the current body of documented impacts literature (pertinent to Alaska) into recommendations that accurately reflect both the state of completeness and the level of specificity present within the literature database. For this reason, there are necessary variations in the degree of resolution among these alternatives pertaining to different topics. References to all source documents are provided here, and annotations to source documents are provided in the companion impacts volume (ADF&G 1986). Additionally, each document is on file in the ADF&G Habitat Library.

Organization

The five sets of impact summaries and habitat management options, or guidelines, presented in this document are organized by type of activity: 1) Channelizing Waterways, 2) Clearing and Tree Harvest, 3) Filling and Pile-supported Structures (Aquatic and Wetland Habitats), 4) Grading and Plowing, and 5) Processing of Minerals. These five activities were selected from among the 30 defined activities on the basis of solicited input from each of the regional supervisors in the Division of Habitat. A list of activities is provided in appendix B. For descriptions of each activity, see part 1 of the impacts volume (ADF&G 1986). With few exceptions, the internal organization of the five guidelines is the same. Minor differences were included to better accommodate differences in the respective literature databases. Details are provided in the respective sections.

Each of the guidelines is comprised of four parts: 1) a definition of the activity, 2) general considerations that are relevant to that activity, 3) environmental impacts associated with the activity, and 4) guidelines that are derived from the impacts section. In some instances, the definition of the activity includes a broader scope than was possible to address here. Where this occurs, the nature of the difference is clearly stated.

The considerations section includes a broad range of physical, biological, and, to a lesser extent, practical topics that should be addressed whenever plans include the activity. They form a checklist of topics and issues that is intended to aid users in the process of making decisions on a particular proposal or plan. The considerations are presented as questions that the user should answer before preparing recommendations on a proposed activity.

The impacts and guidelines sections are presented independently but comprise a single conceptual unit. The impacts section provides the data from which the habitat management options are derived. The impacts section is intended to include representative literature for all major impacts associated with a particular activity. However, it does not necessarily include all pertinent references on topics for which the database is extensive. The primary organizational structure of the impacts section is by major taxonomic groups (freshwater salmonids, freshwater nonsalmonids, marine fish, and marine shellfish). These groups were primarily selected to correspond with the departments' responsibility to manage the state's resources. Several papers that presented deleterious impacts to aquatic habitats with no reference to a specific taxon and/or activity were assigned to the most appropriate heading(s). The impact categories identified in this section are a subset of the ones previously identified in ADF&G (1986). They are provided in appendix C. Explanations of abbreviations that are used in the text are provided in appendix D.

As previously noted, the guidelines section is based on the documented information presented in the impacts section and is therefore only as complete and specific as the available information permitted. The references upon which guidelines are based are identified in each guideline. Where the term "derived from" appears in a citation, it indicates that the stated guideline was deduced from a particular reference or number of references but that the reference source(s) did not explicitely formulate that statement.

Some of these management options may be too general to be of practical value for permitting purposes. In these situations, it is recommended that currently used guidelines or policy continue to be followed. However, in areas where the alternatives presented here offer greater resolution to guidelines currently used, we recommend that users adopt these new management options. The information is presented in two forms:

1) Where documentation clearly indicates that alterations of habitat components adversely affect aquatic biota (especially anadromous fish) or their habitat, guideline statements are presented that recommend "avoiding" such alterations. The wording is formulated to afford maximum protection and is usually less specific than the second type.
2) In light of the fact that avoidance of some recommendations may not be possible because of factors unrelated to resource concerns, additional literature-derived options are presented to help minimize and/or mitigate loss of aquatic resources.

Additional details pertaining to specific activities are provided in the introductory information within each of the five impact summaries and guidelines that follow.

Impact Summaries and Guidelines

CHANNELIZING WATERWAYS

I. DEFINITION

Channelizing Waterways refers to the modification of a stream, river, canal, or other flowing watercourse for the purpose of realigning the flow of water. Channelizing generally results in the physical alteration of bottom substrate, channel geometry, or configuration. Modifications generally include one or more of the following: 1) widening or deepening the channel, 2) installing structures (e.g., dikes or bank stabilization structures), 3) removing structures (e.g., snags or large debris), 4) eliminating channel meanders, 5) creating uniform substrate conditions, or 6) creating a new stream channel (e.g., diversion ditches for irrigation or other purposes). Closely associated activities not included under Channelizing Waterways are the excavation of substrate materials for the purpose of maintaining water transportation routes and boat harbors (see Dredging), the installation of dikes, gabions, jetties, etc., in estuarine environments (see Filling and Pile-supported Structures of Aquatic and Wetland Habitats), and construction of low-water crossings (see Stream Crossings-Fords).

The following is an attempt to translate the current body of documented impacts resulting from channelizing activities into guidelines for habitat management that accurately reflect both the state of completeness and the level of specificity present within the literature database. Literature presented here consists primarily of original documented impact sources. However, a limited number of high-quality review papers that were judged to be objective reviews of documented impacts literature are also included. These include Little (1973), Hill (1976), Simpson et al. (1982), Stern and Stern (1980), Shields (1982), Shields and Palermo (1982), and Thackston and Sneed (1982).

II. IMPACT CATEGORIES

Channelization of natural waterways has been a common practice in the continental United States since the turn of the century. Little (1973) estimated that by 1972, over 200,000 mi of stream channel had been modified in the United States. In many areas in the midwest, channel modifications converted meandering streams and swampland into straight, hydrologically efficient channels, totally eliminating natural aquatic habitat. In the state of Iowa, Bulkley (1976) estimated that somewhere between 1,000 and 3,000 mi of stream has been eliminated. Fortunately, the trend of channelizing long reaches of river has dramatically declined over the past two decades, probably due to economic as well as ecological reasons.

Currently, channelizing activities in Alaska, as well as in the continental United States, are primarily associated with mining (e.g., water diversions and/or dredging), road-building activities (e.g., channel realignment or relocation), or community development (e.g., bank stabilization). In general, these uses involve relatively shorter reaches of stream than those historically modified for agricultural or flood control purposes. This presents the resource manager with a dilemma. Because the immediate loss or damage to aquatic habitat may be perceived as small compared to the enormity of other project considerations, the loss to the resource may be deemed justifiable. Over time, however, this process of decision-making contributes to the progressive and incremental loss of aquatic resources and may collectively result in major adverse effects to aquatic resources.

The impact categories identified in this section differ from the list of defined impacts identified in the companion volume entitled Impacts of Land and Water Use on Fish and their Habitat (ADF&G 1986). Three interrelated impact categories that were previously identified as the addition, removal, and physical disturbance of substrate materials have been combined and included here as a single category entitled Changes in Levels of Turbidity, Settleable Solids, or Substrate Stability. Also, an additional impact category is included that was not previously defined entitled Change in Amount of Aquatic Habitat. This category accommodates literature that involves the elimination of habitat that often results from channelizing activities.

The following impacts were found to be associated with the activity Channelizing Waterways:

- General changes to fish populations
- Change in amount of aquatic habitat
- Change in water temperature
- Change in depth or velocity of water
- Change in level of turbidity, settleable solids, or substrate stability
- Alteration of natural cover - riparian vegetation, aquatic vegetation and debris, and overhanging bank or shoreline
- Change in level of dissolved oxygen
- Change in levels of pH, alkalinity, or hardness
- Change in level of heavy metals
- Introduction or removal of species

III. CONSIDERATIONS

The following considerations should be taken into account whenever channelizing activities are proposed. The list is modified from Wesche (1985).

A. Biological

1. What species/life stages of fish are present in the drainage system during the year?
2. What are the habitat needs and preferences of these species/life stages?
3. Does the time of alteration coincide with critical periods of migration, spawning, incubation, overwintering, or rearing of fish?
4. What types of natural habitat exist in presently altered stream sections (i.e., pool, riffle, cover, spawning, etc.)?
5. Will disruption or loss of a particular habitat type adversely affect any species or life stage of fish?
6. Will instream cover, bank undercuts, or riparian cover be diminished?
7. Are there any chemical constituents of the substrate material that, as a suspended sediment, may adversely affect fish or their prey?

8. Will channelization connect existing waterbodies, which may result in an exchange of previously isolated fish stocks?
9. How can the characteristics of the natural habitat best be preserved?

B. **Hydraulic**

1. What are the shape and dimensions of the channel?
2. What is the natural meander pattern and slope of the reach?
3. What are the shape and dimensions of the normal hydrograph through the stream reach?
4. What are the extremes of flow in the channel over a several year period of record?
5. What are the probabilities of occurrence of various magnitudes of flood and low flows?
6. What is the natural pool-riffle ratio?
7. What is the spacing between successive pools and successive riffles?
8. What is the composition of the stream bed sediments and the stream banks?
9. What hazards to habitat quality (e.g., gully erosion, bank erosion, channel aggradation, or channel degradation) need to be taken into consideration in the project design?
10. Will bank stabilization measures be necessary to control erosion?
11. Considering the size composition of the substrate and water velocity, what is the mobility of the stream bed sediments?
12. Is the stream bed capable of enough scour to form pools, or should structures be designed and installed to accomplish this?
13. What effect will various types of reclamation structures have on channel roughness and the conveyance capacity of the channel?
14. Based upon the flood frequency analysis, what forces should structures (if installed) be designed to withstand?
15. Will the project affect the soil-water relationship between the stream and the riparian zone?
16. Will loss of riparian vegetation significantly affect water temperature (particularly in winter) or carbon/ nutrient inputs into the stream?
17. Will revegetation be required along stream banks?
18. Given the type and condition of the stream bank soils and plant species, what will be the best revegetation plan?
19. To achieve revegetation, will artificial methods such as irrigation, fertilization, and fencing be required?

C. **Practical**

1. Is it possible to avoid or minimize adverse impacts by using special equipment or methods?
2. Given local climatic and hydrologic conditions and biological use patterns, when is the best time for installation?
3. What effects will various treatment options have on the aesthetics of the reach?
4. What effects will various treatment options have on recreational use of the reach?

IV. IMPACTS AND GUIDELINES RELATED TO CHANNELIZING WATERWAYS

In general, channelizing activities are highly detrimental to aquatic biota and their habitats. Whether streams are warm or cold, large or small, or are straight or meandering, the overriding pattern of change is much the same. Channelizing activities tend to decrease the stability and natural diversity of stream habitat. These habitat changes result in similar biological effects to fish communities regardless of stream type. Fish species diversity is often reduced, as are total numbers and standing stock of fish. The magnitude and length of time that a particular stream is destabilized and simplified is highly variable and depends on a variety of site-specific factors, such as the type of channelizing activity, stream characteristics, and biota present, as well as the geographic location and topographic factors.

Regardless of stream size or complexity, the same basic factors govern the natural balance of all streams (Hasfurther 1985). Geologic factors determine the overall soil characteristics and topography of an area, which in turn govern the stream gradient, sediment production, and meander characteristics. Hydrologic factors primarily influence variations in stream flow and overland runoff characteristics. These variables, in turn, are influenced by topography and climate, amount and type of vegetation, and soil infiltration rates. Hydraulic factors include stream depth, gradient, and velocity. In combination with hydrologic factors, these factors directly affect the erosive force of the stream and its sediment transport capability. Collectively, hydraulic factors govern basic channel geometry, such as cross-sectional shape, pool and riffle formation, and meander shape.

In contrast, to the relative stability of geologic and hydrologic factors, stream hydraulics and geometry are easily altered by mechanical means during channelizing activities. For example, a change in the depth, width, or meander pattern of the natural stream directly affects hydraulic characteristics, such as stream gradient and water velocity, which determine habitat characteristics in the stream. These changes in habitat trigger concomitant changes in the biological community as stream biota respond to the altered habitat.

A. Freshwater Salmonids

1. General changes to fish populations:

- Investigations of channelized reaches on six streams in Pennsylvania demonstrated that channelized reaches had lower numbers and total weight of trout than unaltered reaches (Duvel and Volkmar 1976).
- In the St. Regis River, Montana, trout standing stock in old channelized stream sections remained lower than standing crops in natural sections even after a recovery period of more than fifty years (Lund 1976).
- Channelization in Big Beef Creek, Washington, resulted in a reduction in the density of juvenile salmonids (Cederholm and Koski 1977). During the second summer after channelization, densities of juvenile coho salmon and age 0 and age 1+ steelhead trout were 75, 77, and 96% lower, respectively, than densities in comparable control areas. After three summers coho salmon populations demonstrated significant signs of recovery, but steelhead trout recovery was less than preproject

levels even after 5 yr.

- In a small California creek, trout biomass was more than seven times lower and individual trout were smaller in channelized sections than in natural stream sections (Moyle 1976).
- In a small California stream, approximately 4-5 yr after channelization, biomass of benthic invertebrates remained more than three times lower in channelized stream reaches than in natural stream reaches (Moyle 1976).
- In Little Prickly Pear Creek, Montana, channelized stream reaches contained no populations of nontrout fish species and had 78% lower abundance of trout than natural stream reaches (Elser 1968).
- Although the total trout biomass was nearly identical for pre- and post-construction populations in Tenmile Creek, Colorado, fish in the reconstructed channel (i.e., postconstruction) were more abundant but smaller in average size (Babcock 1982).
- In an evaluation of 29 streams in Idaho, Irizarry (1969) found almost 7 times as many catchable-sized trout (i.e., for sport-fishing) and almost 10 times as many whitefish (based on cencus numbers) in natural stream reaches than in channelized reaches. Biomass of game fish in the natural reaches exceeded that in channelized reaches by as much as 112 times. In some channelized reaches, no game fish were found.
- In a Wisconsin marsh, diversity of total invertebrate taxa (benthos and drift) was lowest in newly channelized ditches (6-8 yr old), intermediate in old channelized ditches (52-62 yr old), and was greatest in natural stream sections (76, 81, and 84 taxa, respectively)(Schmal and Sanders 1978). It was noted that stoneflies, mayflies, and caddisflies were more common in natural streams than in ditches.
- In a Wisconsin marsh, newly channelized ditches (6-8 yr old) had higher benthic invertebrate biomass and density than old channelized ditches (52-62 yr old) and natural streams (Schmal and Sanders 1978).
- For several small streams in Delaware, correlation analyses between the length of time elapsed since channelization and five macroinvertebrate diversity indices failed to show significant relationships (Whitaker et al. 1979). The authors concluded that the benthic macroinvertebrate community stabilized within 1 yr after channelization.
- In-stream dredging in a stream in Great Britian resulted in dramatic but relatively short-term effects on benthic invertebrates (Pearson and Jones 1975). The authors suggest that adverse effects of dredging would be further reduced if activities were conducted in early spring or summer (after the reproductive period for most species).

2. **Change in amount of aquatic habitat:**
   - An overall loss of habitat occurred downstream from groins placed in the Tanana River in Alaska as gravel bars became dewatered and subsequently invaded by terrestrial vegetation (Mecum 1984).
   - Straightening and shortening a section of the Peabody River in

New Hampshire increased the streambed gradient, caused significant erosion upstream from the altered site, and increased the deposition of eroded materials downstream from the site (Yearke 1971). Scouring of the streambed within the altered section was severe, lowering the bed elevation by as much as 18 ft in some locations. Bank erosion within the altered reach caused the channel width to increase to four times its original width (ibid).

- Relocation of Tenmile Creek in Colorado resulted in a net loss of approximately 17% of the total area of aquatic habitat (Babcock 1982). The preconstruction area of 32.19 acres was reduced to 26.9 acres.
- In the Clark Fork River, Montana, two artificial meanders were constructed in a reach of the river where extensive channelization had occurred. The meanders increased the length of the river, channel sinuosity, and pool frequency and decreased the gradient (Hunt 1972).

3. Change in water temperature:

- Water temperature was reduced downstream from groins placed in the Tanana River, Alaska, because the relative amount of cold groundwater increased in the areas immediately downstream from the groins (Mecum 1984).
- Although differences were not statistically significant, recently channelized ditches (6-8 yr old) in a Wisconsin marsh had higher daily mean temperatures, higher daily temperature fluctuations, and higher daily maximum temperatures than did old channelized (52-62 yr old) and natural stream sections (Schmal and Sanders 1978). The evaluation period was from September 1974 to May 1976.

4. Change in depth or velocity of water:

- Short-term (10 d) effects of widening and deepening a small Washington stream reduced total salmonid biomass to only 5% of that determined in a control area (Chapman and Knudsen 1980).
- A 3-mo diversion of 90% of the normal flow in Blacktail Creek, Montana, resulted in a 62% reduction in total numbers of brook trout (age 1 and older) in run areas (Kraft 1972).
- Channelization in streams creates a more uniform depth and width profile that increases water velocity and the erosive power of the stream (Simpson et al. 1982, Bottom et al. 1985).
- Instream gravel excavation in several small streams along the trans-Alaska pipeline system caused loss of surface flow, and consequently blocked downstream migrations of grayling to overwintering areas (Elliott 1982).
- The channel of a small tributary of the Sammamish River, Washington, was deepened using a power shovel equipped with a dragline and bucket. This resulted in salmonids being killed by the dragline or being trapped in isolated sections of the channel (Rees 1959).
- Stream straightening and channel dredging in a small tributary of the Sammamish River, Washington, resulted in a 69% and 81% decrease in abundance of zero-group silver salmon and trout

fingerlings, respectively (Rees 1959).

- In a medium sized stream in Montana, a 4200 ft section of naturally meandering channel was straightened using a bulldozer to form a chute 2200 ft long (Baldes 1973). Construction of the new channel resulted in disruption of streambank vegetation, disruption and alteration in composition of streambed materials, and an increase in stream gradient. Bank erosion directly upstream increased the bank-to-bank width by nearly 600% over a fifteen-year period following channelization (note: preproject rate of erosion = 0.3 ft/yr; postproject rate = 9.1 ft/yr) (ibid).
- In channelized stream reaches where pool/riffle sequences were eliminated, the amount of shallow-fast riffle habitat increased from 49 to 87% of stream length, and the amount of available cover decreased by 80% (Elser 1968).
- Channelizing and straightening portions of the St. Regis River, Montana, resulted in increases in channel width, depth, thalweg depth, and thalweg velocity (Lund 1976).
- In a reveiw of the literature pertaining to bank stabilization, Stern and Stern (1980) concluded that bank stabilization precludes stream meandering and will constrain channel migration within the floodplain. Streams with stabilized banks exhibit a wider range in discharges and have increased water velocity within the constrained reach.
- Properly constructed jetties and random rock clusters of large riprap material maintained a variable stream bottom profile (i.e., pool/riffle) that provided good trout habitat (Lund 1976). In reaches where these structures were in place for 2 yr, trout numbers and biomass increased by approximately 200%, while comparable sections of stream without structures showed little variation in numbers or biomass of trout.
- Stream straightening and channel dredging in a small tributary of the Sammamish River, Washington, resulted in the short-term elimination of 97% of the bottom organisms in the test area (Rees 1959). However, after 5 mo the bottom community began to recover and after 1 yr it was comparable to the preproject community.
- Deepening of existing water courses or the construction of new drainage channels will result in the permanent lowering of the water table (Hill 1976). The magnitude of the effects, however, will vary depending on topography and hydraulic conductivity of the soil (ibid). Declines of 1-2 m in the regional water table over considerable areas in south Michigan and the Mississippi delta have been attributed to drainage activities (Little 1973).
- Artificial structures (e.g., gabions, deflectors, spur dams, barriers, and artificial boulders) placed in Douglas Creek, Wyoming, increased water depth and velocity during low flow periods by constricting and consolidating the flow (Cooper and Wesche 1976).
- Low gabion dams (12 in high) installed in two creeks in Colorado did not improve or impair benthic insect production, although they increased the water depth and bottom area,

decreased current velocity, and altered the substrate composition (Luesink 1965).

- In Tenmile Creek, Colorado, dikes were constructed at the edge of the excavated channel to direct the stream flow at periods of high flow (Babcock 1982). However, the dikes were placed too close to the channel to accommodate a 4% chance flood that occurred and actually increased the rate of erosion by restricting the flow in the channel.
- Efforts to dike a portion of a high-energy river in Montana with local materials bulldozed from the streambed were unsuccessful because the materials were entrained and transported downstream at high discharges (Ritter 1979). Also, efforts to riprap the banks of this river were only successful in locations where long reaches were protected with very large pieces of sandstone approximately 1 m^3 in size (ibid).

5. **Change in level of turbidity, settleable solids, or substrate stability:**
   - Following channelization in Big Beef Creek, Washington, streambed scour and streambank erosion resulted in highly unstable substrate conditions during the winter of 1970-1971 and caused the loss of 55% of the chum salmon redds spawned within the channelized reach (Cederholm and Koski 1977).
   - Over a 4-yr period of measurement, a channelized section of Big Beef Creek, Washington, contributed 7.6 times as much sediment per kilometer of stream (6,570 m^3/km) as did the natural upstream reach (870 m^3/km) (Cederholm and Koski 1977).
   - Compared to natural streams, channelized ditches in Wisconsin had reduced in-stream habitat diversity and lacked depositional areas, such as pools and point bars (Schmal and Sanders 1978).
   - In a review of the literature related to the environmentl effects of bank stabilization, Stern and Stern (1980) concluded that bank stabilization leads to increased downcutting erosion (i.e., scour), so that a stream with stabilized banks will tend to be deeper than it would be in its natural state. The depth of a stabilized stream will increase with increased discharge, unless the streambanks are sufficiently rough to dissipate the erosional energy. Bank stabilization activities result in temporary increases in suspended solids during the construction stage but post construction levels usually decrease below normal levels prior to stabilizing activities occurred. With increased bank stabilization, local streambed materials become coarser, and finer materials are transported downstream (ibid).
   - In small streams in Idaho, reduction of pool area or volume due to sedimentation resulted in a reduction in the abundance of salmonids in proportion to the percentage of eliminated habitat area or volume (Bjornn et al. 1974).
   - In laboratory experiments, juvenile steelhead trout and coho salmon tended to emigrate from turbid to less turbid stream sections and consistently exhibited slower growth rates in turbid water than fish reared in clear water (Sigler et al. 1984).
   - Survival of pink and chum salmon has been shown to be inversely related to the amount of sediment within gravel

substrates (Phillips 1971).

- Survival of preemergent salmonids was significantly reduced in gravels containing more than 15% fines (< 0.833 mm diameter), apparently due to reduced permeability of the gravels (McNeil and Ahnell 1964). Permeability of gravel was inversely related to the percentage by volume of sand and silt (< 0.833 mm diameter). Permeability was considered high when substrates contained less than 5% fines, and low when fines exceeded 15% (ibid).
- Suspended sediment concentrations exceeding 200 to 300 ppm for many days (depending upon size, shape, and hardness of particles) can result in mortality due to damaged gill membranes (Phillips 1971, Bottom et al. 1985).
- Using cortisol concentrations to measure stress levels in fish, Redding and Schreck (1980) demonstrated that juvenile coho salmon and steelhead trout were physiologically stressed when suspended concentrations of topsoil were between 1.7-2.7 g/l. They also showed that fish stressed by the suspended sediment had reduced resistance to a pathogenic bacterium.
- Chum salmon smolts developed bacteria-induced tail rot under high concentrations of suspended overburden (Smith 1978).
- In a study conducted on piedmont streams in Virginia, Keefer (1977) found that invertebrate drift densities were higher and benthic biomass was lower in channelized stream reaches than in natural reaches. He suggested that this pattern was due to the instability of benthic substrates in the channelized reaches.
- Groins (L-shaped) placed in the Tanana River near Fairbanks, created downstream habitat that had much lower water velocities and lower turbidities than comparable river reaches without structures (Mecum 1984). In addition, silt deposition occurred at the mouth of the groin.
- In four Michigan watersheds traversing glacial outwash plains, an evaluation of bank stabilization methods indicated that stabilization of the waterline by rock riprap or other mechanical means was "key" to successful bank stabilization (Striffler 1960). After the foot of the bank is stabilized, undercutting of the bank ceases, slumps and slides are reduced, and vegetation becomes established, which further stabilizes the bank.
- Compared to sandy streambanks, clay banks generally had less stabilized waterlines, more bank slumps, and less bank vegetation along previously channelized reaches (Striffler 1960).
- Cut juniper trees anchored along eroded stream banks proved to be an effective means of stabilizing banks against erosion during the first year after channelizing occurred in the South Fork John Day River, Oregon (Sheeter and Claire 1981). Bank failure occurred on only 4% of the banks treated and was the result of improper placement or anchoring of trees.

6. **Alteration of natural cover - riparian vegetation, aquatic vegetation/debris, or overhanging bank or shoreline:**

- In a meandering grassland stream in Montana, there was an average increase of 258% in standing crop of trout in stream reaches where brush cover was experimentally added (Boussu 1954). This compared to an average increase of only 23% in control areas. Conversely, standing crop of trout decreased by an average of 41% in areas where brush cover was experimentally removed compared to an increase of 7% in a control area.

- In a meandering grassland stream in Montana, standing crop of trout decreased by 33% after undercut bank cover was experimentally eliminated. This compared to an average increase of 20% in control sections (Boussu 1954).
- In five of six Iowa streams tested, electrofishing in run, riffle, and brush-pile habitats above, within, and below channelized areas showed that more fish species occurred in unchannelized habitats (Bulkley et al. 1976).
- Ten to 15 yr after channelizing occurred in some Iowa streams, brush cover habitat was still less in channelized areas than in unchannelized areas (Bulkley et al. 1976).
- Bulldozing and straightening a 350-ft reach of a small stream in Montana resulted in a loss in riparian and in-stream brush cover, disturbance of stream substrates, and a direct loss in stream length. These changes resulted in a 94% reduction in numbers and total weight of game fish (mostly salmonids) greater than or equal to 6 inches in length and reductions in numbers and weight (85% and 76%, respectively) of game fish less than 6 inches in length (Whitney and Bailey 1959).
- In a medium-sized stream in Wyoming (average flow of 53 cfs), an area that had undergone channel straightening, cover removal, and bank clearing, the standing stock of trout was more than six times less than an unmodified, upstream reach (Wiley and Dufek 1976). Trout were also smaller in the channelized reach (average sizes were 6.7 in and 7.4 in, respectively).
- Channelized and straightened reaches of the St. Regis River, Montana, had less in-stream and riparian cover for fish (Lund 1976). In-stream cover ranged from a high average of 151 m^2/1,000 m for unaltered reaches to a low of 40 m^2/1,000 m in reaches that were channelized. Riparian cover (0-60 cm above the water) ranged from a high average of 225 m^2/1,000 m for unaltered reaches to a low of 30 m^2/1,000 m for channelized reaches.
- Groins placed in the Tanana River, Alaska, resulted in increased downstream erosion of the banks as the river began to reestablish its former meander pattern (Mecum 1984).
- In Big Beef Creek, Washington, channelization resulted in the complete destruction of fish cover habitat, such as undercut banks, logs, and root wads, and eliminated most stable pool habitat (Cederholm and Koski 1977).
- Two years after channelization in Big Beef Creek, Washington, the number of pools, pool surface area, and streamside cover (i.e., undercut banks and streamside vegetation) were 56, 83, and 52%, respectively, of pretreatment levels (Cederholm 1972).

