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SUSITNA HYDROELECTRIC PROJECT

FEDERAL ENERGY REGULATORY COMMISSION
PROJECT No. 7114

INSTREAM FLOW RELATIONSHIPS REPORT

VOLUME I

ENTRIX, INC. and

Trihey & Associates
Aquatic Resource Specialists

UNDER CONTRACT TO

HARZA-EBASCO
SUSITNA JOINT VENTURE

FINAL REPORT

DECEMBER 1985
DOCUMENT No. 3060

Alaska Power Authority

Document No. 3060
Susitna File No. 4.3.1.3

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VOLUME NO. 1

Prepared by

Trihey and Associates
and
Entrix, Inc.

With assistance from

Harza-Ebasco Susitna Joint Venture
R&M Consultants, Inc.
University of Alaska,
Arctic Environmental Information & Data Center
Woodward-Clyde Consultants, Inc.

Under contract to
Harza-Ebasco Susitna Joint Venture

Prepared for
Alaska Power Authority

Final Report
December 1985

NOTICE

ANY QUESTIONS OR COMMENTS CONCERNING
THIS REPORT SHOULD BE DIRECTED TO
THE ALASKA POWER AUTHORITY
SUSITNA PROJECT OFFICE

ACKNOWLEDGMENTS

Preparation of the Instream Flow Relationship Report (IFRR) and its associated technical report series was funded by the Alaska Power Authority (APA) as part of the feasibility and licensing studies for the proposed Susitna Hydroelectric Project. Much of the IFRR is based on engineering and environmental studies which were initiated by Acres American, Inc. and continued by Harza-Ebasco Susitna Joint Venture. Except for the stream temperature modeling, Harza-Ebasco has conducted all physical process modeling directly or indirectly referenced in this document. Of particular value is their reservoir temperature and instream ice modeling.

Field studies and analyses completed by other members of the Aquatic Study Team are also cited within this report. Most visible are numerous references to the Alaska Department of Fish and Game, Susitna Hydroelectric Aquatic Study Team (ADF&G, Su Hydro). The ADF&G Su Hydro Study Team conducted the baseline field studies to determine the seasonal distribution, relative abundance, and habitat requirements of anadromous and selected resident fish populations within the project area.

The University of Alaska, Arctic Environmental Information and Data Center (AEIDC) performed the instream temperature modeling studies, a key element in the evaluation of project influences on ice processes and on the seasonal quality of fish habitats. Mr. Paul Meyer and Mr. Joe Labelle are recognized for assembling the supporting technical information and drafting portions of section IV of this report.

R&M Consultants conducted the hydrologic and climatologic field studies for the project. Their greatest assistance has been in providing data and technical assistance pertaining to basin hydrology and climatology, slough geohydrology (upwelling), and ice processes. Special recognition is given to Mr. Steve Bredthauer for drafting portions of the basin hydrology and streamflow variability discussion (section IV) and to Mr. Carl Schoch who provided technical information and drafted portions of the instream temperature and ice processes section.

Finally, special recognition is given to Mr. Milo C. Bell for the insights he provided at the onset of the feasibility and licensing studies regarding the fish resource issues that would be of central importance to project licensing and for his wise counsel concerning the potentially beneficial and adverse influences the proposed project may have on the salmon resources in the Susitna River Basin.

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I. INTRODUCTION

Instream Flow Relationships Report

The goal of the Alaska Power Authority in identifying environmentally acceptable flow regimes for the proposed Susitna Hydroelectric Project is the maintenance of existing fish resources and levels of production. This goal is consistent with the preferred mitigation goal of the U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game which encourages the maintenance of naturally occurring fish habitats and populations.

In 1982, following two years of baseline studies, a multi-disciplinary approach to quantify effects of the proposed Susitna Hydroelectric Project on existing fish habitats and to identify mitigation opportunities associated with streamflow and/or stream temperature regulations was initiated by the Power Authority. The Instream Flow Relationships (IFR) studies were initiated to identify the potential beneficial and adverse effects the proposed Susitna Hydroelectric Project might have on fluvial processes and fish habitat in the Talkeetna-to-Devil Canyon segment of the Susitna River (middle Susitna River). The IFR studies focus on quantifying the response of fish habitats in the middle Susitna River to incremental changes in mainstem discharge, temperature, and water quality. As part of this multi-disciplinary effort, a technical report series was planned that would (1) describe the existing fish resources of the Susitna River and identify the seasonal habitat requirements of selected species, and (2) evaluate the effects of alternative project designs and operating scenarios on physical processes which most influence the seasonal availability of fish habitat.

In addition, a summary report, the Instream Flow Relationships Report (IFRR), would (1) identify the biologic significance of the physical processes evaluated in the technical report series, (2) integrate the findings of the technical report series, and (3) provide quantitative relationships and discussions regarding the influences of incremental changes in streamflow, stream temperature, and water quality on fish habitats in the middle Susitna River. By meeting these objectives the IFR studies will assist the Alaska Power Authority (APA) and resource agencies to reach an agreement on an instream flow regime (and associated mitigation plan) that would minimize adverse effects of the proposed project and possibly enhance existing fish habitats and populations in the middle Susitna River.

The IFRR consists of two volumes. Volume I uses project reports, data and professional judgement to identify evaluation species, important life stages, and habitats. The report also ranks a variety of physical habitat variables with regard to their degree of influence of fish habitat at different times of the year. This ranking considers the biologic requirements of the evaluation species and life stage, as well as the physical characteristics of different habitat types, under both natural and anticipated with-project conditions. Volume II of the IFRR, which will be completed during 1986, will provide a quantitative framework and the necessary relationships to evaluate influences of incremental changes in streamflow, stream temperature and water quality on fish habitats in the middle Susitna River on a seasonal basis.

The technical reports which support the IFR Volume I consist of the four reports listed in Table I-1 as well as several reports prepared by the Alaska Department of Fish and Game, Su Hydro Aquatic Studies Group which describe fish habitats, populations and utilization patterns, and reports by the Harza-Ebasco Susitna Joint Venture which address reservoir temperature, instream ice processes, groundwater hydrology, and sediment transport.

Table I-1 IFR Studies Technical Report Series

Technical Report No. 1. Fish Resources and Habitats in the middle Susitna River. This report prepared by Woodward-Clyde Consultants and Entrix, Inc. consolidates information obtained by ADF&G, Su Hydro on the fish resources and habitats in the middle Susitna River and summarizes the relative abundance and seasonal utilization patterns observed in middle Susitna River habitats from 1981 through January 1985.

Technical Report No. 2. Physical Processes of the Middle Susitna River. This report, prepared by Harza-Ebasco and R&M Consultants, describes such naturally occurring physical processes within the middle river segment as: sediment transport, channel stability, ice cover formation and upwelling.

Technical Report No. 3. A Limnological Perspective of Potential Water Quality Changes. This report, prepared by Harza-Ebasco, consolidates existing information on the water quality for the Susitna River and provides technical level discussions of the potential for with-project bioaccumulation of mercury, nitrogen gas supersaturation and changes in downstream nutrients. Particular attention is given to project induced changes in turbidity and suspended sediments concentrations.

Technical Report No. 4. Instream Temperature. This report, prepared by the University of Alaska Arctic Environmental and Data Center, consists of three principal components: (1) instream temperature modeling; (2) development of temperature criteria for Susitna River fish stocks by species and life stage; and (3) a preliminary evaluation of the influences of anticipated with-project stream temperatures on fish habitats and ice processes.

The IFR report and its associated technical report series should not be viewed as an impact assessment. These reports only describe a variety of natural and with-project conditions that govern, or may govern, fluvial processes and the seasonal availability and quality of fish habitat in the middle Susitna River. The IFR studies provide the quantitative basis for others to evaluate alternative streamflow and stream temperature regimes, conduct impact analyses, and prepare mitigation plans. Brief descriptions of anticipated with-project conditions are provided in Section VI of this report. However, these descriptions only serve to establish a basis for understanding the relative importance of anticipated with-project habitat conditions with regard to the life history requirements of the evaluation species. Quantitative descriptions or discussions of project effects on fish habitat, as expected in an impact assessment, are not provided by this report.

Project Setting

The proposed Susitna Hydroelectric project consists of two dams scheduled for construction over a period of 21 years. The three-stage project would be initiated by construction of Watana Dam to a crest elevation of 2,025 feet with a maximum reservoir elevation of 2,000 feet. Construction on Watana Dam would begin when the FERC license is issued, possibly in 1987, and would occur at a site located approximately 184 miles upstream from the mouth of the Susitna River. The first stage of the Watana development would be completed in 1996 and would include a 705-foot-high earth fill dam, which would impound an approximately 21,000-surface-acre reservoir with 2.37 million acre feet (maf) of usable storage. Cone valves and multiple level intake structures would be installed in the dam to control downstream dissolved gas concentrations and temperature. The powerhouse would contain four generators with an installed capacity of 520 megawatts (MW) and would be designed to discharge a 50-year flood before flow would be discharged over the spillway.

The second stage of the proposed development is construction of the 646-foot-high concrete arch Devil Canyon Dam, which is scheduled for completion by 2002. Devil Canyon Dam would be constructed at a site 32 miles downstream of Watana Dam and would impound a 26-mile-long reservoir with 7,800 surface acres and a usable storage capacity of 0.35 maf. Installed generating capacity would be about 600 MW, with an average annual energy output of 3450 gigawatt hours (GWH). Cone valves and multiple level intake structures would also be installed in Devil Canyon Dam. The maximum possible outflow from the four generators in the powerhouse at full pool is 15,000 cubic feet per second (cfs). The cone valves at Devil Canyon Dam would be designed to pass 38,500 cfs. Prior to construction of Devil Canyon Dam, Watana Reservoir would be filled with summer streamflows when energy demand is lowest and would be drawn down to meet high power demands during the winter when streamflows are lowest. When Devil Canyon Dam became operational, Watana Reservoir would operate in a similar manner, however, the level of winter drawdowns may not be as low. Devil

Canyon Reservoir water levels would generally be stable with a small drawdown in the spring of dry years and a larger drawdown in the fall of average and dry years.

The third stage of the project consists of raising the initial crest elevation of Watana Dam from 2,025 feet to 2,205 feet with a maximum normal reservoir elevation of 2,185 feet. Completion of the third stage is scheduled for the year 2008. When completed, Watana Dam would be 885 feet high and would impound a 48-mile-long, 38,000-surface-acre reservoir with a total storage capacity of 9.5 maf and a usable storage capacity of 3.7 maf. Two additional generators would be added to the powerhouse, bringing the total number to six units. After completion of Stage III, the capacity of the powerhouse would increase to 1,020 MW because of the increased head on the four Stage I units and the addition of two more units at 170 MW each. The maximum powerhouse discharge capacity at full pool would be greater than 21,000 cfs (APA 1983). Watana Reservoir, because of its size, would provide the ability to completely regulate Susitna River streamflows except during extreme flood events.

Susitna River Basin

The Susitna River is located in Southcentral Alaska between the major population centers of Anchorage and Fairbanks. The Susitna Valley is a transportation corridor which contains both the Alaska Railroad and the Parks Highway. Even with these transportation facilities, however, the basin remains largely undeveloped except for several small communities in the lower portion of the drainage. Talkeetna, the largest of these communities, with an approximate population of 280, is located on the east bank of the Susitna River at river mile (RM) 98.[1]

The Susitna River is an unregulated glacial river. Typical summer flows range from 16,000 to 30,000 cfs with winter flows ranging between 1,000 and 3,000 cfs. Turbidities in the middle Susitna River average approximately 200 nephelometric turbidity units (NTU) in summer, and less than 10 NTU in winter. Summer flows are quite variable, often changing from 5,000 to 10,000 cfs from one week to the next; peak flows exceeding 50,000 cfs are common. Winter streamflows are maintained principally by groundwater and therefore are quite stable. A thick ice cover generally forms on the river during late November and persists through mid-May.

The drainage area of the Susitna River, the sixth largest river basin in Alaska, is approximately 19,600 square miles. The Susitna Basin is bordered by the Alaska Range to the north, the Chulitna and Talkeetna mountains to the west and south, and the northern Talkeetna plateau and Gulkana uplands to the east. Major tributaries to the Susitna include the Talkeetna, Chulitna, and Yentna Rivers, all of which are glacial streams with characteristically high turbid summer streamflows and ice-covered clearwater winter flows.

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1 River miles are measured upstream from the mouth of the Susitna River which is located in Cook Inlet approximately 25 miles northwest of Anchorage.

The Yentna River, the largest tributary to the Susitna River originates at the Dall and Yentna glaciers in the Alaska Range approximately 130 miles northwest of Anchorage and adjoins the Susitna River at RM 28. The Chulitna River originates in the glaciers on the south slope of Mount McKinley and flows south, entering the Susitna River near Talkeetna at RM 99. The Talkeetna River originates in the Talkeetna Mountains, flows west, and joins the Susitna near the town of Talkeetna (RM 97). The junction of the Susitna, Chulitna and Talkeetna Rivers is commonly referred to as the Three Rivers confluence.

The Susitna River originates as a number of small tributaries draining the East Fork, Susitna, West Fork and MacLaren Glaciers, and follows a disjunct south and west course 320 miles to Cook Inlet (Fig. I-1). The river flows south from these glaciers in a braided channel across a broad alluvial fan for approximately 50 miles, then west in a single channel for the next 75 miles through the steep-walled Vee and Devil Canyons. The two proposed dam sites (Watana at RM 184.4 and Devil Canyon at RM 151.6) are located in this reach. Downstream of Devil Canyon, the river flows south again through a well-defined and relatively stable multiple channel until it meets the Chulitna and Talkeetna Rivers (RM 99). Downstream of the Three Rivers confluence, the Susitna River valley broadens into a large coastal lowland. In this reach the down valley gradient of the river decreases and it flows through a heavily braided segment for the last 100 miles to the estuary.

Overview of Fish Resources and Project-Related Concerns

The Susitna River basin supports populations of both anadromous and resident fish. Commercial or sport fisheries exist for five species of Pacific salmon (chinook, sockeye, coho, chum, and pink), rainbow trout, lake trout, Arctic grayling, Dolly Varden, and burbot. The commercial fishery intercepts returning sockeye, chum, coho and pink salmon in Cook Inlet. A subsistence fishery at Tyonek relies principally on chinook salmon. Sport fishing is concentrated in clearwater

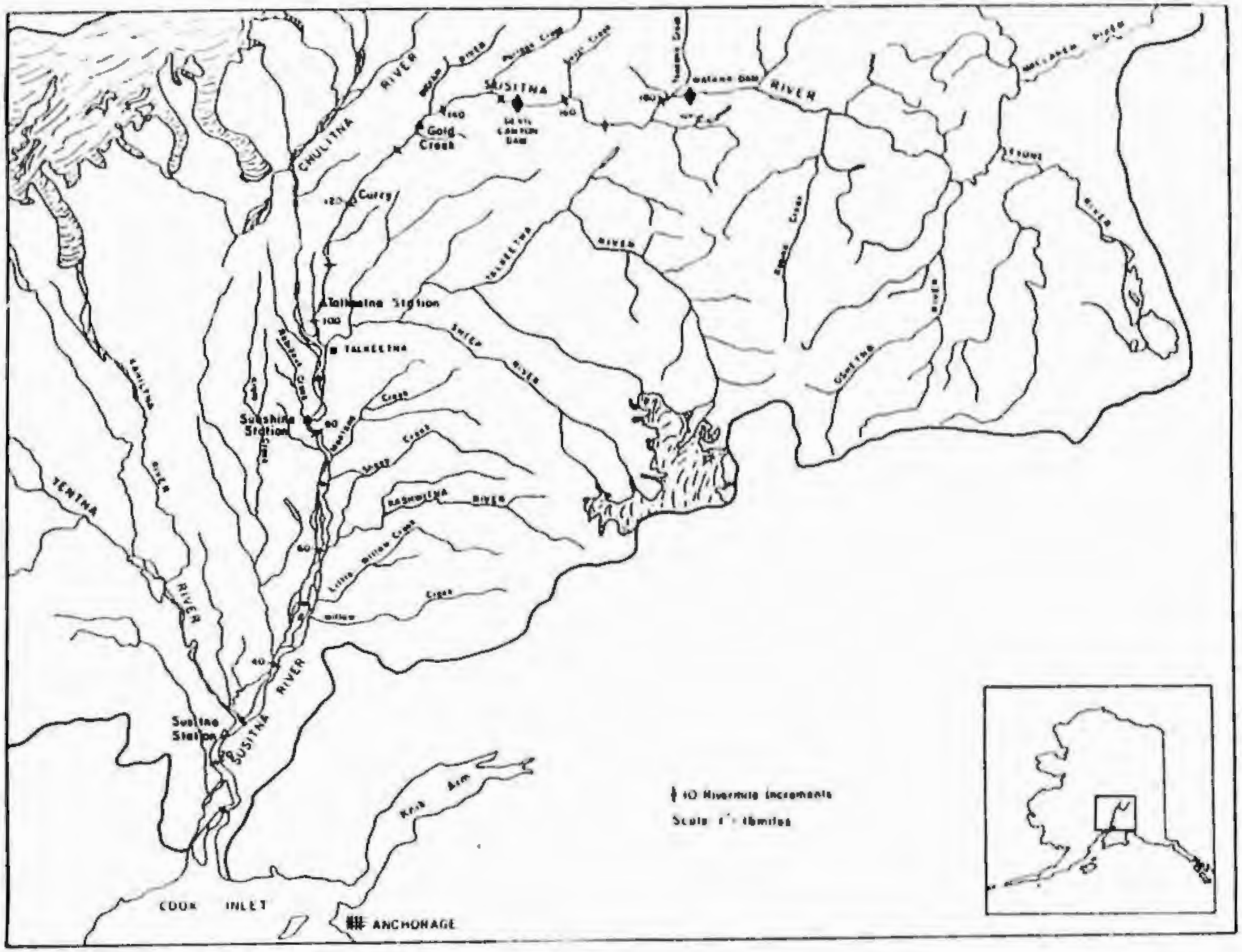


Figure I-1. Project area.

tributaries to the Susitna River for chinook, coho, and pink salmon; rainbow trout; and Arctic grayling. These fish resources are described further in Section III of this report.

Construction and operation of the proposed project will reduce variation in the annual flow cycle by decreasing streamflows during the summer months and increasing them during the winter months. Stream temperatures and turbidities will be similarly affected. The most pronounced changes in stream temperature and turbidity will likely occur in mainstem and side channel areas with somewhat lesser effects occurring in peripheral habitats. Changes in depth and velocity attributable to alteration of natural streamflow patterns will be most pronounced and of greatest concern in peripheral areas; particularly if extensive or untimely dewatering or flooding of fish habitat might occur.

The effects that anticipated changes in streamflow, stream temperature, and turbidity will have on fish populations inhabiting the middle Susitna River depend upon their seasonal habitat requirements and the importance of the requirements to the overall population. Some project-induced changes in environmental conditions may have no appreciable effect on existing fish populations and their associated habitats, whereas other changes may have dramatic consequences. Thus, in order to understand the possible effects of the proposed project on existing fish populations and to identify mitigation opportunities or enhancement potential, it is important to understand 1) the relationships among the naturally occurring physical processes which provide fish habitat, and 2) how fish populations respond to natural variations in habitat availability.

II. OVERVIEW OF THE IFR ANALYSIS

Selection of Fish Habitat Over Fish Populations for Decisionmaking

Identification of an environmentally acceptable flow regime to maintain naturally reproducing fish populations has remained of central importance throughout the evolution of the studies for the proposed Susitna project. In describing the potential effects of the proposed project the IFR studies have focused on identifying the response of fluvial processes and fish habitats to incremental changes in mainstem discharge, temperature, and water quality. This approach is consistent with the mitigation goals of the Alaska Power Authority, U.S. Fish and Wildlife Service, and the Alaska Department of Fish and Game (USFWS 1981; ADF&G 1982; APA 1982). The ultimate goal of these organizations' mitigation policies is the maintenance of natural habitats and production levels.

Fish populations of the Susitna River are thought to fluctuate for many reasons, with some of the factors exerting their influence outside the river basin. This is particularly true for anadromous species such as Pacific salmon, which spend substantial portions of their life cycles in estuarine and marine environments. Ocean survival and commercial catches significantly affect the number of salmon returning to spawn in the Susitna River basin (ADF&G 1985). Within the freshwater environment, factors such as high flows and suspended sediment concentrations during summer, cold stream temperatures, low winter streamflows, predation, and sport fishing appear to affect populations.

Furthermore, adult fish populations seldom show an immediate response to perturbations that may occur either within or outside their freshwater environment. A time-lag, often of several years, usually occurs before an effect, whether beneficial or detrimental, is reflected in the reproductive potential or size of the population.

For these reasons it is often impossible to forecast the response of fish populations to project-induced changes in fluvial processes by monitoring fish populations only.

To avoid many of the uncertainties associated with correlating fish population levels with various environmental parameters, fish habitat is often used as a response variable in determining the effects of altered fluvial processes on fish populations (Stalnaker and Arnette 1976; Olsen 1979; Trihey 1979). The application of physical process modeling is well suited for obtaining reliable forecasts of with-project streamflow, temperature, and water quality conditions which, in turn, can be readily interpreted in terms of habitat suitability. When using fish habitat as the response variable, the direction and magnitude of change in habitat availability or habitat quality are considered indicative of the population response. Although the relationship between habitat availability or quality and fish population is not necessarily linear, it has been found to be positively correlated in several studies (Binns and Eiserman 1979; Wesche 1980; Loar et al. 1985).

Framework for Extrapolation:
River Segmentation, Habitat Types, and Microhabitat Variables

Various approaches exist for evaluating fish habitats associated with fluvial systems. Weighted Usable Area (WUA) is often used at the microhabitat level as an index to evaluate the influence of streamflow variations on the site-specific availability of potential fish habitat. Weighted Usable Area is defined as the total wetted surface area of a study site expressed as an equivalent surface area of optimal (preferred) fish habitat for the life species and stage being evaluated (Stalnaker 1978). This index is most commonly computed using microhabitat variables such as depth, velocity, and substrate composition for spawning fish, and depth, velocity, and cover for rearing fish. Occasionaly stream temperature is also included. WUA forecasts for habitats in the middle Susitna River are enhanced by considering such other microhabitat variables as upwelling groundwater and turbidity.

The microhabitat approach can effectively evaluate habitat suitability in terms of physical conditions occurring at specific locations (areas) within a river system. However, in order to evaluate aquatic habitat responses to physical processes on a larger scale, some method must be established for extrapolating site specific relationships to the remainder of the river.

The representative reach concept (Bovee and Milhous 1978) is often used by instream flow investigators as a basis for extrapolating. This concept is based on the theory of longitudinal succession which describes riverine ecology and fluvial processes from the headwaters to the mouth of a river (Burton and Odum 1945; Mackin 1948; Sheldon 1968). Watershed characteristics such as climate, hydrology, geology, topography, and vegetative cover (land use) are the principal determinants of basin runoff and erosional processes which control longitudinal succession. By applying the longitudinal succession approach to the existing river system and by considering differences project operation would have on the type and magnitude of change in fluvial processes within various river segments, the 320-mile length of the Susitna River was divided into the four discrete segments.

1. Upper Basin (RM 232-320). This segment includes the headwater reach of the Susitna River and its associated glaciers and tributary streams above the elevation of the proposed impoundments.

2. The Impoundment Zone (RM 150-232). This segment includes the 80-mile portion of the Susitna River which will be inundated by the Watana and Devil Canyon impoundments. This single channel reach is characterized by steep gradients and high velocities. Intermittent islands are found in the reach with significant rapids occurring in Vee Canyon and between Devil Creek and Devil Canyon.

3. The Middle River (RM 99-150). This 50-mile segment (the focus of the IFRR) extends from Devil Canyon downstream to the Talkeetna and Chulitna Rivers confluence. It is a relatively stable reach comprised of nearly equal lengths of single channel and split channel characteristics. Construction and operation of the project will alter the quantity and temperature of streamflow and the amount of suspended and bedload sediment in this reach.

4. The Lower River (RM 0-99). This segment extends 100 miles from the three rivers confluence downstream to the estuary. The floodplain is very broad, containing multiple or braided channels which meander laterally. Reworking of streambed gravels in this area is relatively frequent causing instability and migration of the main flow channel or channels. Project induced changes in streamflow, stream temperature, and sediment concentrations will attenuate in this reach due to tributaries such as the Talkeetna, Chulitna, and Yentna Rivers, all of which will be unaffected by project operation.

Extraoolation of microhabitat responses in fish habitat to non-modeled portions of the river using the traditional concepts of longitudinal succession is accomplished by dividing the river into segments of similar channel morphology, water quality or species composition. Likewise, the segments are further subdivided into subsegments of similar hydraulic, hydrologic, and morphologic characteristics. Subsegments are then defined according to habitat type by measurements obtained in representative reaches. Systemwide habitat evaluation is accomplished by extrapolating habitat relationships for representative reaches to the subsegments and segments in which they are located on the basis of proportional length.

The longitudinal succession approach is most applicable to single-thread river systems in which subsegments containing relatively homogeneous habitat types can be identified. In multi-thread systems, such as the Susitna River, the longitudinal succession approach is difficult to apply because the locations of homogeneous habitat types are highly variable, both longitudinally and laterally within the river corridor. Although the Susitna River can be divided into the four discrete segments previously described, subdividing the middle Susitna River segment into subsegments by application of the representative reach concept (Bovee and Milhous 1978) does not provide a practical method of extrapolating site specific relationships to the remainder of the river. Hence, a different method for extrapolating aquatic habitat responses to streamflow is required at this level in the hierarchy of the IFR analysis.

Because of the notable variation and differences in habitat conditions within the middle Susitna River segment, six major <u>habitat types</u> have been defined: mainstem, side channel, side slough, upland slough, tributary, and tributary mouth (ADF&G, Su Hydro 1983a; Klinger & Trihey 1984). Habitat type refers to a major portion of the wetted surface area of the river possessing similar morphologic, hydrologic, and hydraulic characteristics. At some locations, such as major side channels and tributary mouths, a designated habitat type persists over a wide range of mainstem discharge even though the wetted surface area for the location may change significantly. In other instances the habitat type and wetted surface area may change in response to mainstem discharge (Klinger and Trihey 1984). Such an example is the transformation of some turbid-water side channels to clearwater side sloughs when mainstem discharge recedes during late summer and fall.

Habitat transformation categories are used in the IFR analysis to classify specific areas within the river corridor according to the nature of the habitat transformation they undergo as mainstem discharge decreases below typical mid-summer flow levels. The classification of specific areas into habitat dewatered or transformation categories is important because (1) a significant amount of wetted surface area is expected to be transformed from turbid to clear water habitats as a result of project-induced changes in streamflow (Klinger and Trihey 1984); and (2) a large amount of circumstantial evidence exists within the project data base and elsewhere which indicates that turbid water channels which may be transformed into clearwater habitats as a result of the project may provide substantially different habitat conditions than presently exists in these channels. Within the hierarchial structure of the IFR analysis, the eleven habitat transformation categories introduced in Section V provide important indices of site-specific habitat response to large changes in mainstem discharge.

Habitat transformation categories are used in conjunction with hydrologic, hydraulic, and morphological information to group specific areas of the middle Susitna River into representative groups. These groups provide a basis to link microhabitat study sites (modeled sites) with less intensively studied specific areas (nonmodeled sites). Representative groups provide the analytic bridge to extrapolate habitat response functions from modeled to nonmodeled sites.

Figure II-1 diagrams the hierarchial structure of the IFR analysis, proceeding from microhabitat study sites through representative groups and habitat types to the middle Susitna River segment. This analytic structure is similar to the study site and representative reach logic

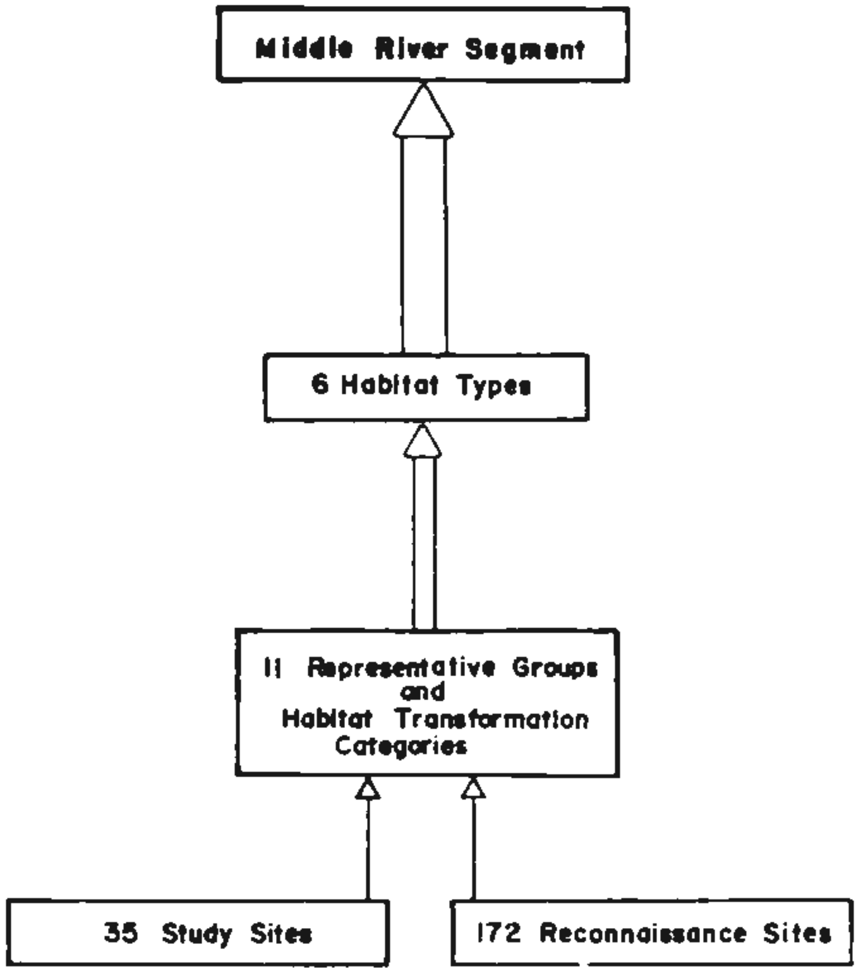


Figure II-1 Hierarchial structure of the relationship analysis.

referenced in the literature and other instream flow studies (Bovee and Milhous 1978; Wilson et al. 1981; Bovee 1982).

However, a basic difference exists between the structure of the extrapolation methodology used in th IFR studies and that used in other instream flow studies. In the IFR extrapolation methodology habitat types and representative groups are substituted for river subsegments and representative reaches. Additionally, the IFR methodology uses wetted surface area rather than reach length as the common denominator for extrapolation. Given the spatial diversity and temporal variation of riverine habitat conditions within the middle Susitna River the hierarchial structure of this analysis is considered more applicable than routine adherence to extrapolation methodologies based on longitudinal succession and the representative reach concept.

Sufficient data is available to identify the seasonal and microhabitat requirements of resident fish, and of adult and juvenile salmon indigenous to the middle Susitna River (ADF&G, Su Hydro 1983d; Estes and Vincent-Lang 1984d; Schmidt et al. 1984). Physical process models have been developed to evaluate stream temperature, ice cover, sediment transport, and site specific hydraulic conditions for a broad range of streamflow and meteorologic conditions (Feratrovich et al. 1982; Univ. of Alaska, AEIDC 1983; Estes and Vincent-Lang 1984d; Harza-Ebasco 1984b; Harza-Ebasco 1984e; Hilliard et al. 1985). The surface area response of aquatic habitat types to mainstem discharge has been estimated (Klinger and Trihey 1984; Klinger-Kingsley 1985), and 172 modeled and non-modeled sites have been classified into ten representative groups (Aaserude et al. 1985). These data bases are sufficient to quantitatively model habitat response to alternative streamflow and stream temperature regimes at both the microhabitat and habitat levels. Finally, knowledge of the influences of mainstem discharge on groundwater upwelling and water quality is sufficient to be incorporated into this analysis in a structured, but subjective manner.

At present, the numerous components and linkages of a habitat response model for the middle Susitna River remain at various stages of development. However, enougn progress has been made to subjectively evaluate the data base and provide various forecasts of streamflow-dependent habitat relationships. To this end, Section III describes the fish resources and habitat types of the middle Susitna River and identifies the evaluation periods and the primary and secondary evaluation species; Section IV discusses the principal watershed characteristics and physical processes which influence the seasonal availability and quality of fish habitat; and Section V describes the influence of streamflow and instream hydraulics on the availability of habitat types and quality of microhabitat conditions. Section VI summarizes the major conclusions which can be obtained from a subjective application of the IFR model (Fig. II-2) using the information presented in sections IV and V. Section VI also describes the relative importance of several physical processes and habitat variables with regard to the primary evaluation species identified in Section III. Anticipated with-project changes to natural processes and relationships are discussed in general terms to introduce the reader to several differences between existing and with-project fluvial processes that will be important to consider in future analyses. A more detailed discussion of the relationships between physical processes and habitat response will be provided in Volume II of the IFRR.

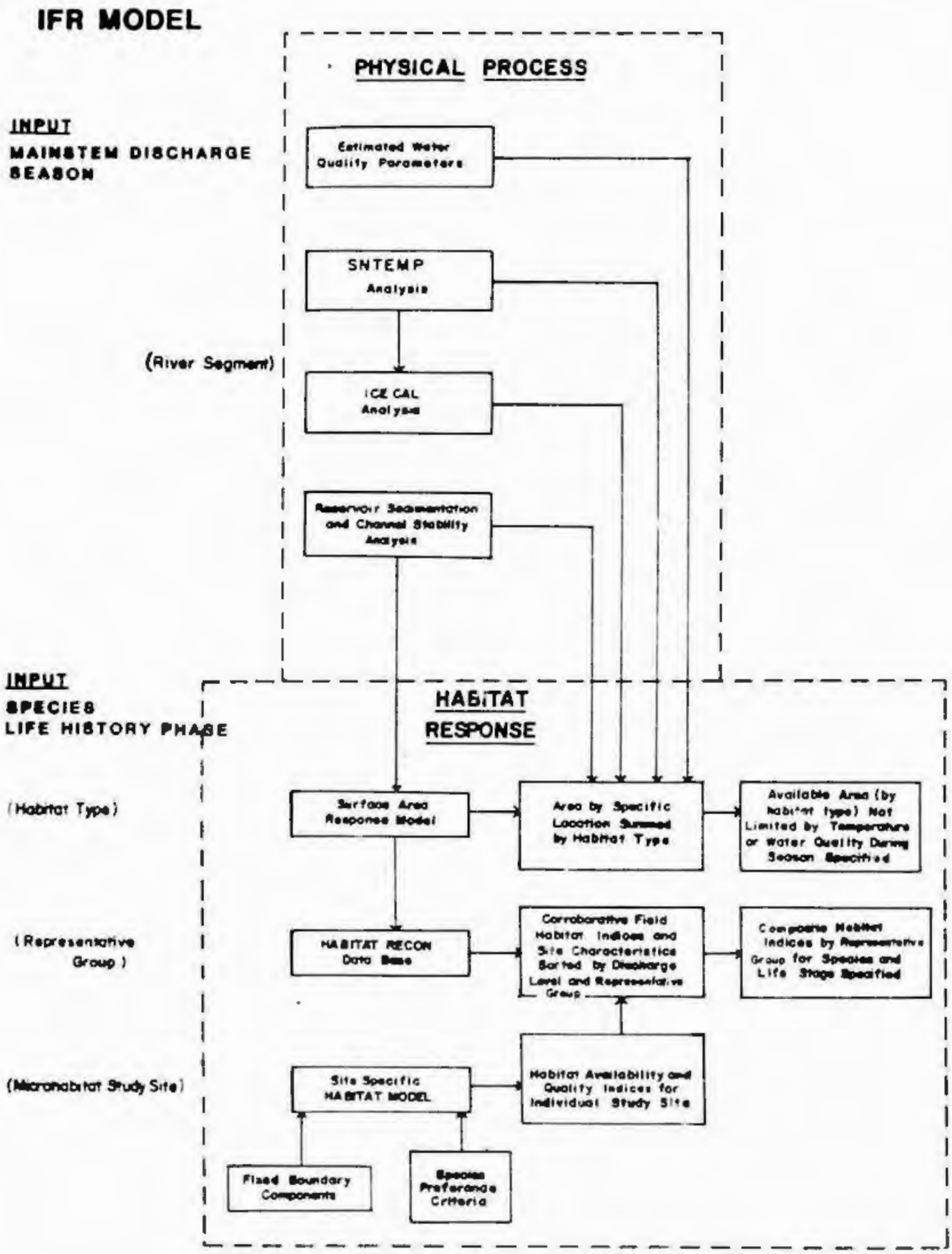


Figure II-2. Schematic diagram showing the integration of physical processes and the habitat response components of the Relationships Model.

III. FISH RESOURCES AND HABITAT TYPES

Overview of Susitna River Fish Resources

Fish resources in the Susitna River comprise a major portion of the Cook Inlet commercial salmon harvest and provide fishing opportunities for sport anglers. Anadromous species that form the base of commercial and sport fisheries include five species of Pacific salmon: chinook, coho, chum, sockeye, and pink. Resident species found in the Susitna River basin include Arctic grayling, rainbow trout, lake trout, burbot, Dolly Varden, and round whitefish. Fish species that inhabit the Susitna River are listed in Table III-1.

Adult Salmon Contribution to Commercial Fishery

With the exception of sockeye and chinook salmon, the majority of the commercial salmon catch in upper Cook Inlet originates in the Susitna River basin (Barrett et al. 1984). The long-term average annual catch of 3.1 million fish is worth approximately $17.9 million to the commercial fishing industry (K. Florey, ADF&G, pers. comm. 1984). In recent years commercial fishermen in upper Cook Inlet have landed record numbers of salmon with over 6.2 million salmon caught in 1982 and over 6.7 million fish in 1983 (Table III-2).

The most important species to the upper Cook Inlet commercial fishing industry is sockeye salmon. In 1984, the sockeye harvest of 2.1 million fish in was valued at $13.5 million (K. Florey, ADF&G pers. comm. 1984). The estimated contribution of Susitna River sockeye to the industry is 10 to 30 percent (Barrett et al. 1984), which, in 1984 was between 210,000 and 630,000 fish. This represented a value of between $1.4 million and $4.1 million.

Chum and coho salmon are the second and third most valuable commercial species. In 1984, the chum salmon harvest of 684,000 fish was valued

Table III-1. Common and scientific names of fish species recorded from the Susitna River Basin (from Alaska Dept. of Fish and Game, Susitna Hydro Aquatic Studies)

Scientific Name	Common Name
Petromyzontidae	
Lampetra japonica	Arctic lamprey
Salmonidae	
Coregonus laurettae	Bering cisco
Coregonus pidschian	humpback whitefish
Oncorhynchus gorbuscha	pink salmon
Oncornynchus keta	chum salmon
Oncorhynchus kisutch	coho salmon
Oncorhynchus nerka	sockeye salmon
Oncorhynchus tshawytscha	chinook salmon
Prosopium cylindraceum	round whitefish
Salmo gairdneri	rainbow trout
Salvelinus malma	Dolly Varden
Salvelinus namaycush	lake trout
Thymallus arcticus	Arctic grayling
Osmeridae	
Thaleichthys pacificus	eulachon
Esocidae	
Esox lucius	northern pike
Catostomidae	
Catostomus catostomus	longnose sucker
Gadidae	
Lota lota	burbot
Gasterosteidae	
Gasterosteus aculeatus	threespine stickleback
Pungitius pungitius	ninespine stickleback
Cottidae	
Cottus spp.	sculpin

Table III-2. Commercial catch of upper Cook Inlet salmon in numbers of fish by species, 1954 - 1984 (from Alaska Dept. of Fish and Game, Commercial Fisheries Div., Anchorage, AK).

Year	Chinook	Sockeye	Coho	Pink	Chum	Total
1954	63,780	1,207,046	321,525	2,189,307	510,068	4,291,726
1955	45,926	1,027,528	170,777	101,680	248,343	1,594,254
1956	64,977	1,258,789	198,189	1,595,375	782,051	3,899,381
1957	42,158	643,712	125,434	21,228	1,001,470	1,834,022
1958	22,727	477,392	239,765	1,648,548	471,697	2,860,129
1959	32,651	612,676	106,312	12,527	300,319	1,064,485
1960	27,512	923,314	311,461	1,411,605	659,997	3,333,889
1961	19,210	1,162,303	117,778	34,017	349,628	1,683,463
1962	20,210	1,147,573	350,324	2,711,689	970,582	5,200,378
1963	17,536	942,980	197,140	30,436	387,027	1,575,119
1964	4,531	970,055	452,654	3,231,961	1,079,084	5,738,285
1965	9,741	1,412,350	153,619	23,963	316,444	1,916,117
1966	9,541	1,851,990	289,690	2,006,580	531,825	4,689,626
1967	7,859	1,380,062	177,729	32,229	296,037	1,894,716
1968	4,536	1,104,904	470,450	2,278,197	1,119,114	4,977,201
1969	12,398	692,254	100,952	33,422	269,855	1,108,881
1970	8,348	731,214	275,296	813,895	775,167	2,603,920
1971	19,765	636,303	100,636	35,624	327,029	1,119,357
1972	16,086	879,824	80,933	628,580	630,148	2,235,571
1973	5,194	670,025	104,420	326,184	667,573	1,773,396
1974	6,596	497,185	200,125	483,730	396,840	1,584,476
1975	4,780	664,818	227,372	336,359	951,796	2,205,135
1976	10,867	1,664,150	208,710	1,256,744	469,807	3,610,278
1977	14,792	2,054,020	192,975	544,184	1,233,733	1,049,704
1978	17,303	2,622,487	219,234	1,687,092	571,925	5,118,041
1979	13,738	924,415	265,166	72,982	650,357	1,926,658
1980	12,497	1,584,392	283,623	1,871,058	387,078	4,138,648
1981	11,548	1,443,294	494,073	127,857	842,849	2,919,621
1982	20,636	3,237,376	777,132	788,972	1,428,621	6,252,737
1983	20,396	5,003,070	520,831	73,555	1,124,421	6,742,273
1984	8,800	2,103,000	443,000	623,000	684,000	3,861,800
Average	19,247	1,340,339	263,785	1,576,646 (even) 120,416 (odd)	659,190	3,058,170

at $2.0 million, while the coho salmon harvest of 443,000 fish was worth $1.8 million (K. Florey, ADF&G, pers. comm. 1984). The estimated contribution of Susitna River chum to the upper Cook Inlet fishing industry is estimated at 85 percent, while coho is approximately 50 percent (Barrett et al. 1984).

Pink salmon is the least desirable of the commercial species in upper Cook Inlet, with a salmon harvest of 623,000 fish worth an estimated $0.5 million (K. Florey, ADF&G, pers. comm. 1984). Susitna River pink salmon contributed about 85 percent to this amount (Barrett et al. 1984).

Since 1964, opening of the commercial salmon season in upper Cook Inlet has been delayed until late June, by which time most chinook salmon have entered their natal streams and harvest of them is incidental to the commercial catch. In 1984, the 8,800 chinook harvested in upper Cook Inlet had a commercial value of $0.3 million (K. Florey, ADF&G, pers. comm. 1984). The Susitna River contribution of chinook salmon is estimated at about 10 percent of the total catch (Barrett et al. 1984).

From 1981 to 1984 sockeye, chum, and coho salmon harvests, which account for over 95 percent of the commercial value in the fishery, have exceeded the long-term average catches for those species (refer Table III-2). Record catches for coho and chum were recorded in 1982 and for sockeye in 1983.

Sport Fishing

The Susitna River, along with many of its tributaries, provides a multi-species sport fishery. Between 1978 and 1983, the Susitna River and its tributaries have accounted for an annual average of 127,100 angler days of sport fishing (Mills 1979, 1980, 1981, 1982, 1983, 1984). This represents approximately 13 percent of the 1977-1983 annual average of 1.0 million total angler days for the Southcentral region. Most of the sport fishing in the Susitna Basin occurs in the lower Susitna River from Alexander Creek (RM 9.8) upstream to the Parks Highway (RM 84).

Sport fishing occurs mainly in tributaries and at tributary mouths, while the mainstem receives less fishing activity. In the Susitna River coho and chinook salmon are most preferred by anglers with many pink salmon taken during even-year runs. In fact, when compared to the estimated total coho escapement, the annual sport harvest of coho salmon in the Susitna River is significant. In 1983, almost one of every five coho salmon entering the Susitna River was caught by sport anglers (Table III-3). The annual harvest of chinook salmon in the Susitna River has increased from 2,850 fish in 1978 to 12,420 fish in 1983 (Table III-4). During this period, the contribution of the Susitna River chinook sport harvest to the Southcentral Alaska chinook sport harvest has increased from 11 to 22 percent. Of the resident species in the Susitna River, rainbow trout and Arctic grayling are caught by anglers in the largest numbers (Mills 1984).

Subsistence Fishing

The only subsistence fishery on Susitna River fish stocks that is officially recognized and monitored by the Alaska Department of Fish and Game is near the village of Tyonek, approximately 30 miles (50 km) southwest of the Susitna River mouth. The Tyonek subsistence fishery was reopened in 1980 after being closed for 16 years. From 1980 through 1983, the annual Tyonek subsistence harvest averaged 2,000 chinook, 250 sockeye, and 80 coho per year (Browning 1984).

Table III-3. Summary of commercial and sport harvest of the Susitna River basin adult salmon returns.

Species	Commercial Harvest: Upper Cook Inlet Harvest[1]	Estimated Percent Susitna[2]: Mean	Estimated Percent Susitna[2]: Range	Estimated Susitna Harvest	Estimated Susitna Escapement[3]	Estimated Total Run	Sport Harvest: Susitna Basin Sport Harvest[4]	Percent of Escapement
Sockeye								
81	1,443,000	20	(10-30)	288,600	287,000	575,600	1,283	0.4
82	3,237,000	20	(10-30)	647,400	279,000	926,400	2,205	0.8
83	5,003,000	10	(10-30)	500,300	185,000	685,300	5,537	3.0
84	2,103,000	20	(10-30)	420,600	605,800[5]	1,026,400	---	---
Pink								
81	128,000	85		108,800	127,000	235,800	8,660	6.8
82	789,000	85		670,650	1,318,000	1,988,650	16,822	1.3
83	74,000	85		62,900	150,000	212,900	4,656	3.1
84	623,000	85		529,550	3,629,900[5]	4,159,450	---	---
Chum								
81	843,000	85		716,550	297,000	1,013,550	4,207	1.4
82	1,429,000	85		1,214,650	481,000	1,695,650	6,843	1.4
83	1,124,000	85		955,400	290,000	1,245,400	5,233	1.8
84	684,000	85		581,400	812,700[5]	1,394,100	---	---
Coho								
81	494,000	50		247,000	68,000	315,000	9,391	13.8
82	777,000	50		388,500	148,000	536,500	16,664	11.3
83	521,000	50		260,500	45,000	305,500	8,425	18.7
84	443,000	50		221,500	190,100[5]	411,600	---	---
Chinook								
81	11,500	10		1,150	---	---	7,576	---
82	20,600	10		2,060	---	---	10,521	---
83	20,400	10		2,040	---	---	12,420	---
84	8,800	10		880	250,000[6]	251,000	---	---

1 ADF&G Commercial Fisheries Division
2 B. Barrett, ADF&G Su Hydro, February 15, 1984 Workshop Presentation
3 Yentna Station (RM 18, TRM 04) + Sunshine Station (RM 80) estimated escapement; + 5% for sockeye + 48% for pink, + 5% for chum, + 85% for coho (B. Barrett, ADF&G Su Hydro, February 15, 1984 Workshop Presentation).
4 Mills 1982, 1983, 1984
5 Talkeetna Station (RM 22) escapements (Barrett et al. 1985)
6 Barrett et al. 1985

Table III-4. Sport fish harvest for Southcentral Alaska and Susitna Basin in numbers of fish by species, 1978-1983 (from Mills 1979, 1980, 1981, 1982, 1983, 1984).

	Arctic Grayling		Rainbow Trout		Pink Salmon		Coho Salmon		Chinook Salmon		Chum Salmon		Sockeye Salmon	
Year	South-central	Susitna Basin	South-central	Susitna Basin	South-central	Susitna Basin	South-central	Susitna Basin	South-central	Susitna Basin	South-central	Susitna Basin	South-central	Susitna Basin
1978	47,866	13,532	107,243	14,925	143,483	55,418	81,990	15,072	26,415	2,843	23,755	15,667	118,299	845
1979	70,316	13,342	129,815	18,354	63,366	12,516	93,234	12,893	34,009	6,910	8,126	4,072	77,655	1,586
1980	69,462	22,083	126,686	15,488	153,794	56,621	127,958	16,499	24,155	7,389	8,660	4,759	105,914	1,304
1981	63,695	21,216	149,460	13,757	64,163	8,660	95,376	9,391	35,822	7,576	7,810	4,207	76,533	1,283
1982	60,972	18,860	142,579	16,979	105,961	16,822	136,153	16,664	46,266	10,521	13,497	6,843	128,015	2,205
1983	56,896	20,235	141,663	16,500	47,264	4,656	87,935	8,425	57,094	12,420	11,043	5,233	170,799	5,537
Average	61,535	18,211	132,908	16,000	134,413 (even) 58,264 (odd)	42,954 (even) 8,611 (odd)	103,774	13,157	37,294	7,943	12,149	6,797	112,869	2,128

Relative Abundance of Adult Salmon

Major salmon-producing tributaries to the Susitna River include the Yentna River drainage (RM 28), the Chulitna River drainage (RM 98.6), and the Talkeetna River drainage (RM 97.1). Numerous other smaller tributaries also contribute to the salmon production of the Susitna River. The average salmon escapements at four locations in the Susitna River for 1981 through 1984 are presented in Table III-5.

The minimum Susitna River escapements of four salmon species can be estimated for 1981 through 1984 by adding the escapements at Yentna Station (RM 28, TRM 04) and Sunshine Station (RM 80) (Barrett et al. 1984). These total escapements are considered minimums because they do not include escapements below RM 80, except at the Yentna River (Barrett et al. 1984). The four-year averages of minimum Susitna River escapements for sockeye, chum and coho salmon are presented in Table III-5. The minimum Susitna River escapement for pink salmon is reported in Table III-5 as a two-year average escapement for odd-year runs (1981, 1983) and a two-year average escapement for even-year runs (1982, 1984). This separation was made because pink salmon runs are numerically dominant in even years (Barrett et al. 1984).

Escapements of chinook salmon at Yentna Station have not been quantified because most of the run passes the station before monitoring begins (ADF&G, Su Hydro 1981, 1982b; Barrett et al. 1984, 1985). Therefore, a minimum Susitna River escapement for chinook salmon cannot be estimated by the same method used for the other salmon species. Chinook escapements have been estimated at Sunshine Station in 1982, 1983, and 1984 (Barrett et al. 1984, 1985). The three-year average of chinook escapements at Sunshine Station is presented in Table III-5.

Most salmon spawn in the Susitna River and its tributaries below Talkeetna Station (RM 103) (ADF&G, Su Hydro 1981, 1982b; Barrett et al. 1984, 1985). Important chinook spawning areas are Alexander Creek (RM 9.8), Lake Creek in the Yentna River drainage (RM 28), the Deshka

Table III-5. Average salmon escapements in the Susitna River by species and location (from Barrett et al. 1984, 1985).

Location River Mile	Sockeye[1]	Chum[2]	Coho[2]	Pink[3]		Chinook[4]	Location Total	
Yentna Station	126,750	21,200	19,600	Odd	48,400	---	Odd	215,950
RM 28, TRM 04				Even	408,300		Even	575,850
Sunshine Station	121,650	431,000	43,900	Odd	45,000	88,200	Odd	729,750
RM 80				Even	730,100		Even	1,414,840
Talkeetna Station	6,300	54,600	5,700	Odd	5,900	16,700	Odd	89,200
RM 103				Even	125,500		Even	208,800
Curry Station	2,400	28,200	1,600	Odd	3,300	13,000	Odd	48,500
RM 120				Even	87,900		Even	133,100
Minimum Susitna[5]	248,400	452,200	63,500	Odd	93,400	---	Odd	857,500
River				Even	1,138,400		Even	1,902,500

[1] Second-run sockeye escapements. Four-year average of 1981, 1982, 1983, and 1984 escapements.

[2] Four-year average of 1981, 1982, 1983, and 1984 escapements.

[3] Odd is average of 1981 and 1983 escapements. Even is average of 1982 and 1984 escapements.

[4] Three-year average of 1982, 1983, and 1984 escapements. Dashes indicate no estimate.

[5] Summation of Yentna Station and Sunshine Station average escapements. Does not include escapement to the Susitna River and tributaries below RM 80, except the Yentna River (RM 28).

River (RM 40.5), and Prairie Creek in the Talkeetna River drainage (RM 97.1) (Barrett et al. 1984, 1985). Most sockeye salmon spawn in the Yentna, Chulitna (RM 98.6) and Talkeetna drainages (Barrett et al. 1984, 1985). The Yentna River is also an important pink salmon spawning area (Barrett et al. 1984). The primary area of chum salmon spawning is the Talkeetna River (Barrett et al. 1984, 1985). Coho salmon spawn mainly in tributaries below RM 80 (Barrett et al. 1985).

In the middle reach of the Susitna River, chum and chinook are the most abundant salmon, excluding even-year pink salmon (Barrett et al. 1984, 1985). In this river reach, salmon escapements have been monitored at Talkeetna (RM 103) and Curry (RM 120) Stations since 1981 (ADF&G, Su Hydro 1981, 1982b; Barrett et al. 1984, 1985).

The contribution of the middle Susitna River salmon escapements to the Susitna River salmon runs can be estimated for 1981 through 1984 by dividing the Talkeetna Station escapements into the minimum Susitna River escapements. Based on the average escapements presented in Table III-5, the average percent contribution in 1981 through 1984 for the middle Susitna River is: 2.5 percent for sockeye, 12.1 percent for chum, 9.0 percent for coho, 6.3 percent for odd-year pink, and 11.0 percent for even-year pink salmon. These estimates should be considered maximum values because (1) the minimum Susitna River escapements, as previously discussed, do not include escapements below RM 80 (except the Yentna River); and (2) the Talkeetna Station escapements overestimate the number of spawning salmon in the middle reach. This overestimation is apparently due to milling fish that return downstream of Talkeetna Station to spawn.

The number of fish that reach Talkeetna Station and later move downstream to spawn is significant. In 1984, 83 percent of the sockeye, 75 percent of the chum, 75 percent of the coho, 85 percent of the pink, and 45 percent of the chinook salmon escapements at Talkeetna Station were milling fish that returned downstream of Talkeetna Station to spawn (Barrett et al. 1985). If the escapement to Talkeetna Station is reduced to account for the milling factor, the contribution of middle Susitna River escapement to the minimum basin escapement in 1984 becomes: 0.8 percent for sockeye, 3.1 percent for chum, 2.6 percent for coho, and 1.9 percent for pink salmon. Chinook salmon were not included in this analysis because of the lack of minimum Susitna River escapements, as previously discussed.

Distribution and Timing of Juvenile Salmon and Resident Species

Juvenile Salmon

Most chum salmon rear in the middle Susitna River from May through mid-August, while juvenile pink salmon spend little time in this reach (Dugan et al. 1984). The outmigration of juvenile chum at Talkeetna Station (RM 103) extends from May through mid-August, whereas most juvenile pink salmon leave this reach of river by June (Roth et al. 1984). Outmigration timing of pink and chum juveniles is positively correlated with mainstem discharges (Roth et al. 1984).

Juvenile chinook and sockeye salmon rear from one to two years in the Susitna River, while coho salmon rear from one to three years before outmigrating (Roth et al. 1984). Although some age 0+ juveniles of chinook, coho, and sockeye salmon move out of the middle Susitna River throughout the summer, peak downstream movements at Talkeetna Station occur in June, July, and August (Roth et al. 1984). Chinook, coho, and sockeye juveniles that remain in the middle Susitna River utilize summer rearing habitats until September and October, when they move to overwintering habitats. Chinook juveniles rear primarily in tributaries and side channels. In 1983, side channel use was highest in July and August (Dugan et al. 1984). Most coho juveniles use tributaries and upland sloughs for summer rearing (Dugan et al. 1984). Sockeye salmon rear principally in natal side and upland sloughs (Dugan et al. 1984). Age 1+ chinook, coho, and sockeye, and age 2+ coho outmigrate primarily in June at Talkeetna Station (Dugan et al. 1984).

Resident Species

Rainbow trout and Arctic grayling spawn and rear principally in tributary and tributary mouth habitat of the middle Susitna River. A limited amount of rearing occurs in mainstem-influenced habitats, and both species use the mainstem for overwintering. Burbot are found almost exclusively in mainstem, side channels, and backwater areas of side sloughs (Sundet and Wenger 1984). Estimates of relative abundance in 1984 indicated that round whitefish are the most abundant resident fish species in the middle river, having highest densities in side sloughs and tributaries (Sundet and Pechek 1985). They may, however, overwinter in the mainstem. Humpback whitefish are relatively scarce in the middle river (Sundet and Pechek 1985). Longnose sucker, Dolly Varden, lake trout, and threespine stickleback are other species found in this segment of the river.

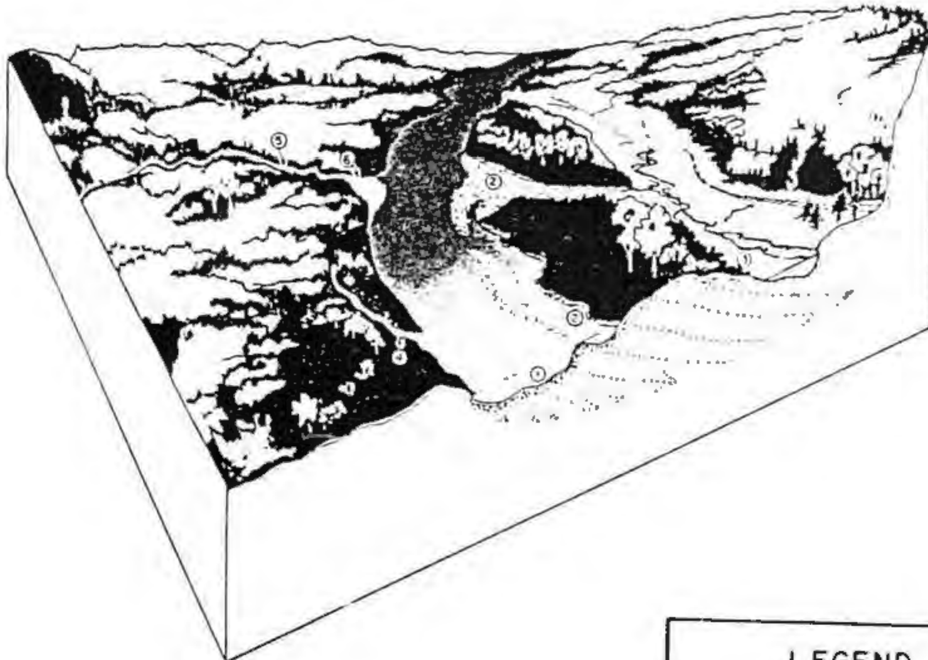
Identification and Utilization of Habitat Types

The variety of primary, secondary and overflow channels that exist within the Talkeetna-to-Devil Canyon segment of the Susitna River provides a great diversity in aquatic habitat conditions. Six major aquatic habitat types, based on similar morphologic, hydrologic, and hydraulic characteristics, have been identified within this river segment: mainstem, side channel, side slough, upland slough, tributary, and, tributary mouth (Fig. III-1). Within these aquatic habitat types, fish habitat of varying quantities and quality may exist depending upon site-specific thermal, water quality, channel structure, and hydraulic conditions. Differentiation of aquatic habitat types is useful for evaluating seasonal movement and utilization patterns if fusg and for identifying microhabitat preferences of the fish species/life stages which inhabit the middle Susitna River.

Mainstem Habitat

Mainstem habitat is defined as those portions of the Susitna River which normally convey the largest amount of streamflow throughout the year. Included in this aquatic habitat category are both single and multiple channel reaches, as well as poorly defined water courses flowing through partially vegetated gravel bars or islands.

Mainstem habitats are thought to be used predominantly as migrational corridors by adult and juvenile salmon during summer. However, isolated observations of chum salmon spawning at upwelling sites along shoreline margins have been reported (ADF&G, Su Hydro 1982b). Mainstem habitats are also used by several resident species, most notably Arctic grayling, burbot, longnose sucker, rainbow trout, and whitefish (Sundet and Wenger 1984).



Note: A more detailed description of these habitat types can be found in this section of this report.

Figure III-1. General habitat types of the Susitna River (ADF&G, Su Hydro 1983a)

Turbid, high-velocity, sediment-laden summer streamflows and low, cold, ice-covered, clearwater winter flows are characteristic of mainstem habitat type. Channels are relatively stable, high gradient and normally well-armored with cobbles and boulders. Interstitial spaces between these large streambed particles are generally filled with a grout-like mixture of small gravels and glacial sands with isolated deposits of small cobbles and gravels. However, the latter are usually unstable.

Groundwater upwellings and clearwater tributary inflow appear to be inconsequential determinants of the overall characteristics of mainstem habitat except during winter when they dominate water quality conditions of the mainstem.

Side Channel Habitats

Side channel habitats are sections of the river which normally convey streamflow during the open water season, but become appreciably dewatered during periods of low flow. For convenience of classification and analysis, side channels are defined as conveying less than 10 percent of the total flow passing a given location in the river. Side channel habitat may exist in well-defined channels, or in poorly-defined water courses flowing through partially submerged gravel islands located in mid-channel or along shoreline margins of mainstem habitat.

Rearing juvenile chinook appear to use side channel habitats most extensively, particularly during July and August (Dugan et al. 1984). A limited amount of chum salmon spawning also occurs in side channel habitats where upwelling and suitable velocities and substrate are present (Estes and Vincent-Lang 1984d). Resident species, such as grayling, rainbow trout, burbot, and whitefish, also use these habitats.

In general, the turbidity, suspended sediment, and thermal characteristics of side channel habitats reflect mainstem conditions, except in quiescent areas, where suspended sediment concentrations are less. Side channel habitats are characterized by shallower depths, lower velocities, and smaller streambed materials than mainstem habitats. However, side channel velocities and substrate composition often provide suboptimal habitat conditions for both adult and juvenile fish.

The presence or absence of clearwater inflow, such as groundwater upwellings or tributaries, is not considered a critical component in the designation of side channel habitat. However, a strong positive correlation exists between the location of such clearwater inflows and the location of chum salmon spawning sites in these habitats (Estes and Vincent-Lang 1984d). In addition, tributary and groundwater inflow prevents some side channel habitat from becoming completely dewatered when mainstem flows recede in September and October. These clearwater areas are suspected of being important for primary production prior to the formation of a winter ice cover.

Side Slough Habitats

With the exception of the clearwater tributaries, side slough habitats are probably the most productive of all the middle Susitna River aquatic habitat types. Side slough habitats typically exist in overflow channels or old side channels which only convey mainstem flow during periods of high streamflow or breakup. Clearwater inflows from local runoff and/or upwelling maintains streamflow through side slough habitats when they are not overtopped by high mainstem discharge.

A non-vegetated alluvial berm connects the head of the slough to the mainstem or a side channel with a well-vegetated gravel bar or island paralleling the slough and separating it from the mainstem (or side channel). During intermediate and low-flow periods, mainstem water surface elevations are insufficient to overtop the alluvial berm at the upstream end (head) of the slough. However, the mainstem stage at these flows is often sufficient at the downstream end (mouth) of the slough to cause a backwater effect to extend a few hundred feet upstream into the slough (Trihey 1982).

In the middle Susitna River approximately 80 percent of all non-tributary spawning by chum salmon and essentially all sockeye salmon spawning occurs in unbreached side slough habitat (ADF&G, Su Hydro 1981, 1982b; Barrett et al. 1984). In early spring, large numbers of juvenile chum and sockeye salmon can be found in unbreached side sloughs. During summer, moderate numbers of juvenile coho and chinook make use of side-slough habitats, with chinook densities increasing during the fall-winter transition (Dugan et al. 1984). Small numbers of resident species, such as rainbow trout, Arctic grayling, burbot, round whitefish, cottids, and longnose suckers, are also found in side slough habitats.

Considerable variation in water chemistry has been documented among side sloughs. This is principally a function of local runoff patterns, basin characteristics, and groundwater upwelling when the side sloughs are not overtopped. Once overtopped, side sloughs display the water quality characteristics of the mainstem (ADF&G, Su Hydro 1982a).

During periods of high mainstem discharge, the water surface elevation of the mainstem is often sufficient to overtop the alluvial berms at the heads of some sloughs. When this occurs, discharge through the side slough increases markedly. Generally from less than 5 cfs to 100 cfs or greater. Such overtopping events affect the thermal, water quality, and hydraulic conditions of side slough habitat (ADF&G, Su Hydro 1982a). Depending upon its severity and frequency, overtopping may flush organic material and fine sediments from the side slough or totally rework the channel geometry and substrate composition.

Streambed materials in side slough habitats tend to be a heterogeneous mixture of coarse sands, gravels and cobbles, often overlain by fine glacial sands in quiescent areas. Perhaps because of the upwelling or the less frequent conveyance of mainstem water, streambed materials in side slough habitats do not appear to be as cemented or grouted as similar sized particles would be in side channel habitats.

When not overtopped, surface water temperatures in side sloughs respond independently of mainstem temperatures (ADF&G, Su Hydro 1982a). Surface water temperatures in unbreached side sloughs are influenced by the temperature of groundwater upwelling, the temperature of surface runoff, and climatologic conditions. In many instances the thermal effect of the upwelling water is sufficient to maintain relatively ice-free conditions in these areas throughout winter (Trihey 1982; ADF&G, Su Hydro 1983c).

Upland Slough Habitats

Upland slough habitats are clearwater systems which exist in relic side channels or overflow channels. They differ in character from side slough habitats in that the elevation of the upstream berm is sufficient to prevent overtopping in all but the most extreme flood or ice jam events. Consequently, upland sloughs typically possess steep, well-vegetated streambanks, near-zero flow velocities, and sand or silt covering larger substrates. In addition, active or abandoned beaver dams and food caches are commonly observed in these habitats.

The primary influence of mainstem or side channel flow on an adjacent upland slough is the regulation of water depth in the slough by backwater effects. The water surface elevation of the adjacent mainstem or side channel often controls the water surface elevation at the mouth of the upland slough. Depending upon the rate at which the mainstem water surface elevation responds to storm events relative to the response of local runoff into the upland slough, turbid mainstem water may enter the slough. The rapid increase in mainstem water surface elevations and suspended sediment concentrations associated with peak flow events is suspected of being a primary transport mechanism of fine sediments into the backwater areas of upland sloughs while local surface water inflow and bank erosion may be major contributors of sediments in reaches upstream of backwater areas and beaver dams.

Although upwelling is often present in upland sloughs, little spawning occurs in these habitats (Barrett et al. 1984). The most extensive use is by rearing juvenile sockeye and coho salmon (Dugan et al. 1984). Resident species common in upland sloughs include round whitefish and rainbow trout.

Tributary Habitats

Tributary habitats reflect the integration of their watershed characteristics and are independent of mainstem flow, temperature, and sediment regimes. Middle Susitna River tributary streams convey clear water which originates from snowmelt, rainfall runoff, or groundwater base flow throughout the year.

Tributaries provide the only reported spawning areas for chinook salmon and nearly all of the coho and pink salmon spawning areas in the middle Susitna River (Barrett et al. 1984). Also, approximately one-third of the chum salmon escapement to the middle Susitna River spawn in tributary habitats. Pink salmon juveniles outmigrate shortly after emergence and most juvenile chum leave within one to three months. However, a large percentage of emergent chinook and coho remain in tributary streams for several months following emergence (Dugan et al. 1984). Resident species, particularly Arctic grayling and rainbow trout, depend principally on tributary streams for spawning and rearing.