- Of several variables evaluated, the percentage of overhead bank cover was the variable that accounted for the greatest amount of variation (63%) among standing stocks of trout populations in small trout streams in Wyoming (Wesche et al. 1985).
- In a review of the literature, Stern and Stern (1980) found that removal of riparian vegetation tends to decrease the amount of surface runoff and lateral flow of groundwater into the stream.
- Floating artificial overhangs placed in Douglas Creek, Wyoming, were found to be just as attractive to brook and brown trout as natural overhangs, as long as depth-velocity criteria were met (Cooper and Wesche 1976). After barrier and artificial overhang installation on the main channel of the creek, the number of trout collected there tripled.
- Four years after channelization in Big Beef Creek, Washington, the amount of stable pool habitat returned to prechannelized levels but streambank cover was only 55% of the pretreatment level (Cederholm and Koski 1977).
- In a laboratory study, fingerling rainbow trout exposed to various light regimes showed no preference for cover habitat, whereas yearling trout did (McCrimmon and Kwain 1966).
- Channelization of several small streams in western Washington significantly decreased channel sinuosity by 10%, wetted surface area by 20%, and overhead canopy by 89%. The effects of these changes on salmonids were related to size of fish, with the smallest fish (0-age trout) least affected and the largest (adult cutthroat trout) most affected (Chapman and Knudsen 1980).
- In field experiments performed on braided rivers in Alberta, results indicated that bank sediment with 16-18% roots (by volume) had 20,000 times more resistance to erosion than comparable bank sediment without roots (Smith 1976).
- Live or dead trees anchored by root wads into the streambank greatly reduce bank erosion and promote the development of small scour holes. The above-ground portion of the trees contributes to channl roughness, thereby reducing the water velocity at the streambank (Keller and Swanson 1979).
- Based on a review of the literature, Karr and Schlosser (1977) concluded that riparian vegetation can act as an important agent to filter-out sediment from both sheet and shallow channel flow and prevent it from entering streams. Variables that interact to determine the effectivness of the filtering process include filter length, bank slope, type of riparian vegetation, and the quantity and size composition of the sediment load.
- Removal of riparian vegetation results in significant reductions in invertebrate and fish production in headwater streams (orders 1,2, and 3) because of loss of energy inputs from terrestrial litter (Karr and Schlosser 1977).
- In a second-order Interior Alaska stream, riparian litter inputs into the stream were determined to be very low (62.5 g ash-free dry weight/m_2/yr) compared to temperate streams (300-700 g ash-free dry weight/m^2/yr)(Cowan and Oswood 1983). This limitation of energy input to Alaska streams has obvious

implications for the productive capabilities of the macroinvertebrate community as a source of food for fish.

- In an evaluation of five small streams in Vermont, it was clearly demonstrated that vegetation influences erosion of channel banks by altering the roughness and shear strength of the streambed and bank (Zimmerman et al. 1967). Channels were wider in areas having forested banks than in areas with sod banks.
- In Tenmile Creek, Colorado, many bank-side trees were left intact, and trees, bushes, and grasses were planted where the banks were denuded during channelizing activities. However, extensive erosion within the channel during a 4% chance flood undermined much of the bank vegetation and resulted in extensive bank slumping (Babcock 1982).
- Based on a review of documented literature, Platts and Rinne (1985) concluded that streambanks of medium-sized streams (3-5 order) are usually stable if they have sufficient brush cover. During floods, high water velocities tend to force the resilient streamside vegetation (willows and grasses) into vegetation mats that shield banks from erosion and reduce the water velocity.

7. **Change in level of dissolved oxygen:**
   - Sediment from channel dredging that settles onto spawning areas reduced the intergravel flow of water, formed a physical barrier to salmonid fry emergence, interfered with the removal of metabolites (carbon dioxide and ammonia), and reduced the level of dissolved oxygen available to pre-emergent salmonids (Wilson 1960, Phillips 1971).
8. **Change in levels of pH, alkalinity, or hardness:**
   - In a Wisconsin marsh, alkalinity, total calcium hardness, and specific conductance were significantly higher in channelized ditches than in natural stream sections, whereas other variables, such as NO^3, PO^4, and pH, were similar (Schmal and Sanders 1978).
9. **Change in levels of heavy metals:**
   - The tolerance of salmonids to suspended sediments from channelization has been found to decrease with high concentrations of dissolved heavy metals (copper, zinc) in glacial till (Smith 1978).
10. **Introduction or removal of species:**
    - Diversion of the Churchhill River into a northern Manitoba lake allowed previously isolated stocks of lake whitefish to redistribute between waterbodies. This changed the average commercial quality of the fish due to an increased rate of parasitic infestation (Bodaly et al. 1984).

B. Freshwater Nonsalmonids

1. **General changes to populations:**
   - Congdon (1971) found an 83% reduction in total standing crop of fish in old channelized sections (20-30 yr) of the Chariton River, Missouri, compared to unaltered sections.
   - Compared to channelized stream segments (new or old), natural

stream reaches of the Luxapalila River, Mississippi, had significantly higher ($P<.05$) average numbers of fish and macroinvertebrates per sample (Arner et al. 1976).

- The average weight of largemouth bass collected in the Luxapalila River, Mississippi, was eight times greater in natural reaches than in sections channelized more than 52 yr ago (Arner et al. 1976).
- Channelizing in a small tributary of the Maumee River, Ohio, resulted in a significant shift in the fish community composition; some species were exterminated, some underwent reductions in numbers, and others became new colonizers or remained the same in abundance (Trautman and Gartman 1974).
- In the Little Sioux River in Iowa, the number of fish species was lower in channelized reaches than in natural reaches (Hansen 1971). Also, the average size of channel catfish captured in the channelized reaches was smaller than in natural reaches.
- In a comparison between channelized and natural river reaches of the Missouri River, Groen and Schmulbach (1978) demonstrated that channelized reaches had lower overall fish harvest rates, lower numbers of fish caught per kilometer of river, lower total weight of fish harvested per kilometer of river, and smaller average size of fish.
- Compared to old channelized (more than 52 yr) and natural reaches of the Luxapalila River, Mississippi, newly channelized reaches had a "preponderance" of migratory, nongame fish species (e.g., suckers)(Arner et al. 1976).
- Compared to natural reaches in the Chariton River, Missouri, fish diversity was still much reduced in channelized reaches that were modified 20 to 30 yr previously (Congdon 1971). Natural reaches had 21 fish species compared to 13 in channelized reaches.
- Reaches of the Missouri River that had been channelized 15 yr previously were compared to reaches channelized for only 6 yr. Diversity of benthic organisms was nearly the same, but density was considerably lower in the more recently channelized reaches than it was in reaches that had been channelized for 15 yr (Wolf et al. 1972).
- In the Olentangy and Hocking rivers, Ohio, macroinvertebrate abundance, diversity, and/or biomass was significantly lower in channelized reaches than in unmodified reaches (Griswold et al. 1978).
- Channelized sections of a small Ohio stream that had rock deflectors supported a significantly greater number of fish species and had higher numbers and biomass of fish than did comparable sections without structures (Carline and Klosiewski 1985). However, despite these improvements, the channel supported few catchable-sized game fish.
- Diversity and relative abundance of game fish (bass, sunfish, and crappies) in the Olentangy River, Ohio, were significantly lower in a channelized area than in natural or channelized reaches containing artificial pools and riffles (Edwards et

al. 1984). Some nongame species (e.g., minnows, suckers, and catfish) were relatively more abundant in mitigated channels than in natural channels.

- In the Weber River, Utah, six instream structures (i.e., gabion deflectors, check dams, rock deflectors, a concrete diversion dam, and random boulders) were placed in a channelized stream. No differences were found in species composition or numbers of fish or macroinvertebrates per acre between channelized and natural stream reaches (Barton and Winger 1973). The authors stated that these conditions existed "a relatively short time" after channelization was completed, but they did not specify the length of time.
- In the Olentangy River, Ohio, the macroinvertebrate abundance, diversity indices, standing stock in the benthos, and drift were significantly lower in a channelized stream reach than in either a natural reach or channelized reach that had been mitigated with artificial riffles and pools (Edwards et al. 1984).
- In a comparison of both macroinvertebrate benthos among natural, channelized/mitigated, and channelized/unmitigated reaches in a river in Ohio, natural and mitigated reaches had significantly higher diversity of taxa, numbers of organisms, and total biomass than the channelized reach that was not mitigated (Woods 1977). Mitigation structures consisted of six-ft-wide artificial riffles and rock riprap in unstable areas. The unmitigated reach had been channelized more than 24 yr ago.
- Rock jetties and revetments provided more productive habitat than steel structures for macroinvertebrates such as mayflies and caddisflies and were judged to be more aesthetically pleasing (Witten and Bulkley 1975). It was noted that large-diameter rock was superior to smaller-diameter rock.

2. **Change in amount of aquatic habitat:**
   - Extensive channel straightening in the Chariton River, Missouri, accounted for the direct loss of more than 55% (103 mi) of the original stream length and facilitated the drainage of many marshes associated with the river floodplain (Congdon 1971).
   - In 54 short-reach channelization projects in Iowa, a total of 34.2 mi of natural stream channel was reduced to 18.7 mi of channelized stream. This constituted an average loss of 45% of original habitat (Bulkley et al. 1976). Similarly, for four long-reach channelization projects, a total of 281 mi of stream was shortened to 156 mi of channel, constituting a 45% reduction in total channel length (Bulkley et al. 1976).
   - In a Tennessee wetland of approximately 19,800 acres, channelizing, stream realignment, and enlargement of existing waterways resulted in a ditch system that eliminated an estimated 95% of the aquatic habitat (Barstow 1971). The estimated loss was made when the project was 32% complete.
   - In two prairie streams in southcentral Oklahoma, channelization resulted in an overall loss of 31% of total stream length since 1871. Loss of stream habitat per channelized segment ranged from 21 to 43% (Barclay 1980).
   - In Nebraska, long-reach channelization of the Missouri River

resulted in a reduction of 67% of available aquatic habitat (Morris et al. 1968). Of the remaining habitat, average standing crops of benthos were similar in natural and channelized reaches. However, the average standing crop of drift invertebrates was over eight-fold less in channelized sections than in unchannelized sections.

- In a large marsh area (4,300 surface acres of still water) of the Colorado River drainage, channelizing for flood control resulted in decreased value of aquatic habitat for game fishes (Beland 1953). Direct loss of habitat occurred from draining of backwater lakes and sloughs, elimination of eddies and holes, and the elimination of spawning habitat. Other forms of degradation included increased turbidity, bank erosion, and elimination of riparian vegetation.
- In a watershed in southwestern Minnesota, channelization of 60 mi of stream resulted in the drainage of several small marshland habitats and a 300-acre lake (Choate 1972).
- In the upper Missouri River, habitat diversity was severely reduced by channelizing. Only two of five identifiable habitat types present in natural river reaches were present after channelizing activities occurred (McMahon et al. 1972).
- Stream straightening in the Little Sioux River in Iowa accounted for the reduction of 54% of the original stream length (Hansen 1971).
- Confinement of the Mississippi River channel by revetments has resulted in a reduction in river surface area, island area, river bend area, and river width that collectively contribute to the overall reduction in the amount and diversity of aquatic habitat (Johnson et al. 1974).
- In Briar Creek, North Carolina, many of the detrimental effects of channelizing activities were minimized by allowing minimal stream straightening, leaving trees along banks to maintain bank stability, allowing minimal alterations in channel morphology and requiring necessary alterations to emulate natural stream characteristics, and employing bank stabilization techniques where necessary (Nunnally 1978).

3. **Change in water temperature:**
   - Channelized reaches of the Little Sioux River, Iowa, had greater average and maximum daily water temperatures (in July) than did comparable natural reaches (Hansen 1971). Increases in temperatures in the channelized reaches averaged 0.3, and 1.3 0.3, and 1.3 0.3, and 1.3 o C, respectively.
   - The lack of canopy cover and shallower depths of a channelized stream segment in the South Carolina Coastal Plains resulted in increased water temperatures compared to an unchannelized stream (O'Rear 1975).
   - A survey of the effects of channelization on stream characteristics in Hawaii indicated that channelized streams had higher diel variations in and higher mean values for pH, temperature, conductivity, and dissolved oxygen levels than natural streams (Parrish et al. 1978).
   - Increased solar radiation (from the reduction of vegeta-

tional stream canopy), and shallow water depths in channelized stream reaches in Hawaii resulted in stream temperatures that exceeded upper lethal limits for some native species of fish and crustaceans (Hathaway 1978).

- In channelized streams in Hawaii where the riparian canopy (mostly trees) was removed, the mean water temperature and variations in water temperature were higher compared to unaltered streams (Norton et al. 1978).

4. **Change in depth or velocity of water:**
   - Channelizing in North Carolina coastal streams resulted in shallow stream channels that had flat bottoms and few pools (Tarplee et al. 1971). In contrast, natural channels characteristically were deep and had many large pools.
   - For several Iowa streams, regression analysis of the abundance of young-of-year fish with channel sinuosity showed a significant positive relationship ($P = 0.01$, $r = 0.75$) (Bulkley et al. 1976).
   - In two prairie streams in southcentral Oklahoma, channelization resulted in a five-to-nine fold increase in channel capacity due to streambank erosion and bed scour (Barclay 1980). In some areas, livestock grazing may also have contributed to increased bank erosion, but the primary factor responsible for bed and bank erosion was the increased water velocity resultant from channelizing.
   - Since the early 1900's, a section of approximately 250 river miles of the Boyer River, Iowa, has been straightened and diked, resulting in a loss of 150 river miles of aquatic habitat (Campbell et al. 1972). These alterations increased the magnitude of the peak discharge and significantly shortened the duration of high-water events. Effects on biota were not evaluated.
   - Channel straightening in tributaries of Des Moines River, Iowa, resulted in reductions in channel sinuosity and variability of water depth and velocity. These variables determine habitat diversity (Zimmer and Bachmann 1978).
   - In the early 1900's, straightening and dredging the Blackwater River, Missouri, nearly doubled the gradient, which subsequently resulted in severe erosion of the river banks and scour of the streambed (Emerson 1971). Over the 60-yr period since the alterations, erosion widened the channel by an average of 1 m/yr and deepened the channel by an average of 0.16 m/yr. Preliminary observations indicated a negative correlation between channelized reaches and density of macroinvertebrates.
   - Impacts resulting from channelizing a tributary of the Pigeon River, Tennessee, included widening the channel from approximately 5 m to 8 m, replacing the natural pool/riffle sequence with a more uniform bottom profile, and replaceing the variable-sized substrate with uniform medium-sized gravel (Etnier 1972).
   - In channelized stream sections associated with highway bridge construction, channelized sections were usually shallower and

wider, had less pool habitat, and contained smaller amounts of brush cover than unaltered sections (Bulkley et al. 1976).

- Reaches of the Missouri River that were channelized 6 yr previously were primarily composed of main channel habitat and had almost no sand-shore, sand-bar, and cattail habitats, which supported nearly 4, 5, and 12 times the density of invertebrates, respectively, than did main channel habitat (Wolf et al. 1972).
- Biomass and total numbers of invertebrate drift had significant positive correlations ($P=0.05$) with channel sinuosity in straightened tributary channels of the Des Moins River drainage, Iowa (Zimmer and Bachmann 1978). This indicates that there is more invertebrate drift available as food for fish in sinuous channels than in straight channels.
- In-stream mitigation structures (gabion check dams and wing deflectors, rock deflectors and check dams, and concrete check dams) were successful in producing deep holes and riffle zones similar to natural stream reaches (Barton and Winger 1973).
- In a comparison of the effectiveness of steel and rock revetments, retards, and jetties, investigators concluded that in order for structures to facilitate the formation of scour pools for game fish habitat, the structures must extend into the stream channel more than a few meters (Witten and Bulkley 1975).
- Instream retards and permeable jetties resulted in the development of scour pools in the streambed (Witten and Bulkley 1975).

5. **Change in level of turbidity, settleable solids, or substrate stability:**
   - Even during periods of low run-off, turbidity measurements in the Little Sioux River, Iowa, were consistently higher in channelized reaches than in natural reaches by an average of over 31% (Hansen 1971).
   - The results of a study on the Vaal River, South Africa, showed that increased silt and sand in the streambed led to increased instability of the substrate, which decreased aquatic invertebrate diversity (Chutter 1969). However, it was noted that density of organisms was not affected.
   - Channelized streams of the North Carolina coastal plain had restricted channels, higher water velocities, higher suspended solids, and were more turbid than corresponding natural streams (Kuenzler et al. 1977).
   - In a comparison of an old channelized segment (over 52 yr), an unchannelized segment, and a newly channelized segment of the Luxapalila River, Mississippi, relatively few differences were found for any water-quality parameters, except for higher turbidity, which occurred in the newly channelized section (Arner et al. 1976).
   - Based on a review of the literature, Brown and Baker (1975) concluded that invertebrate taxa differ in their tolerances of increased levels of turbidity, with mayflies (Ephemeroptera) being very sensitive and true flies (Diptera) being highly tolerant.

6. **Alteration of natural cover - riparian vegetation, aquatic vegetation/debris, or overhanging bank or shoreline:**
   - In six streams in Iowa, the amount of brush cover was less in reaches that had been channelized (16.5 m^2/100 m) than in comparable sites above and below altered sites (50.2 m^2/100 m and 22.2 m^2/100 m, respectively) (Bulkley et al. 1976).
   - In two central Iowa streams, fish catches were significantly less in channelized reaches where brush cover had been removed 2 yr previously (King and Carlander 1976). However, in three other streams that were channelized 10-15 yr previously and where the brush cover had recovered, fish catches were comparable between channelized and unchannelized reaches.
   - Compared to old channelized reaches of the Luxapalila River, Mississippi, the density and diversity of herbaceous riparian vegetation were significantly greater along natural reaches (Arner et al. 1976).
   - An evaluation of Illinois streams with different types of vegetation indicated that angular canopy density (a measure of the shading capability of the vegetation) was the only characteristic of the vegetation correlated with water temperature (Karr and Schlosser 1977).
   - In a comparison of aquatic habitats (i.e., submerged wooden snags, sandy main channel, and muddy backwater) in the Satille River, southeastern United States, benthic invertebrate diversity, standing crop, and production was greatest for snag habitat (Benke et al. 1979). Invertebrate production in snag habitat was roughly two to three times that of the other habitat types (57-72 g dry wt/m^2 of snag habitat compared to 14-28 g dry wt/m^2 of main channel and/or muddy backwater habitat).
   - Roughly 80% of the numbers and biomass of invertebrates captured in the drift of the Satille River, southeastern United States, originated in snag habitat (Benke et al. 1979). This accounted for approximately 9% of the total production for the river.
7. **Change in level of dissolved oxygen:**
   - Dissolved oxygen levels in a channelized section of a stream in the South Carolina coastal plain were consistently higher during low flow conditions than levels in a comparable natural stream section (O'Rear 1975). During low flow periods, average differences typically exceeded 2 mg/l.
8. **Change in levels of pH, alkalinity, or hardness:**
   - In channelized streams in Hawaii where the riparian canopy was removed, pH and conductivity levels were higher than in comparable unaltered streams (Norton et al. 1978).
9. **Change in levels of heavy metals:**
   - Some fish accumulate sediment contaminants (PCB, DDE, zinc, iron, cesium, and selenium) resuspended by dredging (Seelye et al. 1982).
10. **Introduction or removal of species:**
    - A statewide inventory of channel modifications in Hawaii,

indicated that fish community composition was disrupted by channel alterations such that exotic fish species became dominant over native species (Norton et al. 1978, Timbol and Maciolek 1978).

- Also see impact category **General changes to populations.**

C. **Guidelines:**[1]

The following guidelines are derived from the literature presented in the previous section. The guidelines are reasonably complete as to what types of channelizing activities and methods should be avoided and/or minimized, but in many instances they do not provide details regarding how suggusted guidelines should be implemented. The implementation of guidelines will largely depend upon site-specific factors (e.g., stream order, gradient, peak discharge capability, etc.) and should continue to be based upon presently used policy and guidelines until additional data become available. One area of active research that shows much promise for providing valuable insight for managers is the research on stream enhancement and/or restoration techniques. Although not included here, selected references are provided in appendix D of ADF&G (1986).

Channelizing Waterways often involves the mechanical disruption of the terrestrial environment adjacent to the streambank and results in environmental damage similar to that resulting from some types of road-building and mining activities. In particular, the effects of increased sedimentation are common to each of these activities. Although equally pertinent, the attention given to reporting effects from increased upland erosion is relatively small in the channelizing literature compared to that related to hydrologic effects. For additional information regarding effects of increased sedimentation, see impact summaries and guidelines in this volume for the activities Grading and Plowing and Processing of Minerals.

a. General. Avoid straightening the stream channel because it causes a net reduction in the wetted surface area of aquatic habitat (derived from Congdon 1971, Choate 1972, Bulkley et al. 1976, Lund 1976, Nunnally 1978, Barclay 1980, Babcock 1982, Mecum 1984, among others).
   (1) Specific. Minimize loss of aquatic habitat by limiting the channel alterations to the least possible length of stream (derived from Bulkley et al. 1976, Lund 1976, Nunnally 1978).
   (2) Specific. Minimize loss of aquatic habitat by relocating the portion of stream channel that would otherwise be eliminated. The relocated stream section should retain the gradient, length, width, depth, and meander pattern of the original stream channel (derived from Lund 1976, Nunnally 1978, Babcock 1982).

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1 For additional information, see White and Brynildson (1967), U.S. Department of Transportation (1979), Keown (1984), and Entrix, Inc. (1986). These reports contain specific guideline information on channelizing waterways but do not include documented source information and have therefore not been included in this report.

b. General. Avoid straightening the stream channel because this reduces the natural meander pattern of the stream (i.e., channel sinuosity) and introduces a conditon of hydraulic disequilibrium by increasing the stream gradient (derived from Nunnally 1978, Simpson et al. 1982). These changes increase water velocity throughout the channel and increase streambed scour and bank erosion and decrease the pool/riffle ratio of the stream. Collectively, these changes result in decreased stability and diversity of aquatic habitat, which, in turn, result in decreased species diversity and/or standing stock of fish and invertebrates (derived from Etnier 1972, Nunnally 1978, Zimmer and Bachman 1978, Schmal and Sanders 1978, Simpson et al. 1982, Wolf et al. 1972, Bottom 1985).

(1) Specific. Minimize loss of habitat by selecting sites for modification that do not include natural stream meanders (derived from Lund 1976, Bulkley et al. 1978, Nunnally 1978).

(2) Specific. Minimize the increase in streambed and bank erosion from increased water velocity, by selecting sites that result in a minimal change in the streambed gradient (derived from Nunnally 1978).

(3) Specific. Minimize a reduction in habitat diversity by including in-stream structures (e.g., jetties and rock clusters) to create pool habitat (derived from Lund 1976).

- To maximize the pool-forming effect, place in-stream current deflectors at an angle (approximately 45°) in the stream thalweg in small streams (derived from Lund 1976) and one-third or more into the channel of large streams and rivers (derived from Bulkley et al. 1976).
- Maximize production of large mid-channel pool formation by combining the use of jetties and rock clusters (derived from Lund 1976). Place clusters near the outer end of the jetty.
- In-stream structures must be sufficiently anchored into the bed and/or bank of the stream to withstand flood events and/or increased scouring of the streambed (derived from Lund 1976, Babcock 1982).
- Low dams are an effective way to create pool habitat, but care must be taken to ensure that the dams do not impede upstream movements of fish (derived from Babcock 1982).

(4) Specific. Minimize the effect of loss of the meander pattern in gravel-bottomed streams by placing current-deflecting structures on alternate sides of the stream in a longitudinal pattern that approximates the meander pattern of unaltered reaches in the stream (derived from Lund 1976).

(5) Specific. Minimize the loss of habitat diversity for benthic macroinvertebrates by replacing eliminated riffle zones with artificial riffles constructed from natural cobbles (derived from Griswold et al. 1978) and by leaving large snags intact in the streambed (derived from Benke et al. 1979).

(6) Specific. Minimize the period of time that substrate materials are unstable due to bed scour and pool formation by conducting

channelizing activities immediately prior to seasonal high-water discharges.

(7) Specific. Minimize the increase in water velocity and the effects of bank erosion by increasing the roughness of the channel. Use course rock riprap along bank reaches, and place large boulders within the stream and anchor large snags in the streambed (derived from Benke et al. 1979). These additions also provide local variations in depth/velocity conditions, which increase habitat diversity for fish and benthic invertebrates.

c. General. Avoid the disruption or loss of riparian vegetation on stream banks because it provides streamside cover for fish (derived from Boussu 1954, Cooper and Wesche 1976), resistance to bank erosion (derived from Zimmerman et al. 1967, Smith 1976), shading from solar radiation (derived from Hansen 1971, O'Rear 1975, Hathaway 1978, Parrish 1978, Norton et al. 1978), acts as an important source of terrestrial input of carbon and nutrients (derived from Karr and Schlosser 1976, Cowan and Oswood 1983), and affects the amount of surface and groundwater reaching the stream (derived from Stern and Stern 1980).

(1) Specific. Minimize loss of cover by restoring cover areas by constructing artificial bank overhangs (derived from Cooper and Wesche 1976).

(2) Specific. Minimize the loss of vegetation along streams by limiting the points of stream access for equipment, and allow clearing to occur on only one side of the stream (derived from Rees 1959, Dodge et al. 1976). This will reduce the relative magnitude of the effects of loss of shade (derived from, e.g., Hansen 1971), cover (derived from, e.g., Boussu 1954), energy inputs into the stream (derived from Cowan and Oswood 1983), and change to stream hydrology (derived from Stern and Stern 1980).

(3) Specific. Minimize the disruption to the riparian zone by using the smallest or least disruptive type of equipment that is necessary to effectively complete the work (derived from Nunnally 1978). Where it is feasible, hand labor is recommended over use of heavy machinery (ibid).

(4) Specific. Minimize the destabilizing effects of the loss of trees in the riparian zone by leaving their root masses intact (derived from Zimmerman et al. 1967, Smith 1976, Nunnally 1978).

(5) Specific. Minimize erosion of stream banks along denuded bank reaches by revegetating the area with plants that grow quickly, form thick root mats (derived from Lund 1976, Smith 1976), and overhang the stream (derived from Boussu 1954).

(6) Specific. Minimize erosion of stream banks along denuded bank reaches by preventing surface runoff from flowing over bank tops into the stream (derived from Stern and Stern 1982). Redirect water away from the top of the bank by ditching or using a diversion dike.

(7) Specific. Minimize erosion of stream banks in denuded areas that are subject to high erosive forces (e.g., outer banks of meanders) by using bank stabilization techniques (derived from

Stern and Stern 1980).

- Bank protection measures should be designed to resist the effects of large and rapid changes in water level, the effects of water saturation, and repeated freeze/thaw cycles (derived from Stern and Stern 1980).
- Soil characteristics of the bank should be considered when selecting a method or procedure for stabilizing the bank (derived from Striffler 1960).
- Bank revetments should be anchored deeply in the streambed to prevent scouring from undermining the toe of the bank (derived from Stern and Stern 1980).
- Whenever possible, use rock instead of other materials for constructing riprap areas, jetties, revetments, or other in-stream devices because it increases channel roughness, provides substrate for macroinvertebrates, and increases cover for fish (derived from Witten and Bulkley 1975).
- When constructing structures from rock, use rocks of sufficient size to prohibit entrainment and subsequent transport of materials during flood events that could occur at the site (derived from Ritter 1979, Babcock 1982).