Tributary Mouth Habitat

Tributary mouth habitat refers to that portion of the tributary which adjoins the Susitna River. The areal extent of this habitat responds to changes in mainstem discharge. By definition, this habitat extends from the uppermost point in the tributary influenced by mainstem backwater effects to the downstream extent of its clearwater plume.

Though velocities could be limiting, tributary mouth habitat associated with the larger tributaries within the middle Susitna River also provides significant spawning habitat for pink and chum salmon (Barrett et al. 1984). This habitat type is an important feeding station for juvenile chinook (ADF&G, Su Hydro 1983e), rainbow trout, and Arctic grayling (Sundet and Wenger 1984), especially during periods of salmon spawning activity.

Selection of Evaluation Species

Selection of evaluation species for use in the IFRS is consistent with the guidelines and policies of the Alaska Power Authority, Alaska Department of Fish and Game, and U.S. Fish and Wildlife Service (USFWS 1981; ADF&G 1982; APA 1982). These guidelines imply that species with commercial, subsistence, and recreational uses are given high priority. The species of greatest concern are those utilizing habitats that will be most altered by the project. The following discussion provides a synopsis of the baseline data used in the selection of primary and secondary evaluation species.

Side slough and side channel habitats are expected to be affected most significantly by project operation. Consequently, the species and life stages considered for evaluation were those which use these two habitats most extensively. Chum salmon spawners and incubating embryos, and juvenile chinook salmon were selected, for the reasons discussed below, as primary evaluation species and life stages. Secondary evaluation species and life stages that may be considered in subsequent analyses of flow effects on aquatic habitats include: chum salmon juveniles and returning adults, chinook salmon returning adults, all freshwater life phases of sockeye and pink salmon, rearing and overwintering rainbow trout, coho salmon juveniles and returning adults, rearing and overwintering Arctic grayling, and all life phases of burbot.

Salmon spawning surveys conducted during 1981-83 by the Alaska Department of Fish and Game (Barrett et al. 1984) indicate that tributaries and side sloughs are the primary spawning areas for the five species of Pacific salmon that occur in the middle reach of the Susitna River (Figure III-2). Comparatively small numbers of salmon spawn in mainstem, side channel, upland slough, and tributary mouth habitats. Chum and sockeye are the most abundant salmon species that spawn in non-tributary habitats in the Talkeetna-to-Devil Canyon reach of the Susitna River (Barrett et al. 1984). The estimated number of

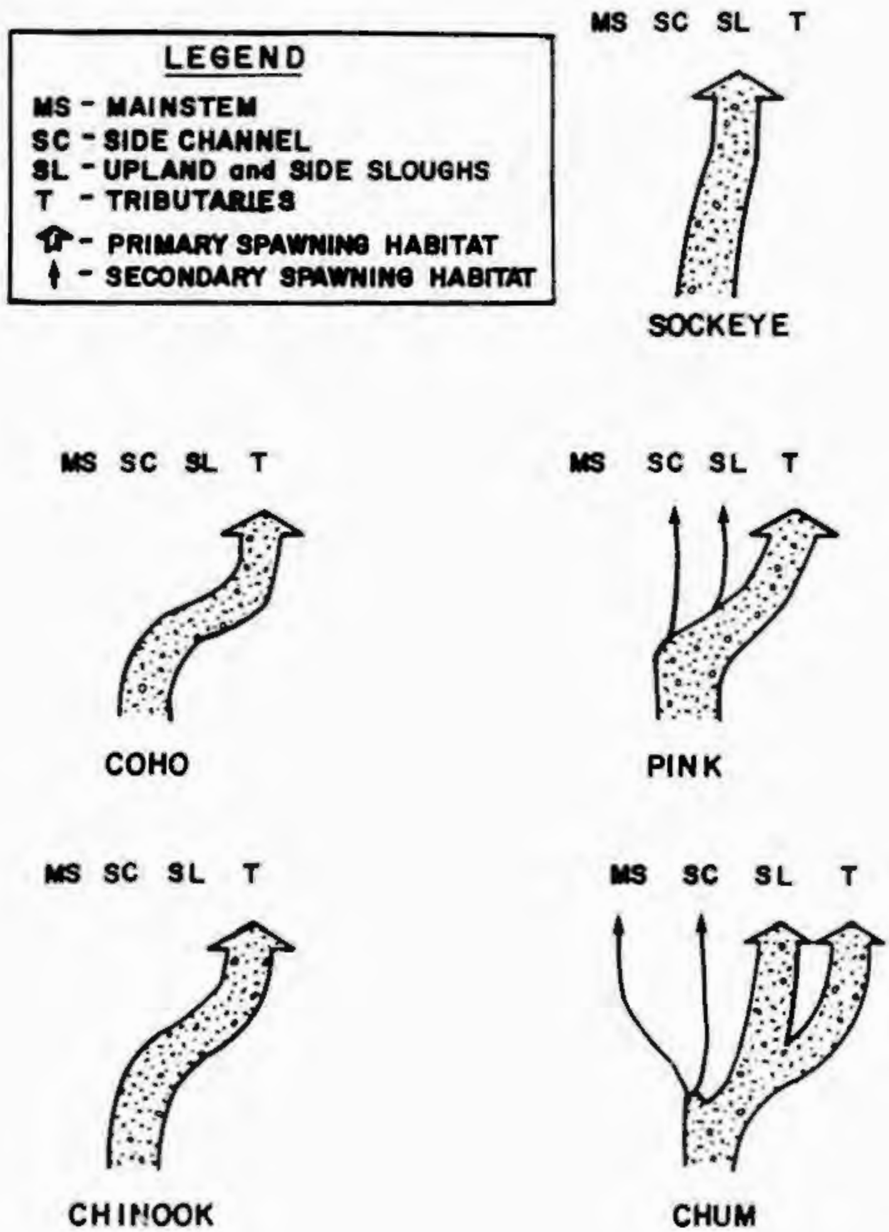


Figure III-2. Relative distribution of salmon spawning within different habitat types of the middle Susitna River (Estes and Vincent-Lang 1984c).

chum salmon spawning in non-tributary habitats within the middle Susitna River averaged 4,200 fish per year for the 1981-83 period of record (Barrett et al. 1984). This represents about two-thirds of the peak survey counts in all habitats during 1981-1983 (Barrett et al. 1984). Approximately 1,600 sockeye per year (99 percent of peak survey counts) spawned in slough habitat during the same period. Limited numbers of pink salmon utilize side channels and side sloughs for spawning during even-numbered years (Barrett et al. 1984). Similarly, only a few coho salmon spawn in non-tributary habitats of the Susitna River (Barrett et al. 1984).

Approximately 10,000 chum salmon have returned annually to the middle Susitna River to spawn during the 1981-1983 period of record, of which nearly half spawned in tributaries. Approximately 80 percent of those non-tributary spawners spawned in side slough habitats. Sloughs 21, 11, 9, 9A and 8A generally account for the majority of slough spawning (ADF&G, Su Hydro 1981, 1982b; Barrett et al. 1984). Extensive surveys of side channel and mainstem areas have documented comparatively low numbers of spawners and spawning areas in side channel and mainstem habitats (ADF&G, Su Hydro 1981, 1982b; Barrett et al. 1984).

Within the Talkeetna-to-Devil Canyon reach, spawning sockeye salmon are distributed among eleven sloughs. Sloughs 11, 8A, and 21 accounted for more than 95 percent of the sockeye spawning in the middle Susitna River during 1981-1983 (Barrett et al. 1984). In 1983, 11 sockeye salmon were observed spawning alongside 56 chum salmon in the mainstem approximately 0.5 miles upstream of the mouth of the Indian River (Barrett et al. 1984). This is the only recorded occurrence of sockeye salmon spawning in middle Susitna River areas other than slough habitats.

Chum salmon spawn at all of the locations where sockeye spawning has been observed (Barrett et al. 1984). This overlap is likely a result of similar timing and habitat requirements (Barrett et al. 1984; Estes and Vincent-Lang 1984d). Chum salmon are more numerous in slough habitats and appear to be more constrained by passage restrictions and low-water depth during spawning than sockeye salmon (Estes and Vincent-Lang 1984c). Hence, the primary evaluation of habitat relationships for analysis of project effects on existing salmon spawning in the middle Susitna River will focus on chum salmon.

Depending upon the season of the year, juvenile salmon utilize all aquatic habitat types found within the middle Susitna River in varying degrees. Among the non-tributary habitats, juvenile salmon densities are highest in sloughs and side channel areas (Fig. III-3). Extensive sampling for juveniles has not been conducted in mainstem habitats, largely due to the inefficiency of sampling gear in typically deep, fast, turbid waters. However, utilization of mainstem habitat is expected to be low except for low velocity shoreline margins.

Coho salmon juveniles are most abundant in tributary and upland slough habitats which generally do not respond significantly to variations in mainstem discharge (Klinger and Trihey 1984). Although relatively few in number, sockeye juveniles make extensive use of upland slough and side slough habitats within the middle Susitna River.

Juvenile chum and chinook salmon are quite abundant in the middle Susitna River; the most extensively used of the non-tributary habitats are side sloughs and side channels (Dugan et al. 1984). These habitats respond markedly to variations in mainstem discharge (Klinger and Trihey 1984). For this reason, chinook and chum have been selected to evaluate project effects on juvenile salmon rearing conditions within the middle Susitna River. Because juvenile chinook have a longer freshwater residence period, they are a primary evaluation species/life stage while juvenile chum are a secondary evaluation species/life stage.

With the exception of burbot, important resident species in the middle Susitna River are mainly associated with tributary habitats. Rainbow trout and Arctic grayling, important to the basin's sport fishery,

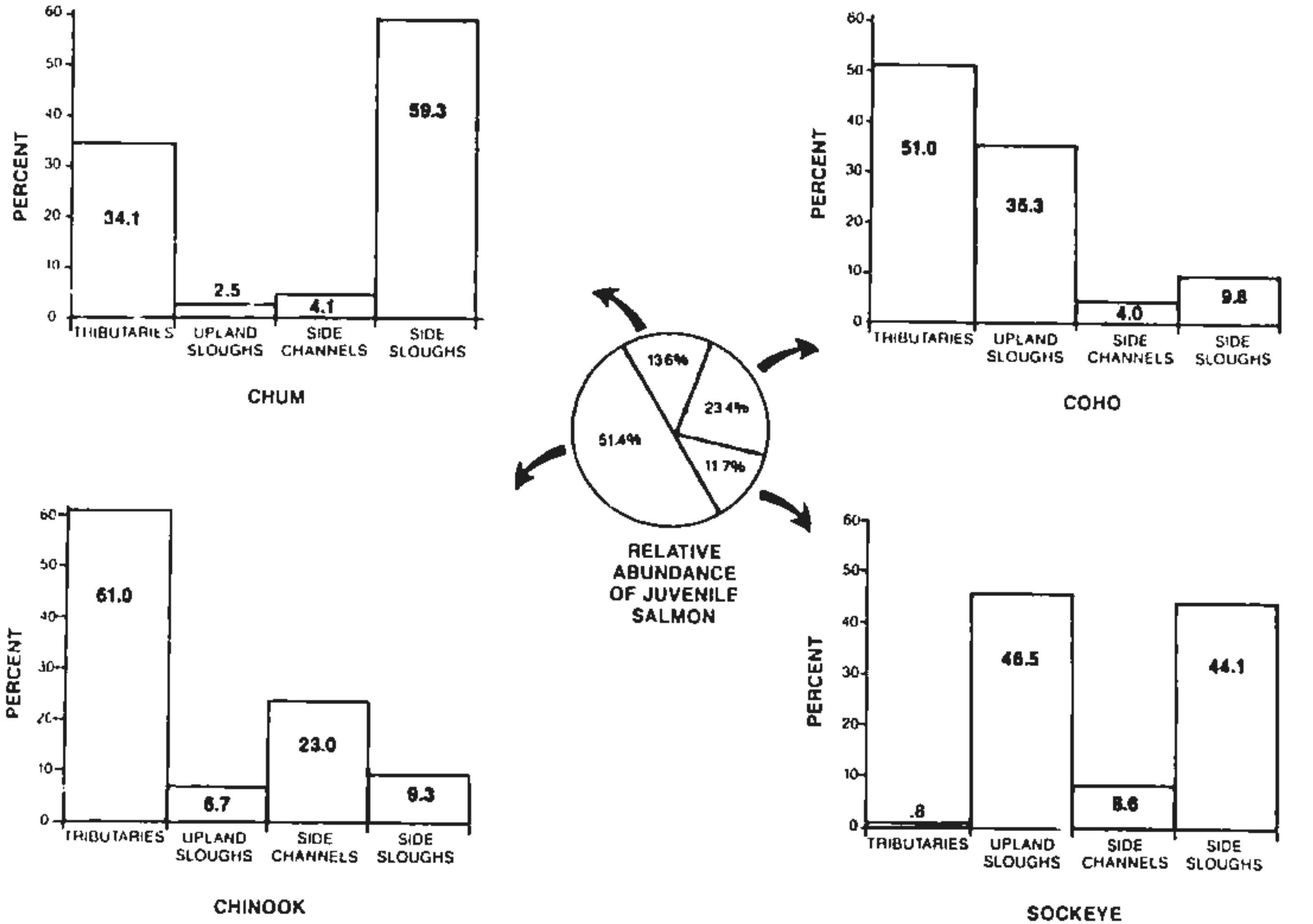


Figure III-3. Relative abundance and distribution of juvenile salmon within different habitat types of the middle Susitna River (adapted from Dugan et al. 1984).

spawn and rear in tributary and tributary mouth habitats. A limited number of rainbow trout and Arctic grayling rear in mainstem-influenced habitats (Sundet and Wenger 1984), and both species use mainstem habitats for overwintering. Due to their use of mainstem-influenced areas, overwintering and rearing Arctic grayling and rainbow trout are selected as secondary evaluation species.

Because burbot apparently prefer turbid habitats, they are found almost exclusively in mainstem, side channels, and slough mouths (Sundet and Wenger 1984). As the IFR analysis continues, burbot and other secondary evaluation species whose populations may be influenced by the project will be considered for more detailed evaluation. Chum, chinook, and pink salmon spawning and incubation in side channel and mainstem habitats are some species and life stages that may be evaluated.

IV. WATERSHED CHARACTERISTICS AND PHYSICAL PROCESSES INFLUENCING MIDDLE SUSITNA RIVER HABITATS

This chapter discusses numerous interrelationships among physical processes associated with streamflow, sediment transport, water quality and stream temperature in the middle Susitna River and also describes their influence on the availability and quality of aquatic habitat. These physical processes and relationships are discussed in association with such important watershed characteristics as climatology, topography and geology. Because of the relatively undistrubed nature of the Susitna Basin and the limited probability of significant disturbance occurring in the near future, land use is considered a constant and is not discussed in this section.

Watershed Characteristics

Basin Overview

Tributaries in the upper portions of the Susitna River basin originate from glacial sources in the Alaska Range which is dominated by Mount Deborah (12,339 feet) and Mount Hayes (13,823 feet). Other peaks in the Alaska Range average between 7,000 and 9,000 feet in altitude. Tributaries in the eastern portion of the Susitna Basin originate in the Copper River lowlands and in the Talkeetna Mountains, having elevations averaging between 6,000 and 7,000 feet. Between the Alaska Range and the Talkeetna Mountains are the Susitna lowlands; a broad basin increasing in elevation from sea level to 500 feet, with local relief of 50 to 250 feet (Fig. IV-1).

In the mountainous areas above 3,000 feet elevation, discontinuous permafrost is often present. Below 3,000 feet elevation, isolated occurrences of permafrost can be found in association with fine-grained soils. The Susitna basin geology consists of extensive unconsolidated glacial deposits. Glacial moraines and outwash are

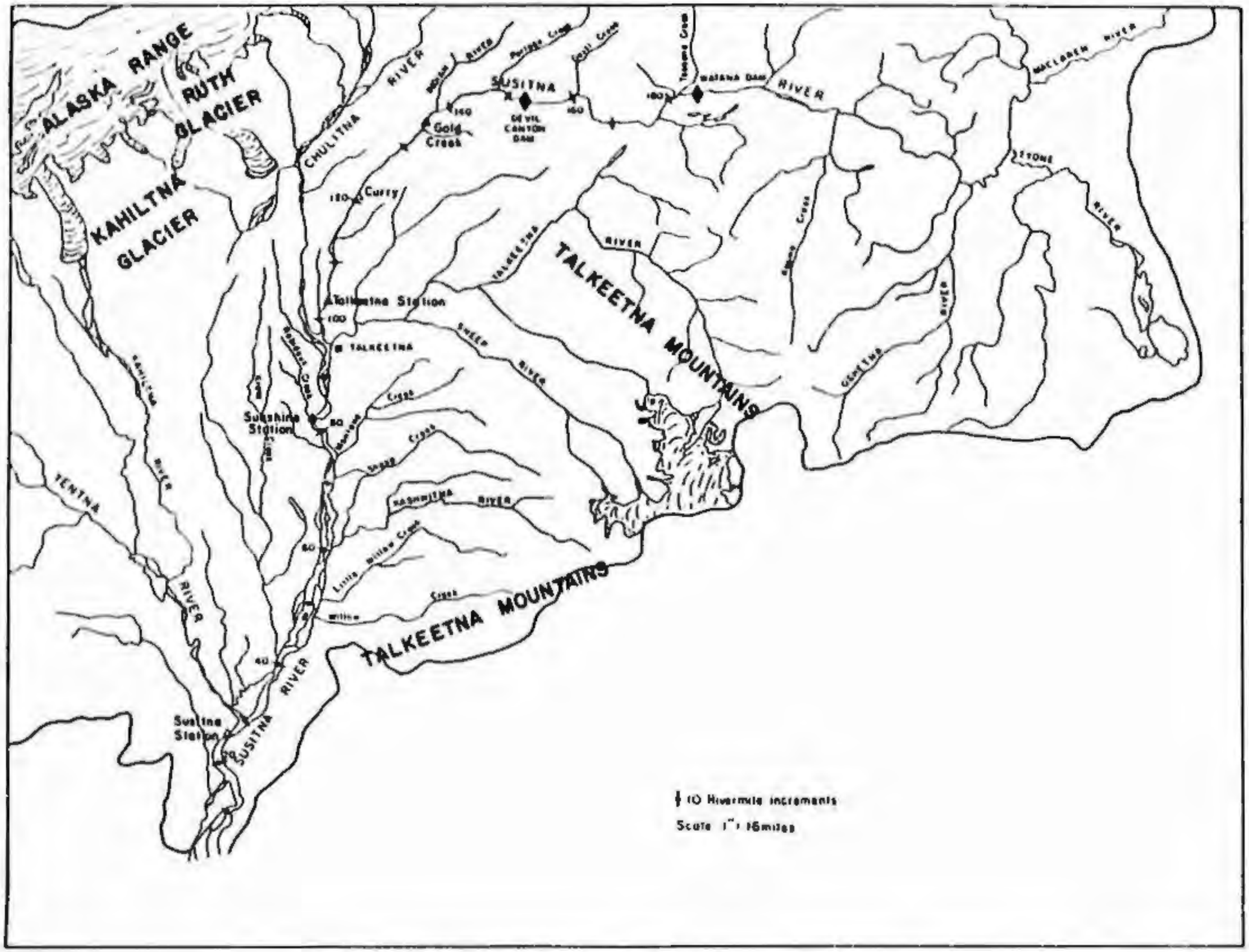


Figure IV-1. Stream network within the Susitna River Basin.

found in many U-shaped valleys in the upland areas. Gravelly till and outwash in the lowlands and on upland slopes are overlain by shallow to moderately deep silty soils. The steep upper slopes have shallow gravel and loam deposits with many bedrock exposures. On the south flank of the Alaska Range and southern slopes of the Talkeetna Mountains, soils are well-drained, dark, and gravelly to loamy. Poorly drained, stony loams with permafrost are present on northern facing slopes. Water erosion ranges from moderate to severe. Vegetation above the tree line in the steep, rocky soils is predominantly alpine tundra, whereas, well-drained upland soils support white spruce and grasses. Poorly drained valley bottom soils support muskeg while well-drained soils support mixed stands of birch and spruce.

The upper Susitna basin is in the continental climatic zone, while the lower portion of the basin is in the transitional climatic zone. Temperatures are more moderate and precipitation is less in the lower basin than in the upper basin (Fig. IV-2).

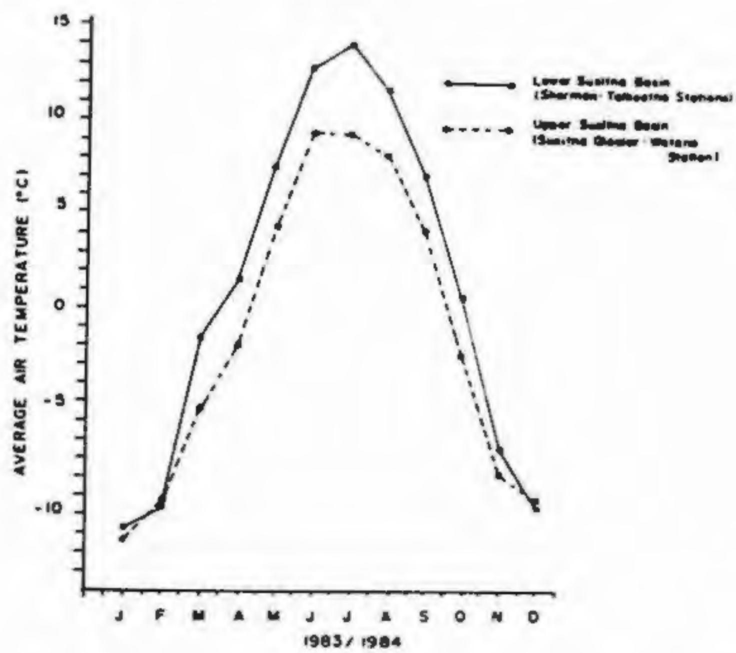


Figure IV-2. Average monthly air temperatures (°C) in the upper and lower basins of the Susitna River (adapted from R&M 1984a, 1985a; U.S. Dept. of Commerce 1983, 1984).

Storms which affect the area generally cross the Chugach Range from the Gulf of Alaska or come from the North Pacific or southern Bering Sea across the Alaska Range west of the upper Susitna Basin. As expected, precipitation is much heavier in the higher elevations than in the valleys. The heaviest precipitation generally falls on the windward side of the Alaska Range, leaving the upper basin in somewhat of a precipitation shadow except for the higher peaks of the Talkeetna Mountains and the southern slopes of the Alaska Range.

Basin Hydrology

The Susitna River is typical of unregulated northern glacial rivers, with relatively high turbid streamflow during summer and low clear-water flow during winter. Approximately 87 percent of the total annual flow of the middle Susitna River occurs from May through September, and over 60 percent occurs during June, July and August (Table IV-1). Snowmelt and rainfall runoff cause a rapid rise in streamflows during late May and early June, and over half of the annual floods occur during this period.

Table IV-1. Summary of monthly streamflow statistics for the Susitna River at Gold Creek from 1949 to 1982 (from Harza-Ebasco 1985g).

Month	Monthly Flow (cfs)		
	Maximum	Mean	Minimum
January	2,452	1,542	724
February	2,028	1,320	723
March	1,900	1,177	713
April	2,650	1,436	745
May	21,890	13,420	3,745
June	50,580	27,520	15,500
July	34,400	24,310	16,100
August	37,870	21,905	8,879
September	21,240	13,340	5,093
October	8,212	5,907	3,124
November	4,192	2,605	1,215
December	3,264	1,844	866
Average	15,900	9,651	4,785

Daily streamflows are relatively high throughout the summer, occasioned by rapid responses to highly variable precipitation patterns. Susitna River streamflows are most variable during the months of May and October, transition periods commonly associated with spring breakup and the onset of freeze up. From November through April, cold air temperatures cause surface runoff to freeze, and stable but gradually declining streamflows are maintained throughout winter by groundwater inflow and baseflow from headwater lakes.

The glaciated portions of the upper Susitna Basin have a distinct influence on the annual hydrograph for the Susitna River at Gold Creek (USGS stream gage station 15292000). R&M Consultants and Harrison (1982) state that "roughly 38 percent of the streamflow at Gold Creek originates above the gaging stations on the MacLaren River near Paxson and on the Susitna River near Denali...". Located on the southern slopes of the Alaska Range, these glaciated regions receive the greatest amount of precipitation that falls in the basin. The glaciers, covering about 290 square miles, or approximately 5 percent of the basin upstream of Gold Creek, act as reservoirs storing water in the form of snow and ice during winter and gradually releasing melt water throughout the summer to maintain moderately high streamflows. Valley walls in those portions of the upper basin not covered by glaciers, consist of steep bedrock exposures or shallow soil systems. Hence rapid surface runoff originates from the glaciers and upper basin whenever rainstorms occur.

Susitna River streamflow originates from glacial melt, surface runoff, and groundwater inflow. The relative importance of each of these contributions to the total discharge of the Susitna River at Gold Creek varies seasonally (Fig. IV-3). Although the amount of groundwater inflow to the middle Susitna is thought to remain fairly constant throughout the year, its relative importance to streamflow and water quality increases significantly during winter as the streamflow contribution from glacial melt and surface runoff decrease. During September as air temperatures in the upper basin fall below freezing, glacial melt subsides, and mainstem streamflows clear. By November below freezing air temperatures occur throughout the basin (refer Fig. IV-2) and streamflows have decreased to approximately one tenth their midsummer values. Streamflow at the Gold Creek gage is maintained by the Tyone River which drains Lake Louise, Susitna Lake and Tyone Lake, and by groundwater inflow to several smaller tributaries and to the Susitna River itself.

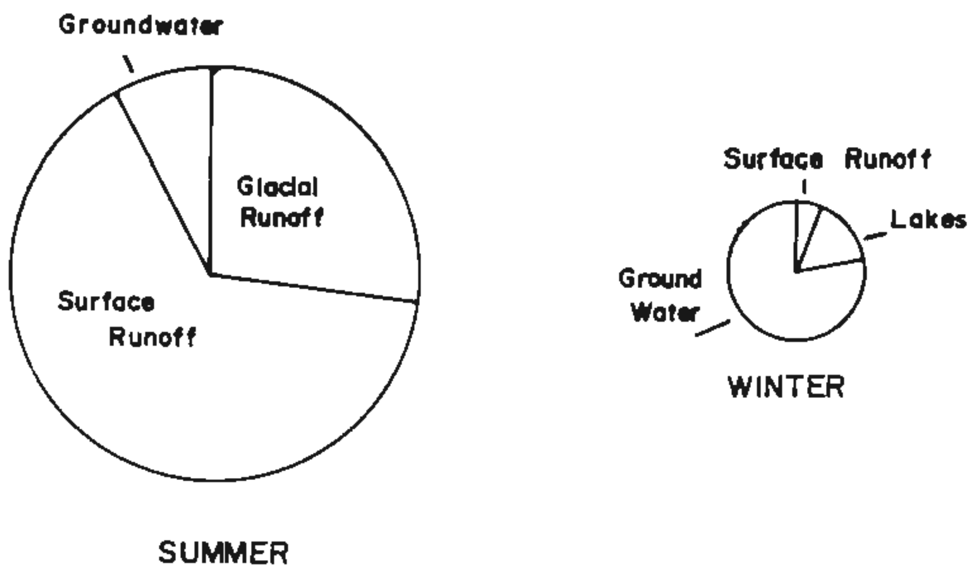


Figure IV-3. Estimated percent contributions to middle Susitna River streamflow.

Streamflow Variability and With-project Operations

The variability of naturally occurring annual peak flows, mean summer discharge, and average annual streamflow for the Susitna River at Gold Creek is illustrated in Figure IV-4. Peak flows for the Susitna River normally occur during June in association with the snowmelt flood, but summer rainstorms often cause floods during August (Table IV-2). Flood peaks are seldom more than double the long term average monthly flow for the month in which they occur (R&M 1981b), however average monthly flows for June, July, and August are nearly 2.5 times the average annual discharge of 9700 cfs (Scully et al. 1978). Although these streamflow statistics are not exceptionally variable, they imply that a very large amount of water typically flows through the middle Susitna River corridor during summer.

Table IV-2 Percent distribution of annual peak flow events for the Susitna River at Gold Creek 1950-1982 (R&M Consultants 1981b).

Month	Percent
May	9
June	55
July	9
August	24
September	3

The natural flow regime of the middle Susitna River is expected to be altered by project operation. With-project streamflows will generally be less than natural streamflows during the May through July period (Phase I and Phase II) as water is stored in the reservoirs for release during the winter. For Phase III, streamflows will be less than natural through the month of August (Fig. IV-5). During the May through August period, variability of middle Susitna River streamflows will be caused by tributary response to snowmelt and rainfall runoff as well as from controlled releases from the reservoirs. With-project floods would still occur in late summer but would be significantly reduced in both frequency and magnitude (Table IV-3).

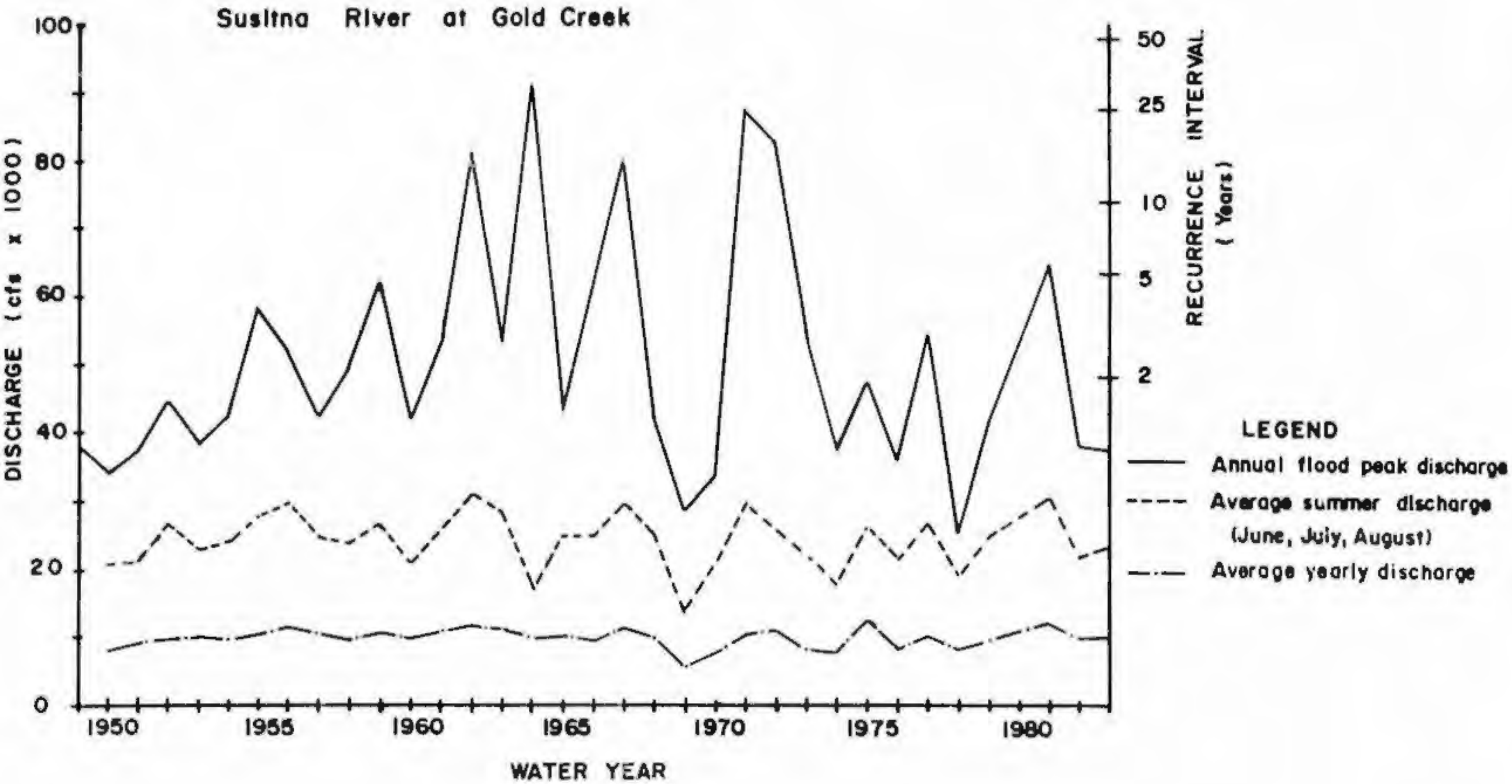


Figure IV-4. Naturally occurring annual peak flows, mean summer discharge, and annual streamflow of the Susitna River at Gold Creek (adapted from Harza-Ebasco 1985c as modified by AEIDC 1985b).