(8) If channelizing activities occur in areas used for livestock grazing, fencing of the riparian zone may be appropriate to minimize trampling of the stream banks (derived from Headrick 1976, Platts and Rinne 1985).

d. General. Avoid unnecessary loss of riparian vegetation by prohibiting the disposal or storage of dredged channel materials from being placed along the stream bank (derived from Dodge et al. 1976, Headrick 1976, Lund 1976).

e. General. Avoid the removal of in-stream brush and snags because these components provide cover for fish (derived from Boussu 1954, Cooper and Wesche 1976), substrate for benthic invertebrates (derived from Bulkley et al. 1976, Benke et al. 1979), and limit increases in water velocity by increasing channel roughness (derived from Zimmerman et al. 1967, Keller and Swanson 1979).

f. General. Avoid the disruption of stream-bank materials because they provide structural stability to the channel (derived from Keller and Swanson 1979) and high-quality cover (i.e., undercut banks) for fish (derived from Boussu 1954).

(1) Minimize loss of undercut bank cover for fish by constructing artificial overhangs along disrupted banks (derived from Boussu 1954).

g. General. Avoid channelizing activities in stream reaches used for spawning or in areas that, if channelization occurs, are likely to result in one or more of the following effects to adjacent upstream or downstream spawning areas: 1) increased turbidity levels (derived from Redding and Schreck 1980, Sigler et al. 1984), 2) increased deposition of fine substrates (derived from McNeil and Ahnell 1964, Phillips 1971, Bjornn et al. 1974, Cederholm and Koski 1977), or 3) decreased stability of substrates (derived from Cederholm and Koski 1977).

h. General. Avoid channelizing activities that connect previously isolated bodies of water that contain genetically isolated populations of fish (derived from Bodally et al. 1984).

i. General. Avoid channelizing in areas where sediments are contaminated with compounds toxic to aquatic biota (derived from Smith 1978, Seelye et al. 1982).

CLEARING AND TREE HARVEST

I. DEFINITION

Clearing and tree harvest refers to the removal of trees or other vegetation, either partially or entirely, by mechanical means. Skidding logs within cutting areas is included in this activity. Clear-cutting and selective tree harvest are often associated with other activities, such as construction of access roads and timber-processing facilities (see activity categories Grading and Plowing, and Processing Lumber, Kraft, or Pulp). Clearing of vegetation prior to new construction projects, such as roads, is included in Clearing and Tree Harvest. [However, no information was found for aquatic species in relation to clearing trees for transportation corridors.] Maintenance clearing of corridors for pipelines, electric power transmission lines, railroads, and highway rights-of-way by mechanical means is included in the activity category Transport of Personnel/Equipment/ Material - Land. The use of herbicides to clear vegetation is included in the activity category Chemical Application.

The following is an attempt to translate the current body of documented impacts resulting from clearing and tree harvest activities into guidelines for habitat management that accurately reflects both the state of completeness and the level of specificity present within the literature database. Literature presented here consists primarily of original documented impact sources. However, a limited number of high-quality review papers that documented impacts literature are also included. These include Koski and Walter (1977), Reiser and Bjornn (1979),Toews and Brownlee (1981), Hall and McKay (1983), Schwan et al. (1985), and Elliott (1986).

II. IMPACT CATEGORIES

Impacts to the aquatic environment from clearing and tree harvest operations have been well documented, primarily in the northwest United States, British Columbia, and Alaska. In presenting the following impact summaries and guidelines, the reader should keep in mind that some documented impacts may be appropriate only in given geographic locations, under specific physical or topographic conditions, or when specific soil characteristics and vegetative types exist. For example, increases in temperature during summer due to reduced canopy may not be as significant in Southeast Alaska because cloud cover and lower summer air temperatures are prevalent. Also, the conditions that exist in some Alaska watersheds may not be understood well enough to apply guidelines derived from more southerly forested watersheds. This is particularly true with the potential of windthrow in buffer strips, which is a common problem in Southeast Alaska. Additionally, a noted data gap exists concerning information on increased introduction of nutrients into stream water as a result of clear-cutting in Alaska. Several papers from other parts of the United States and Canada that document this impact are summarized; however, it may not be appropriate to extrapolate this impact to Alaskan forest systems. Much of the available research and documented impacts of timber harvest, however, are directly applicable to Alaskan forests, and planning and management can be enhanced through the use of this information.

The impact categories identified in this section are a subset of the impacts identified in the companion volume titled Impacts of Land and Water Use on Fish and Their Habitat (ADF&G 1986). Three interrelated impact categories that were previously identified as the addition, removal, and physical disturbance of substrate materials have been combined and included here as a single category titled Changes in Levels of Turbidity, Settleable Solids, or Substrate Stability.

The following impacts were found to be associated with the activity of Clearing and Tree Harvest:

- Change in water temperature
- Change in depth or velocity of water
- Change in level of turbidity, settleable solids, or substrate stability
- Alteration of natural cover - riparian vegetation
- Alteration of natural cover - aquatic vegetation/debris
- Addition of physical barriers - partial obstruction
- Change in level of dissolved oxygen
- Change in levels of other toxic compounds - bark or log leachates
- Change in levels of nutrients
- Introduction or removal of species

III. ACTIVITY-SPECIFIC CONSIDERATIONS

The following are considerations that pertain to Clearing and Tree Harvest and should be taken into account when preparing a response to development proposals:

1. To what extent will trees be cleared; i.e., clear-cutting or selective harvest?
2. What is the slope of the harvest area?
3. What are the soil characteristics of the harvest area?
4. What is the potential for mass slope failures in the harvest area?
5. What will be the total area cut or the size of individual cutting units?
6. How much of the watershed is already clear-cut or in early successional stages?
7. What method(s) of harvest and yarding will be used?
8 What equipment will be used for logging?
9. What method will be used to dispose of slash?
10. What types of aquatic habitat (stream, lake, wetland, estuarine) exist within the forest drainage?
11. Do streams or wetlands that support anadromous salmonids exist within the forest watershed?
12. Will areas immediately adjacent to streams receive site-specific management?
13. What degree of vegetative canopy removal surrounding aquatic habitat is intended (e.g., clearcut to banks, selective harvest, etc.)?
14. What measures will be taken to control erosion?
15. What measures will be taken to minimize the input of logging debris and sediments into aquatic habitat or to maintain long-term sources of large, woody debris into streams?

16. What time of year will harvest operations occur?
17. Will harvest operations alter or inhibit migrations or spawning of anadromous fish?

IV. IMPACTS AND GUIDELINES RELATED TO CLEARING AND TREE HARVEST

A. Marine Vertebrates

Most of the impacts documented in the marine environment (vertebrates or invertebrates) have been researched in association with log handling and transport, and log processing. Therefore, there is a limited amount of information presented under this activity category. For more information, see the activity categories Log Storage/Transport and Processing Lumber/Kraft/Pulp.

1. <u>Summary of documented impacts</u>:
   a. **Change in temperature, change in depth or velocity of water, change in levels of nutrients**
      - In a review of literature, Koski and Walter (1977) state that hydrographic changes (e.g., increased sedimentation, altered salinity, temperature, and nutrient inputs) can occur in tideflats, estuaries, and bays due to logging and resultant streamflow changes.
      - The logging-related impacts of increased streamflow, sedimentation, and debris accumulations in streams can result in continually altered water channels where streams enter tideflats, creating unstable habitat for aquatic organisms (Koski and Walter 1977).

   b. **Change in levels of turbidity, settleable solids, or substrate stability**
      - Exposure to suspended mineral and natural sediments caused lethal effects from anoxia due to clogging and coating of the gill membrane surfaces. These effects of finely divided solids on estuarine fish species (i.e., menhaden, white perch, spot, Atlantic silversides, mummichog, and striped killifish) are dependent on concentration, particle size distribution, and angularity of the suspended particles (O'Connor et al. 1976).
      - Bottom-dwelling fish species were most tolerant of suspended sediments, whereas filter-feeding species and those species with high oxygen requirements (no species specified) were very sensitive (O'Connor et al. 1976).

   c. **No information was found in the following impact categories:**
      - Alteration of natural cover - riparian vegetation
      - Alteration of natural cover - aquatic vegetation and debris
      - Addition of physical barriers - partial obstruction
      - Change in level of dissolved oxygen
      - Change in levels of other toxic compounds - bark or log leachates
      - Introduction or removal of species

2. <u>Guidelines</u>:
   a. General. Avoid clearing and tree harvest immediately adjacent to estuarine waters where the potential for adverse impacts to fish production exists (derived from O'Connor et al. 1976, Koski

and Walter 1977).

(1) Specific. Minimize the addition of suspended sediments, in concentrations likely to have adverse effects on fish, to waters where fish are spawning, rearing, feeding, or overwintering (derived from O'Connor et al. 1976).

(2) Specific. Minimize hydrologic changes and introduction of suspended sediment input into estuarine waters by leaving buffer strips along shorelines during timber harvest operations (derived from O'Connor et al. 1976, Koski and Walter 1977).

(3) Specific. Minimize impacts from sediment and debris accumulations by timing logging activities to reduce adverse impacts on fish migrations, rearing, or spawning in estuarine waters (derived from O'Connor et al. 1976, Koski and Walter 1977).

B. Marine Invertebrates

1. <u>Summary of documented impacts</u>:

a. **Change in levels of turbidity, settleable solids, or substrate stability**

- The development of oyster larvae was arrested at suspended sediment concentrations above 0.75 g/l (Wilson 1960).
- Forest harvesting and extensive soil disturbance along estuarine environments can increase sedimentation and reduce productivity in the marine habitat. Areas such as shallow, narrow estuaries are often less active hydrologically, and sedimentation effects can be severe (USEPA 1975a).

b. **No information was found in the following impact categories (see marine vertebrate section for additional information):**

- Change in water temperature
- Change in depth or velocity of water
- Alteration of natural cover - riparian vegetation
- Alteration of natural cover - aquatic vegetation and debris
- Addition of physical barriers - partial obstruction
- Change in level of dissolved oxygen
- Change in levels of other toxic compounds - bark or log leachates
- Change in levels of nutrients
- Introduction or removal of species

2. <u>Guidelines</u>:

a. General. Avoid clearing and tree harvest immediately adjacent to estuarine waters where the potential for adverse impacts to invertebrate production exists (derived from Wilson 1960, USEPA 1975a).

(1) Specific. Minimize the addition of suspended sediments in concentrations likely to have adverse effects on invertebrates by leaving buffer strips along estuaries and freshwater streams (derived from Wilson 1960, USEPA

1975a).

C. **Freshwater Salmonids**

1. Summary of documented impacts:

a. **Change in water temperature**

- One year after clear-cut logging without leaving protective buffer strips on a small watershed in the Oregon Coast Range average monthly maximum water temperatures increased by 14°F, and annual maximum temperatures increased from 57 to 85°F. In a nearby watershed where strips (greater than 100 m) of brush and trees separated logged areas from streams, no changes in water temperature were observed that could be attributed to clear-cutting (Brown and Krygier 1970).
- Removal of forest cover in headwater streams in the northeastern United States resulted in an increase of 4.4°C for average monthly maximum temperatures. Stream temperatures above 21°C occurred daily in the summer, and diurnal fluctuations as high as 17°C occurred. On an adjacent forested watershed, temperatures rarely exceeded 20°C, and diurnal fluctuations were only 4°C. In another watershed that had been clear-cut but where a buffer zone had been left along the stream bank only slight changes in stream temperature were observed, and the highest temperature recorded was 23°C (Rishel et al. 1982).
- Ringler and Hall (1975) reported increased intragravel water temperatures in salmon and trout spawning beds of Oregon coastal streams. This was related to reduced forest cover over the stream surface. The cutthroat trout population was reduced to about one-third of its prelogging level and persisted at that level for over 6 yr after logging (ibid).
- Increased water temperature due to reduction of forest cover over stream surfaces affected salmonid fish species by changing their metabolic rate and decreasing development time (Narver 1972). It also promoted early hatching and migration, due to the decreased oxygen content of surface and intergravel waters (Burns 1972, Harris 1973, Cederholm 1977, Corbett et al. 1978, Everest and Harr 1982).
- The upper temperature limit for optimum growth and survival of chinook salmon alevins under laboratory incubation conditions was determined to be 12°C (Heming et al. 1982). Chinook salmon eggs reared above 10°C experienced reduced survival, hatched and emerged precociously, and were smaller at hatching, at emergence, at maximum tissue weight, and at complete yolk absorption than fish reared at lower temperatures (Heming 1982).
- Cutthroat trout populations in three Oregon streams declined as a result of increased stream temperatures in logged streams (Hall and Lantz 1969, Oregon Wildlife

Commission 1974).

- High water temperatures in logged streams on Vancouver Island, B.C., in winter caused coho salmon and trout (mainly steelhead) fry to emerge up to six weeks prematurely, grow more rapidly, attain larger than average body size (Hartman et al. 1984), and move seaward more rapidly (Scrivener and Andersen 1984).
- Canopy density along the path of incoming solar radiation was the best criterion for describing the ability of a buffer strip to control stream temperatures, and most buffer strips studied contained more timber than necessary (Brazier and Brown 1973).
- Selected salmonid fishes have successfully migrated upstream in water temperatures ranging from 3 to 20°C. Temperatures above the upper limit have been known to stop salmon migrations (Reiser and Bjornn 1979).
- Abnormal stream temperatures can facilitate disease outbreaks in migrating fish, alter timing of migration, and accelerate or retard maturation (Koski and Walter 1977, Reiser and Bjornn 1979).
- In 38 southern Ontario streams, trout (rainbow, brook, and brown) were found only when weekly maximum water temperatures were less than 22°C. Fifty-six percent of the observed variation in weekly maximum water temperatures could be explained by the fraction of bank forested within 2.5 km upstream of a sample site (Barton et al. 1985).

b. **Change in depth or velocity of water**

- Annual runoff increased 19 in, and high flow volumes increased 1.1 in after logging in a small coastal Oregon watershed. Clear-cutting in small, spaced patches in another watershed did not alter water yields (Harris 1973, 1977).
- Increased peak flows, caused by clear-cut logging (Harr 1979, Toews and Brownlee 1981), can accelerate streambank erosion and sedimentation, alter riffle-pool patterns, and reduce survival of salmonid eggs in the gravel and juveniles rearing in the stream (Bottom et al. 1985).
- Increases in water yield following timber harvest roughly conformed to the proportion of the area cleared (Rothacher 1970, Burns 1972, Meehan 1974) and to the amount of severe soil disturbance (i.e., compaction) within a watershed (Harr et al. 1979).
- Increased streamflows caused by logging of large areas resulted in scouring of the streambed and the loss of salmon eggs and larvae (Cederholm 1977).
- Converting large portions of old-growth forests to rapidly growing second-growth forests can permanently reduce low summer stream flows and thus permanently reduce salmonid production (Myren and Ellis 1984).

c. **Change in levels of turbidity, settleable solids, or substrate stability**

- Removal of ground cover along stream banks increased erosion up to 18 times compared to undisturbed areas (Aldrich and Johnson 1979, Barrick 1984).
- Mass soil movements often destroy the entire productive soil zone and produce a major source of sediment in anadromous streams (Koski and Walter 1977).
- Debris avalanches in timber harvest areas have caused increased debris torrents, i.e., the rapid movement of water-charged soil, rock, and vegetation along stream channels, which destroy riparian vegetation, salmonid habitat, and scour the channel to bedrock (Swanston 1970, Hess 1984, Bottom et al. 1985).
- Debris torrents often originate in steep (> 50% slope) first- and second-order streams that drain areas less than about 50 acres. In the Oregon Coast Range, movement of shallow soil and organic debris in steep headwalls of incipient drainageways resulted in debris torrents (Swanson and Lienkaemper n.d.).
- Slide erosion from clear-cut areas in a zone of unstable soils (underlain with altered volcanic rock) in an Oregon forest increased by a factor of 2.8. During the same period, no slides occurred in clear-cut areas in the stable soil zone (Swanson and Dyrness 1975).
- Soil compaction associated with forest practices reduces soil pore space, thereby reducing infiltration and percolation. This increases surface runoff and can result in erosion (Lull 1959).
- Timber harvest can cause increased groundwater levels and content of water in soils, which weakens soil strength and leads to increased rates of slope mass movements (Swanston 1969, 1970, 1971).
- Clear-cut logging caused mass soil erosion in second- and third-order streams because tree root decay lowered the shear strength of the soil mantle (Swanston 1969, 1970, 1971; Beschta 1978; Wu and Swanston 1980).
- Clear-cut logging and road building on steep mountain slopes (angle greater than or equal to 34) has been the primary cause of mass slope erosion (Swanston 1969, 1970, 1971; Burns 1972; Rice et al. 1972; Platts and Megahan 1975).
- A large clear-cut, cable logging operation in a small Oregon watershed caused an average 181% increase in sediment yield over a 7 yr post-logging period. Smaller, patch clear-cutting in a nearby watershed caused only insignificant increases in sediment yield (Harris 1977).
- Improper logging operations (removal of vegetative ground cover, road building, operation of heavy equipment, and yarding trees through streams) causes erosion and increased stream turbidity, which resulted in filling of pools (Burns 1972, Everest and Harr 1982, Hall and McKay

1983, and riffles of salmonid streams with up to 10 in of sediments (Beschta 1979, Koski et al. 1984).

- Logging to or across streams can destabilize channels and streambanks, increasing erosion, sedimentation, and bedload shift (Toews and Brownlee 1981, Holtby and Hartman 1982).
- Suspended sediments are often deposited in the interstitial gravel spaces, which are important to juvenile fish for foraging and refuge. During winter, stream channels with fully sedimented riffles supported reduced numbers of age O steelhead trout and chinook salmon because of the lack of crevices available for refuge. Larger juveniles resided in pools during winter and were not affected (Bjornn et al. 1974).
- Sedimentation with materials less than 2.0 mm, at 26 and 31% by volume of total substrates, suppressed coho salmon production in laboratory streams (Crouse et al. 1981). Similarly, fine sediment (0.297-9.55 mm) accumulations after clear-cut logging in Carnation Creek, B.C., resulted in reduced coho and chum salmon egg-tofry survival (Holtby and Hartman 1982, Scrivener and Brownlee 1982).
- Slash burning, following clear-cutting, increased sedimentation three times above normal (Brown and Krygier 1971), which continued for 5 yr after tree harvest (Bestcha 1978).
- Deposition of sediments, caused by logging, onto gravel stream beds decreased substrate permeability (Brown 1972, Moring 1982, Scrivener and Brownlee 1982) and resulted in decreased survivorship of preemergent salmonids by blocking exchange of surface and subsurface waters (Wilson 1960, McNeil and Ahnell 1964, Hall and Lantz 1969, Phillips 1971, Ringler and Hall 1975, Everest and Harr 1982, Hall and McKay 1983, Bottom et al. 1985, Elliott 1986).
- Permeability was inversely related to the percentage by volume of sand and silt in bottom substrates. Permeability is high when bottom materials contain less than 5% by volume of sands and silts (< 0.833 mm diameter), and permeability is low when substrates contain more than 15% by volume of sands and silts (McNeil and Ahnell 1964).
- High concentrations of sand in gravel caused earlier emergence of coho salmon and steelhead trout fry as a result of stress from the entrapment effect of sand (Phillips et al. 1975).
- Suspended sediment concentrations exceeding 200 to 300 ppm for many days (dependent upon size, shape, and hardness of particles) can result in fish mortality due to damaged gill membranes (Phillips 1971, Bottom et al. 1985).
- Juvenile steelhead trout and chinook and coho salmon avoided turbid streams and experienced gill damage from suspended sediment (no concentration specified) (Noggle

1978).

- Brown and rainbow trout alevins suffered permanent growth reductions when exposed to 250 ppm ground wood fiber (75% spruce, 25% balsam fir). Concentrations of 60 ppm fiber caused sublethal responses due to reduced breathing rate, heart rate, respiration rate, and growth rate (Kramer and Smith 1965).
- Mortality of salmonid eggs was greatest when exposed to sediment early in the incubation period (Bartsch 1960). Low dissolved oxygen and the physical barrier caused by sedimentation on spawning beds further reduced salmonid survival (Phillips 1971, Hall and McKay 1983).
- Steelhead and coho salmon fry had reduced growth rates and emigrated from stream channels during extended periods (11 to 14 d) of high turbidity (23 to 84 NTUs) (Sigler et al. 1984).
- Streams with water quality adequate to support anadromous salmon stocks average less than 25 mg/l of suspended sediments (Reiser and Bjornn 1979).
- Reduction of pool area or volume due to sedimentation in small streams resulted in a reduction in the summer capacity of a stream to support salmonids proportionally to the percentage of pool area or volume lost (Bjornn et al. 1974).
- Macroinvertebrate densities were reduced in streams without buffer strips because of sediment intrusion into the substrate and the reduction of litter input from riparian vegetation (Culp and Davies 1983).
- Logging of the stream bank significantly decreased macroinvertebrate densities in winter, primarily due to postlogging sedimentation, which increased winter scouring (Culp and Davies 1983).
- When in suspension, logging-produced sediments reduced algal production (Bartsch 1960, Wilson 1960, Phillips 1971, Hall and McKay 1983).

d. **Alteration of natural cover: riparian vegetation**

- Second-growth logged sections (12-35 yr after logging) that were reshaded by deciduous forest canopy had lower biomass of trout than old-growth sites (Murphy and Hall 1981).
- Removal of the canopy surrounding waterways increased solar input, which increased primary productivity and production of benthic and drift organisms. These positive effects often mask negative effects such as loss of benthic habitat due to sediment and/or debris input (Tyler and Gibbons 1973, Murphy et al. 1981, Koski et al. 1984). Note that this impact is distinct from the reduced algal production (stated above) when suspended sediments are high enough to decrease light penetration.
- Streams in clear-cut watersheds of Southeast Alaska had massive growth of filamentous algae due to increased solar radiation after canopy removal and nutrients leached from

slash debris. Poor insect fauna in these streams were attributed to the algal growth (Reed and Elliott 1972).

- Streams exposed to sunlight (between 5 and 17 yr after clear-cutting) generally had greater biomass, density, and species richness of invertebrate predators than did streams in old-growth forest areas (> 450 yr old). This was attributed to greater periphyton production and coarser streambed sediment in first-order, high-gradient (10 to 16%) streams in clear-cut areas, as opposed to streams of the same size and gradient in old-growth forest areas (Murphy and Hall 1981).
- Streams in second-growth forests that were reshaded by deciduous forest canopy (12-35 yr after logging), had fewer predatory invertebrate taxa than old-growth sites (Murphy and Hall 1981).
- Removal of streamside vegetation and other disturbances destabilized or broke up large accumulations of organic debris. As a result, channel and bed morphology changed extensively during major freshets (Bryant 1980, Toews and Brownlee 1981, Bryant 1983, Hartman et al. 1983).
- Undercut banks provide 4.5 times more cover in the streams flowing through forested areas than in the channels in the clearcut areas. This supports other observations that 1) roots of both herbaceous and woody streamside vegetation reinforce the banks, 2) the area of overhanging banks may be reduced by crushing during felling and yarding operations, and 3) aggradation after logging may fill channel margins where cover for fish had been provided by overhanging banks (Swanson et al. 1984).

e. **Alteration of natural cover: aquatic vegetation and debris**

- Stream reaches with no buffer strips and located in clear-cut areas contained the least amount of large natural debris, pool habitat, and, consequently, fewer juvenile salmonids than either buffered or old-growth reaches of stream (Koski et al. 1984).
- The apparent magnitude of the effect logging has on the concentration of organic debris in southeast Alaska streams is similar to situations in western Oregon where the same methods of logging and stream protection were employed (i.e., free-falling without buffer strips). The sampled streams in clearcut areas in southeast Alaska have about three times as much coarse debris and seven times as much fine debris as that measured in streams of forested areas (Swanson et al. 1984).
- Debris accumulations consisting of masses of roots caused substantial erosion in streams that had been logged along the stream banks. Because the masses decompose very slowly in the stream, move readily with high water, and often become stranded on spawning bars, they affect stream stability and productivity for decades after logging (Tyler and Gibbons 1973).
- Debris in streams of a clear-cut drainage accumulated

large amounts of sediments, created numerous obstructions to fish passage, and altered flow characteristics. Removal of debris scoured accumulated sediments and increased turbidity (Burns 1970, Leudtke et al. 1976, Bestcha 1979).

- The accumulation of fine logging debris (bark, leaves, twigs) was shown to decrease salmonid production (Fredriksen 1970, Narver 1971, Meehan 1974, Ruth and Harris 1975).
- Logging debris is generally smaller and accumulations are considerably more dense than naturally occurring debris. Therefore, it can severely constrict streamflows and result in rapid streambank and streambed cutting and destabilization of naturally occurring debris (Tyler and Gibbons 1973; Bryant 1980, 1983; Toews and Moore 1982; Elliott 1986).
- Uncleaned streams in logged areas contained up to seven times the amount of debris found in undisturbed streams on Prince of Wales Island, in Southeast Alaska (Bryant 1983).
- Adverse effects of logging debris arise from water quality impacts such as increased biological oxygen demand (BOD) and decreased instream and intragravel oxygen (Hall and Lantz 1969, Ponce and Brown 1974).
- Stable accumulations of large organic debris (LOD) in streams provides critical winter habitat areas for juvenile coho salmon (Koski et al. 1984). Removal of LOD during or after logging in Carnation Creek, B.C., resulted in a trend towards higher net movement of coho into adjacent sloughs and tributaries; and winter freshets caused large population decreases of coho in the main channel (Toews and Moore 1982, Tschaplinski and Hartman 1983).
- Excessive cleaning of logging debris in a Washington coastal stream caused short-term population reductions of cutthroat trout over winter. Habitat and fish populations recovered within 1 yr because there was a source of large organic debris to replace that which was removed (Lestelle and Cederholm 1984).
- Streamside logging can destabilize undercuts, which contributes to their collapse during freshets and results in reduction of coho abundance (Tschaplinski and Hartman 1983).
- Extremely high levels of debris loading result in abundant habitat for wood-processing organisms but reduces habitat availability for fish (ibid.).
- Slash debris from logging operations in Southeast Alaska was deposited in stream riffle areas and caused destruction of habitat for macroinvertebrates (mayflies and stoneflies) and covered up periphyton food sources of these benthic animals (Reed and Elliott 1972).

f. **Addition of physical barriers: partial obstructions**

- Log bridges on two Southeast Alaska streams were not removed after logging, and they subsequently collapsed, causing erosion and complete diversion of the stream flow. (Tyler and Gibbons 1973).

g. **Change in level of dissolved oxygen**

- Sediment deposited on salmonid spawning grounds filled the interstitial gravel spaces, reducing the interchange of surface and subsurface waters, which decreased the level of dissolved oxygen available to preemergent salmonids (Wilson 1960, Phillips 1971).
- Steelhead trout and coho salmon fry hatched from embryos reared at low and intermediate oxygen concentrations hatched later and were smaller in size at hatching than fry from embryos reared near the air-saturation level. At all oxygen concentrations tested, reduced water velocities resulted in reduced size of hatching fry. Water movement promotes growth of salmonid embryos by delivering oxygen to the surface of the egg membrane and by removing metabolic waste products (Shumway et al. 1964).
- Douglas fir, western hemlock, and red alder twigs and needles caused a substantial depletion of the oxygen under simulated stream conditions at 20°C. Fish growth and development will be inhibited at oxygen concentrations less than 4 or 5 mg/l. Prolonged levels below 1 mg/l will cause death (Ponce and Brown 1974).
- When subjected to fluctuating temperatures (i.e., streams exposed to increased solar radiation after logging), the biological oxygen demand (BOD) for fine logging debris was 58 to 76% higher over a 5 d period than the BOD for fine logging debris in streams at near constant temperatures (Ponce and Brown 1974).
- Canopy reductions decreased dissolved oxygen concentrations and increased temperatures of intragravel water, which reduced coho salmon populations (Meehan 1974, Ringler and Hall 1975).
- Numerous brown trout and other fish died in a New Zealand river due in part to low dissolved oxygen concentrations following logging (Graynoth 1979).
- Reduced dissolved oxygen concentrations can adversely affect the swimming performance of adult migrating salmonids (Reiser and Bjornn 1979). Oxygen levels needed for migrating and spawning fish should remain above 80% saturation, with temporary absolute levels not falling below 5.0 mg/l (Reiser and Bjornn 1979).

h. **Change in levels of other toxic compounds: bark or log leachates**

- Douglas fir and ponderosa pine were found to introduce leachates to fresh water (Graham and Schaumburg 1969). The study did not examine whether these substances have impacts on biological component.
- Water-soluble leachates of western red cedar were toxic to juvenile coho salmon at 0.33 mg/l for foliage terpenes and 2.7 mg/l for tropolones (Peters et al. 1976).

i. **Change in levels of nutrients**

- Stream water quality in old-growth spruce forests was compared to that in second-growth forests that had been logged 45 to 70 yr previously in New Hampshire. Accumulations of nutrients in the increasing biomass of the second-growth forests caused lowered streamwater nutrient concentrations (nitrate, sulfate, phosphate, calcium, magnesium, sodium, and dissolved organic carbon) in the logged areas (Silsbee and Larson 1983). This could cause a long-term indirect effect of decreased fish production (i.e., through decreased primary productivity) (Koski and Walter 1977).
- Clear-cutting on an Oregon watershed caused increases in streamwater NO_3 concentrations that persisted over 5 yr after logging (dependent on rate of revegetation) (Fredriksen et al. 1975).
- Patterns of increased K and NO_3 were observed in British Columbia streams during the first 2 to 3 yr following clear-cut logging and slash burning (Feller and Kimmins 1984).

j. **Introduction or removal of species**

- Observations of streams with narrow buffer strips (less than 30 m wide) indicated that no recovery or incomplete recovery of benthic macroinvertebrates occurred, based on a diversity index and a measure of ecological distance, 6-10 yr after logging (Erman et al. 1977, Newbold et al. 1980, Erman and Mahoney 1983).
- Clear-cut logging and related debris accumulation was found to decrease aquatic macroinvertebrate species diversity (Reed and Elliott 1972, Erman et al. 1977, Erman and Mahoney 1983, Silsbee and Larson 1983). Debris accumulations resulted in reduced flushing and water flow and consequently reduced dissolved oxygen levels, which caused respiratory problems for many aquatic insects (Reed and Elliott 1972).
- Immediately following yarding operations, large quantities of filamentous algae colonized all debris and mud in an Oregon stream, and species composition of algal flora was changed (Hansmann and Phinney 1973). Aquatic invertebrates do not commonly feed on this algae (Gilpin and Brusven 1970, cited in Reed and Elliott 1972).