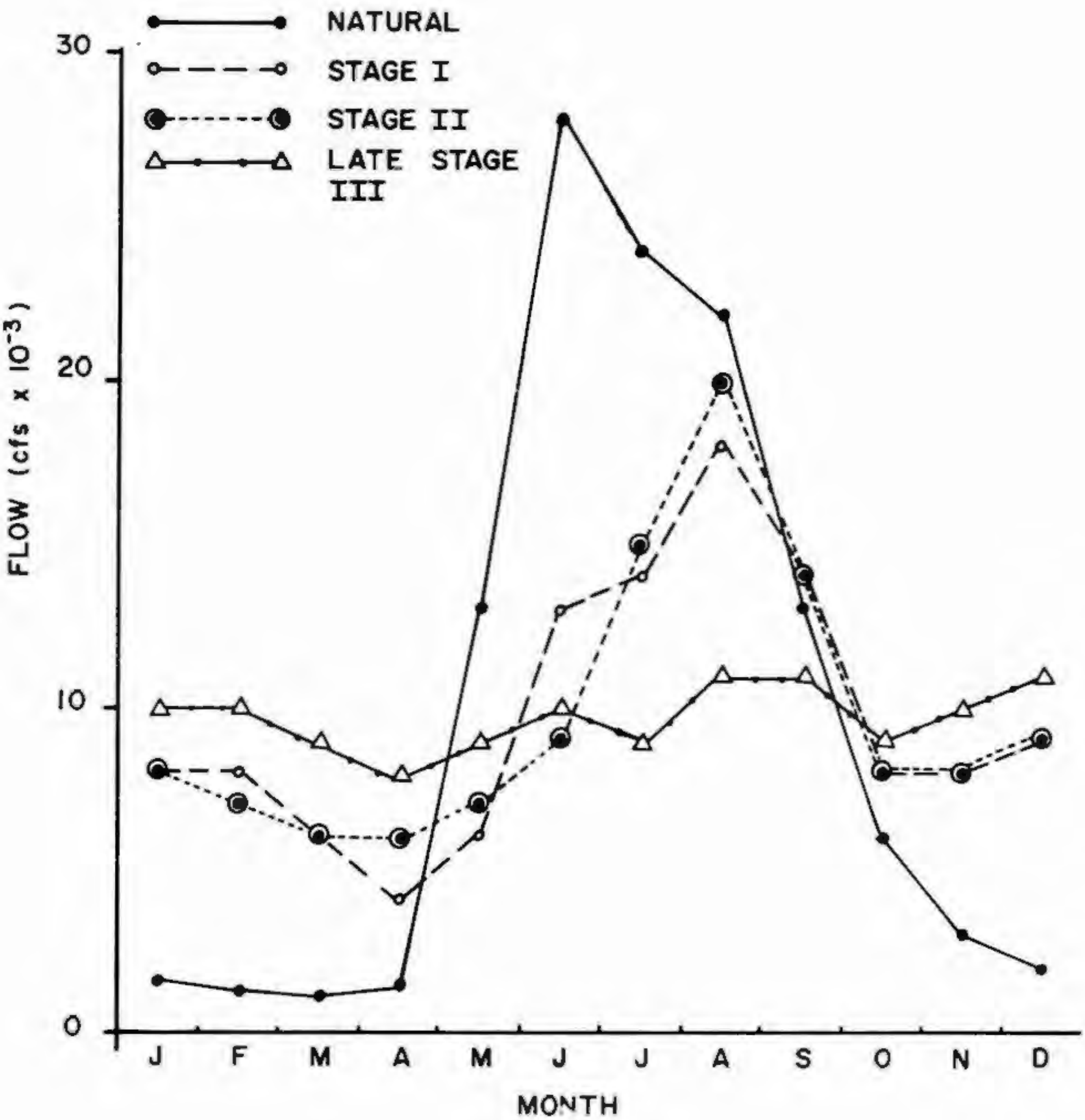


Figure IV-5. Estimated with-project mean monthly flows at Gold Creek compared to natural flows (adapted from APA 1985b).

Table IV-3. Flood peak frequency data at Gold Creek for natural and with-project conditions (Harza-Ebasco 1985c).

Flood Period (1)	Recurrence Interval (Year) (2)	Natural[1] Flood Peak (cfs) (3)	Flood Peaks (cfs) With-Project Stage I (4)	Stage II (5)	Stage III Early (6)	Stage III Late (7)
Annual	2	48,000	25,600	19,200	20,000	22,100
	5	63,300	33,300	26,900	27,700	29,800
	10	73,700	37,700	31,300	32,100	34,200
	25	87,300	41,600	35,200	36,000	38,100
	50	97,700	46,200	39,600	40,600	42,700
May-June	2	42,500	19,800	17,300	18,000	19,700
	5	56,200	26,800	24,300	25,000	26,700
	10	66,300	30,600	28,100	28,800	30,500
	25	80,500	33,900	31,400	32,100	33,800
	50	92,100	37,900	35,400	36,100	37,800
July - September	2	37,300	36,500	36,500	35,500	15,700
	5	49,800	43,100	43,100	43,100	21,300
	10	59,400	43,500	44,500	43,500	24,000
	25	73,200	44,000	45,000	45,000	26,500
	50	84,800	46,600	47,100	47,300	29,500

[1] From Harza-Ebasco 1984a.

With-project streamflow during September is expected to be less variable but near to the long term average monthly natural flow for this month. Streamflows from October through April would be greater in magnitude and more variable than natural winter streamflows. Daily fluctuations in streamflow are expected to occur throughout winter as the hydroelectric project responds to meet varying electric load demands. A family of rule curves will be used as a guide for seasonal adjustment of flow for power generation and downstream flow requirements. The Alaska Power Authority proposed to limit streamflow fluctuations resulting from application of these rule curves to ±10 percent of the average weekly discharge (Harza-Ebasco 1985b).

Influence of Streamflow on Habitats

Mainstem and Side Channel Habitats

Mainstem and side channel gradients within the middle Susitna River are on the order of 8 to 14 ft/mile (Bredthauer and Drage 1982). As a result of this steep channel gradient, mid-channel velocities are often in the range of seven to nine feet per second (fps) during normal mid-summer streamflow conditions. Mainstem velocities of 14 to 15 fps have been measured by the USGS at the Gold Creek stream gage in association with 62,000 to 65,000 cfs flood flows (L. Leveen, USGS, 1984, pers. comm.). For most species of fish and benthic invertebrates high velocity streamflows are considered undesirable. The upper limit for velocity preferred by most juvenile salmonids is generally less than one fps and that for adults seldom exceeds 4 fps (Estes and Vincent-Lang 1934d; Suchanek et al. 1984).

Analysis of hydraulic conditions in the mainstem and large side channels indicates that mid-channel velocities are generally unsuitable for fish over a wide range of mainstem discharge (Williams 1985). Suitable habitat for juvenile fish is usually restricted to a narrow zone associated with the shoreline margin. As mainstem discharge changes, the width (surface area) of this habitat zone remains relatively constant but moves laterally in response to water surface elevation. Because the shoreline margins are almost void of cover objects, habitat quality responds little to changes in the location of the shoreline habitat zone.

Side Slough Habitats

Side sloughs are overflow channels, located along the floodplain margins, which contain important spawning and rearing habitat for salmon. Side slough streambed elevations are higher than those of adjacent side channels or the mainstem. Hence side sloughs only convey water from the mainstem during periods of high streamflow. When mainstem discharge is insufficient to overtop the upstream end of the slough, slough flow, generally less than 5 cfs, is maintained by tributary or groundwater inflow. However, mainstem or side channel water surface elevations at the downstream end of the slough are usually sufficient to cause a backwater pool to extend a few hundred feet upstream into the slough mouth.

Whenever the water surface elevation (stage) of the mainstem or side channel adjacent to the slough is sufficient to overtop the head of the slough, discharge through the side slough increases markedly. These overtopping events also affect the thermal, water quality, and hydraulic characteristics within the slough. Overtopping during breakup and flood events generally provides adequate flow velocities in the side slough to scour debris, beaver dams, and fine sediments from the side sloughs. However, overtoppings associated with normal summer stream flows (20,000 to 30,000 cfs) generally transport large amounts of suspended sand and fine sediments into the slough which then settle out in low velocity areas. Sedimentation is most apparent in the backwater zone at the slough mouth where the deposition may often exceed one foot. Overtopping during early June is thought to assist the outmigration of juvenile chum salmon. During late August and early September, overtopping provides unrestricted passage by adult salmon to spawning areas within the side sloughs.

The frequency at which a particular side slough (or side channel) is overtopped varies according to the relationship between mainstem water surface elevation and the elevation of the streambed at the upstream end (head) of the slough. The mainstem discharge which provides a water surface elevation sufficient to overtop the head of the side slough (or side channel) is referred to as the breaching flow. Each side slough and side channel has a unique breaching flow; however, breaching flows for side channels are typically less than 20,000 cfs whereas side slough breaching flows generally exceed 20,000 cfs.

Passage. Because of the significant influence overtopping events have on habitat conditions and fish passage in side sloughs, special consideration has been given to mainstem stage-discharge relationships and breaching flows by the study team (ADF&G, Su Hydro 1983a; Estes and Vincent-Lang 1984a; Hilliard et al. 1985). Analysis of the thirty-five year period of streamflow record for the middle Susitna River indicates that overtopping events occur rather frequently during the August 12 through September 15 spawning period (Table IV-4). Side sloughs with breaching flows of 23,000 cfs were overtopped for 19.1 percent of the evaluation period. During the thirty-five year period of record, overtopping events were most frequently either 1-, 2- or 3-days in duration (25 events); however, 9 events longer than seven consecutive days also occurred. Side sloughs or side channels with breaching flows in the range of 16,000 to 18,000 cfs were overtopped nearly half of the time with a large number of events (23) being longer than seven consecutive days.

Field observations indicate adult salmon respond rapidly to improved passage conditions and quickly enter side sloughs to spawn (Trihey 1982). Therefore frequent, but short-duration, overtopping events as occur naturally for sloughs with breaching flows as high as 25,000 cfs provide adequate passage condition. In addition, the response of the water surface elevation of the backwater zone at the slough mouth to increased mainstem discharge and the response of slough flow to rainfall often provide short-term improvement of passage conditions when the mainstem discharge is less than the breaching flow. Insufficient data are available at this time to describe the influence of the natural variability in slough flow on passage conditions.

Groundwater Upwelling and Intragravel Flow

Upwelling and intragravel flow have been recognized as strongly influencing the spawning behavior of chum and sockeye salmon in Alaska (Kogl 1965; Koski 1975; Wilson et al. 1981; Estes and Vincent-Lang 1984d). Upwelling has also been credited with maintaining relatively warm open water leads in some side channels and sloughs throughout winter (Barrett 1975; Trihey 1982). These leads are important to the

Table IV-4. Number of times during the spawning period mainstem discharge was equal to or greater than the breaching flow for the consecutive number of days and years indicated.[1]

Breaching Flow (cfs)	Approximate Exceedance Value (%)	AUGUST 12 THROUGH SEPTEMBER 15 1-day		2-day		3-day		4-day		5-day		6-day		7-day		7-day		Total days
		events	in years	events	in years	events	in years	events	in years	events	in years	events	in years	events	in years	events	in years	
12000	79.6	4	4	1	1	2	2	1	1	2	2	3	3	1	1	37	34	975
16000	56.8	6	4	6	6	6	6	2	2	5	5	2	1	0	0	31	29	696
19000	38.2	5	4	5	5	7	5	7	7	4	4	3	3	4	4	23	20	468
21000	19.1	9	9	7	7	9	7	4	3	3	3	2	2	2	2	9	9	242
25000	12.7	6	6	7	6	4	4	3	3	2	2	1	1	2	2	6	6	156
27000	8.7	6	6	3	3	2	2	1	1	3	3	0	0	2	2	4	4	106
33000	4.3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	48
35000	3.5	0	0	1	1	1	1	1	1	2	2	1	1	1	1	1	1	44
40000	2.5	2	2	2	2	1	1	1	1	0	0	2	2	1	1	0	0	32
47000	2.1	0	0	1	1	1	1	1	1	1	1	2	2	0	0	0	0	26

1 Based on Average Daily streamflow records for the Susitna River at Gold Creek 1950-1984.

2 The controlling elevation of the berm at the upstream end of the slough may change over time due to high flow or ice scour.

overwinter survival of incubating eggs and alevins (Vining et al. 1985) and juvenile chinook (Stratton 1985).

In river valleys where the underlying materials originate from glacial outwash, groundwater flow patterns are often complex. In the middle Susitna River there appears to be three main sources of subsurface flow (upwelling) into side channel and slough habitats.

1. Infiltration of surface flow from the mainstem through islands and gravel bars which separate the sloughs and side channels from the mainstem (intragravel flow),

2. Subsurface flow toward the river from upland sources (upland groundwater component), and

3. Subsurface flow in the downstream direction within alluvial materials comprising the flood plain of the middle Susitna River (regional groundwater component).

The relative contribution of these three sources has been examined (APA 1984b) and it appears that infiltration from the mainstem is the primary source of subsurface flow into side channel and slough habitats along the middle Susitna River. In addition, the response of slough flow to changes in mainstem discharge (when the upstream berms are not overtopped) is relatively rapid; often occurring in a matter of hours.

The groundwater flow rate from upland sources is the least influential of these three sources and it varies seasonally; being highest in the summer and lowest in the winter. This is a direct result of the spring snowmelt and summer rainfall which recharge aquifers and raise the water table level, and depletion of the aquifers in the winter due to lack of recharge. The regional groundwater component appears to be the second most important source of subsurface flow which remains relatively constant throughout the year because the down valley gradient of the flood plain is constant.

Relationships between slough flow and mainstem flow (when the berms are not overtopped) indicate that infiltration from the mainstem varies nearly linearly with the mainstem stage. In general, a one foot change in mainstem stage results in a change in slough flow of between 0.3 and 0.6 cfs depending upon the particular side slough (APA 1984b). Relative to normal slough flows which are 3 to 5 cfs the influence of mainstem infiltration on open channel hydraulic conditions within the slough are minor. However, this small change in slough flow appears to have a significant effect on the biologic processes occurring within the streambed of the slough; particularly during fall and early winter.

Seasonal changes in the mainstem water surface elevation also ffect the rate of infiltration or intragravel flows from the mainstem. The annual cycle of mainstem water levels includes two extended periods of relatively constant water surface elevation and two brief transition periods. The two extended periods are mid-May through mid-September and the winter season from December through April. The two transition periods are breakup which generally occurs during the first two weeks of May, and the October-November freeze-up period. The mainstem water levels are highest during the two extended periods and lowest during the October-November freeze-up period.

Middle Susitna River streamflows normally reach 20,000 cfs by the end of May and remain at that level or higher until mid-September. Throughout this period, bank storage and infiltration of mainstem water to the sloughs fluctuates in response to mainstem water levels. Between late September and mid-November, mainstem streamflow often declines to 4000 cfs prior to an ice cover forming on the mainstem. Depending on the reach of the river being considered, the difference in mainstem water surface elevations between streamflows of 20,000 and 4,000 cfs would approximate 5 feet.

The mainstem water levels associated with October and November streamflows appear to result in the lowest infiltration flows and slough flows for the year. During this period, when discharges range from 5,000 to 3,000 cfs, upwelling flow is thought to originate almost entirely from the regional groundwater component. Mainstem stage is too low to significantly contribute to infiltration and cold air temperatures have retarded subsurface flow from upland sources.

As the ice cover forms on the river, the mainstem water level rises in response to the blockage of streamflow by river ice. This natural process of raising mainstem water surface elevations upstream of the ice cover is called "staging". Because of staging, mainstem water levels during winter (December through April) appear similar to those of summer water levels (Trihey 1982). Hence, infiltration from the mainstem into side channel and slough areas during winter is suspected of being similar to that of summer.

In general, intragravel temperatures at upwelling areas remain between 2.5 and 4°C throughout the year (Estes and Vincent-Lang 1984b; Keklak and Quane 1985). This temperature range approximates the mean annual temperature of the Susitna River. Intragravel temperatures in side sloughs are relatively insensitive to surface water temperatures when the upstream berm of the slough is not overtopped by mainstem flow. However, when the upstream berm of a side slough or side channel is overtopped by mainstem flow, intragravel temperatures may be influenced. This is most evident during freeze-up when intragravel temperatures are sometimes depressed to near 0°C in response to the inflow of cold mainstem water caused by staging (see ice processes). Overtopping events during freezeup do not occur at all side sloughs. However, they appear to be more common downstream of River Mile 130 than upstream of this location.

Biological Importance of Upwelling

Intragravel flow and upwelling are two of the most important habitat variables influencing the selection of spawning sites by chum and sockeye salmon in the middle Susitna River (Estes and Vincent-Lang 1984d). In addition, upwelling flows contribute to local flow in sloughs and side channels which may occasionally facilitate fish passage (Estes and Vincent-Lang 1984c).

Incubation appears to be the life stage most critically affected by intragravel flow in the middle Susitna River. Chum and sockeye salmon embryos spawned in areas of upwelling flows benefit if intragravel flow continues throughout the winter. The 2 to 4°C intragravel temperature associated with upwellings in side sloughs maintains a higher rate of survival for the incubation of embryos than do intragravel temperatures in other habitats (Vining et al. 1985). Intragravel flow is also thought to ensure the oxygenation of embryos and alevins, transport metabolites out of the incubating environment, and inhibit the clogging of streambed material by fine sediments.

Groundwater also appears to be an important factor influencing the winter distribution of juvenile salmon and resident fish (Roth and Stratton 1985; Sundet and Pechek 1985). Upwelling flows may comprise the predominant source of water in sloughs when overland runoff from precipitation is inhibited due to freezing. This constant water flow in sloughs and side channels provides over-winter habitat for juvenile sockeye, chinook, and coho salmon and resident species. The warmer temperatures of sloughs and side channels due to the inflow of upland source and bank stored groundwater apparently attract overwintering fish and may reduce their winter mortality (Dugan et al. 1984).

As previously stated, upwelling flows appear to reach their annual minimum during late October and November prior to an ice cover forming on the mainstem. Intragravel temperatures (upwelling rates) during this period probably limit the incubation success of embryos that were spawned when upwelling rates were higher. As a result of decreased upwelling rates during the October-November period many embryos are thought to be dewatered or frozen. The most viable incubation habitat in the middle Susitna River is thought to exist where upwelling flow persists during this fall transition period.

Maintaining higher than natural mainstem discharges during the fall transition would likely increase upwelling rates above natural levels, thereby increasing the incubation success in the effected spawning habitats. Reducing mainstem discharge to below natural levels would likely have an opposite effect on incubation success.

Sediment Transport Processes

Sediment transport is defined as the movement of inorganic material past a particular point in a stream. The total sediment load consists of suspended load and bed load. Suspended load includes wash load, fine material constantly in suspension, and coarser materials transported through intermittent suspension. The bed load consists of all inorganic material moving in constant contact with the streambed.

It is well-documented that sediment transport processes have a significant influence on aquatic habitat. McNeil (1965) has observed that streambed stability can influence the success of salmonid egg incubation. Several researchers have shown that substrate composition influences the survival of eggs to fry in salmonid populations (McNeil and Ahnell 1964; Cooper 1965; McNeil 1965; Phillips et al. 1975). The suitability of a streambed for rearing fish and aquatic insects is also influenced by its stability composition.

On a macrohabitat level, the channels of the middle Susitna River are quite stable given the range of streamflows and ice conditions to which they are subjected. Review of aerial photography taken over an approximate 35 year period (from 1949-51 to 1977-80) indicates that the plan form of the middle Susitna River has experienced little change (Univ. of Alaska, AEIDC 1985b). Although there is some evidence of degradation, and some peripheral areas have changed from one habitat type to another, the plan form of most channels appear unchanged over this period.

The plan form of the middle Susitna River appears to be controlled by geologic features and major floods but is also influenced by ice processes. Stream channel size and streambed composition are primarily the result of hydrologic processes. Flood events are probably the dominant channel forming process whereas normal summer streamflows represent the primary sediment transport process. Channel forming discharges are rare; occurring perhaps once or twice within a

25- to 50-year period (refer Table IV-3). High streamflows, such as the bankfull discharge or 5-year flood might reshape the channel geometry to reflect local hydraulic conditions but have little influence on the overall plan form of the middle Susitna River.

River ice can also influence the plan form of the river by causing ice jams during breakup which divert large quantities of water from primary channels into secondary channels or onto the floodplain forming new channels. Velocities near 10 ft/sec have been measured at constricted areas within ice jams (R&M 1984b). Such velocities have the potential to cause significant local scour. When ice jams fail they release a surge of water and ice which was impounded behind the jam. These surges contain high velocities that erode streambanks, and ice blocks carried in the surge wave often scour banks and knock over vegetation (R&M 1984b). Bank erosion by ice-block abrasion is extensive in some locales of the middle Susitna River (Knott and Lipscomb 1983).

Shore ice forms along the streambanks prior to the upstream progression of the ice cover. This ice may freeze onto the bank material and around vegetation. When the water level rises due to staging associated with the ice cover formation the shore ice may break off from the shoreline carrying bank materials and vegetation with it. The amount of sediment transported by shore ice is insignificant when compared to other transport mechanisms. However, shore ice processes expose the shoreline to scour by floods and significantly influence the character of fish habitat along the channel margin by removing debris jams and other types of shoreline cover.

Influence of Sediment Transport Processes on Habitat Types

A streambed which is in a long term state of sediment equilibrium is generally relatively stable when streamflows are at or below flood levels, but may degrade during a flood and aggrade as the flood peak subsides. The mainstem and large side channels of the middle Susitna River appear to reflect this type of dynamic equilibrium based upon streambed measurements by the U.S. Geological Survey at Gold Creek (Fig. IV-6).

Sediment transport processes exert varying degrees of influence on the streambed composition of the six aquatic habitat types (mainstem, side channels, side sloughs, upland sloughs and tributaries) within the middle Susitna River (Tables IV-5 and IV-6).

Table IV-5. Influence of mainstem sediment load on streambed composition of aquatic habitat types.

Habitat Type	Suspended Load	Bedload
Mainstem and Large Side Channels	Primary	Primary
Side Channels	Primary	Secondary
Side Sloughs	Primary	Minor
Tributary Mouths	minor	Secondary
Upland Sloughs	Secondary	Minor

Mainstem and Large Side Channel Habitats

Summer streamflows transport large amounts of sand both in suspension and as bedload. Streambed materials in the mainstem and large side channels generally range from large gravels (< 3 inches) to cobbles (< 10 inches). Streambed materials in the smaller side channels generally range from large gravels to small cobbles (6 inches). Bed

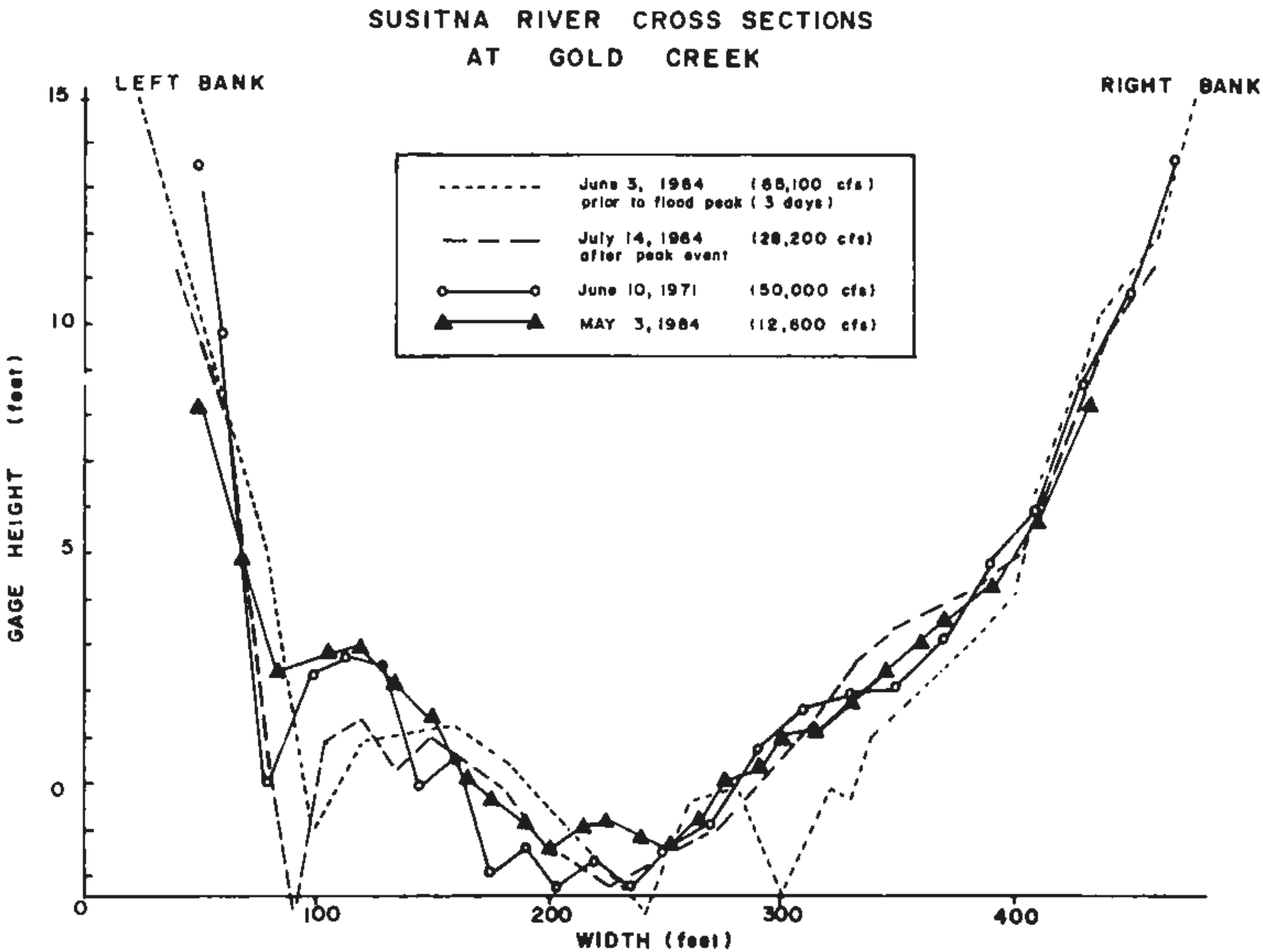


Figure IV-6. Cross sections of the Susitna River at Gold Creek measured at various mainstem discharges.

Table IV-6. Influence of sediment transport processes on streambed stability of aquatic habitat types.

	High Flow Events	Typical Midsummer Discharge	Ice Jam Surges and Diverted Flow	Mechanical Scour by Ice Blocks	Anchor Ice Processes	Shore Ice Processes
Mainstem and Large Side Channels	Primary	Insignificant	Secondary	Secondary	Minor	Secondary
Side Channels	Primary	Minor	Primary	Minor	Minor	Secondary
Side Sloughs	Primary	Minor	Primary	Insignificant	Insignificant	Insignificant
Tributary Mouths	Primary	Insignificant	Minor	Insignificant	Minor	Insignificant
Upland Sloughs	Minor	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant

material sizes are largest near Devil Canyon and generally decrease with distance downstream (Bredthauer and Drage 1982).

Beneath this surface layer is a more heterogenous mixture of material consisting of sands and gravels with some cobbles. Under normal flow conditions the overlying layer of cobbles protects the underlying streambed material from erosion. The ability of this pavement layer to resist erosion is enhanced by the deposition of fine glacial sands within the interstitial spaces between the rubble and cobble. This results in a tightly packed matrix of sands, gravels and cobbles. The fine sands which fill the interstitial spaces within the pavement layer are a part of the suspended sediment load normally transported by summer streamflows.

Except for isolated deposits of sands and gravels, streambed material in the mainstem and large side channels appears sufficient to resist erosion or transport by streamflows less than 35,000 cfs. Flood events (50,000 cfs or greater) have the capacity to erode the pavement layer and transport underlying streambed materials downstream. As the flood crest recedes the large bed elements in motion are redeposited, thereby reforming the protective pavement layer while sands and gravels are transported downstream. As a result the streambed elevation decreases while retaining much of the basic plan form of the river. Evidence of such long-term channel degradation has been documented through analysis of aerial photography (Univ. of Alaska, AEIDC 1985b; Klinger and Trihey 1984; Klinger-Kingsley 1985).

River ice influence the shape and character of mainstem and large side channel habitats in several ways: 1) scour caused by ice jams during breakup, 2) sediment transport by anchor ice and possibly by frazil ice, and 3) scour and sediment transport by shore ice. In comparison to sediment transport associated with high streamflows, scour by ice jams, is of secondary importance. The volumes of sediment transported in the middle Susitna River by anchor ice and shore, are inconsequential. However, the influence of shore ice on streambank vegetation and cover objects for fish appears to be significant.

Side Channel and Side Slough Habitats

Of the sediment transport processes described in the previous section, high flows and flooding caused by ice jams during breakup have a dominant role in the formation and maintenance of side sloughs and side channels. Mechanical scour by block ice, anchor ice processes, and shore ice processes have little influence on substrate composition or streambed stability in these habitats.

Side channels and side sloughs are quite stable when conveying typical mid-summer streamflows. Their width to depth ratios and spatial orientation indicate they were formed by much higher streamflows. Although the temporal frequency of such high flows varies between sites in accord with the breaching flow, it is generally low; occurring perhaps once or twice within a 25-year period.

New channels have also been formed as a result of ice jams which raise the mainstem water level and cause flow to be diverted onto the flood plain. Slough 11, for example, was changed from an upland slough to a side slough in 1976 when an ice jam occurred below the Gold Creek railroad bridge. However, ice jam diversions are generally more important for maintaining substrate quality in side slough habitats by flushing out fine sediments, as observed at Slough 9 during May 1982.

Sediment is transported into side sloughs and side channels from three sources: 1) the mainstem, 2) tributaries, and 3) bank erosion. Of these, the mainstem influence is most significant. Large quantities of suspended sand and smaller sediments are transported into side channel and side slough habitats when the mainstem discharge is sufficient to overtop their upstream berms. Summer streamflows in the range of 20,000 to 30,000 cfs cause significant siltation of pools and backwater areas associated with side channel and side slough habitats.

Tributary and Tributary Mouth Habitats

High flow events are most important for shaping the channel geometry and determining streambed composition of tributary mouths. Most tributaries to the middle Susitna River are small, steep gradient streams with a capacity to transport large quantities of bed load during flood events.

When flood events are caused by regional rainstorms, the Susitna River would have a high discharge concurrent with, or soon after, the high discharge in the tributary. As a result, most sediments delivered to the tributary mouth by the tributary are transported downstream by the Susitna River. However, local storms may cause a tributary to flood while the Susitna River remains relatively low. In such cases, a delta may build up at the mouth of the tributary due to the deposition of the tributary bed load. The delta may extend into the Susitna River until subsequent streamflows in the river are sufficient to erode it and transport the material downstream. This process has been periodically observed at the mouths of Gold Creek and Sherman Creek.

Upland Slough Habitats

In general, upland slough habitats are isolated from mainstem sediment transport processes. However, an exception exists in the vicinity of the slough mouth, where sediment laden mainstem flow often enters the slough as backwater during periods of high mainstem discharge. The suspended sediments contained in the mainstem flow settle out in these low velocity backwater areas and contribute to the long term sedimentation of the slough. If a backwater eddy occurs, as at the mouth of Slough 10, sedimentation of the slough mouth and its downstream approach can be caused by only two or three moderately high flow events. In other instances such as Slough 6A where mainstem water has some difficulty entering the slough mouth, sedimentation is more subtle.

Project Influence on Sediment Transport Processes

Construction and operation of Watana Reservoir will alter the natural streamflow, thermal, and sediment regimes of the middle Susitna River. Flood discharges in the middle Susitna River will be smaller in magnitude and will occur less frequently (refer Table IV-3). In addition most suspended material and all bed load originating upstream of the dam sites will be deposited in the reservoirs (R&M Consultants 1982d; Harza-Ebasco 1984e). Hence, the amount of sediment currently being transported through the middle Susitna will be substantially reduced.

The smaller and less frequent flood flows which would occur are expected to favor streambed and streambank stability in mainstem and side channel habitats. Reduced flood peaks also favor the encroachment of streambank vegetation into side sloughs and on exposed portions of partially vegetated gravel bars. In addition, smaller and less frequent flood events should allow tributary deltas to enlarge over their natural size. Some tributary mouths may become perched but most are expected to adjust themselves to with-project water levels (R&M 1983b). Gravel deposits are expected to occur in mainstem and side channel areas immediately downstream of most tributaries being used by spawning salmon. Access into these tributaries by adult salmon is not expected to be impaired by with-project changes in tributary deltas (Trihey 1983).

Because most sediments entering Watana Reservoir will be trapped, a tendency will exist for fine sediments to be removed from the streambed downstream of the dam. Although peak flood events will be substantially reduced by the reservoirs, regulated flood discharges at the Gold Creek gage will often be in the range of 30,000 to 40,000 cfs (refer Table IV-3). Gravel and smaller sediments are expected to be dislodged from the streambed by these flows and transported downstream. Since the dislodged material will not be replaced as it is under natural conditions, some accelerated degradation of the main channel bed should be expected.

While the actual amount of degradation which would occur cannot be accurately forecast, analysis of bed material samples and inspection of exposed portions of the streambed during periods of low streamflow indicates that degradation of the main channel should not exceed one foot (Harza-Ebasco 1985e). Degradation would be greatest near the dam face and is expected to decrease with distance downstream. In time, a pavement layer would develop due to removal of the smaller bed materials which would retard any further degradation. This layer will consist of a smaller percentage of fines and a greater percentage of voids than occurs naturally.

The influence that with-project ice processes might have on channel stability will, in part, depend upon project design and operation. The effects of alternative intake level design and winter operating policies on downstream ice processes have been evaluated by Harza-Ebasco (1985d) and are summarized in a following section of this report called "Instream Temperature and Ice Processes." For the purpose of discussing with-project ice effects on channel stability and sediment transport processes, it is sufficient to say that only a portion of the middle Susitna is expected to be ice covered.

The with-project ice cover is expected to melt in place rather than break up under hydraulic pressure as it presently does. Breakup ice jams are expected to occur less frequently, if at all, and be of reduced magnitude (Harza-Ebasco 1985d). This is expected to reduce the influence of the river ice cover on naturally occurring sediment transport processes. However, maximum ice cover elevations within the ice-covered portion of the river are expected to be several feet higher than natural during operation of stages I, II and III (Harza-Ebasco 1985d). Thus disturbance of shoreline vegetation and the potential for streambank erosion within the ice covered portion of the middle Susitna is expected to increase above present levels.

Upstream of the ice front, shoreline disturbances by shore ice processes would not be expected to change appreciably. The shore ice that would form upstream of the ice cover is expected to occur at an elevation below the present vegetation level. Melt out in spring is expected to reduce the frequency of shore ice separating from the streambank and floating downstream (as with natural breakup) with encased debris and vegetation. Hence, streambanks should be less prone to erode.

Instream Water Quality and Limnology

Baseline Condition

Water quality encompasses numerous physical and chemical characteristics, including the temperature, density, conductivity, and clarity of the water, as well as the composition and concentration of all the dissolved and particulate matter it contains. Water quality influences the quality of fish habitat by virtue of its direct effects on fish physiology and because it largely governs the type and amount of aquatic food organisms available to support fish growth.

Each of the aquatic habitat types associated with the middle Susitna River differs not only in terms of its morphology and hydraulics, but also in the basic pattern of its water quality regime. Therefore, the relative importance of a specific habitat type to fish may change in response to seasonal change in either streamflow or water quality. In the middle Susitna River, turbidity is an influential and visually detectable water quality parameter that may be used to classify the six aquatic habitat types into two distinct groups during the open water season: clear water or turbid water. In order to gain a greater understanding of each habitat type, it is useful to 1) examine the water quality characteristics of both clear and turbid water aquatic habitats; 2) identify how the water quality of these aquatic habitat types changes on a seasonal basis; and 3) determine how these seasonal changes influence the quality of the aquatic habitat types.

From June to September highly turbid water accounts for the greatest amount of wetted surface area in the middle Susitna River (Klinger and Trihey 1984). During this period, when surface runoff and glacial melting are greatest, total dissolved solids, conductivity, alkalinity, hardness, pH, and the concentrations of the dominant anions and most cations tend to be at their lowest levels of the year, while stream temperature, turbidity, true color, chemical oxygen demand, total suspended solids, total phosphorus, and the total concentrations of a variety of trace metals are at their highest values for the year (Table IV-7). Average nitrate-nitrogen concentrations remain relatively constant throughout the year with greater variation during the summer as discharge fluctuates.

The basic water chemistry of the clear water flow of the middle Susitna River in winter, and of certain groundwater fed habitat types throughout the year, can be generalized from an evaluation of the water quality record for the Susitna River at Gold Creek during winter. Surface water flow throughout the basin is low. Middle Susitna River discharge is comprised almost entirely of outflow from the Tyone River System (lakes Louise, Susitna, and Tyone) and groundwater inflow to tributaries and the mainstem itself. Hence, the concentration of suspended sediment, trace metals, and phosphorous is also low or below detection limits. Groundwater spends a greater amount of time in contact with the soil and underlying rocks of the watershed than surface runoff or glacial meltwater and thus contains more dissolved substances. Groundwater temperatures are warmer in winter and cooler in summer than surface water temperatures.

The specific water quality characteristics of clear or turbid water flowing through a given channel may differ from the general descriptions provided above, depending on local variations in the amount of local surface runoff or the composition and distribution of rocks, soils, and vegetation. Nonetheless, a generalized seasonal water quality regime unique to each habitat type seems to prevail, and having knowledge of it provides useful insight into the direct and indirect role water quality plays as a component of fish habitat within the Talkeetna to Devil Canyon segment of the Susitna River.

Table IV-7. Mean baseline water quality characteristics for middle Susitna River at Gold Creek under (a) turbid summer (June-August) conditions and (b) clear, winter (November-April) conditions (from Alaska Power Authority 1983b).

Parameter (Symbol or Abbreviation)	Units of Measure	Turbid (summer)	Clear (Winter)
Total Suspended Solids (TSS)	mg/l	700	5
Turbidity	NTU	200	<1
Total Dissolved Solids (TDS)	mg/l	90	150
Conductivity	(μmhos cm^{-1}, 25°C)	145	240
pH	pH units	7.3	7.5
Alkalinity	mg/l as $CaCO_3$	50	73
Hardness	mg/l as $CaCO_3$	62	96
Sulfate (SO_4^{-2})	mg/l	14	20
Chloride (Cl^-)	mg/l	5.6	22
Dissolved Calcium (Ca^{+2})	mg/l	19	29
Dissolved Magnesium (Mg^{+2})	mg/l	3.0	5.5
Sodium (Na^+)	mg/l	4.2	11.5
Dissolved Potassium (K^+)	mg/l	2.2	2.2
Dissolved Oxygen (DO)	mg/l	11.5	13.9
DO (% Saturation)	%	102	98.0
Chemical Oxygen Demand (COD)	mg/l	11	9
Total Organic Carbon (TOC)	mg/l	2.5	2.2
True Color	pcu	15	5
Total Phosphorous	µg/l	120	30
Nitrate-nitrogen as N (NO_3-N)	mg/l	0.15	0.15
Total Recoverable Cadmium [Cd(t)]	µg/l	2.0	<1
Total Recoverable Copper [Cu(t)]	µg/l	70	<5
Total Recoverable Iron [Fe(t)]	µg/l	14,000	<100
Total Recoverable Lead [Pb(t)]	µg/l	55	<10
Total Recoverable Mercury [Hg(t)]	µg/l	0.30	0.10
Total Recoverable Nickel [Ni(t)]	µg/l	30	2
Total Recoverable Zinc [Zn(t)]	µg/l	70	10

Effects of Water Quality on Habitat Types

Mainstem and Side Channel Habitats

A comparison of the summer and winter water quality record for the Susitna River at Gold Creek (refer Table IV-7) reveals a seasonal contrast in the water quality conditions of the mainstem and its associated side channels. During winter almost all the flowing water is covered with ice and snow. However, high velocity areas in the mainstem and small isolated areas of warm (3-4°C) upwelling groundwater maintain scattered open leads in side sloughs and some side channels. During late March and April open leads begin to appear where groundwater occurs along mainstem and side channel margins or at mid-channel islands and gravel bars. A winter-spring transition algal bloom probably occurs at these open leads prior to breakup in mid-May.

During May (spring breakup) stream flow rapidly increases from approximately 2,000 cfs to 20,000 cfs or greater. Suspended sediment concentrations fluctuate considerably (9 - 1,670 mg/l), but average approximately 360 mg/l (Peratrovich et al. 1982). Most of the benthic production that occurred during the winter-spring transition is likely dislodged and swept downstream. A portion of this material may follow the natural flow path along the mainstem margin and into peripheral side channels and sloughs. Thus high spring flows may redistribute fish food organisms and some of the organic production associated with the winter-spring transition. At prevailing springtime turbidities (50 to 100 NTU), the euphotic zone is estimated to extend to an average depth of between 1.2 and 3.5 ft (Van Nieuwenhuyse 1984). Hence, the mainstem margin and side channels is capable of supporting a low to moderate level of primary production wherever velocity is not limiting. In summer, mainstem turbidities increase to approximately 200 NTU and limit the total surface area available for primary production by reducing the depth of useful light penetration to less than 0.5 ft (Van Nieuwenhuyse 1984).

Largely because of its water quality (especially its high suspended sediment concentration), high velocities and large substrate, the principal function of mainstem habitat during the summer months is to provide a transportation corridor for inmigrating spawning salmon and outmigrating smolts. Mainstem water quality also has a significant influence on the seasonal water quality regime of side slough habitats when overtopping of side slough occurs.

Field observations made in 1984 by EWT&A suggested that during the autumn transition period, a second pulse of primary production may occur in the mainstem and side channel habitats. The Fall pulse appears, dominated by green filamentous algae rather than diatoms. This second bloom, induced by moderating stream flows and a notable reduction in turbidity levels to less than 20 NTU, probably exceeds the winter-spring transition bloom in terms of surface area affected and biomass produced. This fall-winter bloom probably stops with the onset of freezeup. Hence in some years, as in 1984, the autumn transition may span eight to ten weeks and the primary production can be significant, while in other years, such as 1983, freezeup can occur within three to four weeks after the river begins to clear.

Side Slough Habitats

Side sloughs present a unique seasonal pattern of streamflow and water quality that is important to many fish species inhabiting the middle Susitna River. The most significant changes in side slough water quality are associated with their periodic overtopping by mainstem discharge that temporarily transforms the clear water side slough habitat into turbid water side channel habitat. During each overtopping event, the side slough water quality and temperature are dominated by the prevailing characteristics of the mainstem. Overtopping during summer generally causes an increase in turbidity from zero to near 200 NTU and a temperature increase from 6°C to 10 or 12°C. Overtopping during winter has little effect on turbidity but reduces surface and intragravel water temperatures from 3°C to zero.

Field observations by EWT&A suggest that some of the sediment carried through sloughs seems to become part of an organic matrix of unknown composition (probably involving bacteria, fungi, and other microbes) which in turn is usually covered by a layer of pennate diatoms and/or colonial and filamentous algae. This benthic community, which covers most streambed material greater than 2 to 3 inches in diameter, can be observed throughout the middle Susitna River in mainstem and side channel habitats as well. It is possible that the phosphorus associated with the sediment plays some role in supporting the organic matrix and studies (Stanford, Univ. of Montana, pers. comm. 1984) elsewhere indicate that as much as 6 percent or more of this sediment-bound total phosphorus can become biologically available -- perhaps to the diatoms. This might help explain how primary producers can still maintain a viable presence even under short-term highly turbid conditions.

During late September and early October 1984, fall-winter transitional algal blooms were observed by EWT&A in most side sloughs and are suspected to occur every year. The 1984 bloom was characterized by dense mats of filamentous green algae growing on submerged streambed materials one inch in diameter and larger.

In winter, side slough discharge is often maintained by numerous groundwater upwellings which generally range between 2° and 4°C. During winter upwelling areas often maintain open leads in the ice cover and they provide intragravel habitat for incubating embryos and overwintering opportunities for juvenile anadromous and resident fish (ADF&G, Su Hydro 1983c).

During the winter-spring transition period (late March to mid-May) side slough surface water temperatures exceed intragravel water temperatures during portions of the day but are cooler than intragravel temperatures during the night (Trihey 1982; ADF&G, Su Hydro 1983a). Primary production rates probably increase at this time. Chum, sockeye and pink fry emerge from natal areas within the sloughs during this transition period and can be observed swimming and feeding in quiescent pools during the warm portions of the day. During the remainder of the day the fry appear to have burrowed into the streambed.

Upland Slough Habitats

Upland slough habitat is distinguished from side slough habitat by the lack of overtopping of the upstream slough end by high mainstem discharges. Groundwater upwelling and local runoff dominate the water quality characteristics of these habitats and turbidities are typically less than 5 NTU throughout the year. Surface and intragravel water temperatures are similar to side sloughs. The slough mouths are influenced by turbid backwater effects from the mainstem.

Tributary and Tributary Mouth Habitats

The seasonal water quality pattern displayed by the tributaries is closely linked to their annual flow regimes. This pattern is of considerable interest since it is in the tributaries--most notably Portage Creek, Indian River, and Fourth of July Creek--where most of the fish production for the middle Susitna River originates (ADF&G 1981; ADF&G, Su Hydro 1982b; Barrett et al. 1984). These streams provide spawning, rearing, and overwintering habitat that either does not exist, or only exists in limited amounts in other habitat types. Tributaries, in effect, represent the most productive of the aquatic habitats in the middle Susitna River. Thus, although not influenced by the Susitna River streamflow or water quality regimes, valuable insight can be gained by understanding similarities and differences between the water quality of the tributaries and the Susitna River.

The ionic composition of tributary water likely conforms to the hydrologic principle that the soils of a stream basin generally govern the quantity and the quality of the solids contained in the water flowing from it. The moderate concentrations of macronutrients (phosphorus and nitrogen) that prevail in these streams probably represent only that which leaks from the internal cycling taking place in the soils of the local watershed. Although production levels are thought to be determined by water quality, variations in productivity levels within these tributaries are probably due more to hydraulic and hydrologic conditions than to water quality.

In winter, tributary flow is minimal and is predominantly comprised of groundwater rising up through the bed of the stream channel. Since much of the winter mainstem flow is comprised of contributions made by groundwater and tributary sources, tributary water chemistry is probably reflected in the winter water chemistry characteristics of the mainstem (refer Table IV-7). Thus, the water quality characteristics of tributaries during winter reflect a well-buffered, well-oxygenated environment for embryo incubation and adult and juvenile overwintering.

During the April-May transition between winter and the onset of spring runoff, portions of the ice and snow cover on the tributary melt away. Water temperatures may increase slightly and a pulse of primary production probably occurs in response to a lengthening photoperiod (Hynes 1970). The ability of light to reach the algal community is assisted by the absence of leaf cover on stream bank vegetation and by the presence of rotten ice that effectively transmits light (LaPerriere, Univ. of Alaska, pers. comm. 1984). The emergence of some fish species and many insects is apparently timed to occur during this brief early-spring transition.

By mid-May air temperatures in the middle Susitna have increased to 8°C and spring runoff from melting snow has filled the tributary channel. Spring flooding generally causes redistribution of portions of the streambed, displacement of fish from overwintering habitat, and the flushing of organic and inorganic debris, as well as much of the benthic community from the stream (Hynes 1970). This erosion causes an increase in suspended sediment concentration and turbidity. Likewise, color, total organic carbon, and chemical oxygen demand increase substantially, while the inflow of surface runoff dilutes winter concentrations of dissolved solids. It is likely that the spring freshet serves as a functional reset mechanism for the system; cleansing it in preparation for the sequence of ecological events to follow.

Summer is the season when juvenile fish are most active. Typical water quality in tributaries during the summer (June to mid-September) probably approximates the winter condition except for lesser concentrations of dissolved solids and warmer stream temperatures which fluctuate diurnally. Rearing is supported primarily by the growth and recruitment taking place within the aquatic insect community (especially chironomids). The carrying capacity of tributaries, however, does not appear adequate to support the large numbers of rearing juveniles, so many juveniles outmigrate at this time to continue their development elsewhere (Dugan et al. 1984).

During late September and early October a second transition period occurs as streamflow, photoperiod, and temperature gradually decline. Algal biomass and productivity are probably at their annual peak during this time, as is the standing crop of benthic macroinvertebrates (Hynes 1970). This algal mat is not only a food source for a variety of insect larvae and nymphs, but also serves as microhabitat for many aquatic organisms including juvenile fish. The leaves shed from riparian vegetation may provide further microhabitat and insect food substrate.

By late October, surface water temperatures are 0°C and an ice cover begins to form. Unstable border ice and anchor ice probably dislodge a substantial portion of the benthic community, causing it to be swept downstream. Much of what remains of this community may be frozen in place as the ice cover formation continues. Freezeup is usually complete by late November or early December when the winter phase of the annual cycle begins once again.

With-Project Relationships

Seasonal stream temperatures, suspended sediment concentrations and turbidities influence the quality of aquatic habitat types in the middle Susitna River, and therefore are important to the distribution and production of fish. It is also evident that these water quality parameters will be more directly affected by construction and operation of the proposed project than will other water quality parameters (Peratrovich et al. 1982; Univ. of Alaska, AEIDC 1985a). The following discussion focuses on with-project relationships between suspended sediment and turbidity. Stream temperature is discussed in the following section of this report.

The suspended sediment regime of the Susitna River downstream of the impoundments will change significantly as a result of project construction. Project operation is thought to have a minor influence on downstream suspended sediment concentrations. The reservoir(s) is estimated to trap between 70 and 98 percent of the total volume of sediments that are annually transported through the middle Susitna River (R&M 1982d; Harza-Ebasco 1984e). Very fine sediment particles ($<5\mu$ in diameter) will remain in suspension year round within the reservoirs (APA 1983b). These small particles create a turbidity far greater in proportion to their mass than do larger particles. Estimates for the expected concentration of total suspended solids released year round from the reservoir (s) range from 0 to 345 mg/l, with the expected average to range between 30 and 200 mg/l (Peratrovich et al. 1982). More recent estimates (Harza-Ebasco 1985e) indicate that suspended sediment concentrations in the outflow from Watana Reservoir during the year would range between 30 and 130 mg/l for stages I and II, and between 10 and 80 mg/l during the year for stage III.

Although a relationship between total suspended solids (TSS) and turbidity (NTU) is difficult to define, settling column studies of Susitna River water indicate that turbidity (NTU) is approximately twice the suspended sediment concentration (mg/l) (R&M 1984c). Lloyd (1985) has also compiled a relationship between turbidity and suspended sediment concentrations using data from several glacial streams in Alaska (Fig. IV-7). Unfortunately, an order of magnitude difference in turbidity is calculated for the same suspended sediment concentration using these relationships (Table IV-8). To date, insufficient information is available to determine which of these relationships is more applicable to project conditions.

However, a relationship between turbidity (NTU) and compensation depth (feet) developed by Van Nieuwenhuyse (1984) indicates the depth to which photoactive radiation might penetrate the middle Susitna River under a broad range of turbidities (Fig. IV-8). Evaluation of with-project turbidity and streamflow levels on the euphotic surface area of the middle Susitna River is in progress (Reub et al. 1985).

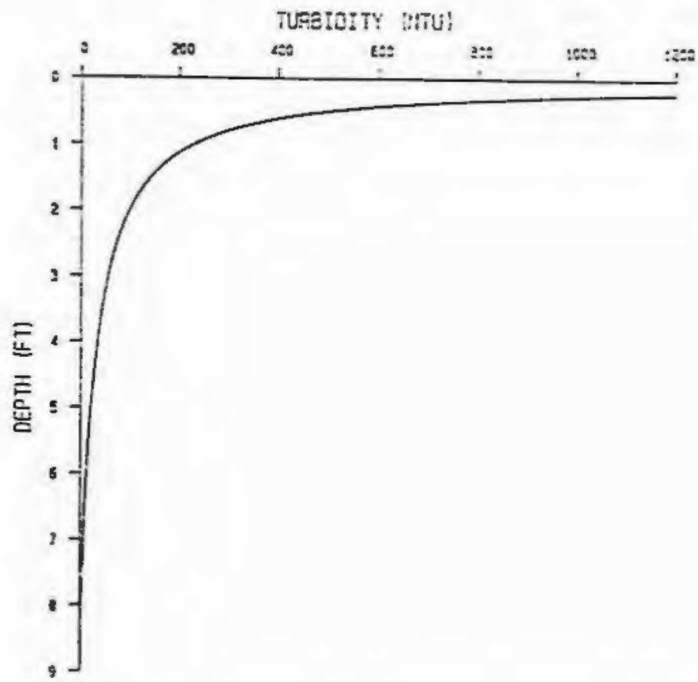


Figure IV-8. Theoretical curve of turbidity versus compensation depth (Reub et al. 1985).

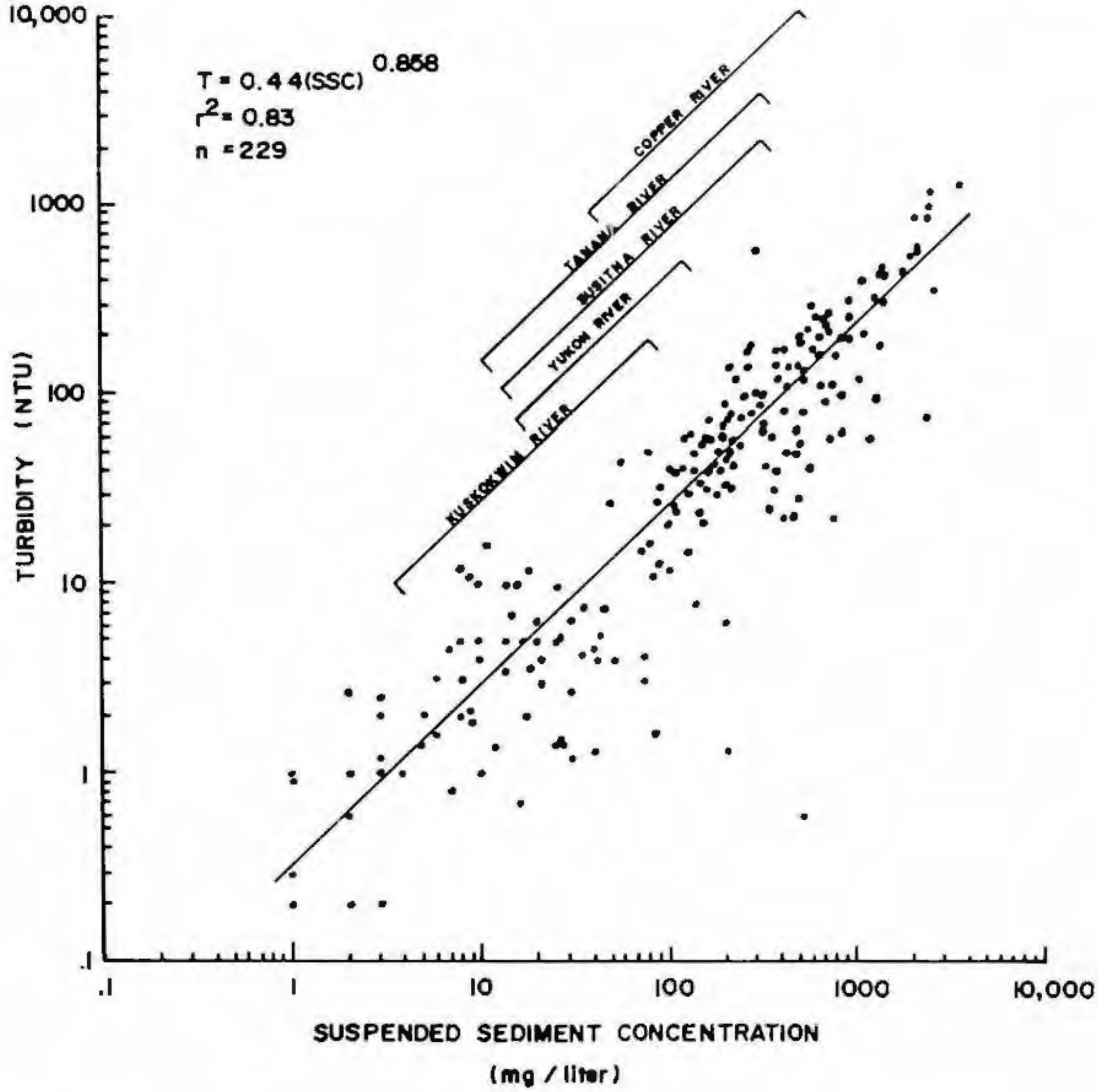


Figure IV-7. Empirical relationship of naturally occurring turbidity versus suspended sediment concentration for rivers in Alaska, sampled during May - October, 1976-1983 (Lloyd 1985, derived from data provided by USGS).

Table IV-8. Difference in compensation depths calculated from with-project suspended sediment concentrations (mg/l) using two different relationships between turbidity (NTU) and TSS.

Forecast TSS Concentrations	Estimated NTU Range	Corresponding Compensation Van Nieuwenhuyse
1. 30 to 200 mg/l	a) 60 to 400 NTU	3.5 to 1 feet
	b) 10 to 40 NTU	4 feet
2. 30 to 130 mg/l	a) 60 to 260 NTU	3.5 to 1 feet
	b) 10 to 30 NTU	4.5 feet
3. 10 to 80 mg/l	a) 20 to 160 NTU	4 to 1.5 feet
	b) 5 to 15 NTU	5 feet

1. Peratrovich, Nottingham and Drage Inc. and Hutchinson 1982.

2. Stages I and II, Harza-Ebasco 1985a.

3. Stage III, Harza-Ebasco 1985a.

a) R&M Consultants 1984c.

b) Lloyd 1985.

Primary production in the middle reach of the Susitna River presently appears to be concentrated in the spring and fall periods of low turbidities, although no quantitative data are available to document this observation. Constant, year-round turbidity levels in the range of 60 to 600 NTU would likely reduce the level of primary production during these transition periods, although primary production may increase during summer months. The net result of these opposing processes has not been forecast at present.

Instream Temperature and Ice Processes

Temperature Criteria for Fish

For the range of stream temperatures encountered in northern rivers, increases in stream temperature generally cause an increase in the rate of chemical reactions, primary production, and cycling of allochthonous food sources. Fish, being poikilothermic inhabitants of the river, adjust their body temperatures to match the temperature of the water. As stream temperatures increase, rates of digestion, circulation and respiration of fish increase. Thus, there is an overall increase in the rate of energy input, nutrient cycling and energy use by fish as any northern river system warms.

Each species of fish is physiologically adapted to survive within a tolerance range of stream temperature. Within this tolerance range there is a narrower range of "preferred" temperatures at which metabolism and growth rates of individuals are most efficient. Outside the tolerance range are upper and lower incipient lethal limits.

For the middle Susitna River, the preferred temperature range of adult salmon is 6 to 12°C (Univ. of Alaska, AEIDC 1985a). Juvenile salmon appear to prefer slightly warmer temperatures, generally ranging from 7 to 14°C (Table IV-9). These temperatures are consistent with the preferred temperature range of 7 to 13°C reported by McNeil and Bailey (1975) for Pacific salmon. The preferred temperature range for salmon incubation is generally between 4 and 10°C.

The time required for the incubation of salmon embryos is directly related to stream temperature. Development rates increase with rising stream temperature up to approximately 14°C. Above this, further temperature increases are considered detrimental. Salmon embryos are also vulnerable to cold temperatures until they have accumulated

Table IV-9. Preliminary stream temperature criteria for Pacific salmon developed from literature sources for application to the Susitna River (University of Alaska, AEIDC 1984).

Species	Life Phase	Temperature Range (°C) Tolerance	Preferred
Chum	Adult Migration	1.5-18.0	6.0-13.0
	Spawning	1.0-14.0	6.0-13.0
	Incubation[1]	0-12.0	2.0-8.0
	Rearing	1.5-16.0	5.0-15.0
	Smolt Migration	3.0-13.0	5.0-12.0
Sockeye	Adult Migration	2.5-16.0	6.0-12.0
	Spawning	4.0-14.0	6.0-12.0
	Incubation[1]	0-14.0	4.5-8.0
	Rearing	2.0-16.0	7.0-14.0
	Smolt Migration	4.0-18.0	5.0-12.0
Pink	Adult Migration	5.0-18.0	7.0-13.0
	Spawning	7.0-18.0	8.0-13.0
	Incubation[1]	0-13.0	4.0-10.0
	Smolt Migration	4.0-13.0	5.0-12.0
Chinook	Adult Migration	2.0-16.0	7.0-13.0
	Spawning	5.0-14.0	7.0-12.0
	Incubation[1]	0-16.0	4.0-12.0
	Rearing	2.0-16.0	7.0-14.0
	Smolt Migration	4.0-16.0	7.0-14.0
Coho	Adult Migration	2.0-18.0	6.0-11.0
	Spawning	2.0-17.0	6.0-13.0
	Incubation[1]	0-14.0	4.0-10.0
	Smolt Migration	2.0-16.0	6.0-12.0

[1] Embryo incubation or development rate increases as temperature rises. Accumulated temperature units or days to emergence should be determined for each species for incubation.

approximately 140 centigrade temperature units (CTU)[1], after which their sensitivity to cold temperatures has passed and the incubating embryos can tolerate water temperatures near 0°C for extended periods of time.

Table IV-10 provides a comparison between the number of CTU that resulted in 50 percent hatching and 50 percent emergence of chum salmon alevins under both field and laboratory environments. The number of temperature units that resulted in 50 percent hatching and 50 percent emergence of chum and sockeye alevins at selected middle Susitna River sloughs appear to be similar to that required by Alaskan stocks of these species under controlled conditions (ADF&G, Su Hydro 1983c). Collectively, these data indicate that 400 to 500 CTU can be used as an index for 50 percent hatching of chum and sockeye eggs.

The relationship between mean incubation temperature and development rate for chum embryos is presented in the form of a nomograph (Fig. IV-9). This nomograph can be used to estimate the date of 50 percent emergence given the spawning date and the mean daily intragravel water temperature for the incubation period. A straight line projected from the spawning date on the left axis through the mean incubation temperature on the middle axis identifies the date of emergence on the right axis.

Instream Temperature Processes

Stream temperature in northern rivers responds primarily to the seasonal variation of the local climate and hydrologic conditions.

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[1] A centigrade temperature unit (CTU) is the index used to measure the influences of temperature on embryonic development and is defined as one 24 hour period 1°C above freezing (0°C). Hence stream temperatures at 4.7°C for 3 days would provide 14 centigrade temperature units.

Table IV-10. Comparison of accumulated centigrade temperature units (CTU) needed to produce 50 percent hatching of chum salmon eggs and 50 percent emergence of chum salmon alevins at selected sites on the Susitna River with those required under controlled incubating environments elsewhere in Alaska (from ADF&G, Su Hydro 1983c).

Location	Brood Year	CTU required for 50% Hatching	CTU required for 50% Emergence[1]
Susitna River - Slough 8A	1982	539	---[2]
Susitna River - Slough 11	1982	501	232
Susitna River - Slough 21 Mouth	1982	534	283
Clear Hatchery[3]	1977	420	313
Clear Hatchery[3]	1978	455	393
Eklutna Hatchery[4]	1981	802	209
USFWS Laboratory - Anchorage[5]	1982	306	---
USFWS Laboratory - Anchorage[5]	1982	448	---
USFWS Laboratory - Anchorage[5]	1982	489	---
USFWS Laboratory - Anchorage[5]	1982	472	---

[1] Calculated from the time of 50 percent hatching to the time of 50 percent emergence.

[2] No emergence had occurred as of April 20.

[3] Raymond (1981).

[4] Loren Waldron, Eklutna Hatchery, personal communication.

[5] Adapted from Waangard and Burger (1983).

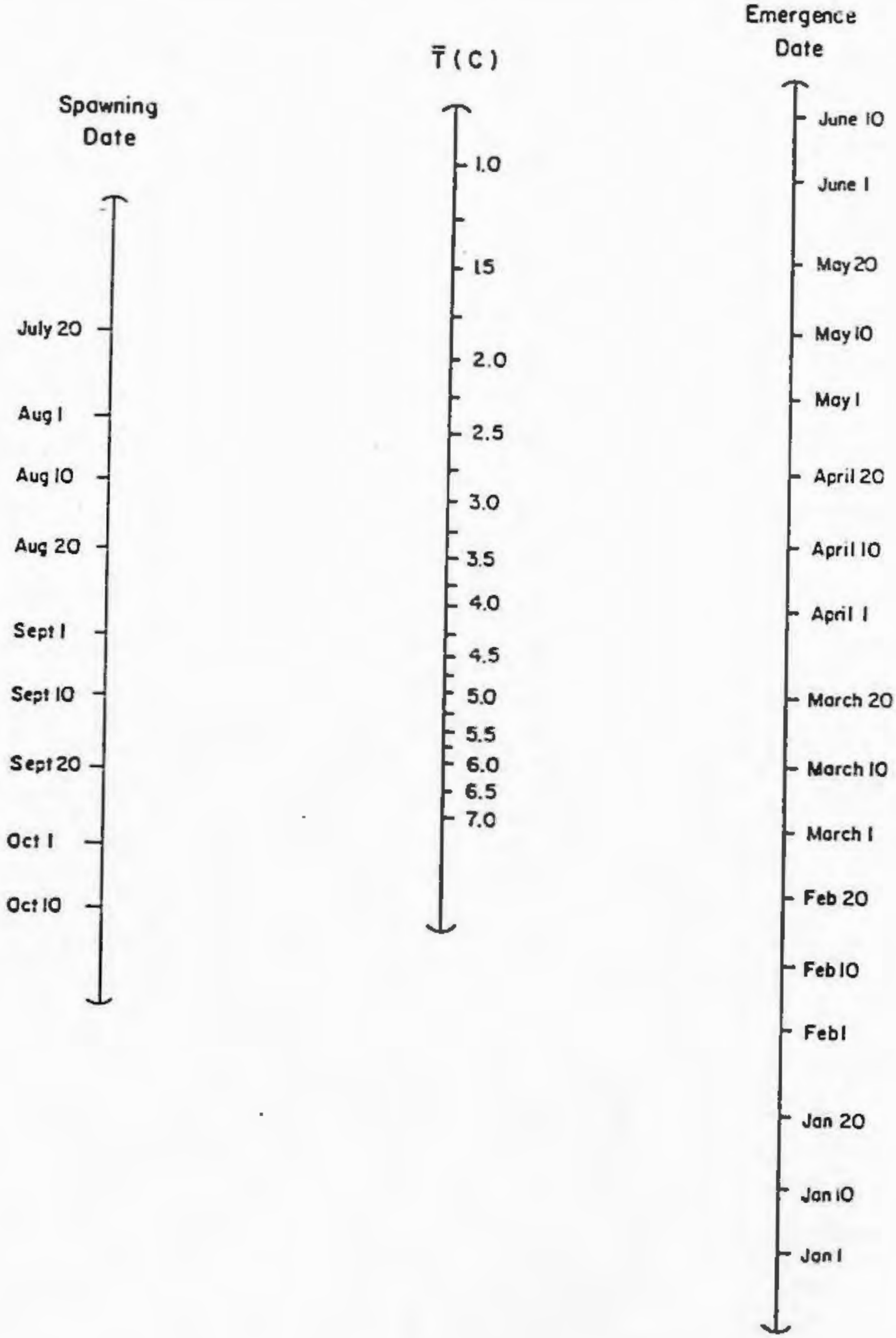

Figure IV-9. Chum salmon spawning time versus mean incubation temperature nomograph (Univ. of Alaska, AEIDC 1985a).

Heat transfer between the atmosphere and an open water surface principally occurs through convection, evaporation/condensation and radiation. Heat transfer by convection and evaporation/condensation responds directly to wind speed and the temperature differential across the air-water interface. Radiative heat transfer consists of two types: shortwave and longwave radiation. Both short- and longwave radiation are significantly influenced by basin topography, percent cloud cover, and surrounding vegetation. At higher latitudes incoming shortwave radiation is highly variable because of seasonal differences in the solar azimuth which influences the intensity of the shortwave radiation per unit area and the length of the daylight period.

In addition to atmospheric processes, water temperature in the middle Susitna River is influenced by its water sources. These are: glacial melt, tributary inflow, and groundwater inflow. The relative importance of each of these to mainstem flow and temperature at Gold Creek varies seasonally.

Tributary inflow increases during snow melt periods and in response to rainstorms, while the occurrence of glacial meltwater is predominantly a summer phenomena. Groundwater inflow, however, appears to remain fairly constant throughout the year. Hence its relative importance increases during winter as inflows from glacial melt and surface runoff cease. Tributary inflows themselves diminish to base levels maintained by groundwater inflow from their sub-basins.