2. Guidelines:

a. **Change in water temperature**[2]

1) General. Avoid increases in stream water temperature in temperature-sensitive streams by leaving buffer strips along riparian zones in forest harvest areas (derived from Brown and Krygier 1970, Ringler and Hall 1975, Rishel et

[2] It is recognized that the impact of increased water temperatures in cold-water streams may result in the positive benefit of increased productivity, however, it is beyond the scope of this document to incorporate positive impacts or enhancement.

al. 1982, Barton et al. 1985).

(a) Specific. Minimize removal of overstory canopy within the riparian zone on streams that are determined to be temperature sensitive (i.e., considering physical parameters of size, gradient, volume, etc., presence of salmon spawning beds, and abundance and distribution of salmonid species) (derived from Brazier and Brown 1973, Koski and Walter 1977, Reiser and Bjornn 1979, Heming et al. 1982, Heming 1982, Rishel et al. 1982, Hartman et al. 1984, Scrivener and Anderson 1984).

(b) Specific. Minimize unacceptable changes in stream water temperature by designing buffer strips that incorporate vegetation that shades the stream (derived from Brazier and Brown 1973, Corbett et al. 1978).

b. **Change in depth or velocity of water**

1) General. Avoid large clear-cut timber operations where increased streamflows are likely and may cause destruction of salmonid stream habitat and/or reduction of salmon populations (derived from Rothacher 1970, Burns 1972, Harris 1973, Cederholm 1977, Harris 1977, Harr et al. 1979, Toews and Brownlee 1981, Bottom et al. 1985).

(a) Specific. Minimize increases in streamflow and sedimentation (caused by clear-cut logging) by harvesting timber in small, spaced patches rather than in large, clear-cut tracts (derived from Rothacher 1970, Burns 1972, Harris 1973, Cederholm 1977, Harris 1977).

(b) Specific. Minimize soil compaction and subsequent runoff, erosion, and turbidity problems in forested watersheds by utilizing high-lead or skyline yarding techniques (derived from Lull 1959, Toews and Brownlee 1981).

(c) Specific. Minimize increases in streamflow from increased runoff (as a result of soil compaction and reduced infiltration) by utilizing uphill, cable yarding techniques that fan out water run-off rather than concentrating it, as occurs with downhill skidding (derived from Lull 1959, Ponce and Brown 1974, Harr et al. 1979, Toews and Brownlee 1981).

c. **Change in levels of turbidity, settleable solids, or substrate stability**

1) General. Avoid clearing and tree harvest operations in areas where resulting introduction of sediments into important aquatic environments (i.e., stream spawning gravels, pools and riffles, and rearing and feeding areas) will occur (derived from McNeil and Ahnell 1964; Phillips 1971; Swanston 1969, 1970, 1971; Bjornn et al. 1974; Phillips et al. 1975; Swanson and Dyrness 1975; Harris 1977; Koski and Walter 1977; Holtby and Hartman 1982; Scrivener and

Brownlee 1982; Hall and McKay 1983; among others).

(a) Specific. Minimize introduction of sediments into streams by leaving buffer strips along riparian zones in forest harvest areas (derived from Aldrich and Johnson 1979, Barrick 1984).

(b) Specific. Minimize introduction of sediments into streams by allowing only light, selective timber harvest and minimal soil disturbance within designated stream buffer strips (derived from Lull 1959, Corbett et al. 1978, Aldrich and Johnson 1979, Barrick 1984).

2) General. Avoid clear-cut timber harvests in areas where steep slopes and unstable soils are likely to result in mass slope failure (derived from Swanston 1969, 1970, 1971; Burns 1972; Rice et al. 1972; Swanson and Dyrness 1975; Harris 1977; Koski and Walter 1977; Beschta 1978; Toews and Brownlee; among others).

(a) Specific. Minimize introduction of sediments and slash debris into streams by seeding disturbed areas when buffer strips are not maintained along stream corridors (derived from Burns 1972).

(b) Specific. Minimize sediment yield in steep slope areas by harvesting in small, patch clear-cuts as opposed to large clear-cuts (derived from Harris 1977).

3) General. Avoid harvesting timber on steep slopes with shallow, unstable soils, in order to lessen the occurrence of debris avalanches and debris torrents (derived from Swanston 1970, Toews and Brownlee 1981, Hess 1984, Bottom et al. 1985, Swanson and Lienkaemper n.d.).

4) General. Avoid felling trees into or yarding logs across streams which can cause excessive streambank erosion, addition of coarse and fine woody debris, and channel instability, by leaving buffer strips along stream channels (derived from Toews and Brownlee 1981, Holtby and Hartman 1982, Swanson et al. 1984).

(a) Specific. Minimize impacts from logging in the riparian zone by utilizing directional falling techniques (i.e., conventional wedging, hydraulic jacks, or cable-assisted falling) (derived from Toews and Brownlee 1981).

(b) Specific. Minimize addition of unacceptable levels of sediment into streams by limiting stream access points for yarding and limiting soil disturbance within the riparian corridor (derived from Burns 1972, Everest and Harr 1982, Holtby and Hartman 1982, Hall and McKay 1983).

(c) Specific. Minimize impacts of streamside logging by utilizing logging methods that 1) introduce little or no new debris into stream channels, 2) maintain the natural debris present in stream channels, and 3) manage streamside vegetation as a future source of large debris for stream channels (Swanson et al. 1984)

5) General. Avoid introduction of sediments into streams when salmonids are present (derived from McNeil and Ahnell 1964, Hall and Lantz 1969, Phillips 1971, Phillips et al. 1975, Ringler and Hall 1975, Hall and McKay 1983, Sigler et al. 1984, Bottom et al. 1985, among others).
   (a) Specific. Minimize the potential for sedimentation of spawning beds from clear-cut logging operations in salmonid streams during the time that eggs are incubating in the gravel (derived from Bartsch 1960, Phillips et al. 1975, Crouse et al. 1981, Holtby and Hartman 1982, Scrivener and Brownlee 1982, Hall and McKay 1983).
   (b) Specific. Minimize the potential for sedimentation of important rearing areas from clear-cut logging operations in salmonid streams when juvenile fish are feeding and rearing (derived from Bjornn et al. 1974, Phillips et al. 1975, Noggle 1978, Sigler et al. 1984).

d. **Alteration of natural cover: riparian vegetation**

1) General. Avoid removal of riparian vegetation by designing buffer strips which maintain the integrity of the streambank (derived from Reed and Elliott 1972, Bryant 1980, Murphy and Hall 1981, Bryant 1983, Hartman et al. 1983, Koski et al. 1984, Swanson et al. 1984).
   (a) Specific. Minimize logging operations in the riparian zone by selectively harvesting mature timber and leaving non-merchantable trees and shrubs (derived from Toews and Brownlee 1981, Swanson et al. 1984).
   (b) Specific. Minimize impacts from logging in the riparian zone by utilizing directional falling techniques (i.e., conventional wedging, hydraulic jacks, or cable-assisted falling) (Toews and Brownlee 1981).

e. **Alteration of natural cover: aquatic vegetation and debris**

Guidelines derived in this section from documented impacts of addition of debris from logging operations in streams are oriented towards the negative aspects of excessive additions of such large and/or fine debris. It is beyond the scope of this document to incorporate positive impacts or enhancement effects related to logging practices. However, it is necessary for the user to realize that woody debris in streams can also have an important effect of enhancement (i.e., by providing cover for rearing salmonids, creating pool habitat, providing substrate for aquatic insects to colonize, etc.). Research has documented that natural debris is critical for providing such habitat, and addition of some debris can be beneficial to salmonids; however, the addition of excessive amounts of debris from logging in and adjacent to small streams can cause adverse impacts. An additional controversy stems from practices of cleanup of debris in streams, i.e., how much and what size of material should be left for stream enhancement and rehabilitation. Thus the literature available on the topic of woody debris in streams is represented by much conflicting information. The best approach to avoiding or minimizing adverse impacts to aquatic habitats and resources requires analysis of the specific conditions present at a given site and review of literature pertinent to the site conditions. The user of these guidelines should also consult any newly published literature.

1) General. Avoid introduction of logging debris into streams where such addition will cause negative impacts on fish and fish habitat (derived from Burns 1970, Fredriksen 1970, Reed and Elliott 1972, Tyler and Gibbons 1973, Ruth and Harris 1975, Beschta 1979, Toews and Moore 1982, Bryant 1983, Koski et al. 1984, among others).
   - (a) Specific. Minimize stream habitat destruction (i.e. filling pools, destabilizing natural debris cover, scouring gravel spawning beds, etc.) caused by the addition of excessive levels of logging debris into streams (derived from Hall and Lantz 1969; Tyler and Gibbons 1973; Beschta 1979; Bryant 1980, 1983).
   - (b) Specific. Minimize introduction of logging debris into streams by utilizing specific techniques such as cable-assisted felling, jacking trees, leaving high stumps above the stream, and leaving buffer strips along the stream (derived from Ponce and Brown 1974, Bryant 1983).
   - (c) Specific. Minimize high biological oxygen demand and/or blockages to fish passage caused by excessive introduction of fine logging debris in streams by restricting its introduction into streams when stream flow is low and/or temperatures are high (derived from Ponce and Brown 1974).
   - (d) Specific. Minimize impacts of decreased water quality (i.e., increased biological oxygen demand and decreased instream and intragravel oxygen) caused from accumulations of debris in streams by removing such accumulations soon after logging (derived from Hall and Lantz 1969, Ponce and Brown 1974).

2) General. Avoid excessive debris removal in small, low-gradient streams after clearcut logging (derived from Toews and Moore 1982, Bryant 1983, Tschaplinski and Hartman 1983, Lestelle and Cederholm 1984, Swanson et al. 1984).
   - (a) Specific. Minimize damage to stream habitat and important fish cover by considering, prior to debris removal, 1) distribution and relative abundance of fish species; 2) the physical habitat estimates of streambed and bank stability, and gradient; and 3) the age, size, and density of debris (derived from Bryant 1983). Also consider how channel geometry, sediment deposition and streamside vegetation have responded to existing debris conditions (Swanson et

al. 1984).

(b) Specific. Minimize increases in sedimentation during debris removal by removing only accumulations of fine debris which is not buried in sediment (derived from Swanson et al. 1984).

(c) Specific. Minimize loss of critical salmonid refuge cover by leaving large, stable pieces of debris in streams in quantities and spatial distributions typical of forested stream areas during and after logging operations (derived from Toews and Moore 1982, Koski et al. 1984, Swanson et al. 1984).

(d) Specific. Minimize damage to streambed and bank by removing logging debris by hand, not with mechanical equipment (derived from Lantz 1971a, Ponce and Brown 1974).

(e) Specific. Minimize loss of aquatic habitat downstream of debris-removal sites due to increased turbidity and sedimentation by considering the amount of sediment that will be produced (i.e., collected behind debris accumulations) prior to debris removal (derived from Leudtke et al. 1976, Beschta 1979).

3) General. Avoid harvesting all mature timber adjacent to streams, in order to provide and maintain a future source of large organic debris to the stream (derived from Toews and Moore 1982, Lestelle and Cederholm 1984).

(a) Specific. Minimize debris avalanche potential, hence debris torrent potential, by considering soil and slope stability prior to logging operations and utilizing improved harvest practices (e.g., balloon, helicopter, or skyline cable yarding) to reduce soil disturbance (derived from Swanson and Lienkaemper n.d.).

f. **Change in level of dissolved oxygen**

1) General. Avoid the reduction of dissolved oxygen levels in streams vital to the production of salmonids, whether the reduction is caused by increased sediment loads, increased biological oxygen demand due to debris accumulations, reduced water velocities, or increased temperatures related to logging operations (derived from Shumway et al. 1964, Phillips 1971, Ponce and Brown 1974, Ringler and Hall 1975, Reiser and Bjornn 1979).

g. **Change in levels of other toxic compounds: bark or log leachates**

1) General. Avoid the introduction of red cedar logs and debris into aquatic habitats (derived from Peters et al. 1976).

h. **Change in levels of nutrients**

1) General. Avoid increases in nutrients leached from disturbed soils and logging debris by leaving buffer strips along riparian corridors (derived from Fredriksen et al. 1975, Koski and Walter 1977, Silsbee and Larson 1983, Feller and Kimmins 1984).

i. **Introduction or removal of species**

1) General. Avoid alterations of aquatic invertebrate species diversity by controlling sedimentation, debris accumulation, and algae blooms through the maintenance of riparian buffer strips (derived from Reed and Elliott 1972, Hansmann and Phinney 1973, Erman et al. 1977, Newbold et al. 1980, Erman and Mahoney 1983, Silsbee and Larson 1983).

D. **Freshwater Nonsalmonids**

1. **Summary of documented impacts:**

a. **Change in levels of turbidity and settleable solids and Change in depth or velocity of water**

- Streams in clear-cut watersheds of New Brunswick had 17% fewer trout, over 200% more sculpins, and 26% less benthos than control streams, due to sedimentation, channelization, and to a lesser extent lack of riparian buffer strips (Welch et al. 1977).

b. **No information was found in the following impact categories (see freshwater salmonid section for additional information):**

° Change in water temperature
° Alteration of natural cover - riparian vegetation
° Alteration of natural cover - aquatic vegetation and debris
° Addition of physical barriers - partial obstruction
° Change in level of dissolved oxygen
° Change in level of other toxic compounds - bark or log leachates
° Change in levels of nutrients
° Introduction or removal of species

2. Guidelines:

a. General. Avoid clearing and tree harvest activities immediately adjacent to waters where the potential for adverse impacts to fish production exists (derived from Welch et al. 1977).

b. **See guidelines presented above in the section Freshwater Salmonids.**

FILLING AND PILE-SUPPORTED STRUCTURES

I. DEFINITION

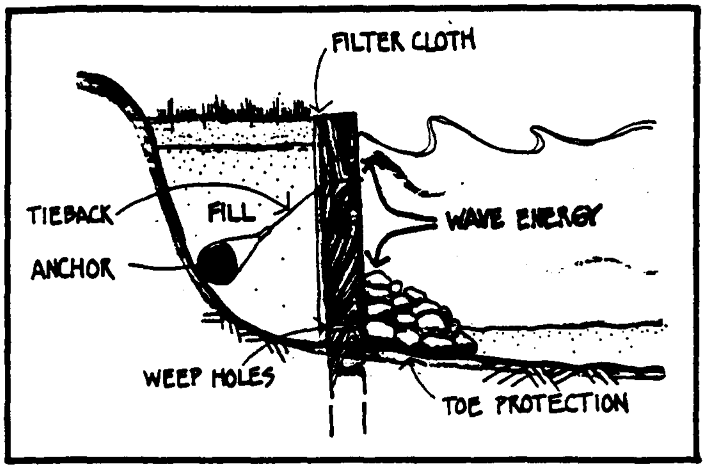
Aquatic filling refers to the deposition or placement of material (e.g., gravel, rock, soil, concrete, wood, steel) into aquatic and wetland habitats for the purpose of making the habitat suitable for constructing various types of structures or water impoundments. Examples of structures include buildings, drilling islands, breakwaters, jetties, groins, bulkheads, revetments, dikes, and causeways. Filling also includes pile-supported structures, such as bridges, piers, and docks. Filling of aquatic and wetland habitats during the construction phase of various types of water impoundments is included here (e.g., hydroelectric dams, wastewater treatment, water cooling ponds, or ponds used for aquacultural purposes). After impoundments have been constructed and are being filled with water, they are considered under the activity category Water Regulation/Withdrawal/Irrigation. Deposition of waste materials, including nonsewage waste and drilling muds, for the purpose of disposal is not included here (see Solid Waste Disposal) except in cases where materials are used for preparing sites for construction of the structures indicated above.

The following is an attempt to translate the current body of documented impacts resulting from filling activities into guidelines for habitat management that accurately reflects both the state of completeness and the level of specificity present within the literature database. Literature presented here consists primarily of original documented impact sources. However, a limited number of high-quality review papers that documented impacts literature are also included. These include Mulvihill et al. (1980) and Sigman (1985).

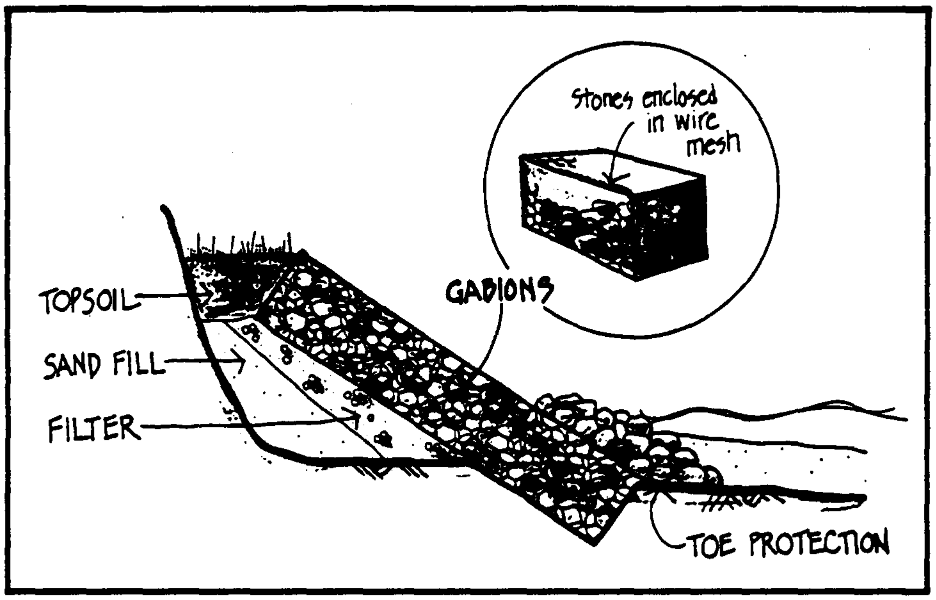
II. IMPACT CATEGORIES

Impacts from shoreline alteration projects have been well documented in the contiguous United States, but relatively few impacts have been documented in Alaska. Consequently, guidelines presented in this document are based on documentation from the southern, eastern, and northwestern portions of the country. Also, the activity of filling and associated construction of structures is relevant to both the marine and the freshwater aquatic environments. Impacts resulting from placement of a structure or deposition of fill will affect the aquatic habitat and the species present in either environment. The impact summaries and guidelines in this document are appropriate for either the marine or the freshwater habitat, however, the hydrological characteristics (e.g., current vs. no current) of a given site should be considered and incorporated into the design of any proposed structure. Examples of major shoreline alteration structures that are dealt with in this document are presented in figure 2.

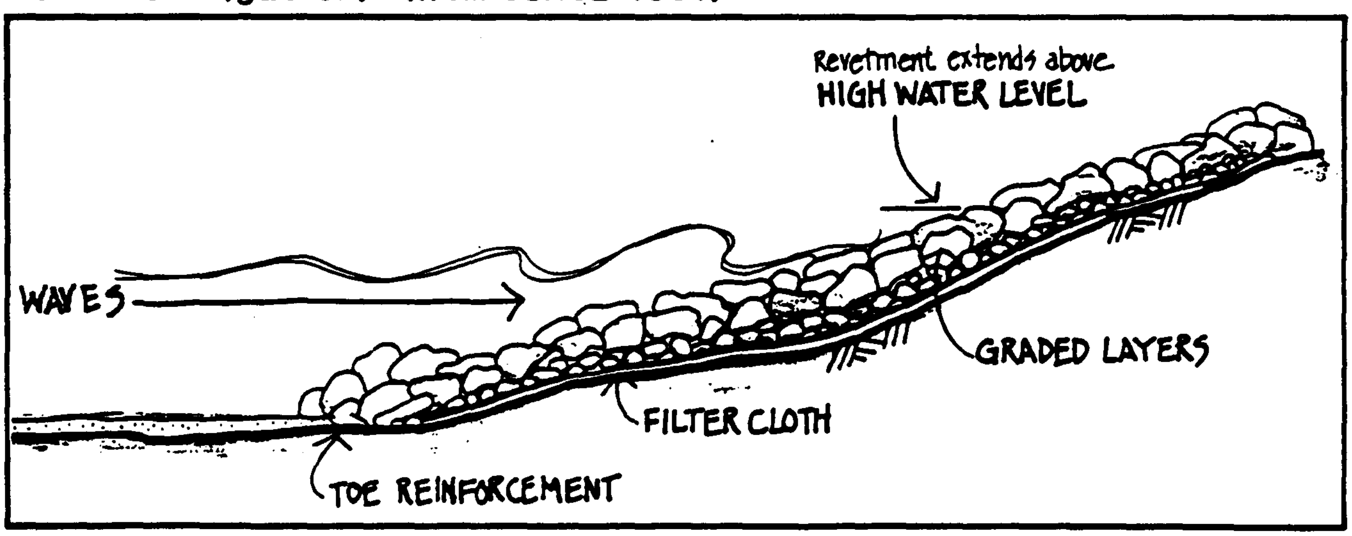
The impacts from shoreline alteration are typically defined by impacts from construction of structures and impacts from the subsequent presence of the structures. Although impacts from construction are most often of short-term duration to aquatic species and their habitats, those impacts that result from the presence of the structure tend to be permanent. Consequently, for an evaluation of a proposed project involving shoreline alteration, it will be critical to consider site-specific parameters, as well as cumulative effects of



Bulkheads and Seawalls (from USACE 1981)

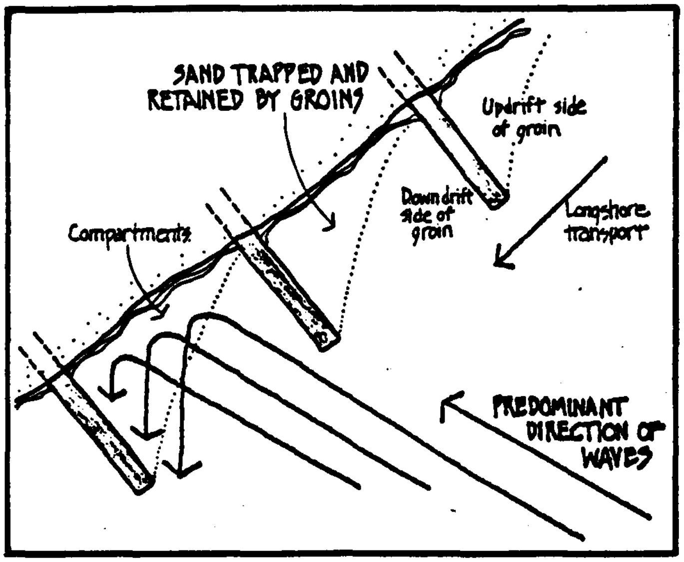


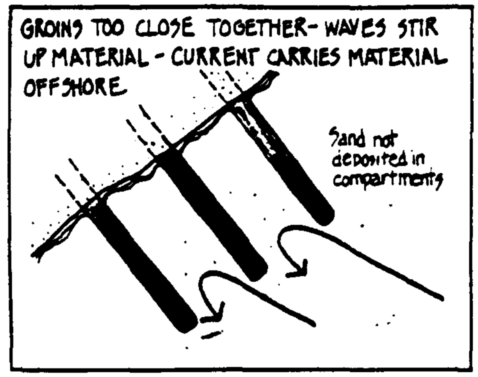
Revetment (gabion) (from USACE 1981)



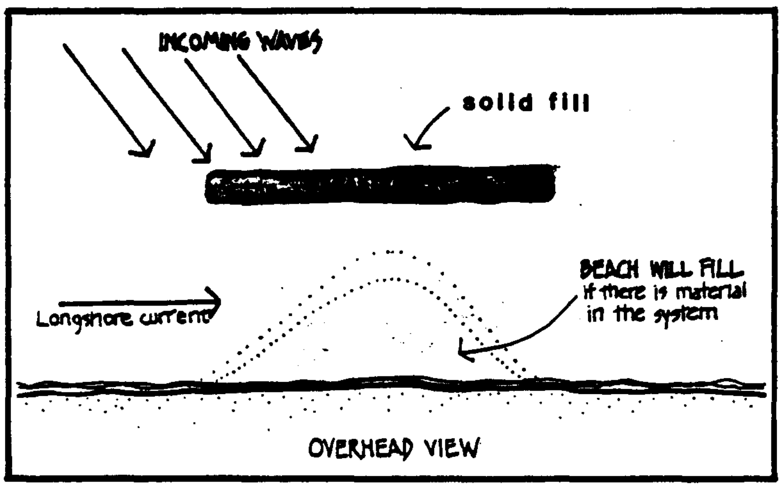
Revetment (riprap) (from USACE 1981)

Figure 2. Examples of shoreline alteration structures.