The temperature of these influent sources also varies. Groundwater remains near 3 to 4°C throughout the year (ADF&G, Su Hydro 1983c). While glacial meltwater at the headwaters of the Susitna River is near 0°C, but it is warmed by the heat transfer processes described earlier as it flows downstream. Temperature of tributary waters are generally cooler than the temperature of the mainstem, especially during May and June when most of their streamflow consists of snow melt (Fig. IV-10). Tributary inflows characteristically hug the mainstem shoreline after

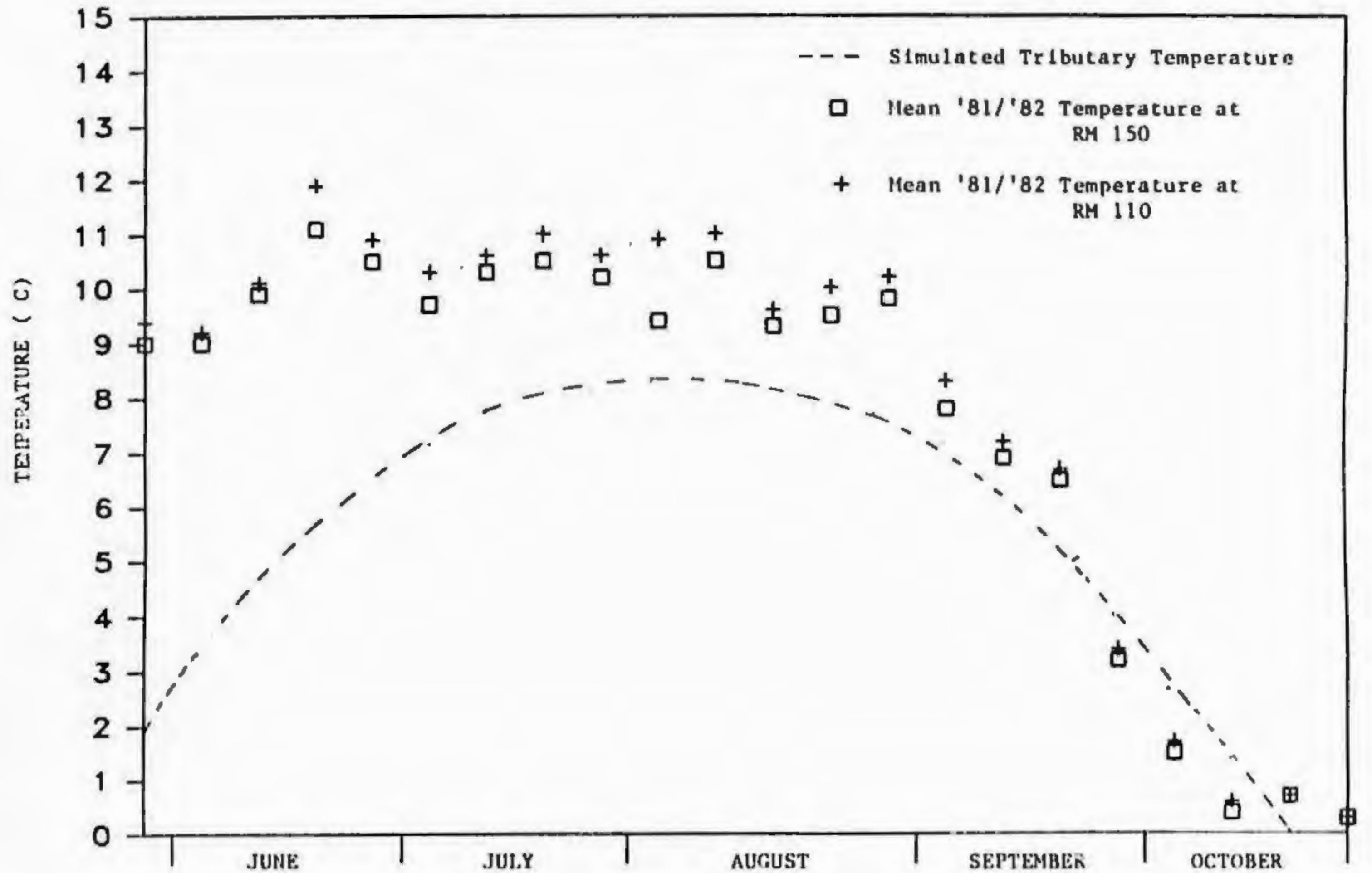

Figure IV-10. Comparison between average weekly stream temperatures for the Susitna River and its tributaries (adapted from Univ. of Alaska, AEIDC 1985a).

converging with the Susitna River, forming a plume that may extend several hundred feet downstream. Hence, tributary water temperatures determine surface water temperatures in tributary mouth habitats but have little effect on mainstem water temperatures.

In general, mainstem water temperatures normally range from zero during the November-April period to 11 or 12°C from late June to mid-July. Water temperatures typically increase from 0 to 8°C during May and gradually decrease from 9 or 10°C in early September to 0°C by mid to late October. Water temperatures in side channels reflect mainstem temperatures unless the mainstem discharge is too low for the side channel to convey mainstem water. Surface water temperatures in side sloughs, except when overtopped by mainstem flow, are independent of mainstem water temperatures even though both may occasionally be the same temperature (Table IV-11).

Sloughs receive nearly al f their clear water flow from local runoff and groundwater inflow. sloughs receive substantial inflow from snowmelt or rainfall runo f, face water temperatures will reflect the temperature of that ru ue to relatively large surface areas in comparison to flow rat , rface water temperatures in side sloughs respond markedly to changes in solar radiation and air temperature. Surface water temperatures typically reach 5 or 6°C in quiescent areas within side sloughs by mid-April, approximately one month before similar water temperatures are reached in mainstem and side channel areas. Daily fluctuations in side slough surface water temperatures are more exaggerated than for mainstem or side channel water temperatures (Estes and Vincent-Lang 1984b). During winter, slough flow is primarily maintained by upwelling groundwater which possesses very stable temperatures around 3°C (ADF&G, Su Hydro 1983c). Hence, surface water temperatures in side sloughs are significantly influenced by the thermal quality of the upwellings; often remaining well above 0°C throughout most of the winter.

Side sloughs are occasionally overtopped by mainstem water when the mainstem ice cover is forming. The sudden influx of large volumes of

Table IV-11. Comparison between measured surface water temperatures (°C) in side sloughs and simulated average monthly mainstem temperatures (from ADF&G, Su Hydro 1983b, 1983c).

Location	RM	1982			1982					1983				
		Feb	Mar	Apr	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Slough 8A Mouth	125.4					6.5	2.4	1.7		0	0	0.4	1.3	
Slough 8A Upper	126.4					5.8	4.4					2.5	3.8	3.3
Slough 9	128.7				8.9	5.9	2.3						3.8	4.7
Slough 11	135.7		2.5	3.1		3.3	3.1	2.9	2.9	2.9	2.9	3.0	3.5	6.0
Slough 21	141.8	1.6	1.9	3.1			2.2	1.1	0.8					
Mainstem														
LRX 29	126.1	0.0	0.0	2.9	10.9	6.5	0.6	0.0	0.0	0.0	0.0	0.0	3.0	---
LRX 53	140.2	0.0	0.0	2.5	10.8	6.4	0.6	0.0	0.0	0.0	0.0	0.0	2.6	---

Note: Mainstem temperatures are simulated without an ice cover and warm earlier in the spring than what naturally occurs. Thus the April mainstem temperatures are probably warmer than what would occur.

zero degree water during freezeup severely disrupts the normal relationship between intragravel and surface water temperatures. Once the slough is overtopped, the small volume of relatively warm slough water, which serves to buffer submerged upwelling areas from extreme cold, is immediately replaced by a large volume of 0°C water and slush ice. As a result, the warm influence of the upwelling groundwater is diminished and intragravel water temperatures decrease from approximately 3°C to near 0°C (ADF&G, Su Hydro 1983c).

A similar condition occurs during spring breakup if ice jams cause large volumes of near-zero degree mainstem water to flow through side sloughs, flushing them of their substantially warmer surface water. Although little data are available for this period, intragravel water temperatures are not suspected to be as adversely affected by overtopping events during breakup as they are by overtopping during freeze-up because of the shorter duration of the breakup events.

With-Project Temperature Conditions

The cooling and warming of the middle Susitna River by the atmospheric processes would not be altered by the proposed project. However, construction and operation of the proposed Susitna Project would redistribute the available water supply and its associated heat energy through the year. During the summer months the reservoir would store heat while releasing smaller than natural flows having lower than natural temperatures. For the remainder of the year, both the amount and temperature of the released water would be greater than natural.

Addition of Devil Canyon reservoir would amplify the deviation of with-project stream temperatures from naturally occurring summer and winter temperatures at any given location within the middle Susitna River. In effect, the addition of Devil Canyon Reservoir would result in naturally occurring stream temperatures being affected further downstream. Those portions of the Susitna River most affected by with-project stream temperatures will be mainstem and side channel areas upstream from the three rivers confluence (RM 99) (Univ. of Alaska, AEIDC 1985a).

Project design and operation will influence the temperature and flow rate of water discharged from the dam(s). Table IV-12 displays the simulated downstream temperatures for two summer situations: water week 34 (May 20-26), where the downstream release temperatures are equal but release rates differ, and water week 45 (August 5-11) where release rates are equal but their temperatures differ. The 1.8°C temperature difference shown in the second case results in a greater difference in downstream temperature than occurs by changing streamflow 810 cfs, as shown in the first case. Table IV-13 displays downstream temperatures for two winter cases: (1) where reservoir outflows are the same but flow volumes change (in this case a 59 percent increase) and (2) where dam release flows are relatively constant (note: actually an 11 percent increase) but the temperatures of the reservoir outflows differ by approximately 1°C. As indicated by the previous example for summer releases, varying the temperature of the reservoir outflow results in greater downstream temperature differences than does varying the reservoir outflow. Hence, it can be concluded that within the anticipated operating range of the project, the temperature of the reservoir outflow has a greater influence on downstream water temperatures than flow rate.

However, basin climate is the most significant variable influencing winter stream temperature and river ice conditions (APA 1984a). Table IV-14 illustrates the substantial influence winter air temperature has on downstream water temperatures. A decrease in air temperature of approximately 8°C resulted in stream temperatures of 0.5°C to occur about 20 miles farther upstream.

Because of the possibility of using warm water releases from Watana Reservoirs to control ice cover formation on the middle Susitna River, Harza-Ebasco (1985c) evaluated alternative winter operating policies and intake designs which might effect the temperature of reservoir

Table IV-12. Downstream temperatures (°C) resulting from differences in summer reservoir release flows and temperatures.

		Water Week 34 (May 20 - 26, 1981)		Water Week 45 (August 5 - 11, 1974)	
		Dam Release: 6080 cfs Temp: 3.9°C	5270 cfs 3.9°C	Dam Release: 10,950 cfs Temp: 8.1°C	10,950 cfs 9.9°C
Middle River Cross Section	River Mile	2002 Demand	2020 Demand	2002 Demand	2020 Demand
68	150	4.5	4.5	8.2	9.9
53	140	4.9	5.0	8.5	10.1
33	130	5.4	5.5	8.6	10.1
23	120	6.0	6.1	9.0	10.4
13	110	6.5	6.7	9.4	10.7
3	99	7.1	7.3	9.8	11.0

Table IV-13. Downstream temperatures (°C) resulting from differences in winter reservoir release flows and temperatures.

Middle River Cross Section	River Mile	Water Week 9 (Nov. 26 - Dec. 2 1970)		Water Week 22 (Feb. 25 - March 3, 1982)	
		Dam Release: 7770 cfs Temp: 1.3 °C	12,370 cfs 1.3°C	Dam Release: 7190 cfs Temp: 2.8°C	8000 cfs 1.7°C
		2002 Demand	2020 Demand	2002 Demand	2020 Demand
68	150	1.3	1.3	2.7	1.7
53	140	0.7	0.9	2.2	1.2
33	130	0	0.4	1.5	0.7
23	120	0	0	0.8	0.1
13	110	0	0	0.2	0
3	99	0	0	0	0

Table IV-14. Comparison between simulated downstream water temperatures for constant reservoir outflow conditions and different air temperatures.

Middle River Cross Section	River Mile	Water Week 8 (Nov. 19-26, 1981) Dam Release: 7,590 cfs Release Temp: 1.9°C Air Temp: (Talkeetna) -11.6°C	Water Week 18 (Jan. 28-Feb. 3, 1983) Dam Release: 7,600 cfs Release Temp: 1.9°C Air Temp: (Talkeetna) -3.4°C
68	150	1.8	1.9
53	140	1.3	1.6
33	130	0.6	1.2
23	120	0	.8
13	110	0	.5
3	99	0	0

Note: Both simulations are for Devil Canyon dam, 2002 Demand.

outflows. The alternative policies evaluated include "inflow temperature matching," "warmest water available" and "lowest port."

The inflow-matching policy, which was used for the "Instream Ice Simulation Study" (Harza-Ebasco 1984c) and has been adopted by the Alaska Power Authority for the License Application studies (APA 1983, 1985), represents a year-round attempt to match the reservoir release temperatures with the natural temperature of the flow entering the reservoir. Inflow temperature matching results in the release of the coldest water available to the power intakes during winter. The warmest water policy represents a year-round policy of releasing the warmest water available to the power intakes. For both inflow-matching and warmest water policies, the particular intake port selected for operation will vary with the changing reservoir levels and temperature profiles. The lowest port operating policy means that the lowest port of the multi-level power intake will be operated year-round regardless of water temperatures.

The warmest water and lowest port operating policies tend to reduce the maximum upstream extent of the ice cover as well as its thickness. These reductions result in fewer sloughs being overtopped relative to the inflow matching policy. However this trend does not hold for all situations due to the influence of antecedent seasonal climatic conditions. With the addition of Devil Canyon Dam (Stages II and III) these alternative operating policies have no significant effect on ice cover over the inflow matching policy.

Use of a low level intake port would also tend to reduce somewhat the upstream extent and thickness of the ice cover. However, substantial reductions in the ice conditions are not expected to occur consistently unless a very low intake port is provided (Harza-Ebasco 1985d).

Ice Processes

Figure IV-11 diagrams ice formation processes within the middle Susitna River. In order to understand the flow chart and subsequent discussions in this text, the following definitions for the most common types of ice found in the middle Susitna River have been adopted from R&M (1984b).

- Frazil - Individual crystals of ice generally believed to form around a nucleating agent when water becomes super-cooled.

- Frazil slush - Frazil ice that agglomerates into loosely packed clusters resembling slush. The slush eventually gains sufficient mass and buoyancy to counteract the flow turbulence and float on the water surface.

- Snow slush - Similar to frazil slush but formed by loosely packed snow particles in the stream.

- Black ice - Black ice initially forms as individual crystals on the water surface in near-zero velocity areas in rivers or underneath an existing ice cover. These crystals develop in an orderly arrangement resulting in a compact structure which is far stronger than slush ice covers. Black ice developing in the absence of frazil crystals is characteristically translucent. This type of ice can also grow into clear layers several feet thick within the Susitna slush ice cover.

- Shore ice or Border ice - This forms along flow margins as a result of slush ice drifting into low velocity areas and freezing against the channel bed.

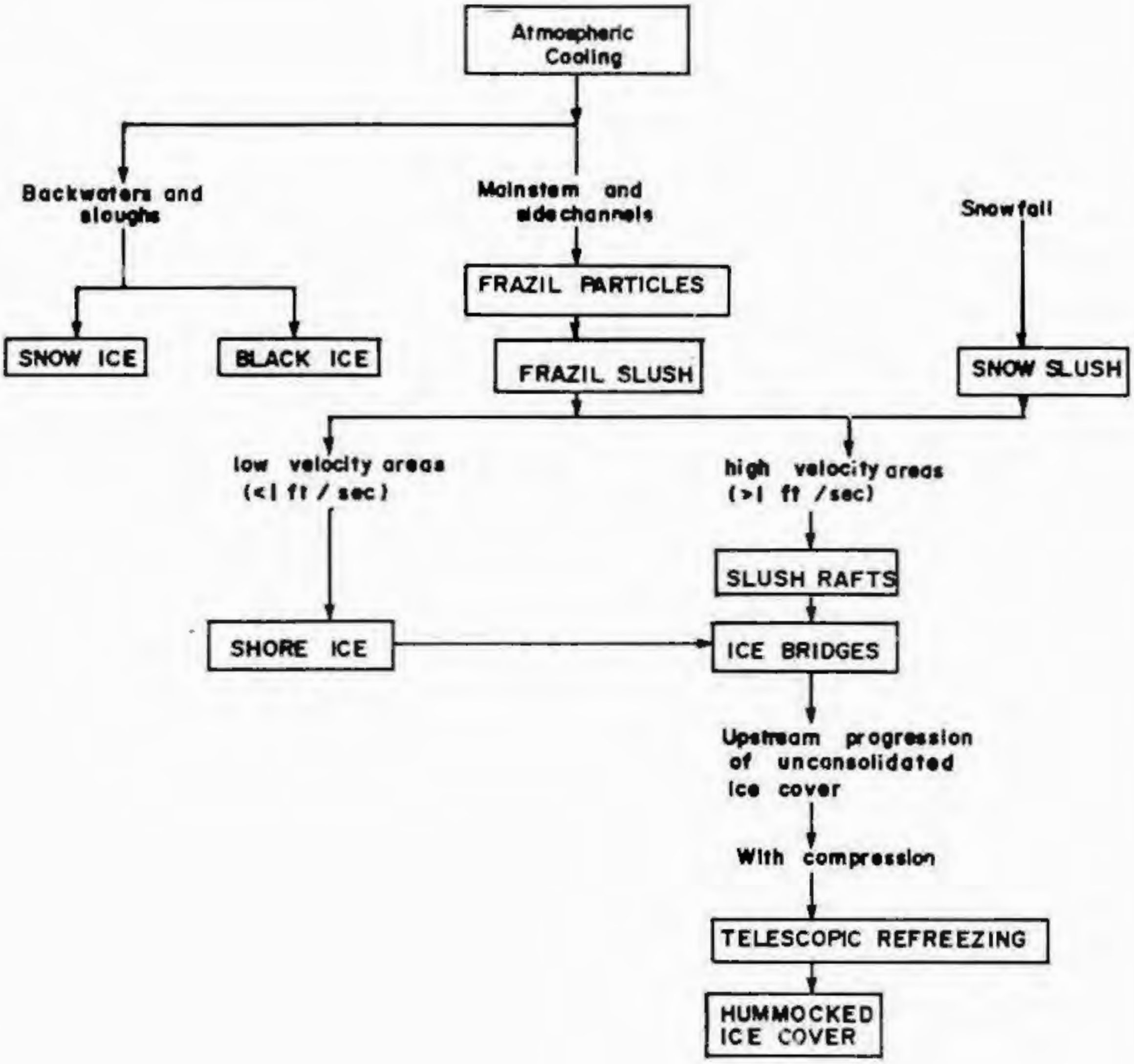

Figure IV-11. Generalized flowchart of ice formation processes within the middle reach of the Susitna River.

- Ice bridges - These generally form when shore ice grows out from the banks to such an extent that a local water surface constriction results. Large volumes of slush ice may not be able to negotiate this constriction at the same rate as the water velocity. An accumulation of slush subsequently occurs at the constriction, sometimes freezing into a continuous solid ice cover or bridge. This ice bridge usually prevents slush rafts from continuing downstream, initiating an upstream accumulation or progression of ice.

- Hummocked ice - This is the most common form of ice cover on the Susitna mainstem and side channel areas. It is formed by continuous accumulation of consolidated slush rafts that progressively build up behind ice bridges, causing the ice cover to migrate upstream during freezeup.

Freezeup

Frazil Ice Generation. Most river ice covers are formed as a result of the formation and concentration of frazil ice. When river water becomes slightly supercooled (0°C), frazil crystals begin to form by nucleation or by a mass exchange mechanism between the water surface and the cold air. In the Susitna River fine suspended sediments may be the nucleating agent in the Susitna River. In the mass exchange mechanism, initial nucleation occurs in the air above the water surface and the ice crystals fall into the water (Ashton 1978). Frazil crystals initially form as small disk-shaped crystals only a few millimeters in diameter. However, these small ice crystals grow rapidly in cold water and accumulate as frazil slush masses, float along on the stream surface. Snowfall often contributes to nucleation and accelerates frazil formation of floating snow slush. The slush mass usually breaks up into individual slush floes within turbulent portions of the river and continue drifting downriver until stopped by ice bridges at river constrictions (Michel 1971; Ashton 1978; Osterkamp 1978). The accumulation of drifting slush masses against an ice bridge results in the upstream progression of the river ice cover.

Frazil ice which contacts and attaches itself t the streambed is called anchor ice. Frazil ice only attaches to the bed when it is in the "active" state. That is, when climate conditions are such that the entire body of water at a given location is supercooled. Anchor ice often accumulates fine sediment by filtering water flowing over and through it. When air temperature rise or solar radiation increases, the stream temperature will warm from a supercooled condition to freezing. This results in a weakening of the bond between the anchor ice and the streambed. Flow momentum and buoyancy forces may become sufficient to discharge the anchor along with attached fine sediment and gravels. The buoyant anchor floats downstream to become included in the ice cover or to melt and release its sediment load.

Generally, frazil ice first appears in the Susitna River by mid-September between the Denali Highway bridge and Vee Canyon. This ice drifts downriver, often accumulating into loosely-bonded slush floes, until it melts or exits the lower Susitna River into Cook Inlet. Approximately 80 percent of the ice passing through the three rivers confluence into the lower Susitna River during freezeup, is produced in the upper and middle Susitna River, while the remaining 20 percent is produced in the Talkeetna and Chulitna Rivers (R&M 1985b). An excess of 50 percent of the ice occurring in the lower Susitna River downstream from the Yentna River confluence is produced by the Yentna River (APA 1984a).

Talkeetna to Gold Creek. The leading edge of the ice cover usually arrives at the confluence of the Susitna and Chulitna Rivers (RM 99) during November or early December (Table IV-15). The slush ice front progression from the Susitna/Chulitna confluence generally terminates in the vicinity of Gold Creek, about 35 to 40 miles upstream from the confluence, by late December or early January. Water flowing under the river ice cover often erodes the underside of the ice, causing open leads in the river ice cover downstream of the ice front. This usually occurs sh rtly after the initial stabilization of a slush ice

Table IV-15. Summary of freeze up observations for several locations within the Talkeetna to Devil Canyon reach of the Susitna River (R&M Consultants 1981a, 1982b, 1983a, 1984b).

Location	River Mile	1980-1981	1981-1982	1982-1983	1983-1984
<u>Ice Bridge or Ice Front At</u>					
Susitna-Chulitna confluence		Nov. 29	Nov. 18	Nov. 5	Dec. [illegible]
<u>Leading Edge Near</u>					
Gold Creek		Dec. 12	Dec. 31	Dec. 27	Jan. [illegible]
<u>Approximate Freezing Dates at</u>					
Susitna Chulitna					
Confluence	98.6		Mid-Nov.	Nov. 5	Dec. 9
"	103.3			Nov. 8	
"	104.3	Dec. 1			
"	106.2			Nov. 9	
"	108.0	Dec. 2			
"	112.9	Dec. 3			
Lane Creek	113.7			Nov. 15	
McKenzie Creek	116.7			Nov. 18	
"	118.8	Dec. 5			
Curry	120.7			Nov. 20	Dec. 11
Slough 8	124.5			Nov. 20	
"	126.5	Dec. 8			
"	127.0		Mid-Dec.	Nov. 22	
Slough 9	128.3			Nov. 29	
"	130.9			Dec. 1	Jan. 5
Slough 11	135.3			Dec. 6	
Gold Creek	136.6	Dec. 12	Early Jan.	Jan. 14	Jan. 1[illegible]
Portage Creek	148.9			Dec. 23	

cover. These leads may freeze over with the onset of very cold air temperatures. Generally most leads are closed by early March.

As the ice front moves upriver its rate of progression generally decreases. In 1982, the progression rate slowed from an average of 3.5 miles per day near the confluence to 0.05 miles per day by the time it reached Gold Creek (RM 136). This was attributed to the increased river gradient near Gold Creek and to the reduction in frazil ice input from the upper Susitna River because it had developed a continuous ice cover. The upper Susitna River generally freezes over by border ice growth and intermediate bridging before the leading edge of the middle river ice cover reaches Gold Creek.

Local groundwater levels are often raised as the leading edge of the ice cover approaches. As the ice cover forms on the river, mainstem water surface elevations rise in response to the blockage of streamflow by river ice. This process of raising the water level in the mainstem upstream of the ice cover is called staging. Increased water surface elevations are then propagated through permeable river sediments into surrounding sloughs and side channels.

Many sloughs do not form a continuous ice cover or an ice cover which persists all winter due to the relatively warm (1-3°C) temperature of upwelling groundwater (Trihey 1982; ADF&G, Su Hydro 1983c). However, ice does form along slough margins, restricting the open water area to a narrow, open lead. Some portions of the sloughs that form black ice covers during the fall and early winter later melt out because mainstem staging increases upwelling rates and the associated thermal influence of the groundwater. These leads often remain open through the remainder of winter.

Generally, an ice cover has formed on the Susitna River at Devil Canyon (RM 150) by the time the ice front reaches Gold Creek (RM 136) in early January (R&M 1983a). Hence, the ice front is slow to advance upstream of Gold Creek because of the lack of slush ice from above

Devil Canyon. Also the higher mainstem velocities above Gold Creek, caused by the steeper channel gradient, make it more difficult for the ice cover to advance by accumulation of slush ice against its leading edge. Hence that portion of the river between Gold Creek and Devil Canyon forms its ice cover later in the year and by a different process than the sub reach below Gold Creek.

Throughout the freezeup period shore ice extends out into the river continually incorporating slush ice, snow, and black ice into the formation. Extensive shore ice formations constrict the open water channel of the mainstem and frequently form ice bridges across the river. In the open water areas between the ice bridges, frazil ice adheres to the channel bottom, forming anchor ice. Anchor ice often accumulates forming submerged obstructions (dams) on the stream bed, increasing local water turbulence which then contributes to increased frazil generation. Slight backwaters are sometimes induced by the anchor ice obstructions which affect flow distribution between channels and cause overflow onto the shore ice. Within these backwater areas, slush ice may freeze into ice bridges because of reduced surface velocity.

Little staging has been observed on the middle Susitna River between Gold Creek and Devil Canyon. Accordingly, sloughs and side channels in this portion of the river are seldom overtopped during freezeup. Open leads often exist in side sloughs during winter due to groundwater inflow. Open leads also occur in the mainstem, but in association with high velocity areas between ice bridges. As opposed to the segment downstream of Gold Creek few leads reopen in this segment after the formation of the initial ice cover.

Breakup

The ice cover on the Susitna River presently disintegrates in the spring by a progression beginning with a slow, gradual deterioration and ending with a dramatic breakup drive accompanied by ice jams, flooding, and erosion (R&M 1983a). Although breakup always occurs between late April and mid-May, its duration depends on the intensity of solar radiation, air temperatures, and precipitation.

A pre-breakup period usually occurs by early April as snowmelt begins. Snowmelt begins first at the lower elevations near the Susitna River mouth and slowly works northward up the river. By late April, snow has usually disappeared on the river south of Talkeetna and the snowmelt is proceeding into the reach above the Susitna/Chulitna confluence. Tributaries to the lower river have usually broken out in their lower elevations, and open water exists at their confluences with the Susitna River. Increased flows from the tributaries erode the Susitna ice cover for considerable distances downstream from their confluences.

As water levels in the lower Susitna River begin to rise and fluctuate with spring snowmelt and precipitation, overflow onto the ice often occurs. Standing water which accumulates in depressions on the ice cover reduces the albedo (reflectivity) of the ice surface, and open leads quickly appear. In the steeper gradient middle Susitna River, the rising water level erodes the under-side of the ice cover and portions collapse into the river and drift downstream forming small ice jams at the end of the open lead. In this way, open leads continually become wider and longer until the ice cover is weakened and breaks up in a dramatic drive.

The disintegration of the ice cover into individual fragments, or floes, and the drift of these floes downstream and out of the river is called the "breakup drive". The natural spring breakup drive is largely associated with rapid flow increases, due to precipitation and snowmelt, which lift and fracture the ice surface. When the river discharge becomes high enough to break and move the ice sheet, the breakup drive begins. Its intensity is dependent upon meteorological conditions during the pre-breakup period.

Generally, the final destruction of the ice cover occurs in early to mid-May when a series of ice jams break in succession, adding their mass and momentum to the next jam downstream. This continues until the river is swept clean of ice, except for stranded ice floes along shore. Ice that has been pushed well up onto banks above the water level may last for several weeks before melting.

Major ice jams generally occur in shallow reaches with a narrow confining thalweg channel along one bank, or at sharp river bends. Major jams are commonly found adjacent to side channels or sloughs and may have played a part in their formation by causing catastrophic overflow and scouring at some time in the past. This is known to have happened at Slough 11 in 1976, as reported by local residents in the area, when a large ice jam flood transformed a small upland slough into a major side slough.

Breakup ice jams commonly cause rapid, local stage increases that continue rising until either the jam releases or the adjacent sloughs or side channels become flooded. While the jam holds, flow and large amounts of ice are diverted into adjacent side channels or sloughs, rapidly eroding away sections of riverbank and often pushing ice well up into the trees.

Effects of With-Project Instream Temperatures on Susitna River Ice Processes

The most important factors affecting freezeup of the Susitna River are air and water temperature, instream hydraulics, and channel morphology. The headwaters of the Susitna River are commonly subjected to freezing air temperature by mid-September, and slush ice has been observed in the Talkeetna-to-Devil Canyon reach as early as late September. Breakup is primarily influenced by antecedent snowpack conditions, air temperature and spring rainfall. Initial phases of ice cover deterioration commonly begin by mid-April, with ice-out generally completed by mid-May (R&M 1983a).

Instream ice modeling studies indicate that operation of the Susitna River Hydroelectric Project would have significant effects on downstream ice processes due to project-induced changes to winter streamflows and temperatures (Harza-Ebasco 1984c). Winter streamflows would be several times greater than natural and stream temperatures would increase from 0°C to between 0.5°C and 3°C depending upon the location downstream of the dam(s) (Univ. of Alaska, AEIDC 1985a).

With-Project Simulations, Freeze-up. The rate at which a river produces frazil ice is dependent upon the heat transfer across the air water interface. Therefore, the magnitude of below freezing air temperatures and the amount of open-water surface area are important considerations. The rate of frazil ice generation has been observed to decrease as surface area of a river segment conveys greater concentrations of floating slush ice. Therefore the ice discharge from a long river segment may approach a "saturation" condition in a relatively short distance dependent upon the air-water temperature differential. This "saturation" condition has been observed to occur naturally. The upper Susitna River often produces large volumes of frazil ice and no substantial additional generation is visually discernable below Devil Canyon (R&M 1983a).

Frazil ice generated in the Vee Canyon to Denali Highway river segment normally drifts through the middle Susitna River and provides a principal source of slush ice for ice cover formation on the lower Susitna River. The volume of ice supplied by the middle Susitna River during freeze-up has been estimated to be approximately 80% of the total ice supply at the Chulitna-Susitna confluence. With construction of Watana dam and reservoir this frazil ice would be trapped in the reservoir, unable to reach its normal destinations. Additionally, there would be a completely ice-free zone downstream of Watana Dam due to above 0°C reservoir outflow. With the construction of Devil Canyon Dam the location of the zero degree isotherm would be extended downstream, further reducing the amount of surface area within the middle Susitna River available for frazil ice production.

Downstream of the 0°C isotherm frazil ice would be produced as a function of air temperature and open water surface area. Therefore, if the 0°C isotherm is relatively close to the dam(s), large volumes of ice can still be produced in the middle Susitna River, and the effects of "trapping" the upper river ice supply and providing an ice-free zone downstream of dams would delay, but not prevent, formation of an ice cover on the lower Susitna River.

Arrival of the lower Susitna ice front at the confluence of the Yentna River (RM 26) usually occurs in late October or early November. This timing is not expected to be significantly altered by the project in spite of the reduced frazil ice supply from the middle Susitna River. Frazil ice contributions from the Yentna River and other major tributaries (Talkeetna and Chulitna Rivers) would not be influenced by the project and are considered adequate to maintain initial bridging of the lower Susitna River near RM 10 (APA 1984a). Based on this assumption, November 1 was used in the instream ice analysis (Harza-Ebasco 1984b) as a representative date for the ice front to pass above the Yentna River confluence. However, reduced frazil input from the middle Susitna River, combined with higher winter streamflows and temperatures would cause about a three-week delay (relative to natural conditions) of the ice front progression upstream of the three rivers confluence with Stage I operating. With stage II and III of the project in operation, the ice front progression would be further delayed from mid-December until late December or early January (Fig. IV-12a).