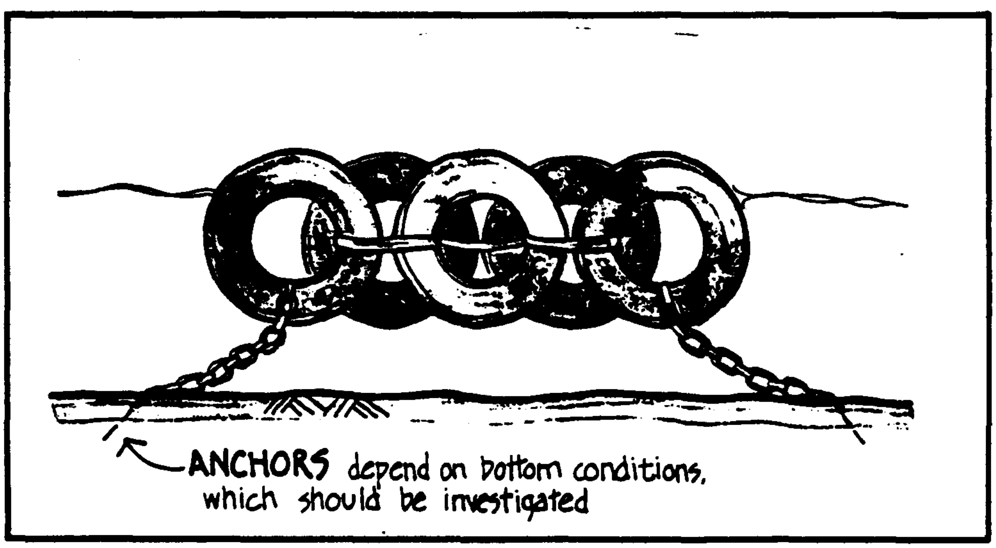




Groins (aerial view) (from USACE 1981)

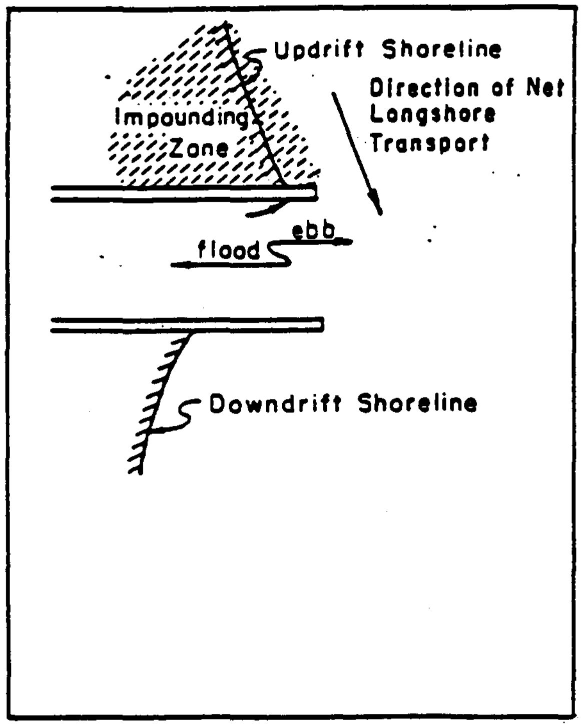


Breakwater (solid-fill) (from USACE 1981)

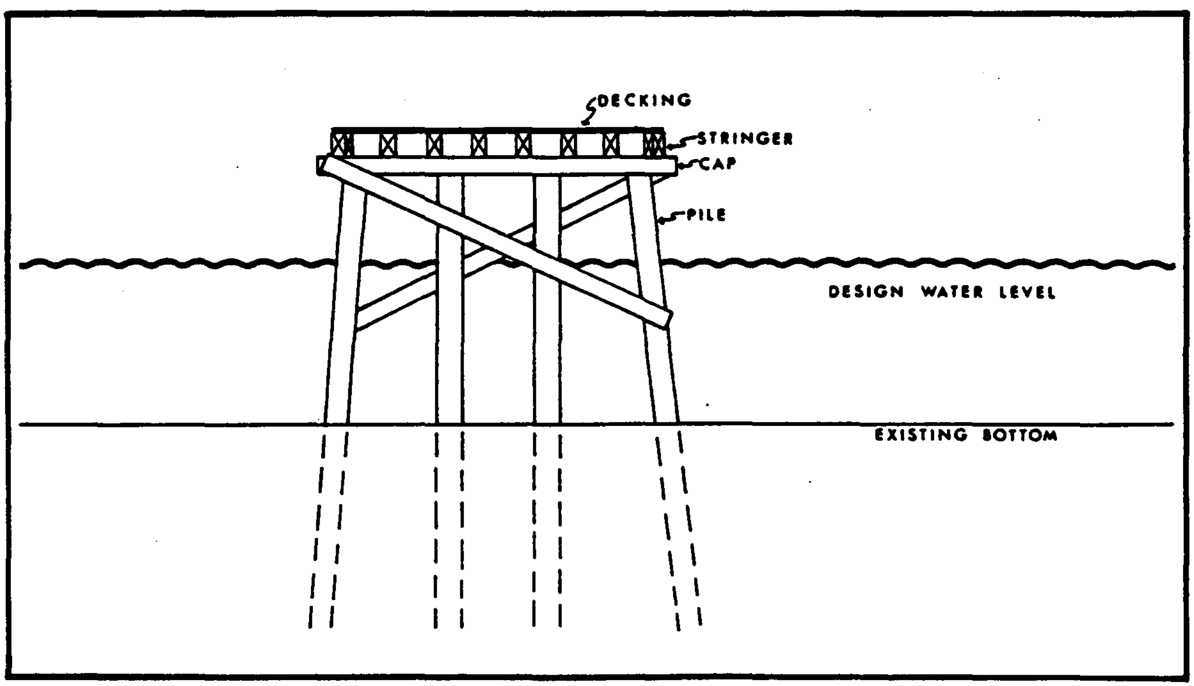


Breakwater (floating tires) (from USACE 1981)

Figure 2 (cont.).

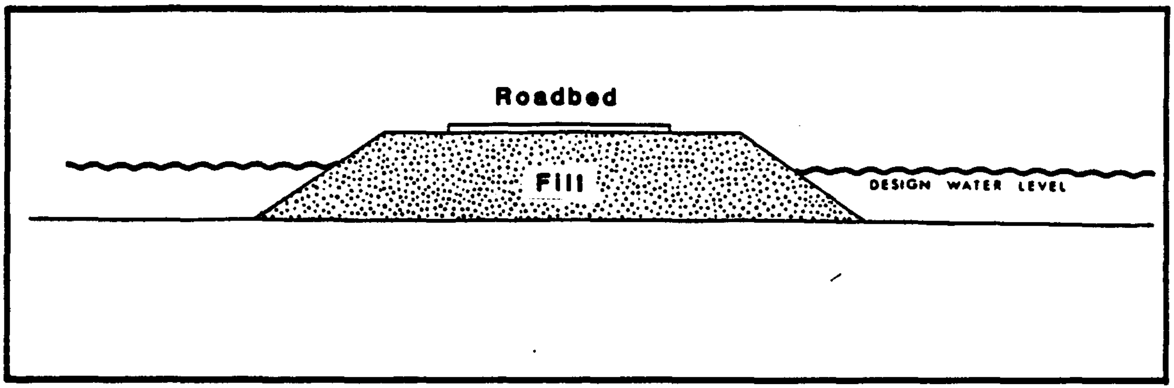


Jetties (from USACE 1977)

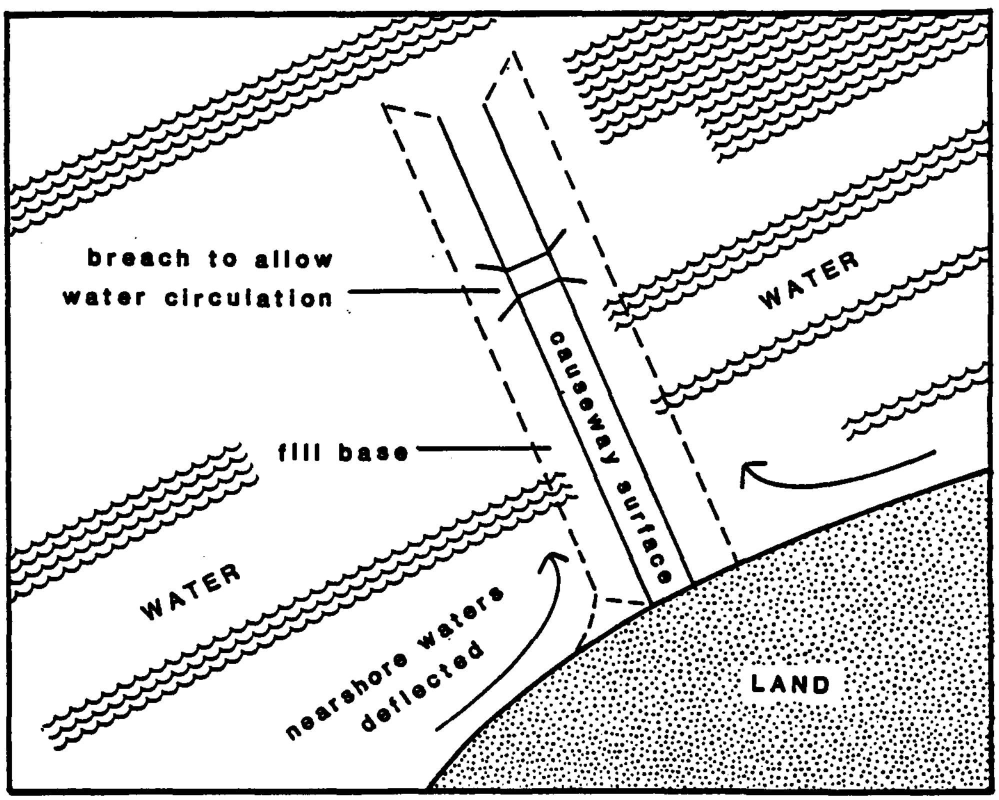


Cross-sectional view of a typical pier (from Mulhiville et al. 1980)

Figure 2. (cont.).



Causeway (cross-sectional view) with fill material
(from Mulhiville et al. 1980)



Causeway (aerial view)

Figure 2. (cont.).

adjacent structures (existing or proposed). It is also of great importance to evaluate the long-term effects of the structure.

The impact categories identified in this section are a subset of the impacts identified in the companion volume titled Impacts of Land and Water Use on Fish and Their Habitat (ADF&G 1986). Three interrelated impact categories that were previously identified as the addition, removal, and physical disturbance of substrate materials have been combined and included here as a single category titled Changes in Levels of Turbidity, Settleable Solids, or Substrate Stability.

The following impacts were found to be associated with the activity of Filling and Pile-Supported Structures:

- Change in water temperature
- Change in depth or velocity of water
- Change in levels of turbidity, settleable solids, or substrate stability
- Addition of physical barriers: partial obstructions
- Change in level of dissolved oxygen
- Change in level of salinity
- Change in levels of heavy metals
- Change in levels of hydrocarbons
- Change in levels of nutrients
- Introduction or removal of species

III. ACTIVITY-SPECIFIC CONSIDERATIONS

The following are considerations that pertain to filling and pile-supported structures and should be taken into account when preparing a response to development proposals:

1. What type of material will be used for the fill project (e.g., riprap, gravel, concrete, sand, dredge spoil, etc.), and will the fill material used contribute to siltation?
2. Do fill materials contain contaminants that may be toxic to aquatic life?
3. Will fill materials contribute to siltation either on a short-term basis or as a chronic sediment source?
4. How much aquatic habitat will be lost due to burial or excavation of fill material?
5. What magnitude of aquatic animals will be killed due to burial or excavation of fill material?
6. What are the slope and dimensions of the fill project (e.g., wide, gradually sloping vs. steep and narrow)?
7. Will water quality parameters be changed (e.g., temperature, salinity, dissolved oxygen)?

8. What changes in hydrological characteristics at the proposed project area will occur (i.e., water circulation and tidal patterns)?
9. Will the deposition of fill alter or inhibit movements or migrations of aquatic species?
10. Will the deposition of fill material cause destruction of critical habitat areas of aquatic species (e.g., spawning, rearing, overwintering, feeding)?
11. Will interactions occur between the fill project and other proposed or existing fill projects in the area?
12. Will the presence of the structure or fill project result in an increase in human use in the area?
13. Does timing of construction of the structure or fill coincide with critical periods in migration, spawning, rearing, overwintering, or feeding of aquatic species?
14. What types of preservatives will be used on pilings?
15. How will piles be driven? Does pile-driving coincide with concentrations of aquatic species in life history stages that are sensitive and vulnerable to effects of vibration and/or noise?

IV. IMPACTS AND GUIDELINES RELATED TO FILLING AND PILE-SUPPORTED STRUCTURES (STRUCTURE-SPECIFIC)

A. Breakwaters

1. <u>Summary of documented impacts:</u>

a. Change in levels of turbidity, settleable solids, or substrate stability and Change in depth or velocity of water

- Waves reflected off breakwaters with smooth, vertical walls have had a scouring effect at the base of the structure (Heiser and Finn 1970).
- Breakwaters have caused disruption of longshore sediment and littoral transport. This caused fine sediment deposition shoreward of the structure (US Army Coastal Engineering Research 1977).

b. Addition of physical barriers: partial obstructions

- Shore-connected breakwaters altered patterns of longshore salmon migration (Heiser and Finn 1970).
- Migrating juvenile chum and pink salmon (35-45 mm length) did not migrate around a breakwater or through inadequately designed fish passages (e.g., enclosed, dark culverts or sediment-filled breaches). Larger juvenile chum and pink salmon (50-70 mm) were subject to increased predation by coho salmon smolts and cutthroat trout when they migrated around breakwaters and into deeper waters (Heiser and Finn 1970, Orrell and Johnson 1975).

c. Change in water temperature and Change in level of salinity

- Breakwaters have negatively interfered with tides and currents. Breakwaters with restricted openings resulted in reduced flushing rates, which in turn resulted in fluctuations of temperature and salinity on the lee side (Hastings 1972, Nece et al. 1975).
- Floating breakwaters (with bottom anchors) have caused fewer problems with circulation, obstructed sediment

transport, water quality degradation, and obstruction to fish movements (Hales 1981, Bishop et al. 1983, USACE 1985).

d. **No information was found on the following impact categories:**
   - Change in level of dissolved oxygen
   - Change in levels of heavy metals
   - Change in levels of hydrocarbons
   - Change in levels of nutrients
   - Introduction or removal of species

2. **Guidelines:**

a. General. Avoid constructing breakwaters that have smooth, vertical walls. Breakwaters constructed of riprap or other natural materials provides rough, irregular surfaces that allow wave energy to dissipate and habitat where aquatic organisms can find protection from waves and juvenile fish can hide from predators (derived from Heiser and Finn 1970, Orrell and Johnson 1975).

   (1) Specific. Minimize the above stated impacts by constructing breakwaters with side slope angles of 45 degrees or less (derived from Heiser and Finn 1970).

b. General. Avoid constructing breakwaters where strong longshore currents are present if the breakwater will cause severe disruption of sediment transport in the littoral zone (derived from US Army Coastal Engineering Research Center 1977).

c. General. Avoid constructing breakwaters in areas where subtidal or intertidal shellfish populations and/or fish-rearing, spawning, or migration routes will be destroyed by deposition of sediments (derived from US Army Coastal Engineering Research Center 1977).

d. General. Avoid constructing breakwaters in areas that do not have naturally high flushing or water exchange characteristics sufficient to preclude water quality degradation (derived from Heiser and Finn 1970, Hastings 1972, Nece et al. 1975, Orrell and Johnson 1975, Hales 1981, USACE 1985).

   (1) Specific. Minimize impoundment of water by designing breakwaters that have breaches wide enough and spaced frequently enough to maintain adequate flushing rates and to allow fish passage (derived from Heiser and Finn 1970, Hastings 1972, Nece et al. 1975, Orrell and Johnson 1975). Alaska State Water Quality Standards should be adhered to.

   (2) Specific. Minimize obstructions to anadromous and nearshore fish movements and water circulation by maintaining breaches at the bottom depth of the breakwater and throughout the lifetime of the structure (derived from Orrell and Johnson 1975).

   (3) Specific. Minimize impacts of poor water circulation, obstructed sediment transport, water quality degradation,

and obstruction of fish migrations by utilizing floating-breakwater designs where adequate wave reduction or energy attenuation can be attained by a floating structure (i.e., where incident wave height does not exceed 4 ft, with a corresponding wave period not exceeding 4 sec (derived from Hales 1981).

B. Jetties and Groins

1. <u>Summary of documented impacts</u>:
   a. **Change in water temperature, Change in level of salinity, Change in depth or velocity of water, and Change in levels of nutrients**
      - The presence of jetties at river or bay mouths have altered both river outflow and tidal currents. This changed temperatures and salinity levels in estuaries and nutrient deposition in adjacent salt marshes (Carstea et al. 1975, US Army Coastal Engineering Research Center 1977).
      - Jetties exceeding some limit in length (related to site-specific hydrological characteristics) cause a decrease in water level in the river mouth (Sawaragi and Kobune 1970).

   b. **Change in levels of turbidity, settleable solids, or substrate stability**
      - Solid jetties and groins that do not allow littoral drift to pass the structures have resulted in erosion of downdrift beaches (US Army Coastal Engineering Research Center 1977).
      - Filling of groins has caused scouring and a buildup of material around the structures. This has created an unstable turbid water environment and resulted in poor habitat for benthic organisms and fish in the littoral zone (Cronin et al. 1971).

   c. **Addition of physical barriers: partial obstructions**
      - Jetties were found to cause changes in the migratory runs of fish and crustaceans into and out of estuaries. Juvenile out-migrating salmon were funnelled away from estuarine rearing areas (Cronin et al. 1971, Orrell and Johnson 1975).

   d. **No information was found in the following impact categories:**
      - Change in level of dissolved oxygen
      - Change in levels of heavy metals
      - Change in levels of hydrocarbons
      - Introduction or removal of species

2. <u>Guidelines</u>:
   a. General. Avoid placing jetties at the mouths of productive anadromous fish streams or estuaries (derived from Cronin et al. 1971, Carstea et al. 1975, Orrell and Johnson 1975, US Army Coastal Engineering Research Center 1977).
      (1) Specific. Minimize restricted passage of anadromous fish

into estuarine rearing areas by placing a sufficient number of breaches along jetties (derived from Orrell and Johnson 1975).

b. General. Avoid constructing groins in order to stabilize or widen beaches (derived from US Army Coastal Engineering Research Center 1975).

(1) Specific. Minimize impoundment of all littoral drift by accommodating site specific hydrological characteristics in the design of groin lengths and the distances apart, as well as in the selection of construction materials (derived from Cronin et al. 1971, US Army Coastal Engineering Research Center 1977).

C. Bulkheads, Seawalls, and Revetments

1. <u>Summary of documented impacts</u>:

a. **Change in levels of turbidity, settleable solids, or substrate stability**

- Bulkheads and seawalls with smooth, vertical surfaces created bottom-scouring effects due to wave energy reflected off the face of the structure. This caused destruction of stable benthic habitat in front of the structures (Heiser and Finn 1970, Harris 1981).
- Bulkheads extending into aquatic habitats altered circulation patterns and increased scouring of bottom sediments. This resulted in changing important tidal and intertidal marine habitats and reduced or destroyed the productivity of shellfish beds and surf smelt spawning habitat (Mock 1966, Millikan and Penttila 1974, Trent et al. 1976).

b. **Addition of physical barriers: partial obstructions**

- Bulkheads placed channelward of wetlands caused destruction of the aquatic wetland habitat and communities (Harris 1981).
- Bulkheads placed below the mean high higher water level (MHHW) resulted in the loss of fringe marsh vegetation due to dewatering and/or filling behind the bulkheads (Harris 1981).
- Bulkheads placed below MHHW have been observed to cause drastic reductions in spawning habitat of surf smelt in Washington State (Millikan and Penttila 1974).
- Revetments constructed in wetlands destroyed narrow fringe marshes and altered water circulation patterns in larger shorefront marsh areas (Carstea et al. 1975, Harris 1981). These neritic areas are important feeding grounds for juvenile chum and pink salmon (Simenstad et al. 1980).
- Revetments that have irregular surfaces (e.g., riprap) and a shallow slope provided protected habitat that could support a wide diversity of marine life (Heiser and Finn 1970, Harris 1981).

c. **No information was found on the following impact categories:**

- Changes in water temperature
- Change in depth or velocity or water

- Change in level of dissolved oxygen
- Change in level of salinity
- Change in levels of heavy metals
- Change in levels of hydrocarbons
- Change in levels of nutrients
- Introduction or removal of species

2. Guidelines:
   a. General. Avoid building bulkheads unless no alternatives for reducing shoreline erosion are available (derived from Mock 1966, Heiser and Finn 1970, Millikan and Penttila 1974, Carstea et al. 1975, Trent et al. 1976, Harris 1981).
      (1) Specific. Minimize construction of bulkheads and placement of resultant backfill channelward of wetland habitat and aquatic vegetation. Preservation of stable vegetative communities will help prevent scouring and destruction of marine benthos (derived from Harris 1981).
      (2) Specific. Minimize the placement of bulkheads, revetments, and riprap toe protection associated with these structures, below the mean high higher water level (MHHW) in wetlands or in intertidal areas known to be productive fish-spawning habitat (derived from Millikan and Penttila 1974, Simenstad et al. 1980, Harris 1981).
      (3) Specific. Minimize placement of bulkheads in or adjacent to productive shellfish beds (derived from Mock 1966, Trent et al. 1976).
      (4) Specific. Minimize placement of bulkheads for shore or bank stabilization when such stabilization can be achieved by the construction of revetments. Revetment designs with shallow slopes and constructed with riprap or other materials that have irregular surfaces are preferrable to smooth, vertical bulkheads (derived from Heiser and Finn 1970, Carstea et al. 1975, Harris 1981).

D. Piers, Pilings, and Support Structures

1. Summary of documented impacts:
   a. **Change in water temperature**
      - Shading from pile-supported structures reduced water temperature and caused a decrease or absence of algae and wetland vegetation under such structures (Carstea et al. 1975).
   b. **Change in levels of turbidity, settleable solids, or substrate stability**
      - Pilings that were placed too close together restricted water circulation and sediment transport (Mulvihill et al. 1980).
   c. **Addition of physical barriers: partial obstructions**
      - Piers set on pilings typically had fewer adverse impacts on aquatic habitat than did piers constructed as solid-fill structures (Mulvihill et al. 1980).
      - Migration routes of small juvenile chum salmon were altered by the presence of piers. Juveniles migrated

offshore around the structures (Salo et al. 1980).

d. **Change in levels of hydrocarbons**

- Water quality can be degraded by polycyclic aromatic hydrocarbon (PAH) leachates from wood piers and pilings that were treated with chemicals or creosote to prevent decay and destruction due to marine borers (Dunn and Fee 1979).
- Leaching of chemicals or creosote from wood pilings would occur at the highest rates during construction and initial placement, in areas with poor water circulation, and during periods of warm weather (Uthe et al. 1984).
- Elevated levels of PAH were measured in sediments within a tidal impoundment used for holding lobsters for commercial sale. The impoundment was constructed of creosote-treated timbers, and the contamination was attributed to leaching of creosote (Uthe et al. 1984).
- Lobsters held within the impoundment were found to have increased levels of PAH in the hepatopancrease and tail muscle after storage in the impoundment for 1 to 3 mo (Dunn and Fee 1979, Uthe et al. 1984).
- Contamination of commercial shellfish and crustaceans with benzo(a)pyrene (a polycyclic aromatic hydrocarbon) was reported to be widespread, as samples from nine countries in geographically separate parts of the world were analyzed (Dunn and Fee 1979). Molluscs were found to be the most susceptible of all shellfish groups to contamination by polycyclic aromatic hydrocarbons (ibid.).
- Detectable levels of benzo(a)pyrene (BAP) were present in bivalves (clams-<u>Tresus capax</u>, <u>Saxidomus giganteys</u>, <u>Mya arenaria</u>, mussels-<u>Mytilus edulis</u>, and oysters-<u>Crassostrea gigas</u>) collected from 38 of 44 sites in five Oregon coastal bays (Mix et al. 1977). High levels of BAP (greater than 15 ng/g) were sampled in some locations, but the sources of the BAP were not determined (ibid.).
- Mysids were the most sensitive species of aquatic organisms tested (tests included oysters, mysids, pink shrimp, and sheepshead minnows) in laboratory tests; mysids showed an acute toxicity (96-h LC_{50}) to creosote of 0.018 mg/l (Borthwick and Patrick 1982).
- Sublethal effects of mysids to creosote were erratic swimming, loss of equilibrium, and lethargy preceeding death (ibid.).
- Sublethal effects of sheepshead minnows and of rainbow trout to creosote were immobilization, lost equilibrium, and respiratory distress (reddened gills and flared opercula) (Borthwick and Patrick 1982, DeGraeve 1982).
- Effects of subacute and acute levels of poisoning of rainbow trout by phenol were internal hemorrhaging, swelling of the spleen, liver, kidneys, gills and pharynx, hemorrhage at the base of the anal and pectoral fins, skin lesions, and excessive mucus secretion through the skin (Mitrovic et al. 1968).

- Rainbow trout showed a threshold avoidance to water contaminated with levels of phenol somewhere between 3.2 and 6.5 mg/l (DeGraeve 1982).
- Rainbow trout exposed to phenol concentrations below 9 mg/l for 24 h accumulated phenol in muscle tissues to a level approximately the same as that in the water (Swift 1978). Above 10 mg/l the tissue level was considerably greater than the water's concentration, with a concomitant decrease in survival time (ibid.). After exposure to 5 mg/l phenol for 5 d, the muscle concentration was similar to that after 24 h exposure (ibid.). The equilibrium concentration of phenol in fish was reached after 2 to 3 h exposure to a phenol solution; fish exposed to phenol for 24 h were found to rapidly lose absorbed phenol from the muscle when the phenol solution was replaced with uncontaminated water (ibid.).
- The 48-h LC_{50} value for phenol for rainbow trout (5 to 9 cm fork length) was determined to be 8.0 mg/l; 95% confidence limits for this value were 7.4 to 8.6 mg/l (ave. water temperature=12 C, ave. pH=7.8) (Brown et al. 1969). Mitrovic et al. (1968) reported similar values.
- The excretion rate of mono- and di-nuclear aromatic compounds (phenol, cresol, toulene, and naphthalene) from the gills of Dolly Varden char generally peaked by 2 h after intragastric administration (Thomas and Rice 1982). Excretion rates of larger polynuclear aromatic hydrocarbon compounds (anthracene and benzo(a)pyrene) were lower and increased up to 24 h (ibid.).
- In a review of the literature, Sigman (1985) summarized that trout and other fish species seem to have a limited capability to detoxify phenols. Rainbow trout accumulate compounds in blood and muscle at chronic, sub-lethal phenol concentrations. It is likely that excretion occurs across the gills when concentrations in the water are decreased. Dolly varden char can rapidly absorb phenols and cresols ingested with food items in sea water and then excrete the compounds through the gills and cloaca (ibid.).
- The half-life of creosote in sea water was estimated to be less than 1 wk, as determined from mysid bioassays and chemical analyses. However, this result does not consider natural environmental conditions of sunlight penetration, temperatures, and biodegradation (Borthwick and Patrick 1982).

e. **No information was found on the following impact categories:**
   - Change in depth or velocity of water
   - Change in level of dissolved oxygen
   - Change in level of salinity
   - Change in levels of heavy metals
   - Change in levels of nutrients
   - Introduction or removal of species

2. <u>Guidelines</u>:
   a. General. Avoid constructing solid-fill pier structures (derived from Mulvihill et al. 1980).
   b. General. Avoid shading of vegetation and bottom habitat by elevating piers and pile-supported structures that are constructed in marshes or wetlands (derived from Carstea et al. 1975).
   c. General. Avoid impeding water circulation and tidal flux by spacing pilings wide enough apart, as determined by site-specific hydrological characteristics (derived from Mulvihill et al. 1980).
   d. General. Avoid constructing piers, pilings, and support structures in juvenile salmonid rearing areas or where such structures will impede outmigrations through estuaries (derived from Salo et al. 1980).
   e. General. Avoid constructing piers, pilings, and support structures with chemically or creosote-treated wood (derived from Mitrovic et al. 1968, Brown et al. 1969, Mix et al. 1977, Swift 1978, Dunn and Fee 1979, Borthwick and Patrick 1982, DeGraeve 1982, Thomas and Rice 1982, Uthe et al. 1984).
      (1) Specific. If it is necessary to construct pile-supported structures with creosote-treated wood, timing of construction should not coincide with spawning, rearing, or migration periods for fish and/or shellfish.
      (2) Specific. Minimize the use of creosote- and chemically treated materials in the construction of piers, pilings, and support structures where shellfish and crustaceans are harvested for human consumption.

E. Small Boat Harbors/Marinas

1. <u>Summary of documented impacts:</u>
   a. **Change in water temperature, change in level of dissolved oxygen, change in levels of nutrients**
      - Marinas that restricted water circulation and reduced flushing rates were impacted by degradation of water quality. Designs such as narrow, dead-end channels or square-shaped boat basins allowed poor flushing characteristics and stagnant water areas (Nece et al. 1975; Cardwell et al. 1980a, 1980b).
      - Marinas constructed at or near sewage treatment outfalls resulted in increased biological oxygen demand (BOD) and decreased dissolved oxygen levels, particularly in areas where water circulation was poor (USACE 1985, Heiser and Finn 1970).
      - Marinas constructed at or near sites where fish-processing wastes were dumped were shown to have increased levels of ammonia and phosphate during dumping operations (Anderson et al. 1981a).
      - Marinas placed in or near productive wetland, littoral, and intertidal habitat, which is critical to shellfish populations and salmon migration, rearing, feeding, and spawning,

caused degradation of the water quality of such resources (Cardwell et al. 1980a, 1980b; Cardwell and Koons 1981).

b. **Introduction or removal of species**
   - Abundance and diversity of benthic organsims were reduced in areas where seafood-processing wastes were dumped (Lees et al. 1981), but the effect of reduced quality of benthic sediments was considered small due to existing adequate water circulation within the Homer, Alaska, small boat harbor (Erickson 1984).

c. **No information was found on the following impact categories:**
   - Change in depth or velocity of water
   - Change in levels of turbidity, settleable solids, or substrate stability
   - Addition of physical barriers: partial obstructions
   - Change in level of salinity
   - Change in levels of hydrocarbons

2. <u>Guidelines</u>:

a. General. Avoid constructing small boat harbors in areas that do not naturally have high flushing/water exchange characteristics sufficient to preclude phytoplankton blooms (derived from Nece et al. 1975; Cardwell et al. 1980a, 1980b).
   (1) Specific. Minimize impoundment of water in marinas by utilizing harbor designs that allow water to flow through the marinas (derived from Nece et al. 1975).

b. General. Avoid constructing small boat harbors at or near sites that will result in a significant loss of wetland, littoral, and intertidal habitat areas critical to shellfish populations and fish migration, spawning, rearing, and feeding (derived from Cardwell et al. 1980a, 1980b; Cardwell and Koons 1981).

c. General. Avoid constructing marinas in the vicinity of sewage or industrial waste outfalls or near fish- or shellfish-processing plants (derived from Heiser and Finn 1970, Anderson et al. 1981, Lees et al. 1981, Erickson 1984, USACE 1985).
   (1) Specific. If marina site selection cannot avoid an area where seafood wastes are dumped, then degradation of water quality and loss of sedentary shellfish species due to burial may be minimized if the waste outfall is moved to a deep-water location where water circulaton patterns would aid in more rapid dispersal of the waste over a wide area (derived from Lees et al. 1981).

F. Causeways, Dikes, and Bridges

1. <u>Summary of documented impacts:</u>

a. **Change in water temperature, change in level of salinity**
   - Causeways and bridge structures may cause changes in water circulation and flow, which result in changes in water temperature and salinity regimes in the aquatic habitat (Drinkwater 1979, Johnson 1984a, Moulton et al. 1985).
   - Movements of anadromous fish species were reported to be

disrupted by temperature and salinity gradients caused by a solid-fill causeway in the nearshore coastal zone of the Beaufort Sea (Moulton et al. 1985). The causeway resulted in colder, marine waters present in the nearshore zone, which inhibited coastal movements of least cisco, arctic cisco, arctic char, and broad whitefish. Migration timing could be altered (arrival to overwintering areas) and/or stress-related mortality could have occurred due to the physiological intolerance of lower temperatures and higher salinities (Johnson 1984a, Moulton et al. 1985).

b. **Addition of physical barriers: partial obstructions and change in levels of nutrients**

- The main effect of construction of a dike on the marsh ecosystem along an estuary was to eliminate tidal influence between the marsh and estuary. Consequently, floral and faunal species diversity behind the dike was destroyed, species diversity in the estuary was decreased, chemical parameters of the water were altered, and nutrient deposition in the marsh and exchange of nutrients between the marsh and estuary were altered (Heckman 1984).

c. **No information was found on the following impact categories:**

- Change in depth or velocity of water
- Change in levels of turbidity, settleable solids, or substrate stability
- Change in level of dissolved oxygen
- Change in levels of heavy metals
- Change in levels of hydrocarbons
- Introduction or removal of species

2. Guidelines:

a. General. Avoid constructing solid-fill causeways and dikes across wetland habitat and in the nearshore coastal zone (derived from Heckman 1984, Johnson 1984, Moulton et al. 1985).

(1) Specific. Minimize partial obstruction of movements and migrations of coastal and anadromous fish species by constructing raised structures across wetland or nearshore areas, as opposed to solid-fill structures (derived from Heckman 1984, Moulton et al. 1985).

b. General. Avoid building solid-fill causeways in the nearshore coastal zone used by anadromous fish species for migration, spawning, and/or rearing (derived from Moulton et al. 1985).

(1) Specific. Minimize obstructions to water circulation and altered water temperature and salinity regimes by constructing sufficient breaches along the length of the causeway (derived from Moulton et al. 1985).

(2) Specific. Minimize impacts to fish by timing construction activities to avoid critical periods of migration, spawning, and rearing for anadromous fish species (derived from Moulton et al. 1985).

GRADING AND PLOWING

I. DEFINITION

Grading and plowing are interrelated activities that involve the alteration or disruption of terrestrial substrates. Plowing is an agricultural practice and involves breaking and turning the soil such that the vegetative cover is eliminated and the root or moss mat is disrupted. Activities associated with growing agricultural crops such as grains or vegetables are also included here. Grading includes the disruption of substrate strata beneath the soil surface and may result in the alteration of the contours of land by movement of soil, subsoil, or other substrate within a localized area. Typical equipment used for grading includes scrapers, bulldozers, backhoes, draglines, or clam shovels. Grading is used during several developmental activities, including road construction and maintenance, preparation of sites for building structures, and surface mining. Grading usually involves some filling as well as excavating, but if extensive filling is involved, the activity categories Filling and Pile-supported Structures (Aquatic and Wetland Habitats) and Filling (Terrestrial) or Solid Waste Disposal should be consulted instead. Grading that facilitates drainage by removing excess soil water is considered under the activity category Draining. The removal of soil or substrates in floodplains and wetlands is considered under the activity category Dredging.

The following is an attempt to translate the current body of documented impacts resulting from grading and plowing activities into guidelines for habitat management that accurately reflects both the state of completeness and the level of specificity present within the literature database. Literature presented here consists primarily of original documented impact sources. However, a limited number of high-quality review papers that documented impacts literature are also included. These include Rosenberg and Snow (1975), Koski and Walter (1977), Reiser and Bjornn (1979), Yee and Rolofs (1980), Toews and Brownlee (1981), Hall and McKay (1983), Bottom et al. (1985), Lloyd (1985).

II. IMPACT CATEGORIES

The main body of this document is based on literature concerning road-building associated with logging operations in Southeast Alaska and the Pacific Northwest, and gravel roads in Arctic and Interior Alaska. In reviewing the following impact summaries and guidelines, the reader should keep in mind that some documented impacts may be appropriate only in given geographic locations. That is, road construction in Southeast Alaska is not typical of other timber harvest regions because of the steep topography, the nature of the soil, and the drainage problems. Koski and Walter (1977) point out that the soil is thixotropic in nature and that, consequently, roads are commonly constructed by overlay of rock and gravel directly onto the undisturbed forest organic mat. Megahan (1972) states that the road location and position must be considered with respect to the amount of subsurface flow drainage area above the road at each site. That is, road cuts that intercept subsurface water flow present significant problems with mass slope erosion and soil slumps. Koski and Walter (1977) state that mass wasting of unstable slopes is a major source of sediment from roads and is nearly impossible to control. However, maximum control of mass wasting can be achieved by preventive measures carried out prior to (i.e., through planning of road location and design) and during road construction.

Many of the impacts associated with grading and plowing occur where aquatic systems are either crossed or paralleled (e.g., roads), and the primary impact is that of introduction of sediments into aquatic systems. It is recognized that stream crossings (e.g., culverts, bridges, wet crossings, etc.) are inherently a part of road-building and grading activities. A small amount of incidental information on culverts and bridges is presented in this document; however, this topic is more thoroughly addressed under the activity category of Stream Crossings - Structures.

Agricultural activities are included in the definition of Grading and Plowing and are addressed in this document. However, time restraints in preparation of this document precluded a thorough literature search of documented impacts.

Grading that is conducted during surface mining operations conceptually overlaps in the two activity definitions of Grading/Plowing and Processing of Minerals. Therefore, impacts associated with grading in mineral excavation is addressed under the activity category Processing Minerals. However, road-building for the purpose of reaching a mine site directly relates to the impacts documented in this report. Thus the reader is advised to examine the impacts and guidelines presented here.

The impact categories identified in this section are a subset of the impacts identified in the companion volume titled Impacts of Land and Water Use on Fish and Their Habitat (ADF&G 1986). Three interrelated impact categories that were previously identified as the addition, removal, and physical disturbance of substrate materials have been combined and included here as a single category titled Changes in Levels of Turbidity, Settleable Solids, or Substrate Stability.

The following impacts were associated with the activity of Grading and Plowing:

- Change in water temperature
- Change in levels of turbidity, settleable solids, or substrate stability
- Alteration of natural cover - riparian vegetation
- Change in level of dissolved oxygen
- Change in levels of pH, alkalinity, or hardness
- Change in levels of other toxic compounds - sulfurous compounds and others
- Introduction or removal of species

III. ACTIVITY-SPECIFIC CONSIDERATIONS

The following are considerations that pertain to Grading and Plowing and should be taken into account when preparing a response to development proposals:

1. To what extent will surrounding vegetation be cleared?

2. What will be the total area effected by the intended activity?
3. What methods will be used for the prevention of water and wind erosion?
4. What numbers and types of aquatic habitat (stream, lake, estuarine) exist within the affected area?
5. What types (anadromous, resident), age classes, and numbers of fish utilize the aquatic habitat in the affected area?
6. What degree of vegetation canopy removal surrounding aquatic habitat is intended?
7. What methods will be used to remove overburden, e.g., tractors, bulldozers?
8. What ecologically sensitive areas (i.e., permafrost, ice-rich soils, wetlands, muskeg, tundra) exist in the project vicinity, and what methods will be used to minimize disturbance to these areas?
9. What are the physical characteristics (i.e., soil structure, topography, slope, gradient) of the area?
10. Will streams with anadromous fish need to be crossed?
11. What are the projected loads, long-term use, and size of the grading operation?
12. What volume of water will be intercepted by roads? What proportions of this volume can be attributed to subsurface seepage and to overland flow during the snowmelt season?

IV. IMPACTS AND GUIDELINES RELATED TO GRADING AND PLOWING

A. Marine Vertebrates

1. <u>Summary of documented impacts</u>:
   No information was found.

B. Marine Invertebrates

1. <u>Summary of documented impacts</u>:
   a. **Change in levels of turbidity, settleable solids, or substrate stability**
      - Forest harvesting and extensive soil disturbance along estuarine environments can increase sedimentation and reduce productivity in the marine habitat. Areas such as shallow, narrow estuaries are often less active hydrologically, and sedimentation effects can be severe (USEPA 1975a).

   b. **No information was found on the following impact categories:**
      - Change in water temperature
      - Alteration of natural cover - riparian vegetation
      - Change in level of dissolved oxygen
      - Change in levels of pH, alkalinity, or hardness
      - Change in levels of other toxic compounds - sulfurous compounds and others
      - Introduction or removal of species

2. <u>Guidelines</u>:
   a. General. Avoid grading and plowing activities that cause exposure of soil, and will likely result in surface erosion, in areas immediately adjacent to estuarine and marine waters where the potential for adverse impacts to invertebrate

production exists (derived from USEPA 1975a).

(1) Specific. Minimize the addition of suspended sediments, in concentrations likely to have adverse effects on invertebrates, by leaving buffer strips along estuaries and marine shorelines (derived from USEPA 1975a).

C. **Freshwater Salmonids**

1. **Summary of documented impacts:**

a. **Change in water temperature**

- Clearing of riparian vegetation during road construction destroys both the temperature regulating benefit and the vegetation mat. Results are higher stream temperatures and lost bank stability; and, in the arctic, the equilibrium of permafrost ground conditions is destroyed (Dryden and Stein 1975).
- Increased water temperature due to reduction of forest cover over stream surfaces affected salmonid fish species by changing their metabolic rate and decreasing development time (Narver 1972). It also promoted early hatching and migration, due to the decreased oxygen content of surface and intergravel waters (Burns 1972, Harris 1973, Cederholm 1977, Corbett et al. 1978, Everest and Harr 1982).
- Selected salmonid fishes have successfully migrated upstream in water temperatures ranging from 3 to 20°C. Temperatures above the upper limit have been known to stop salmon migrations (Reiser and Bjornn 1979).
- Abnormal stream temperatures can facilitate disease outbreaks in migrating fish, alter timing of migration, and accelerate or retard maturation (Koski and Walter 1977, Reiser and Bjornn 1979).
- In 38 southern Ontario streams, trout (rainbow, brook, and brown) were found only when weekly maximum water temperatures were less than 22°C. Fifty-six percent of the observed variation in weekly maximum water temperatures could be explained by the fraction of bank forested within 2.5 km upstream of a sample site (Barton et al. 1985).
- Canopy density along the path of incoming solar radiation was the best criterion for describing the ability of a buffer strip to control stream temperatures; and, most buffer strips studied contained more timber than necessary (Brazier and Brown 1973).

b. **Changes in levels of turbidity, settleable solids, or substrate stability**

1) Erosion

- The primary mechanisms by which sediment from roads reaches streams are mass soil movement and surface erosion (Yee and Roelofs 1980, Toews and Brownlee 1981).
- Removal of ground cover along stream banks increased erosion up to 18 times compared to undisturbed areas (Aldrich and Johnson 1979, Barrick 1984, Bottom et

al. 1985).

- The combined impact of roads and clear-cut logging in the Oregon Cascade Mountains has constituted a fivefold increase in landslide erosion relative to undisturbed forested areas (Swanson and Dyrness 1975).
- Mass soil movements often destroy the entire productive soil zone and produce a major source of sediment in anadromous streams (Koski and Walter 1977).
- Road construction and maintenance caused sluiceouts and mass erosion slides to occur in small, steep headwater streams because of alterations in natural drainage patterns (Cederholm 1977).
- Mass failures associated with logging roads are largely the result of side casting and addition of road fill, inadequate or poorly designed road drainages, and oversteepened back slopes (Swanston 1971).
- Road-related debris avalanches in the Oregon Cascades increased erosion from 50 to 340 times the rate in forested areas (Bottom et al. 1985).
- Debris torrents often originate in steep (> 50% slope) first- and second-order streams that drain areas less than about 50 acres. In the Oregon Coast Range, movement of shallow soil and organic debris in steep headwalls of incipient drainageways resulted in debris torrents (Swanson and Lienkaemper n.d.).
- In permafrost zones, the exposure of ice-laden river slopes for an extended time can result in mass wasting of the slope and heavy siltation of the stream (Dryden and Stein 1975).
- In permafrost zones along the Livengood-Yukon River road, sloped road cuts resulted in rapid thawing and continued erosion and slope instability (Lotspeich 1971).
- Roads that cross steep slopes cause much greater sedimentation than roads on ridgetops or gradual slopes (Fredriksen 1970).
- Clear-cut logging and road building on steep mountain slopes (angle greater than or equal to 34°) has been the primary cause of mass slope erosion (Swanston 1969, 1970, 1971; Burns 1972; Rice et al. 1972; Platts and Megahan 1975).
- Road construction across steep slopes can initiate or accelerate slope failure from several to hundreds of times, depending on variables such as soil type, slope steepness, subsurface water flow, and road location (Yee and Roelofs 1980).
- Road construction across steep slopes can initiate mass soil movement by overloading the slope from improper fill construction, undercutting a slope that is marginally stable, and impeding or altering subsurface flow regimes (Lantz 1971a, Larse 1971, Yee and Roelofs 1980).
- Accumulation of fine sediments on stream substrates were

highest where road surface exceeded 2.5% of the basin area (Swanson and Dyrness 1975, Cederholm et al. 1981) or where logging and road construction was allowed to progress without restriction on steep mountain lands (Brown and Krygier 1971, Platts and Megahan 1975).

- Roads associated with the jammer logging method of forest harvest in Idaho caused increased sediment production by an average of 800 times and 730 times for the first 1.35 yr and subsequent 4.8 yr postconstruction periods, respectively (Megahan and Kidd 1972).
- On 30,300 acres of commercial timberland in northwestern California, an estimated 40% of the total erosion associated with management of the area was derived from the road system. Seventy-six percent of the erosion measured on logging roads was caused by site conditions and choice of alignment (McCashion and Rice 1983).
- Research and field observations have established that the causes of road-related landslides and/or siltations on stable ground are that "excess excavated material overloads the hillside, causing either sheet or rotational slides" and that "excess material itself erodes away" (Nagygyor 1984, in Cummins 1985).
- The extent of damage from erosion is dependent upon the rate and quantity of runoff, the depth and velocity the runoff attains, and the resistance of the soil's surface to soil particle detachment (R and M Consultants 1977).
- Nonpoint source erosion associated with agricultural land and rural dirt roads in North Carolina resulted in stream sedimentation (Lenat et al. 1981).
- Agricultural practices such as tillage methods that invert the soil generate the highest potential for erosion (USEPA 1973).
- Intense row crop production makes streams unsuitable for salmonid production by introducing warm, sediment-laden irrigation water (Bottom et al. 1985).
- Erosion rates in the Umatilla Plateau region of Oregon are estimated at a high level of 1,0002,000 tons of sediment/mi^2/yr. The fallow system of dryland wheat farming used extensively in this area exposes bare soil for extended periods and accelerates soil loss (Bottom et al. 1985).

2) Sedimentation and suspended sediments

- Road construction caused increased sediment yields in coastal streams in Oregon and California (Burns 1970, Brown and Krygier 1971). The biggest changes in sediment concentrations in small streams in the Pacific Northwest occur in association with road-building operations that preceed logging (Brown and Krygier 1971, Brown 1972).
- Improper logging operations (removal of vege-tative ground cover, road-building, operation of heavy equipment, and yarding trees through streams) causes erosion and

increased stream turbidity, which results in filling of pools (Burns 1972, Everest and Harr 1982, Hall and McKay 1983) and riffles of salmonid streams with up to 10 in of sediments (Bachman 1958, Beschta 1979, Koski et al. 1984).

- Maximum impact of sedimentation caused by logging roads occurs during the first few severe storms after construction (Swanson and Dyrness 1975).
- A significant positive relationship (at 1% level) was found between thepercentage of watershed area in a logging road area and levels of fine sediments in downstream spawning gravels. When the area of logging roads in a Washington Coastal watershed exceeded 2.5% of the basin area, fine sediments began to accumulate in downstream spawning gravels (Cederholm et al. 1981).
- Suspended sediments are often deposited in the interstitial gravel spaces, which are important to juvenile fish for foraging and refuge. During winter, stream channels with fully sedimented riffles supported reduced numbers of age O steelhead trout and chinook salmon because of the lack of crevices available for refuge. Larger juveniles resided in pools during winter and were not affected (Bjornn et al. 1974).
- Reduction of pool area or volume due to sedimentation in small streams resulted in a reduction in the summer capacity of a stream to support salmonids proportionally to the percentage of pool area or volume lost (Bjornn et al. 1974).
- Sedimentation with materials less than 2.0 mm, at 26 and 31% by volume of total substrates, suppressed coho salmon production in laboratory streams (Crouse et al. 1981).
- Permeability was inversely related to the percentage by volume of sand and silt in bottom substrates. Permeability is high when bottom materials contain less than 5% by volume of sands and silts (< 0.833 mm diameter), and permeability is low when substrates contain more than 15% by volume of sands and silts (McNeil and Ahnell 1964).
- High levels of turbidity caused from road construction impede salmonid migration, feeding, and spawning (Bottom et al. 1985).
- High concentrations of sand in gravel caused earlier emergence of coho salmon and steelhead trout fry as a result of stress from the entrapment effect of sand (Phillips et al. 1975).
- Streams with water quality adequate to support anadromous salmon stocks average less than 25 mg/l of suspended sediments (Reiser and Bjornn 1979).
- Suspended sediment concentrations exceeding 200 to 300 ppm for many days (dependent upon size, shape, and hardness of particles) can result in fish mortality due to damaged gill membranes (Phillips 1971, Bottom et al. 1985).
- Juvenile steelhead trout and chinook and coho salmon

avoided turbid streams and experienced gill damage from suspended sediment (no concentration specified) (Noggle 1978).

- Fish (arctic grayling, steelhead trout, and coho salmon) and macroinvertebrate abundances were reduced or eliminated in turbid and sedimented streams (Burns 1972, Lloyd 1985).
- Mortality of salmonid eggs was greatest when exposed to sediment early in the incubation period (Bartsch 1960). Low dissolved oxygen and the physical barrier caused by sedimentation on spawning beds further reduced salmonid survival (Phillips 1971, Hall and McKay 1983).
- Fine road silt has been shown to interfere with gas exchange through egg membranes and result in increased egg mortality (Wilson 1960, Bartsch 1960).
- Steelhead trout and coho salmon fry had reduced growth rates and emigrated from laboratory stream channels during extended periods (11 to 14 d) of high turbidity (23 to 84 NTU's) (Sigler et al. 1984).
- Juvenile coho salmon and steelhead trout showed physiological stress when exposed to concentrations of suspended topsoil between 1.7-2.7 g/l (Redding and Schreck 1980).
- Underyearling (age-0) grayling showed physiological stress (i.e., elevated and/or more varied blood sugar levels and depressed leucocrit levels) when exposed to suspended overburden concentrations as low as 50 mg/l (McLeay et al. 1983, 1984).
- Chronic exposure of arctic grayling to suspended sediment concentrations above 100 mg/l caused sublethal effects, including impaired feeding ability, reduced growth rates, downstream displacement, decreased area for activity, and decreased resistance to other environmental stressors (McLeay et al. 1984).
- Increases in the amount of fine sediments over natural levels resulted in a significant decrease in coho salmon survival to emergence and reduced postemergent fitness in a coastal Washington river system (Cederholm 1977, Cederholm et al. 1981).
- Suspended sediment (turbidity) at very high levels produced from logging road-related erosion has been found to cause physical abrasion to the respiratory structures of fish and aquatic insects, affect the feeding behavior of coho salmon smolts, and reduce the photosynthetic processes of aquatic algae by inhibiting light penetration to the stream bed (Cederholm 1977).
- During construction of a highway across a small stream in southern Ontario, suspended solids increased to as high as 1,390 mg/l but later returned to preconstruction levels of <5 mg/l (Barton 1977).
- Recovery rates of flowing waters from increased sedimentation vary from a few days to not at all and

depend on the characteristics of the river or stream, the quantity and duration of sediment addition, and the availability of undamaged areas as sources of macroinvertebrate recolonization (Rice et al. 1972, Rosenberg and Snow 1975).

- Macroinvertebrate densities were reduced in streams without buffer strips because of sediment intrusion into the substrate and the reduction of litter input from riparian vegetation (Culp and Davies 1983).
- Benthic macroinvertebrate fauna reacted to sediment addition from improper road construction in two ways. During low flow conditions, a stable-sand community developed, composed of small grazing organisms capable of rapid colonization. During periods of high water, substrates became unsuitable for any benthic organism (Lenat et al. 1981).
- Total numbers of riffle-inhabiting macroinvertebrates such as caddisflies and mayflies (sediment-intolerant species) decreased, and total numbers of chironomids and water mites (sediment-tolerant species) increased in a sedimented stream section directly below a road construction site in southern Ontario (Barton 1977).

3) Road drainage/crossings

- Improperly designed highway cuts and ditches on the approaches to stream crossings can channel surface water flows carrying heavy sediment loads into streams (Dryden and Stein 1975).
- Problems associated with parallel drainage on the Prudhoe Bay haul road include erosion of exposed fine-grained soils in cuts, ponding, promotion of thaw weakening and road subsidence, gully formation, and downslope siltation in streams and fish habitats (ADEC and R and M Consultants 1980, U.S. Army Cold Regions Research and Engineering Laboratory 1980).
- Roadway surface drainage problems on gravel roads are related to blockage of drainage and erosion due to gravel berms on the roadway shoulders. The berms keep runoff on the road until it breaks through the berm and can cause sideslope gullying and stream siltation (U.S. Army Cold Regions Research and Engineering Laboratory 1980).
- Streams used as wet crossings for construction equipment can suffer physical damage or siltation to spawning areas and other fish habitat (Dryden and Stein 1975).
- Temporary diversion of streams during construction of bridge or culvert crossings can cause obstructions to fish migration or deposition of excess amounts of fine material in the stream (Dryden and Stein 1975).

4) Subsurface flow interception

- Subsurface flows occur during large rains and/or snowmelt when large volumes of water are supplied to the soil (Megahan 1972).
- Overland flow and subsurface seepage conditions occurred

in a region with intense snowmelt seasons in Idaho and Montana. Normal hydrologic conditions were drastically altered by logging road cuts. Logging roads collect snowmelt and convert it to rapid surface runoff, which, in turn, can negatively affect channel stability in mountain streams (Burroughs et al. 1972).