The warm water temperatures released from the dams would not cool to the freezing level for several miles downstream of the dams. Except for some shoreline border ice, ice would not form in this reach with Stage I operating. The maximum upstream extent of the ice cover during an average winter is expected to be in the vicinity of RM 139, however, it could vary from RM 124 to RM 142 depending upon winter climate and project operation. The extent of the ice cover would be reduced to the vicinity of RM 133 with Stage II operating and to

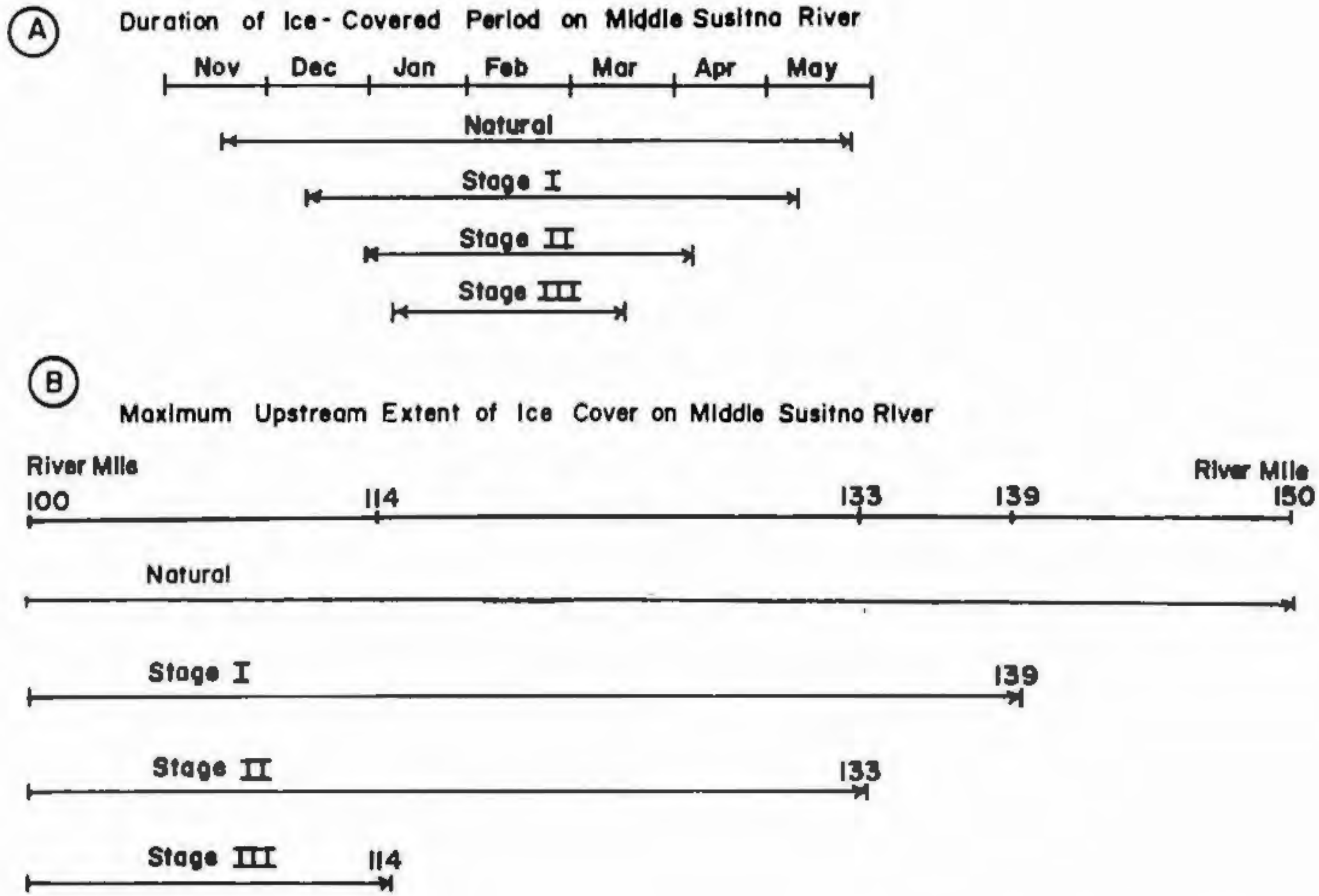

Figure IV-12. Duration of the ice-covered period and maximum upstream extent of ice cover on the middle Susitna River under natural and with-project conditions (adapted from Harza-Ebasco 1985d).

RM 114 under Stage III (Fig. IV-12b)). The ice front would reach its maximum upstream position between January and late March for Stage I and late January to early March for Stage III. The location of the ice front would fluctuate considerably throughout winter depending on prevailing air temperatures and project operation.

Under natural conditions, low streamflows occasionally cause secondary ice bridges to form upstream of the Susitna/Chulitna in advance of the main ice front. With the project in place, these low flow conditions would not occur and intermediate ice bridging is not expected to occur in the middle Susitna River. Increased winter streamflows would also cause water surface elevations of the mainstem to be significantly higher than natural. In the ice covered portion of the middle Susitna, winter staging is forecast between two and seven feet higher than natural. Downstream from the ice front, a greater number of sloughs and side channels would be more frequently overtopped than occurs naturally (Table IV-16).

Upstream from the ice front's maximum progression, water surface elevations would be higher than normal but freezeup staging would not occur. Water levels in that reach would be 1 to 3 feet lower than natural freezeup levels with Stage I operating and 1 to 5 feet lower with Stage III operating. No sloughs are expected to be overtopped in this reach by winter streamflows. However, the lower water levels in this reach may reduce the naturally occurring rate of groundwater upwelling in the sloughs.

Simulations generally have been made using an inflow-matching temperature criterion for operation of the multi-level intakes at Watana Dam. That is, power flows will be selected from levels which provide outflow temperatures most nearly equal to inflow temperatures. During winter, the inflow temperature is 0°C, but the outflow temperature is generally in the range of 1 to 3°C. Additional ice cover simulations have been made by Harza-Ebasco using a warmest water available and lowest intake port operating policies (Harza-Ebasco

Table IV-16. Occurrences where with-project[1] maximum river stages are higher than natural conditions (Harza-Ebasco Susitna Joint Venture 1984c).

Slough or Side Channel	River Mile	Watana Only Operating[2]	Watana and Devil Canyon[2] Operating
Whiskers	101.5	6/6	6/6
Gash Creek	112.0	6/6	5/6
6A	112.3	6/6	5/6
8	114.1	6/6	6/6
MSII	115.5	6/6	6/6
MSII	115.9	6/6	6/6
Curry	120.0	6/6	3/6
Moose	123.5	6/6	4/6
8A West	126.1	5/6	4/6
8A East	127.1	4/6	2/6
9	129.3	4/6	2/6
9 u/s	130.6	3/6	0/6
4th July	131.8	3/6	2/6
9A	133.7	3/6	1/6
10 u/s	134.3	4/6	1/6
11 d/s	135.3	3/6	0/6
11	136.5	4/6	2/6

Notes:

1 "Case C" instream flow requirements and "inflow-matching" reservoir release temperatures are assumed for with-project simulations.

2 For example, 4/6 means that 4 of the 6 with-project simulations resulted in a higher maximum river stage than the natural conditions for corresponding winters.

1985c). Both of these alternative temperature policies are only marginally effective for preventing ice cover formation on the middle Susitna River. In addition, water quality effects such as increased turbidity and reduced, dissolved oxygen may be other factors to consider with releases from very low levels.

With-Project Simulations, Breakup. The normal spring breakup drive which occurs on the middle Susitna River in early May is brought on by streamflow increases that lift and fracture the ice cover. The higher than natural water temperature released from the reservoirs during winter would cause the upstream end of the ice cover to decay as soon as air temperatures began to warm to near freezing. Additionally, the reservoirs would retain spring runoff, yielding a stable or gradually declining downstream flow regime that would favor "meltout" rather than "breakup" of the ice cover. Spring meltout in the Middle Susitna River with Stage I operating would be completed by late April, about two weeks earlier than the natural breakup. With the addition of Stages II and III, the meltout would be further advanced, occurring in late to early March, respectively (refer Fig. IV-12a).

Effects of Ice Processes on Environmental Conditions

Ice processes in the middle Susitna River are important for maintaining the character of side slough habitats. Besides reworking substrates and flushing debris and beaver dams from the sloughs that could otherwise be potential barriers to upstream migrants, ice processes are also considered important for maintaining the groundwater upwelling in the side sloughs during winter months. The alluvial deposits that form gravel bars and islands between the mainstem and side sloughs appear to be highly permeable, making it possible for water to infiltrate from the river into the sloughs. The increased stage associated with a winter ice cover makes it possible for approximately the same hydraulic head to exist between the mainstem and an adjacent side slough during the ice-covered period of the year as that which exists during summer. Water surface elevations observed in association with the March 1982 ice cover appeared very similar to water surface elevations resulting from summer discharges of 18,000 to 19,000 cfs (Trihey 1982). Thus, the increased stage associated with an ice cover on the river may provide an important driving mechanism for maintaining the upwelling in the side sloughs throughout the winter.

However, ice processes also have negative effects on fish habitat in side sloughs. During freeze-up, staging may cause zero degree mainstem water to enter side sloughs and negate the thermal value of the upwelling groundwater. Juvenile fish and incubating eggs exposed to zero degree water for extended periods are likely to suffer a high mortality.

Ice jams during breakup commonly cause rapid and pronounced increases in the water surface elevations of the mainstem. The water continues to rise until either the ice jam releases or the water can spill out of the mainstem into adjacent side channels or sloughs. This may cause sections of riverbank to be eroded. Ice scars have been observed on trees in some areas as high as 15 feet above the stream bank. The sediment transport associated with these events can raise or lower the elevations of berms at the upstream end of sloughs and side channels. Ice floes left stranded in channels and sloughs during breakup can influence flow velocities and cause alteration of the local channel geometry.

As a result of project construction and operation it is expected that only a portion of the middle Susitna River will be ice covered and that the naturally occurring breakup drive would be effectively eliminated. This would substantially reduce the effects of breakup on side slough and side channel habitats. Vegetation and beaver dams may become better established, and streambed geometry should become more stable. The higher stages forecast for the ice covered portion of the middle Susitna would result in more frequent and longer duration overtopping of side slough habitats than occurs naturally. Because of the adverse effects of zero degree water on incubating embryos and juvenile fish, the increase in ice stage is generally considered undesirable.

V. INFLUENCE OF STREAMFLOW AND INSTREAM HYDRAULICS ON MIDDLE RIVER HABITATS

Habitat Types and Transformation Categories

Habitat type referred to in this document are portions of the riverine environment having visually distinguishable morphologic, hydrologic, and hydraulic characteristics that are comparatively similar. Six major aquatic habitat types were described in Sections II and III: mainstem, side channel, side slough, upland slough, tributary, and tributary mouth. These habitat types are not defined by biological criteria; rather, they are characterized by differences in hydraulics and turbidity. Thus, both high and low quality fish habitat may exist within the same habitat type.

In our analysis of the influence of streamflow and instream hydraulics on habitat, we must consider the relative amounts of each habitat type available. To this end, the total surface area of each habitat type in the middle Susitna River has been estimated for mainstem discharges ranging from 5,100 to 23,000 cfs using digital measurements on 1 inch = 1,000 feet aerial photographs (Klinger-Kingsley 1985). The results show that surface areas of some habitat types, such as upland sloughs and tributary mouths, exhibit little response to mainstem discharge (Fig. V-1), often, their wetted surface areas respond more to local runoff from summer precipitation than to variations in mainstem discharge.

Comparatively large differences exist between responses of mainstem, side channel, and side slough surface areas, to mainstem discharges. At 5,100 cfs, the combined wetted surface areas of mainstem and side channel habitat types is approximately 36 percent less than their combined surface area at 23,000 cfs. Side slough surface area peaks at 7,400 cfs, approximately 175 percent greater than at 23,000 cfs. As a result, the total surface area of all clearwater habitat types

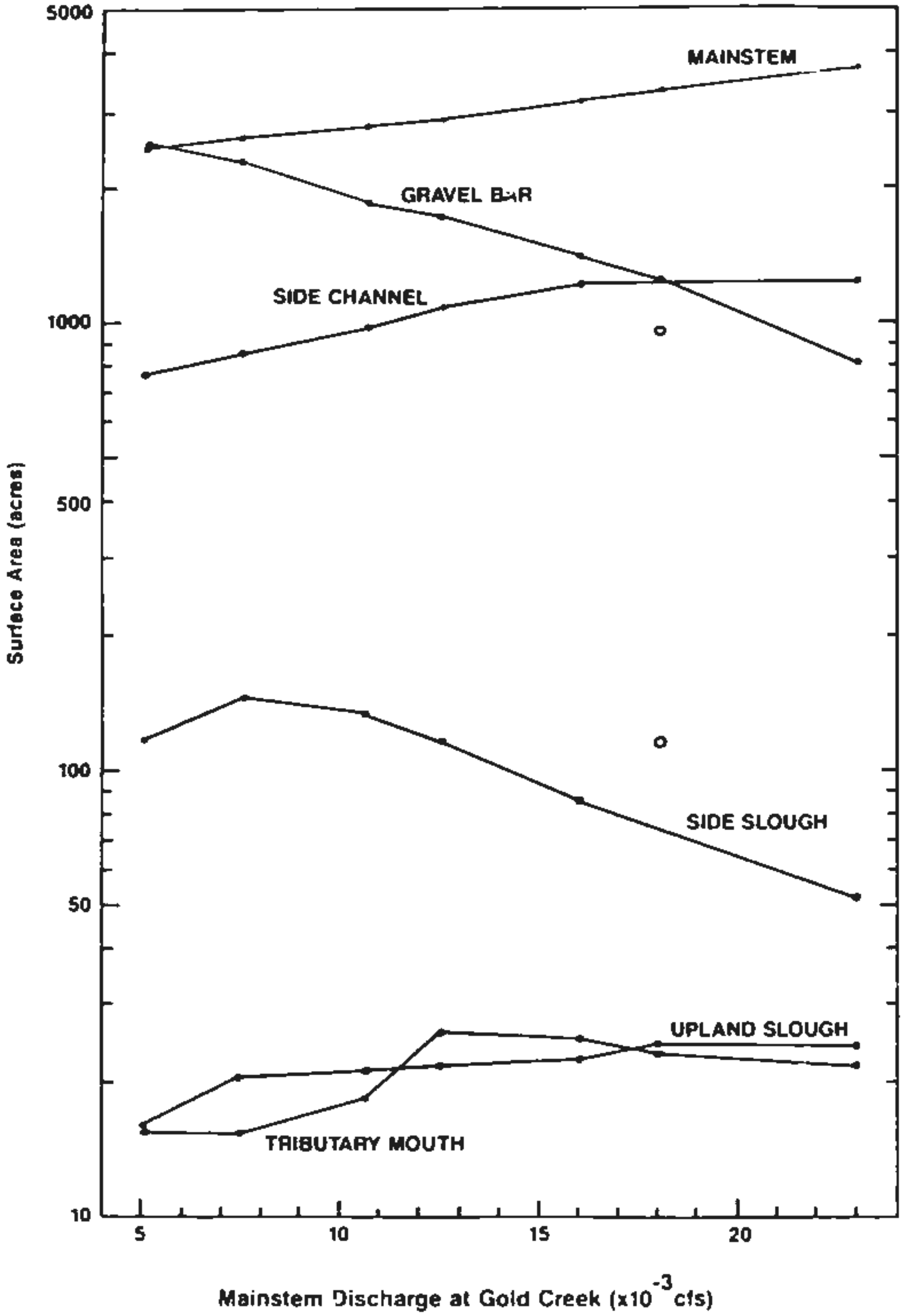

Figure V-1. Surface area response to mainstem discharge in the Talkeetna-to-Devil Canyon reach of the Susitna River (RM 101 to 149).

within the river corridor increases from 65 acres at 23,000 cfs to 145 acres of the river corridor at 7,400 cfs. This represents four percent of the total wetted surface area at 7,400 cfs, as compared to only one percent at 23,000 cfs (Klinger-Kingsley 1985).

At some locations, such as major side channels and tributary mouths, a designated habitat type persists over a wide range of mainstem discharge even though the wetted surface area and habitat quality at the location may change significantly. In other locations, the type of habitat available may change from one type to another in response to mainstem discharge (Klinger and Trihey 1984). An example is the transformation of some side channels which convey turbid water when mainstem discharge is near 23,000 cfs to clearwater side sloughs at lower mainstem flows.

To facilitate tracking habitat transformation the location of 172 specific areas were marked on aerial photography (Klinger-Kingsley 1985). Each specific area was classified by habitat type and its wetted surface area measured on aerial photography which had been obtained at several mainstem discharges. From this, eleven habitat transformation categories were used by Aaserude et al. (1985) to describe the transformation of specific areas from one habitat type to another as mainstem discharge decreases below 23,000 cfs (Table V-1). Figure V-2 presents a flow chart of the possible habitat transformations that may occur between mainstem discharges of 23,000 cfs and 9,000 cfs.

Habitat transformations are referenced from a mainstem discharge of 23,000 cfs because that discharge approximates a typical summer flow the (50 percent exceedance flow) for the months of June, July and August (APA 1983b). Analysis can be performed for any stream flow less than 23,000 cfs for which aerial photography exists. Photomosaics of the middle Susitna River are available for mainstem discharges of: 23,000; 18,000; 16,000; 12,500; 10,600; 9,000; 7,400 and 5,100 cfs (Klinger-Kingsley 1985). The influence of declining

Table V-1. Description of habitat transformation categories (Aaserude et al. 1985)*

Category 0 -	Tributary mouth habitats that persist as tributary mouth habitat at a lower flow.
Category 1 -	Upland slough and side slough habitats that persist as the same habitat type at a lower flow.
Category 2 -	Side channel habitats that transform to side slough habitat at a lower flow and possess upwelling which appears to persist throughout winter.
Category 3 -	Side channel habitats that transform to side slough habitats at a lower fow but do not appear to possess upwelling that persists throughout winter.
Category 4 -	Side channel habitats that persist as side channel habitats at a lower flow.
Category 5 -	Indistinct mainstem or side channel areas that transform into distinct side channels at a lower flow.
Category 6 -	Indistinct mainstem or side channel habitats that persist as indistinct areas at a lower flow.
Category 7 -	Indistinct mainstem or side channel areas that transform to side slough habitats at a lower flow and possess upwelling that appears to persist throughout winter.
Category 8 -	Indistinct mainstem or side channel habitats that transform to side slough habitats at a lower flow but do not appear to possess upwelling which persists throughout winter.
Category 9 -	Any water course that is wetted that dewaters or consists of isolated pools without habitat value at a lower flow.
Category 10 -	Mainstem habitats that persist as mainstem habitat at a lower flow.

* Habitats were based on a reference flow of 23,000 cfs.

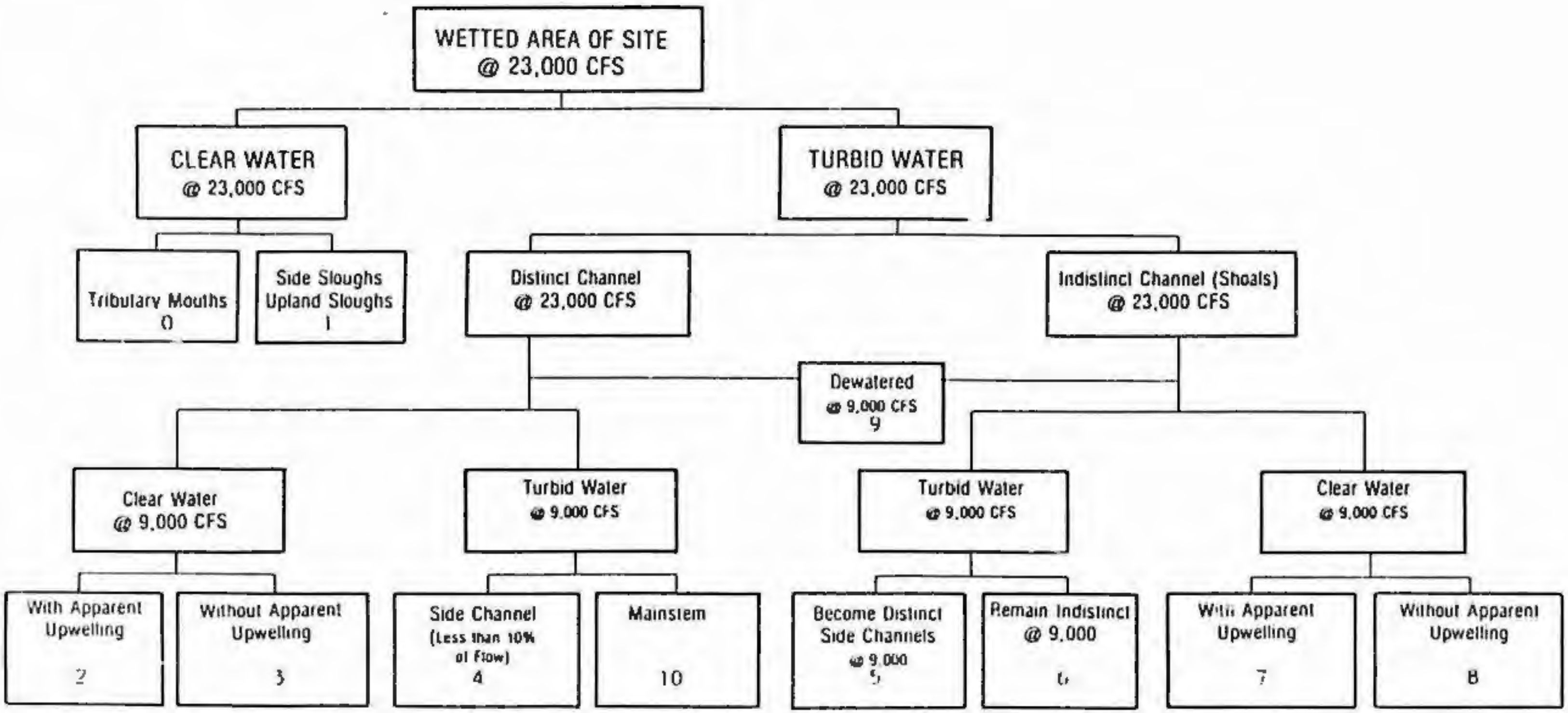

Figure V-2. Flow chart classifying the transformation of middle Susitna River aquatic habitat types between two flows (Habitat Transformation Categories 0-10).

mainstem discharge levels on habitat transformation is quite apparent when the number of specific areas within each habitat transformation category is plotted for each of these photomosaics (Fig. V-3). As mainstem discharge decreases, the number of side channel sites (Category IV) decreases, whereas the number of side sloughs (Category V) and dewatered areas (Category IX) increase. Although it is possible to describe the general availability of fish habitat using Figure V-3, changes in the quality of side channel and side slough habitat are not obvious. Hence, a more detailed analysis using microhabitat variables (e.g., depth, velocity, substrate, etc.) is necessary to assess the significance of these habitat transformations in terms of the ability of the middle Susitna River to support fish.

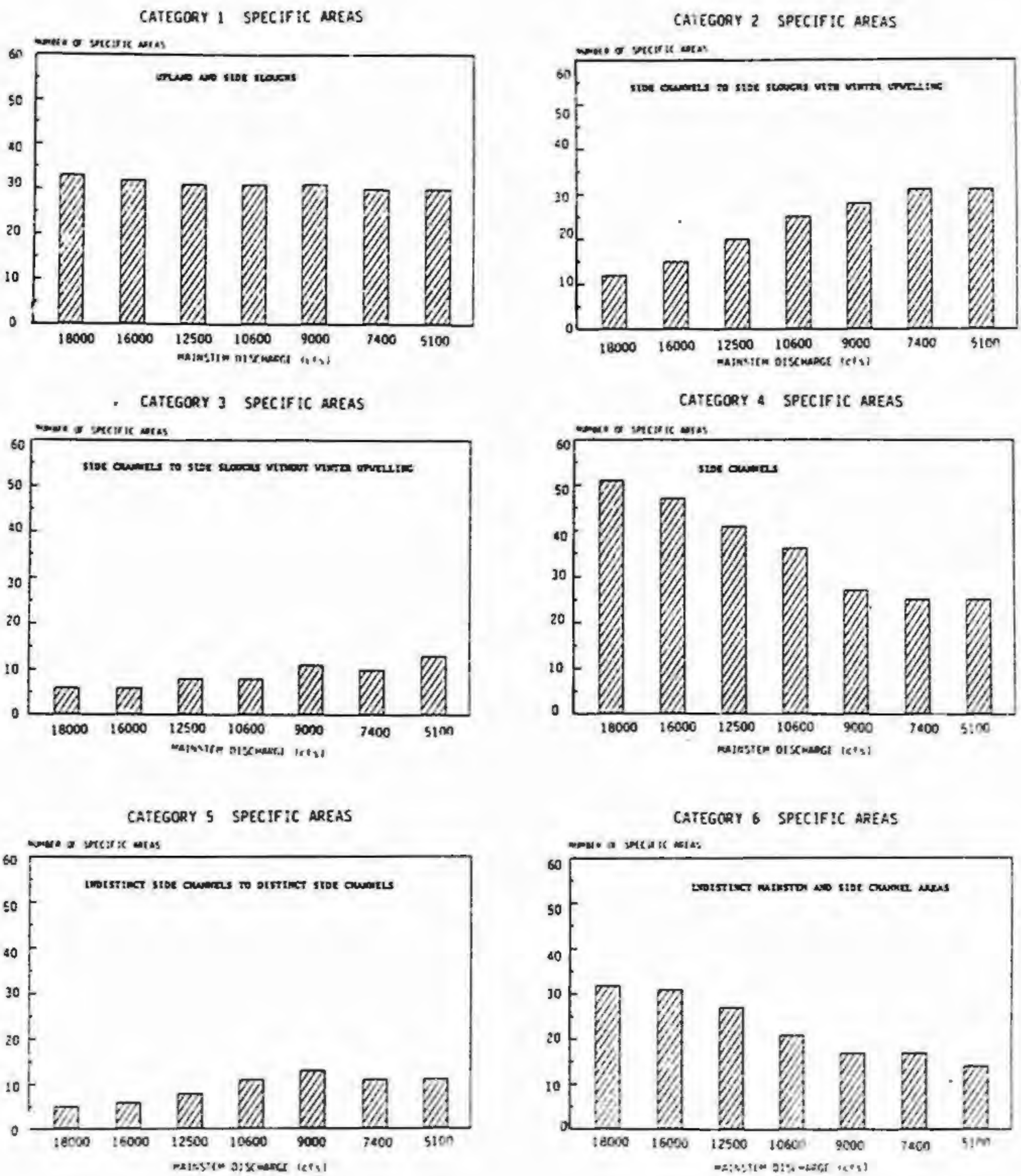

Figure V-3. Number of specific areas classified in each habitat category for various Gold Creek mainstem discharges.

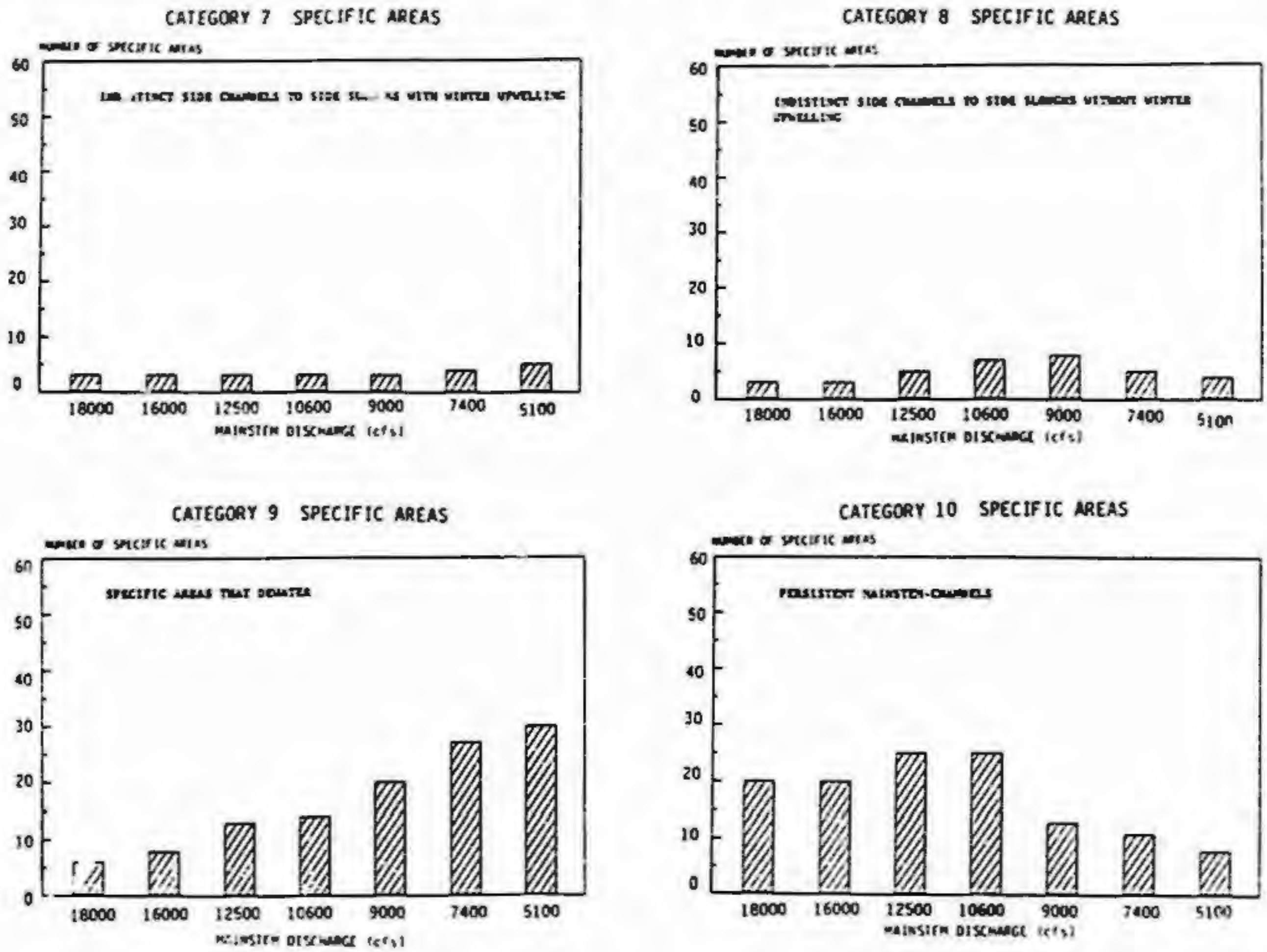

Figure V-3 (Continued).

Microhabitat Response to Instream Hydraulics

The response of depth and velocity of flow to variations in streamflow. In part, the availability and quality of fish habitat is affected by the effect of streamflow variations on the availability and quality of spawning and rearing habitat has been modeled at several side slough and side channel study sites (Estes and Vincent-Lang 1984d; Schmidt et al. 1984). Computer software used for the model was developed by the USFWS Instream Flow and Aquatic Systems Group (Bovee and Milhous 1978; Bovee 1982; Milhous et al. 1984).

Spatial distribution of depths and velocities within a study site were simulated at several different site-specific flows using the IFG-4 and IFG-2 hydraulic models. The simulated depths and velocities were then used in combination with numeric descriptors for other microhabitat variables (upwelling, cover, and substrate) to describe physical habitat at the study site as a function of streamflow. Thus, integrated numeric descriptions of upwelling, depth, velocity, substrate, and cover at each study site were obtained at various flows. These descriptions were then weighed according to their suitability for fish. Because of their sensitivity, spawning and rearing salmon were chosen as indicator species and life stages (refer to Section III). An index of habitat availability called Weighted Usable Area (WUA) was calculated for both spawning and rearing. Because all of the microhabitat variables respond, either directly or indirectly, to streamflow variations, weighted usable area can be considered a streamflow-dependent habitat availability index. The macrohabitat responses of the evaluation species and life stages are described below.

Spawning Salmon

Microhabitat Preferences. Generally, the influence of streamflow variations on spawning habitat is evaluated using three microhabitat variables: depth, velocity, and streambed composition (substrate)

(Wesche and Rechard 1980; Bovee 1982). However, a fourth variable, upwelling, is also considered important for successful chum and sockeye salmon spawning in the middle Susitna River (Estes and Vincent-Lang 1984d). Upwelling has also been identified as an important habitat component for spawning chum salmon at other locations in Alaska (Kogl 1965; Koski 1975; Hale 1981; Wilson et al. 1981).

Of the four microhabitat variables used in the modeling processes, upwelling is probably the most important variable influencing the selection of redd sites by spawning chum and sockeye salmon. Spawning is commonly observed at upwelling sites in side sloughs and side channels possessing relatively broad ranges of depths, velocities, and substrate sizes. However, portions of these same habitats possessing similar depths, velocities, and substrate sizes, but lacking upwelling, are not used by spawning chum or sockeye salmon (Estes and Vincent-Lang 1984d). Because of this strong preference for upwelling evident in field observations, a binary criterion was used for this microhabitat variable. The habitat suitability criterion for upwelling assumes optimal suitability for areas with upwelling and non-suitability for areas without upwelling.

Streambed material size generally has an influence on the quality of spawning habitat. The habitat suitability criteria developed by ADF&G for chum and sockeye salmon spawning in side slough and side channel habitats indicate that streambed materials one to five inches in diameter provide optimal spawning substrates (Fig. V-4a). This size range includes notably larger particles than the 1/4-to-3 inch size range commonly cited in the literature (Hale 1981) as being most suitable for spawning chum and sockeye salmon. The discrepancy between the ADF&G and literature criteria may, in part, be attributable to sampling procedures. However, it probably reflects the dominant influence upwelling has on the selection of redd sites. Apparently, such a small amount of good quality spawning substrate exists in middle Susitna River habitats that both chum and sockeye salmon use whatever streambed material sizes are associated with the upwellings.