- Logging roads caused 1) interruption of subsurface drainage associated with road surfaces, ditches, and culverts; 2) alteration of subsurface water movement due to redistribution of soil and rock material, especially where road cuts intersect a water table; and 3) changes in distribution of mass on a slope surface by cut-and-fill construction (Burns 1970, Brown and Krygier 1971, Larse 1971, Gibbons and Salo 1973, Swanson and Dyrness 1975).
- Excess soil water, in addition to surface flow in road ditches, on road treads, or on road cut and fill slopes, raises pore water pressures that reduce the shear strength of the soil and can result in mass erosion above road cuts, in road fills and underlying soils, and in soils below the road (Megahan 1972).
- Soil compaction associated with forest practices reduces soil pore space, thereby reducing infiltration and percolation. This increases surface runoff and can result in erosion (Lull 1959).
- Where fine-grained frozen sedimentary soils exist, sediment-loading from increased meltwater has occurred where cuts for road construction have been made. Slope stabilization can take up to 6 yr (R and M Consultants 1977).
- Excavation in frozen soil at the beginning of summer can result in excessive thermal erosion, which in turn results in sloughing and siltation (R and M Consultants 1977). Summer is important to feeding, growth, and reproduction of fish in arctic environments (Cowan 1974).
- Seepage of water between the organic mat and the underlying soils at an excavated road cut can cause gullying on the cut slope and/or severe icing, which can contribute to erosion and siltation during breakup (R and M Consultants 1977).

c. **Alteration of natural cover: riparian vegetation**
   - Removal of streamside vegetation and other disturbances destabilized or broke up large accumulations of organic debris. As a result, channel and bed morphology changed extensively during major freshets (Bryant 1980, 1983; Hartman et al. 1983).
   - Note: See impacts and guidelines for Channelization for additional information.

d. **Change in level of dissolved oxygen**
   - Sediment deposited on salmonid spawning grounds filled the interstitial gravel spaces, reducing the interchange of surface and subsurface waters, which decreased the level of dissolved oxygen available to preemergent salmonids

(Wilson 1960, Phillips 1971).

- Steelhead trout and coho salmon fry hatched from embryos reared at low and intermediate oxygen concentrations hatched later and were smaller in size at hatching than fry from embryos reared near the air-saturation level. At all oxygen concentrations tested, reduced water velocities resulted in reduced size of hatching fry. Water movement promotes growth of salmonid embryos by delivering oxygen to the surface of the egg membrane and by removing metabolic waste products (Shumway et al. 1964).
- Canopy reductions decreased dissolved oxygen concentrations and increased temperatures of intragravel water, which reduced coho salmon populations (Meehan 1974, Ringler and Hall 1975).
- Dissolved oxygen concentrations downstream of highway activities in the Mackenzie River valley were low enough to be lethal to fish (Rosenberg and Snow 1975).
- Reduced dissolved oxygen concentrations can adversely affect the swimming performance of adult migrating salmonids (Reiser and Bjornn 1979). The authors concluded that oxygen levels needed for migrating and spawning fish should remain above 80% saturation, with temporary absolute levels not falling below 5.0 mg/l.

e. **Introduction or removal of species**

- Observations of streams with narrow buffer strips (less than 30 m wide) indicated that no recovery or incomplete recovery of benthic macroinvertebrates occurred, based on a diversity index and a measure of ecological distance, 6-10 yr after logging (Erman et al. 1977, Newbold et al. 1980, Erman and Mahoney 1983).

f. **No information was found on the following impact category:**

- Change in levels of pH, alkalinity, or hardness
- Change in levels of other toxic compounds - sulfurous compounds and others

2. Guidelines:

a. **Change in water temperature**[3]

1) General. Avoid increases in stream water temperature in temperature-sensitive streams by leaving buffer strips along riparian zones (derived from Burns 1972, Narver 1972, Brazier and Brown 1973, Dryden and Stein 1975, Barton et al. 1985, among others).

(a) Specific. Minimize removal of overstory canopy within the riparian zone on streams that are determined to be temperature-sensitive (i.e., considering physical parameters of size, gradient,

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3 It is recognized that the impact of increased water temperatures in cold-water streams may result in the positive benefit of increased productivity; however, it is beyond the scope of this document to incorporate positive impacts or enhancement.

volume, etc., presence of salmon spawning beds, and abundance and distribution of salmonid species) (derived from Brazier and Brown 1973, Koski and Walter 1977, Reiser and Bjornn 1979).

(b) Specific. Minimize unacceptable increases in stream water temperature by designing buffer strips that incorporate vegetation that shades the stream (derived from Brazier and Brown 1973, Corbett et al. 1978).

b. **Change in levels of turbidity, settleable solids, or substrate stability**

1) General. Avoid grading and plowing operations in areas where introduction of sediments into aquatic environments resulting from mass soil movements and/or surface erosion will occur (derived from Swanson and Dyrness 1975, Cederholm 1977, Koski and Walter 1977, Yee and Roelofs 1980, Toews and Brownlee 1981, among others).

(a) Specific. Minimize introduction of unacceptable levels of sediments to streams by leaving buffer strips along riparian zones and adjacent to road right-of-ways (derived from Aldrich and Johnson 1979, Barrick 1984, Bottom et al. 1985).

(b) Specific. Minimize introduction of unacceptable levels of sediments into streams by building sediment traps below landslides (derived from Dryden and Stein 1975, Cederholm et al. 1981).

2) General. Avoid constructing logging roads on steep slopes with shallow, unstable soils, in order to lessen the occurrence of debris avalanches and debris torrents (derived from Bottom et al. 1985, Swanson and Lienkaemper n.d.).

(a) Specific. Minimize debris avalanche potential, hence debris torrent potential, by considering soil and slope stability prior to logging and road-building operations and by utilizing improved harvest practices (e.g., balloon, helicopter, or skyline cable yarding) to reduce soil disturbance (derived from Swanson and Lienkaemper n.d.).

3) General. Avoid making road cuts through ice-laden, frozen soils (derived from Lotspeich 1971, Dryden and Stein 1975, R and M Consultants 1977).

(a) Specific. Minimize sediment loading at cuts through ice-laden soils by stabilizing slopes (i.e., through seeding, mulching, planting, or the placement of mat binders, soil binders, rock or gravel blankets) during road construction (derived from Lotspeich 1971, Dryden and Stein 1975, R and M Consultants 1977).

(b) Specific. Minimize the rate of thawing in permafrost areas by using overlay (i.e., gravel, dirt, straw, mulch) of sufficient thickness (derived from Lotspeich 1971).

(c) Specific. Minimize the rate of thawing on ice-laden cuts by making such cuts vertical rather than sloped, which is a common practice on unfrozen soils (derived from Lotspeich 1971).

(d) Specific. Minimize the rate of thawing on ice-laden cuts by leaving an overhanging vegetation mat at the top of the vertical cut (derived from Lotspeich 1971).

4) General. Avoid mid-slope location of roads on steep, unstable slopes (derived from Swanston 1969, 1970, 1971; Fredriksen 1970; Lantz 1971a, Larse 1971; Burns 1972; Rice et al. 1972; Platts and Megahan 1975; Yee and Roelofs 1980).

(a) Specific. Minimize erosion by locating roads on benches or ridges and by keeping road gradients low (derived from Lantz 1971a, Toews and Brownlee 1981).

5) General. Avoid excessive soil erosion and stream sedimentation by examining natural drainage patterns, soils, and geology of an area prior to route selection (derived from Brown and Krygier 1971; Lotspeich 1971; Dryden and Stein 1975; Platts and Megahan 1975; Toews and Brownlee 1981; McCashion and Rice 1983; Nagygyor 1984, in Cummins 1985).

(a) Specific. Minimize road mileage and soil disturbance in timber harvest areas by utilizing cable-yarding or balloon- and helicopter-yarding techniques in areas with steep, unstable soils and difficult access (derived from Cederholm 1977, Cederholm et al. 1981).

6) General. Avoid conducting grading operations in streambeds (derived from Bachman 1958, Burns 1972, Beschta 1979, Everest and Harr 1982, Hall and McKay 1983, Koski et al. 1984).

7) General. Avoid introduction of sediments into critical salmonid and aquatic invertebrate habitats (i.e., stream spawning gravels, pools and riffles, and rearing and feeding areas) (derived from McNeil and Ahnell 1964, Phillips 1971, Bjornn et al. 1974, Phillips et al. 1975, Noggle 1978, Reiser and Bjornn 1979, Crouse et al. 1981, Bottom et al. 1985, Lloyd 1985, among others).

8) General. Avoid introduction of sediments into streams when salmonids are present (derived from McNeill and Ahnell 1964; Phillips 1971; Phillips et al. 1975; Redding and Schreck 1980; Hall and McKay 1983; McLeay et al. 1983, 1984; Sigler et al. 1984, among others).

(a) Specific. Minimize the potential for sedimentation from grading and plowing activities in salmonid streams during the time that eggs are incubating in the gravel (derived from Bartsch 1960, Phillips et al. 1975, Cederholm 1977, Cederholm et al. 1981).

(b) Specific. Minimize the potential for sedimentation from grading and plowing activities in salmonid streams when juvenile fish are feeding and rearing (derived from Bjornn et al. 1974; Noggle 1978; Redding and Schreck 1980; Crouse et al. 1981; McLeay et al. 1983, 1984; Sigler et al. 1984; Bottom et al. 1985).

9) General. Avoid using agricultural practices that result in high amounts of soil surface exposure and promote accelerated erosion and contribute to nonpoint source erosion (derived from USEPA 1973, Lenat et al. 1981, Bottom et al. 1985).

10) General. Avoid removing the organic material layer in permafrost areas during road construction (derived from ADEC and R and M Consultants 1980, U.S. Army Cold Regions Research and Engineering Laboratory 1980).

11) General. Avoid concentrated discharges from highway drainage structures onto undisturbed terrain (derived from ADEC and R and M Consultants 1980, U.S. Army Cold Regions Research and Engineering Laboratory 1980).

12) General. Avoid induced drainage or standing water over permafrost areas, which can result in rapid thermal degradation (derived from ADEC and R and M Consultants 1980, U.S. Army Cold Regions Research and Engineering Laboratory 1980).

    (a) Specific. Minimize water accumulation and subsequent erosion of temporary road surfaces (e.g., skid trails, seasonal roads) by utilizing dips, water bars, and cross drains (derived from Dryden and Stein 1975, ADEC and R and M Consultants 1980, U.S. Army Cold Regions Research and Engineering Laboratory 1980).

    (b) Specific. Minimize the effect of higher road gradients by reducing the distance between culverts to prevent water accumulation in ditches (derived from Dryden and Stein 1975, U.S. Army Cold Regions Research and Engineering Laboratory 1980).

13) General. Avoid leaving gravel berms (that can block surface drainage) on roadway shoulders during maintenance grading (derived from U.S. Army Cold Regions Research and Engineering Laboratory 1980).

14) General. Avoid using wet crossings for construction equipment in streams critical to salmonid or other fish-spawning (derived from Dryden and Stein 1975).

15) General. Avoid erosion problems by not leaving cut slopes, fills, and other exposed soils over winter and unprotected by vegetation or coarse, adhesive, or blanketing materials (derived from Megahan 1972, R and M Consultants 1977).

    (a) Specific. Minimize surface erosion and mass slope failure by not conducting grading and plowing activities during spring melt periods and periods of heavy rainfall (derived from Burroughs et al. 1972, Megahan 1972, R and M Consultants 1977).

    (b) Specific. Minimize erosion by utilizing surface preparation techniques such as scarification, using excavated topsoil for revegetation substrate, applying a cover or clean aggregate materials to the road surface, or crowning or sloping the roadbed (derived from Lull 1959, R and M Consultants 1977, ADEC and R and M Consultants 1980).

c. **Alteration of natural cover: riparian vegetation**

1) General. Avoid removal of riparian vegetation by designing buffer strips which maintain the integrity of the streambank (derived from Bryant 1980, 1983; Hartman et al. 1983).

d. **Change in level of dissolved oxygen**

1) General. Avoid the reduction of dissolved oxygen levels in streams vital to the production of salmonids, whether the reduction is caused by increased sediment loads, increased biological oxygen demand due to debris accumulations, reduced water velocities, or increased temperatures related to grading and plowing activities (derived from Shumway et al. 1964, Phillips 1971, Meehan 1974, Ringler and Hall 1975, Rosenberg and Snow 1975, Reiser and Bjornn 1979).

D. **Freshwater Nonsalmonid Species**

1. **Summary of documented impacts**:

a. **Change in levels of turbidity, suspended solids, or substrate stability**

- Total numbers of fish (blacknose dace, mottled sculpin, and creek chub) decreased significantly from 109 fish/30 m of stream to 26.9 fish/30 m of stream due to sedimentation immediately below a road construction site in southern Ontario (Barton 1977).
- Spring migrations of northern pike were prevented by a culvert and high sediment loads from roadfill (Rosenburg and Snow 1975).
- The standing crop of fish in a southern Ontario stream reduced from 24 to 10 kg/ha immediately following sediment input resulting from bridge construction (Barton 1977).
- Streams in clear-cut watersheds of New Brunswick had 17% fewer trout, over 200% more sculpins, and 26% less benthos than control streams, due to sedimentation, channelization, and, to a lesser extent, lack of riparian buffer strips (Welch et al. 1977).
- Streams in farmed watersheds of New Brunswick had 52% fewer trout, 92% fewer sculpins, and 64% less benthos than control streams. Low numbers of fish and benthos were associated with chemical contamination, sedimentation being a contributing factor in all farmed watersheds (Welch et al. 1977).

b. **Change in levels of pH, alkalinity, or hardness; change in levels of other toxic compounds - sulfurous compounds and others**

- Lowered ph and increased sulfate and metals concentrations derived from the leaching of sulfide-rich rocks following road construction in North Carolina caused brook trout and salamander mortalities (Huckabee et al. 1975). After 10 yr, the stream remained devoid of fish for at least 8 km downstream from the roadbed fill (ibid.).

c. **No information was found on the following impact categories:**
   - Change in water temperature
   - Alteration of natural cover - riparian vegetation
   - Change in level of dissolved oxygen
   - Introduction or removal of species

2. <u>Guidelines</u>:
   a. General. Avoid conducting grading and plowing activities immediately adjacent to waters where the potential for adverse impacts to fish production exists (derived from Barton 1977, Welch et al. 1977).
   b. **See the guidelines presented above in the section Freshwater Salmonid Species.**

PROCESSING OF MINERALS

I. DEFINITION

Processing minerals involves the storage, sorting, milling, crushing, washing, sluicing, concentrating, smelting, and refining of minerals such as coal, gold, gravel, molybdenum, lead, and zinc. The impacts from disposal of tailings and waste rock are included under the activity heading of Solid Waste Disposal. The extraction of minerals is included under the activities of Grading and Plowing, Dredging, and Blasting.

Because of time restrictions in production and the broad scope of the activity of Processing of Minerals it was necessary to reduce the number of issues to be incorporated in this document. At this time, the major form of mineral processing within Alaska occurs with placer mining for gold, and the primary impact for which documented literature exists relates to degradation of water quality. Thus the scope of this document will be restricted to this issue until the additional literature search is completed.

The following is an attempt to translate the current body of documented impacts resulting from placer mining activities into guidelines for habitat management that accurately reflects both the state of completeness and the level of specificity present within the literature database. Literature presented here consists primarily of original documented impact sources. However, a limited number of high-quality review papers that documented impacts literature are also included. These include Reiser and Bjornn (1979), Martin and Platts (1981), Hall and McKay (1983), Bottom et al. (1985), Lloyd (1985), Shannon and Wilson (1985).

II. IMPACT CATEGORIES

This document primarily addresses the activities and impacts associated with placer mining and the resultant degradation of water quality. Nearly all of the documented literature is from studies conducted in either Alaska or northern Canada. In reviewing the following impact summaries and guidelines, the reader should keep in mind that some documented impacts may be appropriate only in given geographic locations. For example, high levels of arsenic and other heavy metals may cause toxicity to aquatic organisms only in regions where such materials are naturally present in the substrate being mined.

In light of the narrowed scope of this document, as was mentioned above, the effects of placer mining relate to freshwater environments, and the fish species of primary concern are the salmonids. Much of the documented information presented here may be appropriate to nonsalmonid species as well, but most research has been concentrated on the salmonids because of their importance for commercial, sport, and subsistence uses. Therefore, guidelines are presented only under the category of freshwater salmonids. It is left to the discretion of the user to apply the guidelines to freshwater nonsalmonid fishes.

Placer-mining operations typically incorporate a wide range of activities that result in disturbance of fish and aquatic habitat. For example, placer-mining operations in the Kantishna Hills area of Interior Alaska have extensively altered large areas of riparian vegetation and aquatic habitat on at least 15 streams. Habitat alterations observed in the Kantishna Hills include removal of riparian vegetation, processing of stream gravels, channel straightening, channel diversion, road construction in streams and to the mine sites, extremely high turbidity, sedimentation, litter, and the construction of settling ponds, waterfalls, and/or other barriers to fish movement (Meyer and Kavanagh 1983). For additional information, see the impact summaries and guidelines prepared for the appropriate activities (i.e., channelization, grading and plowing, etc.).

The impact categories identified in this section are a subset of the impacts identified in the companion volume titled Impacts of Land and Water Use on Fish and Their Habitat (ADF&G 1986). Three interrelated impact categories that were previously identified as the addition, removal, and physical disturbance of substrate materials have been combined and included here as a single category titled Changes in Levels of Turbidity, Settleable Solids, or Substrate Stability.

The following impacts were found to be associated with the activity of Processing of Minerals:

- Change in water temperature
- Change in levels of turbidity, settleable solids, or substrate stability
- Alteration of natural cover - riparian vegetation
- Change in level of dissolved oxygen
- Change in levels of pH, alkalinity, or hardness
- Change in levels of heavy metals
- Change in levels of other toxic compounds - sulfurous compounds and other
- Introduction or removal of species

III. ACTIVITY-SPECIFIC CONSIDERATIONS

The following are considerations that pertain to mineral-processing activities and should be taken into account when preparing a response to development proposals:

1. Has a mining operations plan been completed that details the site characteristics and proposed construction, operation, maintenance, and rehabilitation activities?
2. What processing methods will be used (i.e., mechanical or hydraulic overburden removal, sluicing, settling ponds, recycling waste water, etc.)?
3. What equipment will be used (i.e., bulldozers, backhoes, draglines, hydraulic giants, etc.)?
4. On what dates will equipment be moved to and from the mine site?
5. In what months will various processing methods occur (i.e., clearing, construction of settling ponds, sluicing, grading of tailing piles, constructing and maintaining drainage-control structures, and site rehabilitation)?

6. What fish species are present (including abundances and life history stages)?
7. What type and quantity of aquatic habitat will be disturbed or removed?
8. Does any habitat exist in the project area that is critical to fish migration, spawning, rearing, overwintering, or feeding?
9. What will be the area and depth of each mining cut, i.e., the expected overall size of the project?
10. How much riparian habitat will be disturbed or removed?
11. What reductions in fish or invertebrate habitat may result?
12. What restrictions may be imposed on fish migrations?
13. Will any changes in the physical or chemical properties of the water result from processing?
14. Are there characteristics of the material being processed that, as a suspended sediment, will adversely impact biological aquatic components?
15. What size classes of materials will be produced from the mining operation (i.e., sludge, sand, gravel, cobbles)?
16. Is site rehabilitation planned?
17. What is the depth and quantity of overburden?
18. Will overburden be stockpiled for site rehabilitation after mining has ceased?
19. What erosion-control measures will be conducted during mining operations (i.e., site sloping and contouring, stockpiles, timing of various activities)?
20. What measures will be taken to be sure that abandoned mine wastes and/or settling ponds do not contribute to adverse water quality in the future?
21. Does the terrain at the mine site preclude the proper sizing, construction, and maintenance of adequate wastewater treatment systems (e.g., narrow valley)?
22. Will settling ponds be located in the active floodplain?
23. Will settling ponds be large enough to adequately accommodate the quantity of settleable solids that will be produced from mining?
24. What is the potential for flooding and subsequent erosion at the mine site?
25. Will a temporary or permanent stream channel diversion be necessary?

IV. IMPACTS AND GUIDELINES RELATED TO PROCESSING OF MINERALS

A. Freshwater Salmonids

1. Summary of documented impacts:

a. Change in water temperature

- Water temperature increases slightly during sluicing and continues to increase slightly in settling ponds (R and M Consultants 1982, Shannon and Wilson 1985).
- Comparison of temperatures at six mining operations near Fairbanks indicated that there was no change or a slight decrease in water temperature at one mine and a net temperature increase of 0.1 to 4.8 C at the other five mines (Shannon and Wilson 1985).

b. Change in levels of turbidity, settleable solids, or substrate stability

1) Erosion

- Erosion of overburden is not confined to the period of active mining but can recur on steep slopes due to rain and snowmelt long after mining has ceased (ADEC 1979).

- Excavation in frozen soil at the beginning of summer can result in sloughing and increased siltation to streams (R and M Consultants 1977, ADEC 1979).
- Eroded topsoils can produce increases in color, iron, tannin and lignon, electrical conductivity, total organic carbon, and, in some cases, low pH and high concentrations of ammonia in receiving waters (ADEC 1979).

2) **Turbidity and Suspended Sediments**

- Significant differences in turbidity and settleable solids were observed between sluice wastewater, road-building, and pond-breakage wastewater. Sluicing alone generated lower turbidity and settleable solids than other mining-related activities (Deschu 1985a).
- Significant changes in water quality resulting from placer mining include increased total residues, settleable solids and turbidity, and increased total iron and total phosphorus concentrations (Van Niewenhuyse 1983, Bjerklie and LaPerriere 1985).
- Turbidity and total suspended solids levels increased from a background average of 0.27 NTU and 0.7 mg/l, respectively, above mining to an average of 243 NTU and 224 mg/l below the first mine on Porcupine Creek in Interior Alaska. At 92 km below active mining on Birch Creek, and 80 km below all mining input, an average turbidity of 32 NTU, and total suspended solids of 48 mg/l were measured (Weber 1986).
- In heavily mined streams of Interior Alaska, turbidity and total residue concentrations were two orders of magnitude higher than in unmined streams, and settleable solids nearly always exceeded the state water quality standards (Shannon and Wilson 1985, Van Niewenhuyse and LaPerriere 1986).
- Streams with water quality adequate to support anadromous salmon stocks average less than 25 mg/l of suspended sediments (Reiser and Bjornn 1979).
- In relation to the types of mining operations (i.e., hydraulic, suction-dredge, dozer-fed sluicing, etc.) more sediment was stirred up with greater amounts of water being used, and downstream effects of sedimentation and turbidity were more significant (Blanchet 1981).
- Mines that did not use equipment to classify materials to remove large rocks prior to sluicing require approximately 50% more water than mines that utilize classification systems (e.g., grizzlies, trommels, screens, wobblers, vibrating tables, washing plants, or conveyors). The higher water use, in turn, requires larger settling ponds to achieve the required wastewater quality. Additionally, a larger volume of flow in the receiving stream is needed in order to sufficiently dilute the discharge (R and M

Consultants 1982).

- Hydraulic stripping of overburden accounts for the most severe water quality problems associated with overburden removal. As well, inadequate planning for overburden storage or stockpiling during mechanical stripping can result in such material being subjected to erosion and causing stream sedimentation (Federal Water Pollution Control Administration 1969, ADEC 1979).
- Turbidity levels at various locations throughout mining operations (having ponds) were measured. Turbidity levels upstream from the sluice box ranged up to 15 NTU, 9,000 NTU at the sluice box effluent, 7,000 NTU at the pond influent, 1,700 NTU at the pond effluent, and 900 NTU at a station 500 ft downstream (R and M Consultants 1982; Dames and Moore 1976, in Shannon and Wilson 1985).
- From data presented by R and M Consultants (1982) on wastewater discharge from 16 placer mines in Interior Alaska, Lloyd (1985) calculated mean mine-induced increases of turbidity and suspended sediment concentrations (SSC) of 2,500 NTU and 3,600 mg/l, respectively. When these downstream effluent data are compared with natural upstream levels (both on mined streams and on natural Alaskan streams) of turbidity and SSC, Lloyd (1985) showed that placer mining can increase turbidity and SSC well above natural clear-water levels and above levels found in naturally turbid rivers such as the Copper, Susitna, Kuskokwim, and Yukon.
- Examination of 16 placer mines in Interior Alaska revealed that only one mine was able to meet federal and state water quality standards at the points 500 ft downstream from effluent discharge. Characteristics of this mine were 1) the mine site was located away from the stream; 2) the parent material contained less than 3% of very fine material (< 0.02 mm); 3) the mine utilized a material classification technique, a long section between the sluice box and settling pond, and multiple ponds with baffles in the final pond; and 4) there was an effluent dilution factor of three times in the receiving stream (R and M Consultants 1982).
- In the Livengood Creek mining district of Interior Alaska, water samples taken 1.5 mi downstream from the sluice box had turbidities ranging from 6,300 to 27,500 NTU. Turbidity of the mine discharge waters was significantly reduced by increasing the area of the settling pond (Cook 1979). A series of settling ponds were shown to be more effective in reducing turbidity than a single pond (ibid.). Noncompliance of state water quality standards at Kantishna Hills mines was attributed to inadequately sized settling ponds (Sexton 1983).
- Of six mine operations studied in the Fairbanks area, five used settling ponds and one used a filtration system for sediment removal of wastewater. Total suspended solids

removal at the five mines ranged from 82 to 99.8%, with an average removal of 92%. Turbidity removal in the ponds averaged 70% and ranged from 13 to 86% (Shannon and Wilson 1985).

- Water quality 500 ft downstream of a placer mine on Gold Dust Creek, near Fairbanks, was better than other mines examined, because a bypass was utilized that diverted the portion of the natural drainage not needed for sluicing around the processing area and settling ponds. Even though the pond effluent had decreased water quality compared to effluent at other mines, the bypass helped dilute the effluent to provide overall better water quality downstream (Shannon and Wilson 1985).
- Results of turbidity and settleable solids studies in some Kantishna Hills area streams showed a degradation of water quality over a 4 yr period (1980-1984), which coincided with an increase in heavy mine activities upstream (Deschu 1985a).
- Significant negative differences between upstream and downstream levels of turbidity and settleable solids were recorded in mined streams of the Kantishna Hills area and in the Birch Creek watershed, of Interior Alaska (Deschu 1985a, Weber 1986).
- Settleable solids and turbidity were similar upstream and downstream of mines active in previous years (i.e., inactive at the time of sampling), indicating that downstream waters have the ability to recover to near natural levels. An exception to this is after heavy rainfall, when runoff over mine-disturbed land increases the introduction of solids and turbidity levels (Deschu 1985a).
- Recontouring mined areas improved the return of stream water to natural levels of settleable solids and turbidity (Deschu 1985a).
- Several streams in the Kantishna Hills area contained arctic grayling populations in years prior to mining activities. Fish sampling after mining operations had begun indicated that grayling avoided these streams or stream sections due to the increased turbidity and settleable solids from mining (Deschu and Kavanagh 1985).
- Many juvenile and adult grayling were found in unmined Interior Alaska streams; however, no grayling were found in streams undergoing active mining. Caged adult fish studies showed that grayling held in streams that carried mining sediments suffered direct, chronic effects, including gill damage, dietary deficiencies, and slowed maturation (Simmons 1984).
- Arctic grayling were found in streams carrying high levels of mining sediments (<500 mg/l total residues) only during the fall downstream migration. In the Chatanika River and Birch Creek area of Interior Alaska, grayling spawn in

spring in clear-water streams and remain there throughout summer to feed and grow (Simmons 1984).

- Juvenile grayling can tolerate short-term exposure to moderate levels (150-300 mg/l) of sedimentation with no apparent physical damage. However, sediment added to spawning and rearing areas, particularly during low stream flows, has the greatest impact on grayling populations (Simmons 1984).
- Arctic grayling in unmined tributaries to Minto Creek and in Minto Creek, Yukon Territory, upstream of the mined tributary, had consumed the greatest number and diversity of prey items, relying primarily on dipteran, ephemeropteran, and trichopteran larvae. Arctic grayling in Highet Creek, a tributary stream subjected to active placer mining, consumed few prey items, mainly dipterans (Birtwell et al. 1984).
- A placer mining dredge operation in Seigel Creek, Idaho, caused a reduction of trout and whitefish populations downstream from dredging and eliminated the populations in the dredged stream section. The fish populations returned to the area shortly after dredging stopped (Caplice 1959).
- Steelhead trout and coho salmon fry had reduced growth rates and emigrated from laboratory stream channels during extended periods (11 to 14 d) of high turbidity (23 to 84 NTUs) (Sigler et al. 1984).
- Physiological studies were conducted by Redding and Schreck (1980) using cortisol concentrations of fish blood (juvenile coho salmon and steelhead trout) to indicate stress caused by physical disturbance, discomfort, or fright. Juvenile coho salmon and steelhead trout showed physiological stress when exposed to concentrations of suspended topsoil between 1.7 and 2.7 g/l (ibid.).
- Juvenile coho salmon and steelhead trout became acclimated (i.e., plasma cortisol levels returned to basal levels) to high levels (1.7-2.7 g/l) of suspended solids within 7-8 d of continuous exposure (Redding and Schreck 1980). Short-term exposure to suspended sediments were less severe and more transient than those effects induced by long-term exposure (ibid).
- Rapid reduction of light, which would occur with turbidity, did not increase plasma cortisol levels, indicating that the stress factor of turbidity is the physical or chemical nature of the suspended sediments (Redding and Schreck 1980).
- Exposure of coho salmon and steelhead trout to suspended organic sediments significantly reduced the fishes' tolerance to pathogenic bacterium (Redding and Schreck 1980).
- Underyearling (age-0) grayling showed physiological stress (i.e., elevated and/or more varied blood sugar levels and depressed leucocrit levels) when exposed to suspended

sediment concentrations as low as 50 mg/l (McLeay et al. 1983, 1984). Noggle (1978) also found that blood glucose levels of juvenile salmonids were elevated at sublethal suspended sediment concentrations.

- Chronic exposure (6 wk) of arctic grayling to suspended sediment concentrations above 100 mg/l caused sublethal physiological and behavioral effects, including impaired feeding ability, reduced growth rates, downstream displacement, decreased area for activity, and decreased resistance to other environmental stressors (McLeay et al. 1984).
- Laboratory-reared grayling acclimated to 15 C survived a 4-d exposure to inorganic sediment suspensions less than 250,000 mg/l and a 16-d exposure to 50,000 mg/l. These fish also survived acute (4-d) exposure to organic sediment concentrations less than 50,000 mg/l. All grayling acclimated to 5 C and held in inorganic sediment suspensions of less than 10,000 mg/l survived for 4 d, whereas mortalities of 10-20% occurred at the higher concentration levels (McLeay et al. 1983).
- Inorganic sediment strengths less than 10,000 mg/l caused grayling to surface, a direct response to elevated sediment levels (McLeay et al. 1983).
- Suspended sediments are often deposited in the interstitial gravel spaces, which are important to juvenile fish for foraging and refuge. During winter, stream channels with fully sedimented riffles supported reduced numbers of age 0 steelhead trout and chinook salmon because of the lack of crevices available for refuge. Larger juveniles resided in pools during winter and were not affected (Bjornn et al. 1974).
- High levels of turbidity can impede salmonid migration, feeding, and spawning (Bottom et al. 1985).
- Suspended sediment concentrations exceeding 200 to 300 ppm for many days (dependent upon size, shape, and hardness of particles) can result in fish mortality due to damaged gill membranes (Phillips 1971, Bottom et al. 1985).
- Juvenile steelhead trout and chinook and coho salmon avoided turbid streams and experienced gill damage from suspended sediment (no concentration specified) (Noggle 1978).
- Suspended sediment particles cause direct physical injury to fish and aquatic invertebrates (i.e., gill irritation) that can increase incidence of fungal and bacterial infection, reduced feeding, and slowed maturation and development (Bartsch 1960, Reiser and Bjornn 1979, Martin and Platts 1981, LaPerriere et al. 1983).
- Fish (arctic grayling, steelhead trout, and coho salmon) and macroinvertebrate abundances were reduced or eliminated in turbid and sedimented streams (Burns 1972, Lloyd 1985).
- Water quality degradation from placer mining caused

decreased invertebrate density and biomass and altered community structure. Invertebrate communities in mined streams of Interior Alaska contained higher proportions of collector-gatherers and lower proportions of crawlers, shredders, filter-feeders, predators, and oligochaetes compared to unmined streams (Wagener 1984).

- Productivity in undisturbed streams was positively correlated with incident photosynthetically active radiation and averaged 0.8 g $O_2/m^2/d$. Mean productivity for a moderately mined stream in which settleable solids never exceeded 0.1 ml/l was reduced by about 50% (at mean turbidities < 200 NTU). No primary production occurred in heavily mined streams when mean settleable solids levels (including toxic heavy metals associated with solids) exceeded 0.2 ml/l (Van Niewenhuyse 1983).

3) **Sedimentation and Substrate Stability**

- The impacts on salmonids from sedimentation caused by mineral processing include the reduction of available habitat through siltation of pools and a decrease in the amount of spawning riffles (Caplice 1959, Phillips 1971, Brown and Baker 1975, Bottom et al. 1985).
- Siltation can alter streamflow characteristics by decreasing stream depth, widening streams, changing bed material roughness, and eliminating riffle areas (ADEC 1979).
- Streambeds of mined streams in Interior Alaska were heavily embedded and compacted with silt (LaPerriere et al. 1983). Increased sediment in the streambed changed the stream hydrology by isolating the interchange of surface and subsurface waters. This resulted in the stream being perched above the groundwater either by aggradation of the stream channel bottom or by reduced replenishment of the groundwater and subsequent lowering of the water table (Bjerklie and LaPerriere 1985).
- Solids settled out on wide, shallow sections of lower Caribou Creek, in the Kantishna Hills area of Interior Alaska, show signs of forming an armor layer. Once formed, armor layers can make it difficult for stream waters to resuspend and transport sediments, even during high runoff from major storms (Deschu 1985a).
- Deposition of sediments during periods of low water flow is the most detrimental to salmonid productivity because accumulated sediments remain on streambeds for longer periods of time and are not flushed away until the next storm flood (Shaw and Maga 1943, Hall and McKay 1983).
- Deposition of silt occurred (in laboratory test streams) within the streambed gravel and reduced gravel permeability, even though velocities were too high to permit deposition on the gravel surface (Cooper 1965).
- Observations in sedimented and control riffles indicate that the amount of sediment settling to the stream bottom decreases exponentially with distance downstream (Shapely and Bishop 1965).

- Sand released from suction dredges comprised 25 to 40% of the substrate and was found downstream for a distance of 30 m below the dredge where virtually no sand was present prior to dredging. This effect was observable to a lesser extent as far as 60 m downstream. The sand embedded the cobble substrate and reduced or eliminated preferred aquatic habitat (Harvey et al. 1982).
- Reduction of pool area or volume due to sedimentation in small streams resulted in a reduction in the capacity of a stream to support salmonids in proportion to the percentage of pool area and volume lost (Bjornn et al. 1974).
- Sedimentation with materials less than 2.0 mm, at 26 and 31% by volume of total substrates, suppressed coho salmon production in laboratory streams (Crouse et al. 1981).
- Permeability of gravel substrates was inversely related to the percentage by volume of sand and silt in bottom substrates. Permeability is high when bottom materials contain less than 5% by volume of sands and silts (< 0.833 mm diameter), and permeability is low when substrates contain more than 15% by volume of sands and silts (McNeil and Ahnell 1964).
- High concentrations of sand in gravel caused earlier emergence of coho salmon and steelhead trout as a result of stress from the entrapment effect of sand (Phillips et al. 1975).
- Mine silt deposited on gravel spawning beds during either the early or later stages of incubation resulted in negligible yields of fry (mean yield = 1.16%) (Shaw and Maga 1943).

c. **Alteration of natural cover - riparian vegetation**
- Elimination of riparian vegetation is a relatively long-term effect. Revegetation of placer mine tailings was sparse, even after 60 yr, on some Interior Alaska streams. Rates of revegetation can be enhanced by stockpiling the overburden and replacing it on contoured tailings (Weber and Post 1985).
- Note: See impacts and guidelines for Channelization for additional information.

d. **Change in level of dissolved oxygen and Change in level of pH**
- Sediment deposited on salmonid spawning grounds filled the interstitial gravel spaces, reducing the interchange of surface and subsurface waters, which decreased the level of dissolved oxygen available to preemergent salmonids (Wilson 1960, Phillips 1971, Martin and Platts 1981).
- Mortality of salmonid eggs was greatest when exposed to sediment early in the incubation period (Bartsch 1960). Low dissolved oxygen and the physical barrier caused by sedimentation on spawning beds further reduced salmonid survival (Phillips 1971, Hall and McKay 1983).
- The dissolved oxygen conditions of the groundwaters under Interior Alaska streams indicated that the groundwaters of the mined streams are isolated from the

surface waters. Unmined streams had dissolved oxygen concentrations near saturation, whereas mined streams were depleted of dissolved oxygen (LaPerriere et al. 1983, Bjerklie and LaPerriere 1985).

- Steelhead trout and coho salmon fry hatched from embryos reared at low and intermediate oxygen concentrations hatched later and were smaller in size at hatching than fry from embryos reared near the air-saturation level. At all oxygen concentrations tested, reduced water velocities resulted in reduced size of hatching fry. Water movement promotes growth of salmonid embryos by delivering oxygen to the surface of the egg membrane and by removing metabolic waste products (Shumway et al. 1964).
- Water quality parameters were dramatically influenced by activity at a placer mine on Little Gold Creek, Yukon Territory. Dissolved oxygen levels and pH values were lower at downstream locations during sluicing (Soroka and Mackenzie-Grieve 1983).

e. **Change in levels of heavy metals and Change in levels of other toxic compounds - sulfurous compounds and others**

The topic of impacts of heavy metals on fish and in aquatic habitats during mining is extensive and is poorly documented. Many papers mention that the problem exists, but sound documentation of concentrations present and lethal concentrations to fish and invertebrates is not abundant. The issue is easily complicated by site-specific conditions and interrelated factors. In each case, toxicity will depend on such factors as the fish species and life history stages, water temperature and pH, dissolved oxygen concentration, total hardness, and other chemical parameters (Chapman 1973). In addition, metals, sediments, and other elements may interact antagonistically to negate the toxicity of a metal in solution (Platts and Martin 1978). Metsker (1982) states that heavy metals that may be added to the aquatic environment in toxic amounts with the expanding placer mining ventures are iron, cadmium, chromium, tin, antimony, aluminum, manganese, mercury, arsenic, and selenium. Salts such as sodium, calcium, and magnesium are commonly discharged along with these metals and may buffer their toxic effects. However, sulfates may be released as well and can add to the toxicity of the heavy metals (ibid.).

The following impact summaries represent only a small portion of the information available on the change in levels of heavy metals in aquatic habitats due to the activities associated with processing of minerals:

- Due to the ameliorating effects of high pH, hard waters, low water temperatures, and high dissolved oxygen present in the streams of the Kantishna area, these stream biotas have a relatively high tolerance to high levels of heavy metals (West and Deschu 1984).

- A significant portion of arsenic in mining sluice effluents settled out in the pond system (Shannon and Wilson 1985).
- In mined streams of the Kantishna Hills area, mining effluents release significant amounts of settleable solids into the streams. Heavy metals are bound within and adhere to sediments; thus as long as settleable solids continue to enter the streams at high levels, metals will also be present (Sexton 1983, West and Deschu 1984).
- Arctic grayling showed several common nonspecific tissue damage responses frequently associated with heavy metal irritation in streams subjected to gold mining activity (West and Deschu 1984).
- Arsenic exists naturally in many surface waters in concentrations of 0.01 mg/l or less. Arsenic concentrations as high as 15 mg/l have been found in some Alaska streams, particularly in the Ester Dome and Pedro Dome-Cleary Summit areas near Fairbanks (ADEC 1979). Wilson (1975) concluded that placer mines located in this region caused high levels of arsenic to be present in streams after mining exposed large quantities of arsenic-containing rocks to streamwaters.
- Arsenic and mercury were evidenced as being the two metals of highest concern when all Kantishna area streams were examined as a whole. Iron and manganese water quality criteria were also exceeded in streams, but these metals are less toxic than arsenic and mercury. Other metals that were found in high concentrations in some Kantishna area streams include antimony, cadmium, copper, lead, nickel, and zinc (West and Deschu 1984).
- Metal concentrations in Kantishna area streams were usually found to be substantially higher below active mining operations than above operations and were higher below mining during operation than below abandoned mines (West and Deschu 1984).
- Runoff from abandoned mines had metal input into the streams but was not as great as that sampled from active mines (West and Deschu 1984).
- Placer mining activity caused a decrease in invertebrate density and biomass due to increases in turbidity, settleable solids, nonfilterable residue, and total recoverable arsenic, lead, zinc, and copper (LaPerriere et al. 1983, Soroka and Mackenzie-Grieve 1983, Birtwell et al. 1984, Wagner 1984).
- In laboratory experiments, sockeye salmon fry had a 168 h LC_{50} equal to 8 ug/l cadmium. Fry were less tolerant of cadmium than eggs, alevins, or smolts (Servizi and Martens 1978).
- Sockeye and pink salmon embryos were malformed when eggs were continuously exposed to 2.5 ug/l mercury beginning shortly after fertilization (Servizi and Martens 1978).

- Sockeye and pink salmon concentrated mercury during the egg-to-fry stage in proportion to exposure concentration. Mercury concentrations of 1.87 ppm in eyed eggs caused malformations in hatched embryos (Servizi and Martens 1978).
- In laboratory experiments, the lethal level of copper was between 37 and 78 ug/l for sockeye salmon and between 25 and 55 ug/l for pink salmon during the egg-to-fry stage (Servizi and Martens 1978).
- Pink salmon concentrated copper during the egg-to-fry stage proportionally to the level of exposure. Copper concentrations of 105 and 6.8 ppm in pink salmon eyed eggs and fry, respectively, caused mortalities (Servizi and Martens 1978).
- Numbers of an acidophilic iron- and sulfur- oxidizing bacterium were found in 8 of 9 streams affected by gold mine drainage and in only 1 of 22 streams not affected by gold mine drainage (Brown et al. 1982). The presence of this bacterium is associated with high arsenic levels (ibid.).
- Chinook salmon and steelhead trout newly hatched alevins were more resistant to cadmium and zinc than were other life stages (i.e., swim-up alevins, 5-8 mo fry, and smolts) (Chapman 1978).
- The variables of species, type of metal, and life stage were significant contributors to the observed variation in tolerances to zinc, cadmium, and copper. Chinook salmon were generally more tolerant than steelhead trout to these metals (Chapman 1978).

f. **Introduction or removal of species**

- Trout sac fry were extremely susceptible to damage from entrainment by a small suction gold-dredge. About 25% of newly hatched fry survived, and the period of susceptibility was 10-15 d after hatching (depending on species and temperature) (Griffith and Andrews 1981).
- Un-eyed cutthroat trout eggs experienced 100% mortality within 1 hr after entrainment by a small suction gold dredge (Griffith and Andrews 1981).

2. Guidelines:[4]

a. General. Avoid excessive soil erosion and stream sedimentation by incorporating natural drainage patterns, soils, geology, and site-specific topography into a comprehensive mining plan prior to development (derived from Van Niewenhuyse 1983, Bjerklie and LaPerriere 1985, Deschu 1985a, Shannon and Wilson 1985).

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4 For additional information, see Entrix, Inc. 1986a and 1986b, Best management practices for placer mining, ADF&G, Division of Habitat, Anchorage, Ak. This report has thorough and updated specific guidance information on placer mining, but it does not include documented source information and has therefore not been included in this report.

b. General. Avoid mineral-processing activities in areas where introduction of sediments into aquatic environments resulting from soil erosion will occur (derived from ADEC 1979, Van Niewenhuyse 1983, Bjerklie and LaPerriere 1985, Deschu 1985a, Shannon and Wilson 1985).
   (1) Specific. Minimize surface erosion by minimizing the amount of time between stripping of overburden and mining the substrate in order to reduce the amount of time that soils are subjected to surface runoff (derived from R and M Consultants 1977, ADEC 1979).
   (2) Specific. Minimize the introduction of sediment-laden runoff into streams from slopes by constructing berms along the slope perimeters (derived from ADEC 1979).
   (3) Specific. Minimize erosion by grading tailing piles and overburden stockpiles concurrently with seasonal mining activity (derived from ADEC 1979).
   (4) Specific. Minimize erosion by constructing terraces on floodplains and recontouring side slopes of mine tailings and overburden stockpiles during the grading process (derived from ADEC 1979, Deschu 1985a).
   (5) Specific. Minimize erosion of overburden stockpiles by revegetating or armoring them where needed (derived from ADEC 1979).
   (6) Specific. Minimize erosion of stockpiles by locating them away from surface flow (i.e., stream channel and/or runoff from rain or snowmelt) (derived from ADEC 1979).
   (7) Specific. Minimize unnecessary handling of overburden materials by locating stockpiles out of the way of future mining activities (derived from ADEC 1979).
c. General. Avoid hydraulic stripping of overburden by using mechanical stripping techniques (e.g., scraping and stockpiling material with a dozer, scraper, or backhoe; ripping and stockpiling frozen substrate; etc.) (derived from Federal Water Pollution Control Administration 1969, ADEC 1979).
d. General. Avoid excessive or unnecessary use of processing water in order to minimize the quantity of mining wastewater (derived from ADEC 1979, Blanchet 1981, R and M Consultants 1982, Shannon and Wilson 1985).
   (1) Specific. Minimize the quantity of processing water used by utilizing techniques such as classifying large material (using grizzlies, trommels, screens, wobblers, vibrating tables, washing plants, and conveyors), separating sluice channels, and recycling mining wastewater (derived from ADEC 1979, R and M Consultants 1982).
   (2) Specific. Minimize excessive use of stream water by constructing a bypass drainage ditch that will divert the portion of natural drainage not needed for sluicing around the processing area and settling ponds (derived from Shannon and Wilson 1985).
e. General. Avoid introduction of placer mining sediments in streams or stream sections critical to migration, feeding,

spawning, and/or rearing of arctic grayling and salmonids (derived from Redding and Schreck 1980, McLeay et al. 1983, Birtwell et al. 1984, McLeay et al. 1984, Sigler et al. 1984, Simmons 1984, Bottom et al. 1985, Deschu and Kavanagh 1985, among others).

(1) Specific. Minimize the addition of unacceptable levels of sediment in placer-mined streams and the resultant stress on fish populations by constructing and maintaining adequately sized settling ponds and not mining areas where the soil structure will result in excessive fine suspended sediment (i.e., clay) or in areas where no space is available for settling pond construction (i.e., narrow valleys) (derived from R and M Consultants 1982, Sexton 1983, Deschu 1985a, Deschu and Kavanagh 1985, Lloyd 1985, Shannon and Wilson 1985).

(2) Specific. Minimize excessive turbidity and the addition of suspended sediments to streams from mining operations by constructing and maintaining settling ponds that are 1) deep enough for the amounts of sediments being produced from mining; 2) large enough so that the flow rate through the pond is sufficient to allow maximum removal of suspended sediments; and 3) set up so routine cleaning of accumulated sediments is practically accomplished (derived from R and M Consultants 1982, Sexton 1983, Shannon and Wilson 1985).

(3) Specific. Minimize the addition of unacceptable levels of sediment to streams and the resultant effects on fish populations by combining alternative treatment techniques with settling ponds for wastewater treatment (e.g., baffles in ponds, series of ponds, stream bypass, recycling, filtration, hydrocyclone, flocculants/coagulants) (derived from R and M Consultants 1982, Shannon and Wilson 1985).

(4) Specific. Minimize the potential for sedimentation from placer-mining activities in salmonid streams during the time that eggs are incubating in the gravel (derived from Shaw and Maga 1943, Shumway et al. 1964, Phillips 1971, Phillips et al. 1975, Griffith and Andrews 1981, Martin and Platts 1981, Hall and McKay 1983).

(5) Specific. Minimize the potential for sedimentation from placer-mining activities in salmonid streams when juvenile fish are feeding and rearing (derived from McLeay et al. 1983, Birtwell et al. 1984, McLeay et al. 1984, Simmons 1984, Wagener 1984).

(6) Specific. Minimize the impacts of excessive sediment on grayling and salmonid populations by minimizing sediment additions from mining operations to streams during low flow periods (derived from Shaw and Maga 1943, Caplice 1959, Hall and McKay 1983, LaPerriere et al. 1983, Simmons 1984).

f. General. Avoid constructing settling ponds in the streams, where high flows may wash out the pond dam or the accumulated sediments (derived from R and M Consultants 1982).

g. General. Avoid removal of all riparian vegetation along streambanks (derived from Weber and Post 1985).
   (1) Specific. Minimize removal of riparian vegetation by limiting access points of heavy equipment in streams (derived from Weber and Post 1985).
   (2) Specific. Minimize the effects of removal of riparian vegetation by redistributing stockpiled overburden over mine tailings and revegetating such areas (derived from Weber and Post 1985).

h. General. Avoid sedimentation from placer mining in critical salmonid habitats (i.e., spawning gravels) where such sedimentation will result in reduction of dissolved oxygen levels and subsequent mortality of incubating eggs and preemergent salmonids (derived from Shumway et al. 1964, Phillips 1971, Martin and Platts 1981, LaPerriere et al. 1983, Bjerklie and LaPerriere 1985).

i. General. Avoid the negative effects of high heavy metal concentrations in streams by conducting pre-mining studies of the parent substrate and stream waters. Avoid mining development in areas where high natural levels of heavy metals exist and where development will cause increased concentrations in streams (derived from Platts and Martin 1978, ADEC 1979, Wagener 1984, West and Deschu 1984, Shannon and Wilson 1985).
   (1) Specific. Minimize introduction of high levels of suspended heavy metals into streams by providing settling ponds that allow adequate settling of suspended materials (Sexton 1983, West and Deschu 1984, Shannon and Wilson 1985).
   (2) Specific. Minimize introduction of high levels of suspended heavy metals and sediments into streams by utilizing alternative techniques of wastewater management (e.g., baffles, recycling, chemical flocculants, etc.) (derived from Sexton 1983, West and Deschu 1984, Shannon and Wilson 1985).

B. Freshwater Nonsalmonids

1. <u>Summary of documented impacts</u>:

a. No information was found (see freshwater salmonid section for additional information)

2. <u>Guidelines</u>:

a. See the guidelines presented above in the section Freshwater Salmonids

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Appendices

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B. LIST OF ACTIVITIES

1. Blasting
2. Burning
3. Channelizing
4. Chemical application
5. Clearing and tree harvest
6. Draining
7. Dredging
8. Drilling
9. Fencing
10. Filling and pile-supported structures (aquatic and wetland habitats)
11. Filling (terrestrial)
12. Grading/plowing
13. Grazing
14. Human disturbance
15. Log storage/transport
16. Netting
17. Processing geothermal energy
18. Processing lumber/kraft/pulp
19. Processing minerals
20. Processing oil/gas
21. Sewage disposal
22. Solid waste disposal
23. Stream crossing - fords
24. Stream crossing - structures
25. Transport of oil/gas/water - land
26. Transport of oil/gas/water - water
27. Transport of personnel/equipment/material - air
28. Transport of personnel/equipment/material - land
29. Transport of personnel/equipment/material - water
30. Water regulation/withdrawal/irrigation

C. LIST OF IMPACT CATEGORIES

1. Change in water temperature
2. Change in depth or velocity of water
3. Change in turbidity or suspended sediments
4. Addition of substrate materials
5. Removal of substrate materials
6. Physical disturbance of substrate materials
7. Alteration of natural cover:
   a. Riparian vegetation
   b. Aquatic vegetation (including algae)
   c. Overhanging bank or shoreline
8. Addition of physical barriers:
   a. Impoundments (e.g., hydroelectric dams, settling ponds)
   b. Diversions (e.g., channels, canals)
9. Increase in hydrostatic pressure or noise
10. Impingement or entrainment or entanglement
11. Physical trampling or crushing
12. Change in levels of dissolved oxygen or nitrogen
13. Change in levels of pH, alkalinity, or hardness
14. Change in level of salinity
15. Change in levels of heavy metals
16. Change in levels of chlorinated compounds other than biocides
17. Change in levels of biocides (e.g., herbicides, insecticides, etc.).
18. Change in levels of other toxic compounds:
    a. Bark or log leachates
    b. Sulfurous compounds
    c. Others
19. Change in levels of hydrocarbons (other than biocides)
20. Change in levels of nutrients (phosphoric or nitrogenous compounds)
21. Introduction or removal of species
22. Artificial attractant to biological organisms (e.g., organic waste)

D. ABBREVIATIONS

Units of Measure

Length

kilometerkm	
	meterm
	centimetercm
millimeter	mm
micrometer	um
nanometer	nm
mile	mi
yard	yd
foot	ft
inch	in

Weight

kilogram	kg
gra	mg
milligram	mg
microgram	ug
nanogram	ng
pound	lb
ounce	oz

Volume/area

hectare	ha
liter	l
milliliters	ml
microliter	ul
nanoliter	nl
square units	$unit^2$
cubic unit	$unit^3$

Time

year	yr
month	mo
week	wk
day	d
hour	h or hr
minute	min
second	s

Other units

degrees Celsius	•C
degrees Fahrenheit	•F
percent	%
parts per thousand	ppt or 0/00
parts per million	ppm
parts per billion	ppb
hertz	Hz

Agencies, Organizations, and Other Terms

ACMP	Alaska Coastal Management Program
ADCED	Alaska Department of Commerce and Economic Development
ADCRA	Alaska Department of Community and Regional Affairs
ADEC	Alaska Department of Environmental Conservation
ADF&G	Alaska Department of Fish and Game
ADL	Alaska Department of Labor
ADNR	Alaska Department of Natural Resources
ADR	Alaska Department of Revenue
AEIDC	Arctic Environmental Information and Data Center
ATPase	Adenosine triphosphatase
BLM	Bureau of Land Management
BOD	Biological oxygen demand
CPUE	Catch per unit effort
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DO	Dissolved oxygen
ED50	Effective dose, 50%
EPA	Environmental Protection Agency
EPS	Environmental Protection Service (Canada)
ERL	Environmental Research Laboratory
FAO	Food and Agriculture Organization of the United Nations
FTU	Formazin turbidity unit
ID50	Infective dose, 50%
IMS	Institute of Marine Science
INPFC	International North Pacific Fisheries Commission
IPHC	International Pacific Halibut Commission
LC50	Lethal concentration, 50%
LD50	Lethal dose, 50%
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPFMC	North Pacific Fishery Management Council
NPS	National Park Service
NWAFC	Northwest and Alaska Fisheries Center
NWR	National Wildlife Refuge
PCB	Polychlorinated biphenols
PWS	Prince William Sound
TLM	Median tolerance limit
TU	Temperature units
USACRREL	U.S. Army Cold Regions Research and Engineering
USDA	United States Department of Agriculture
USDC	United States Department of Commerce
USDI	United States Department of Interior
USDL	United States Department of Labor
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
V/V	Volume per volume ratio
WSF	Water-soluble fraction