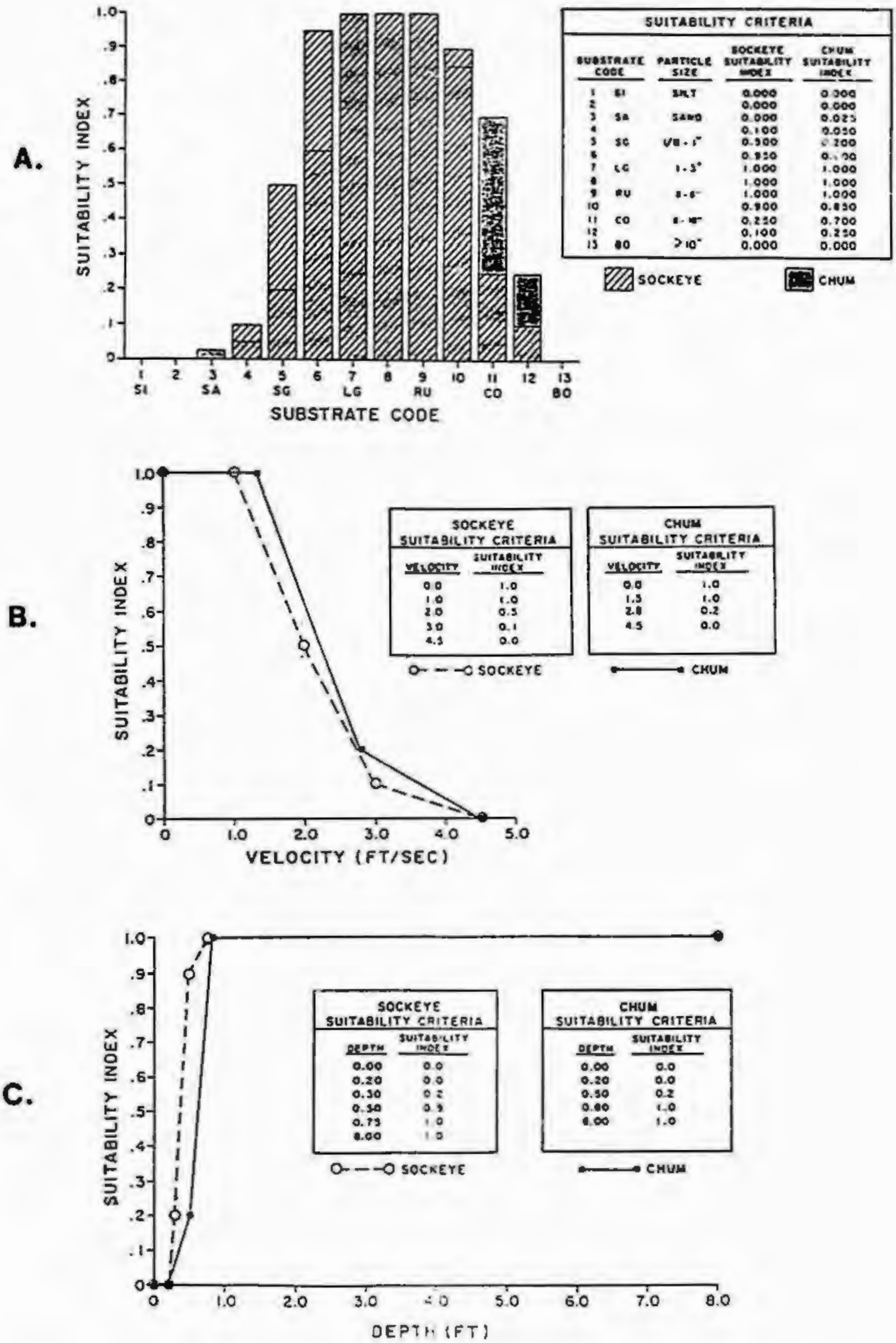

Figure V-4. Habitat suitability criteria for slough spawning chum and sockeye salmon (Estes and Vincent-Lang 1984d).

Stream velocity is often considered one of the most important microhabitat variables affecting spawning salmon (Thompson 1974; Giger 1973; Wilson et al. 1981). The habitat suitability criteria developed by ADF&G for both spawning chum and sockeye salmon assigns optimal suitabilities to mean column velocities less than 1.3 fps (Fig. V-4b). As the velocity at the spawning site increases above 1.0 fps, suitability declines more rapidly for sockeye than for chum. Microhabitat areas with mean column velocities exceeding 4.5 fps are considered unusable by both species.

The ADF&G criteria assign slightly lower suitabilities to velocities between 2 and 3 fps than criteria available in the literature (Bovee 1978; Estes et al. 1980; Hale 1981; Wilson et al. 1981). This discrepancy may exist because most data used to develop velocity suitability criteria for spawning chum and sockeye salmon in the middle Susitna River were collected in side slough habitats that typically have a narrow range of low velocities.

Chum spawning data from streams and rivers in Washington state indicate that higher velocities are frequently associated with chum salmon spawning in mainstems than in side sloughs (Johnson et al. 1971; Crumley and Stober 1984). Table V-2 summarizes velocity data collected at mainstem, tributary, and side slough locations of several rivers of moderate size. Velocities measured over redds in Nooksack, Illabot (Skagit), Skykomish, and Satsop sloughs averaged slightly lower than spawning velocities determined for other habitat types.

We conducted sensitivity analyses in which WUA indices for spawning chum salmon were calculated using both the ADF&G velocity criteria and modified velocity criteria identical to the ADF&G velocity suitability curve (Fig. V-4b) except that the optimal range of velocities for the modified velocity criteria was extended from 1.3 to 1.8 fps. Comparisons between the two WUA forecasts indicated an insignificant

Table V-2. Mean column velocity measurements (fps) collected at chum salmon redds in several rivers of Washington state (Johnson et al. 1971).

River	Number of Measurements	Velocity Range	Mean Velocity
Nooksack River			
Nooksack Slough	24	0.21-1.34	0.61
Maple Creek	20	1.22-4.11	2.52
Kendall Creek	21	0.31-3.76	2.30
Skagit River			
Main River	40	0.67-3.86	1.82
Illabot Creek	17	0.31-2.78	1.56
Illabot Slough	25	0.58-2.93	1.20
Dan Creek	50	0.52-3.09	1.81
Skykomish River			
Skykomish Slough	31	0.41-2.22	1.31
Chico Creek	50	0.16-3.97	1.95
Kennedy Creek	50	0.47-3.16	1.60
Twanoh Creek	25	0.31-2.83	1.25
Jorsted Creek	50	0.60-3.16	1.68
Satsop River			
Main River	50	0.14-2.33	1.25
Satsop Slough	50	0.00-2.27	0.56
Satsop Springs	30	0.12-1.70	1.22

difference ($\leq$ 5%) at low-to-moderate mainstem discharges. Even at high mainstem discharges, where the modified velocity criteria with its higher optimum might be expected to be significant, WUA forecasts associated with the modified criteria did not exceed the forecasts obtained using ADF&G velocity criteria by more than 10 percent.

These results do not appear to justify modifying the ADF&G velocity suitability curve to include optimal velocities in excess of 1.3 fps. Therefore, the velocity suitability criteria developed by ADF&G for chum spawning will be used for the IFR analyses of side channel and mainstem chum spawning potential.

The ADF&G habitat suitability criteria also indicate that depths in excess of 0.8 feet are most suitable for spawning chum and sockeye salmon (Fig. V-4c). This depth is slightly more conservative but consistent with the 0.6 foot depths used elsewhere (Thompson 1972; Smith 1973). Microhabitat areas with depths less than 0.8 feet provide suboptimal spawning and depths of 0.2 feet or less are unusable. These minimum depth criteria are consistent with values presented by others as minimum depth requirements for spawning chum salmon (Kogl 1965; Wilson et al. 1981). The suitability criteria developed by ADF&G for depth are consistent with criteria used by others and will be used in the IFR analyses.

Habitat Availability. WUA indices (habitat response curves) for spawning chum and sockeye salmon at three side slough and four side channel locations were developed by ADF&G using the variables and suitability criteria discussed above. Both chum and sockeye salmon have been observed spawning within, or in the immediate vicinity of, four of these seven study sites (Barrett et al. 1984; Estes and Vincent-Lang 1984d). Although minor differences exist between the habitat response curves for spawning chum and sockeye salmon at each of these four study sites, the curves for the two species are similar (Fig. V-5). The minor differences that exist between the curves are

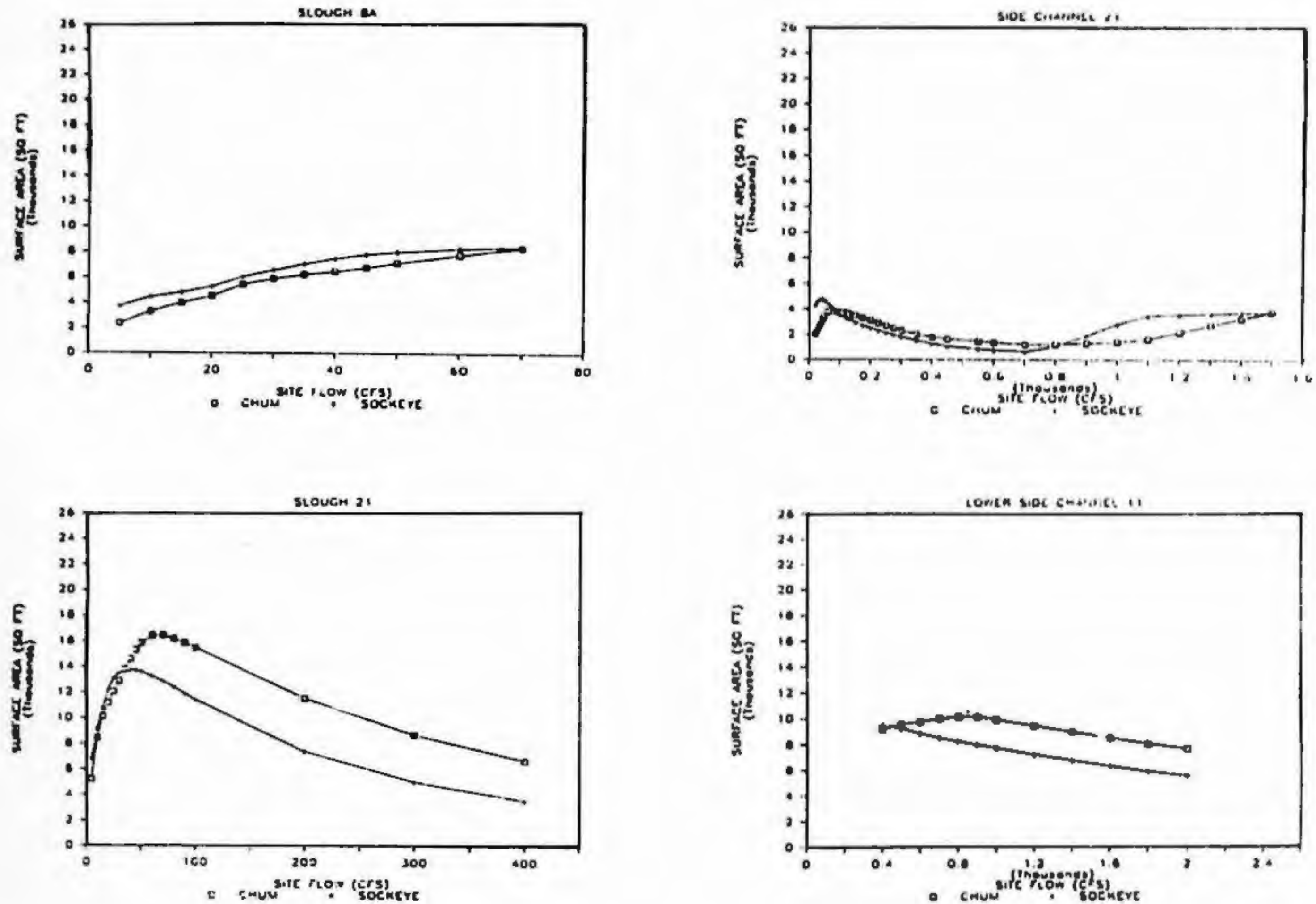

Figure V-5. Comparison of WUA responses to site flow for spawning chum and sockeye salmon at four middle Susitna River study sites (adapted from Estes and Vincent-Lang 1984d).

attributable to differences between depth and velocity suitability criteria. A slightly higher suitability is assigned to depths between 0.2 and 0.8 feet for sockeye, whereas a slightly higher suitability is assigned to velocities in excess of 1 fps for chum salmon.

Except for a few isolated observations, all sockeye salmon spawning in the middle Susitna River occurs in side sloughs that are also utilized by chum salmon. The timing and spawning habitat requirements of sockeye salmon are similar to chum salmon (Estes and Vincent-Lang 1984d), and chum salmon are both more numerous and widespread than sockeye in middle Susitna River spawning habitats. Because of this, and because of the similarities between habitat response curves, the IFR analysis will focus on the response of chum salmon spawning habitats and will use those WUA indices to estimate the response of sockeye salmon spawning habitats.

Total wetted surface area and weighted usable area for spawning chum salmon at six study sites are presented in Figure V-6. These sites are grouped into three distinct habitat categories based on channel morphology and hydraulics. In comparison to total surface area, low WUA indices are forecast at all sites. By arbitrarily increasing the total surface area of groundwater upwelling at Side Slough 21 to 15 percent and at Upper Side Channel 11 to 50 percent, WUA forecasts increased at both sites without a notable change occurring in the shape of the habitat response curve for either site (Fig. V-7). This demonstrates that the maximum amount of spawning habitat potentially available is determined by the total surface area of the upwelling.

The habitat response curve at Slough 21 peaks when the mainstem discharge is approximately 28,500 cfs, while that for Upper Side Channel 11 peaks near 23,000 cfs (Fig. V-8). At these discharge levels, the alluvial berm at the upstream end of each site is overtopped and the site- specific flows are approximately 70 cfs in Slough 21 and 150 cfs in Upper Side Channel 11 (Estes and Vincent-Lang 1984d). Whenever the mainstem discharge is insufficient to overtop

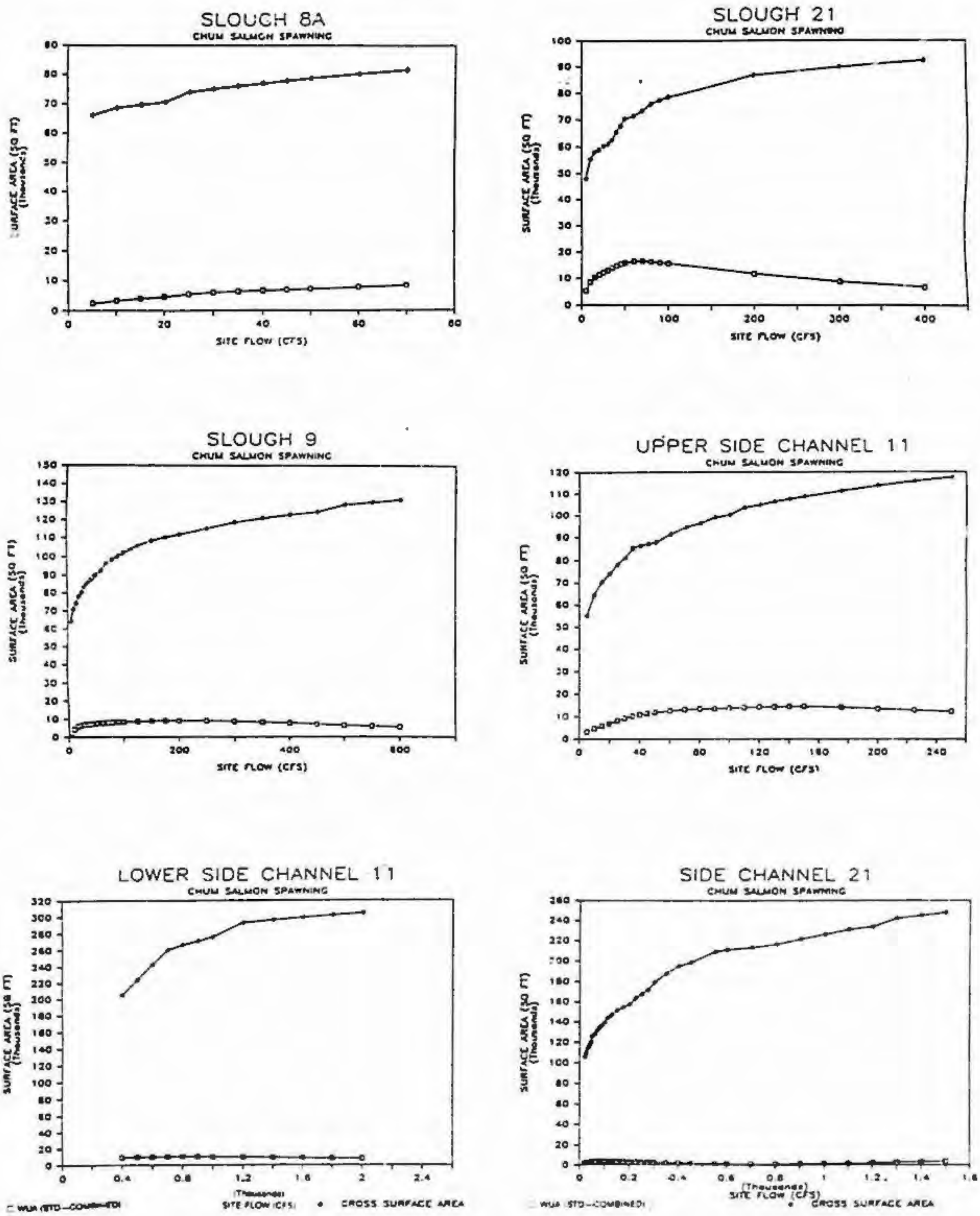

Figure V-6. Total surface area and WUA index for spawning chum salmon at Habitat Category I, II, and III study sites (adapted from Estes and Vincent-Lang 1984d).

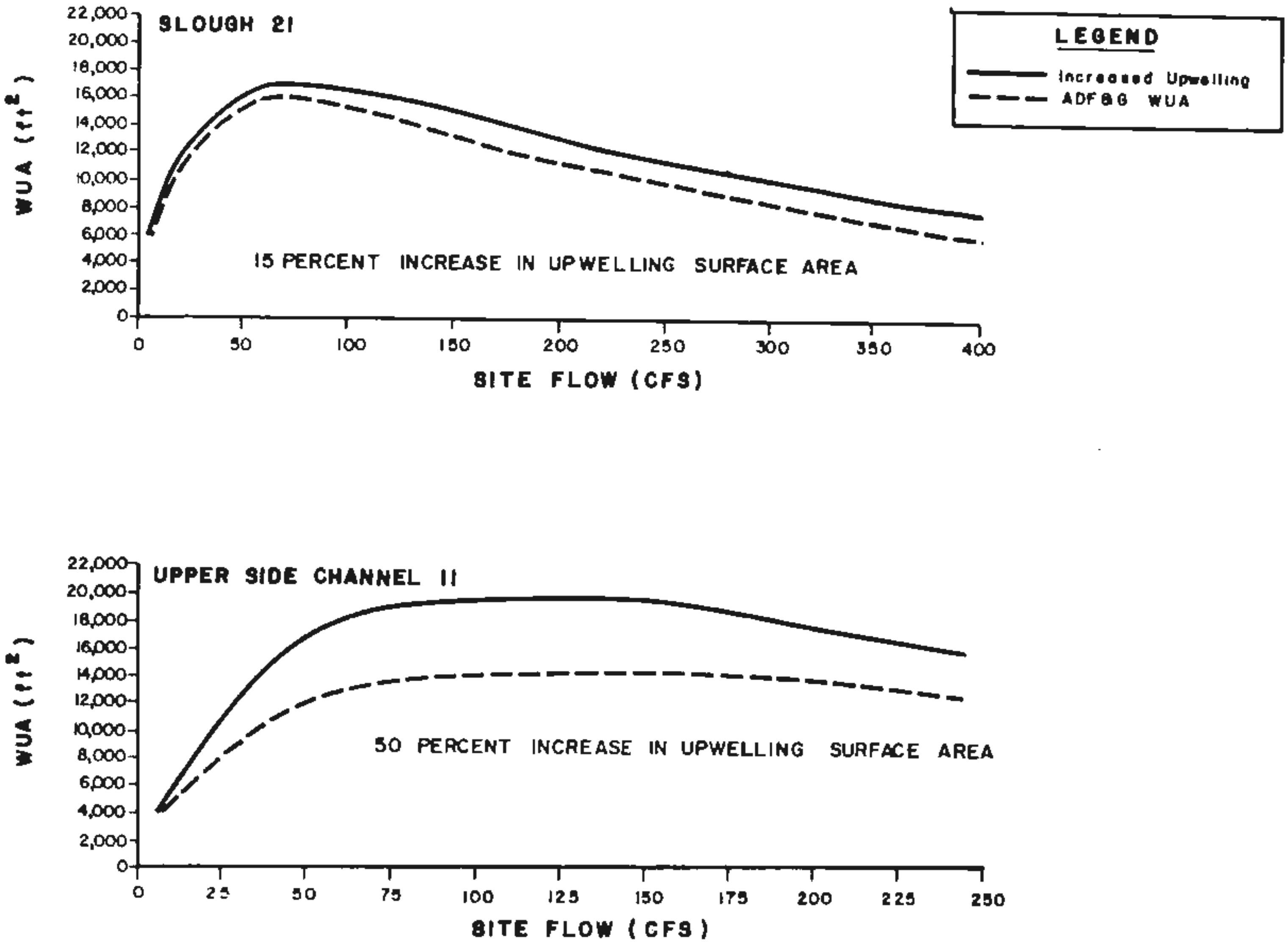

Figure V-7. Simulated influence of increased upwelling on WUA for spawning chum salmon at Slough 21 and Upper Side Channel 11.

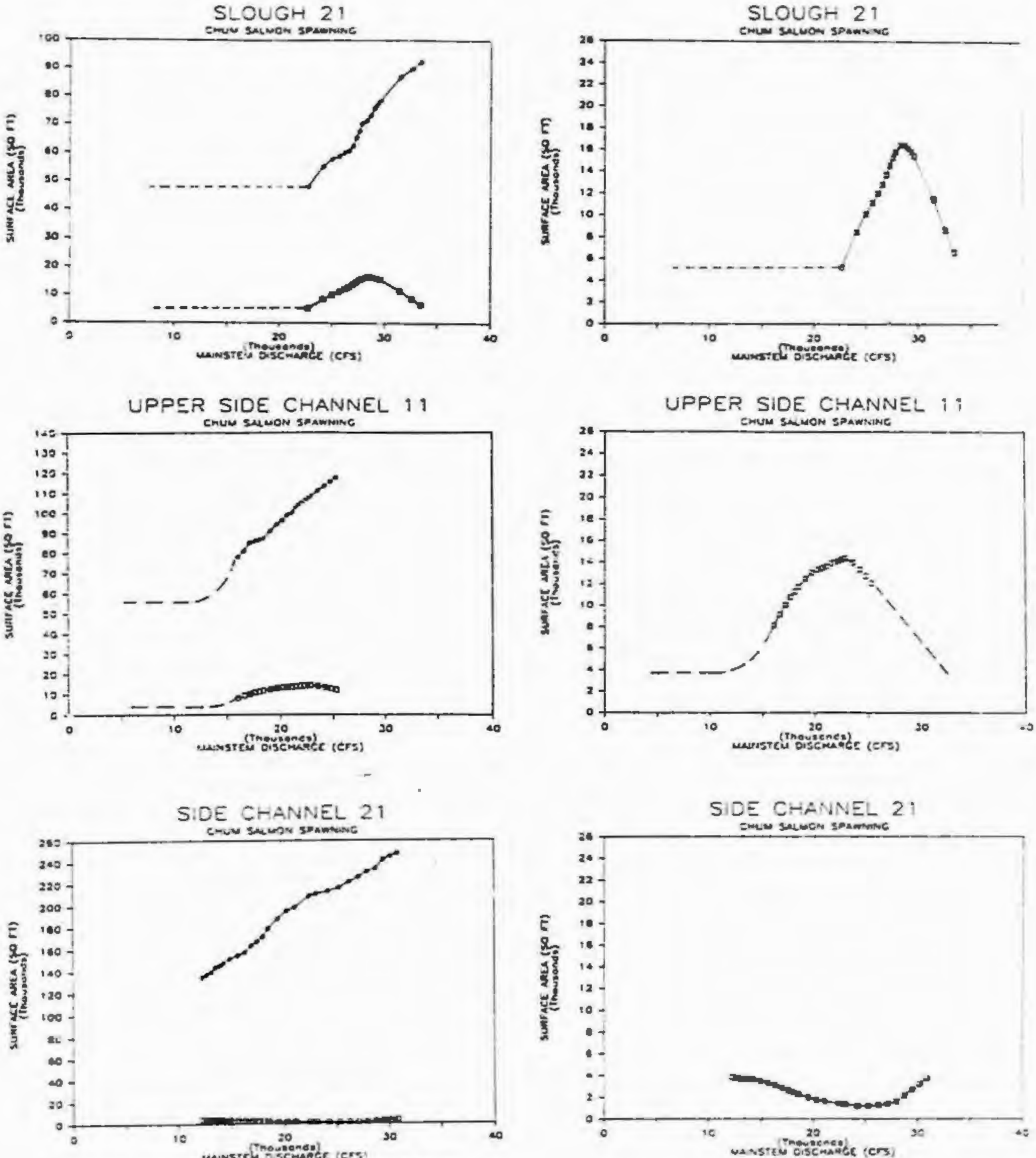

Figure V-8. Surface area and WUA response to mainstem discharge at Habitat Category I, II, and III spawning sites (adapted from Estes and Vincent-Lang 1984a).

their upstream berms, base flow at both sites is less than 5 cfs (Estes and Vincent-Lang 1984d). The depth of flow at upwelling areas is typically less than 0.5 feet at base flow, but increases to 1.0 foot or more when the upstream berms are overtopped (Fig. V-9). Velocities respond similarly to overtopping, typically increasing from the 0 to 0.5 fps range to approximately 1.5 fps (Fig. V-10).

Depths and velocities associated with baseflow and overtopped conditions were compared to habitat suitability criteria for spawning chum salmon (refer Fig. V-4). The comparison indicates that the rapid increase in WUA indices following overtopping (refer Fig. V-8) is attributable to an increase of depth over upwelling areas. The gradual decrease in WUA indices at higher site flows is due to mean column velocities over upwelling areas exceeding the 1.3 fps optimum. It is important to recognize the degree to which shallow depth restrict both the availability and the quality of side slough spawning habitat under nonbreached conditions.

Figure V-11 presents streamflow and habitat duration curves at four study sites which overtop at different mainstem discharges. Each habitat duration curve was constructed using daily WUA values derived from average daily site flows. Daily site flows were determined using the mainstem flow at Gold Creek and the site flow versus mainstem discharge regression equations presented by ADF&G (Estes and Vincent-Lang 1984d) for breached conditions. For nonbreached conditions average daily site flows were estimated at 3 cfs on the basis of field experience and a limited number of flow measurements reported by ADF&G (Estes and Vincent-Lang 1984d).

These duration curves accent the influence of the upstream berm elevation (breaching flow) on site-specific streamflow and habitat conditions. Category I sites which require the highest mainstem discharges for overtopping possess the most persistent WUA indices during the spawning season. Category II sites which overtop when mainstem discharge is between 10,000 to 20,000 cfs show distinct

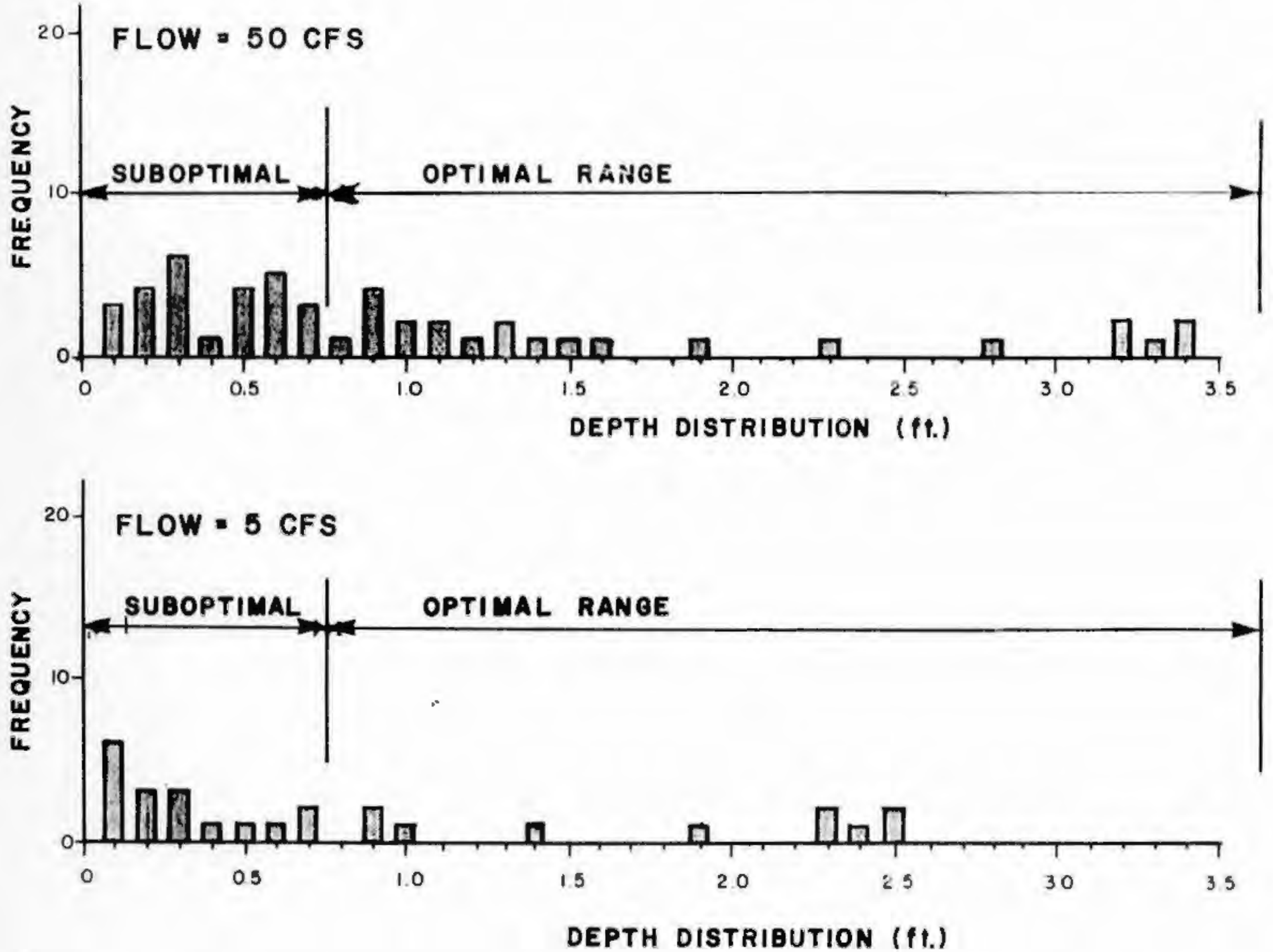

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Figure V-9. Frequency distribution of cell depth over upwelling areas in Upper Side Channel 11 at site flows of 5 and 50 cfs.

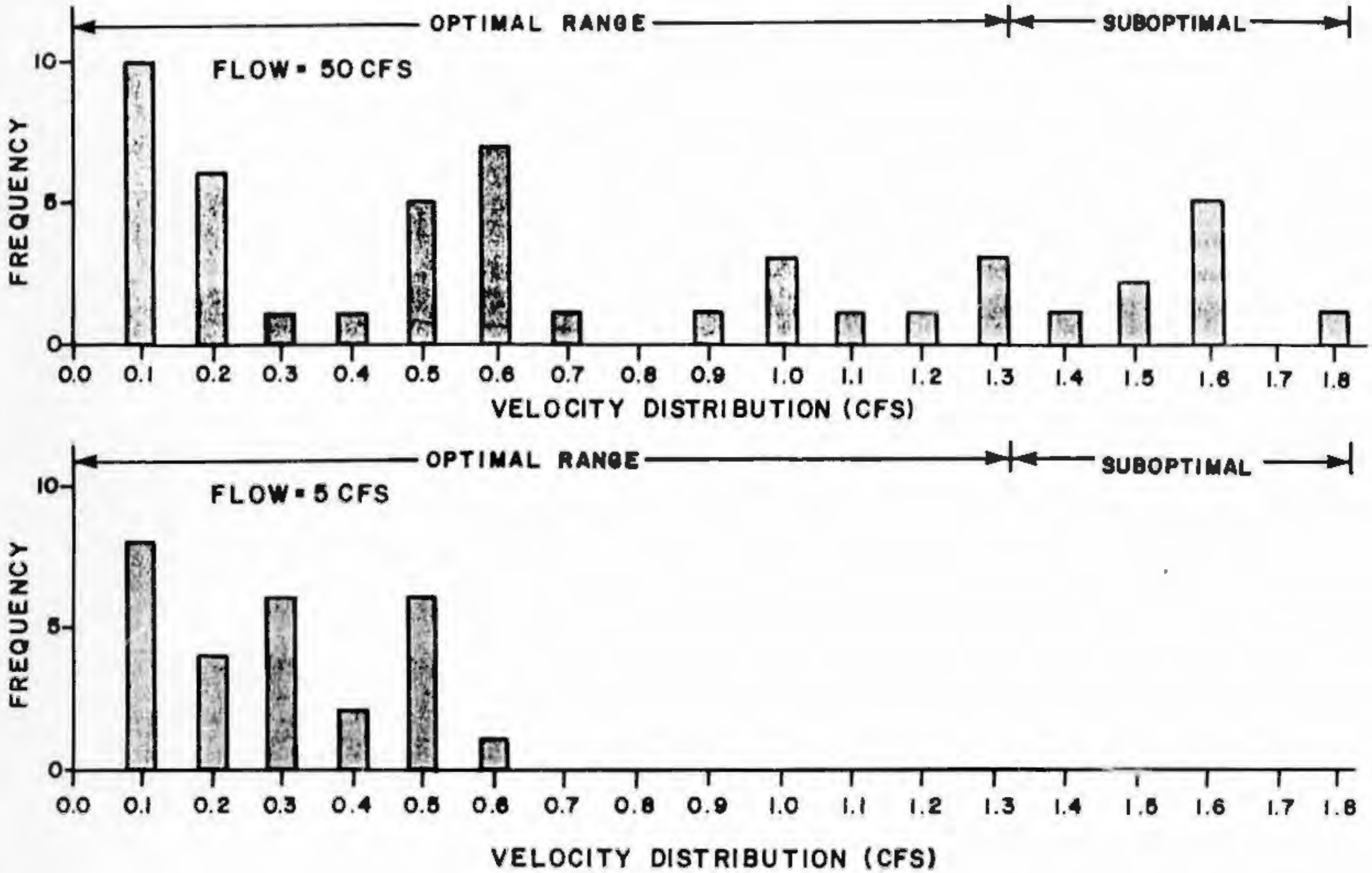

Figure V-10. Frequency distribution of cell velocity over upwelling areas in Upper Side Channel 11 at site flows of 5 and 50 cfs.

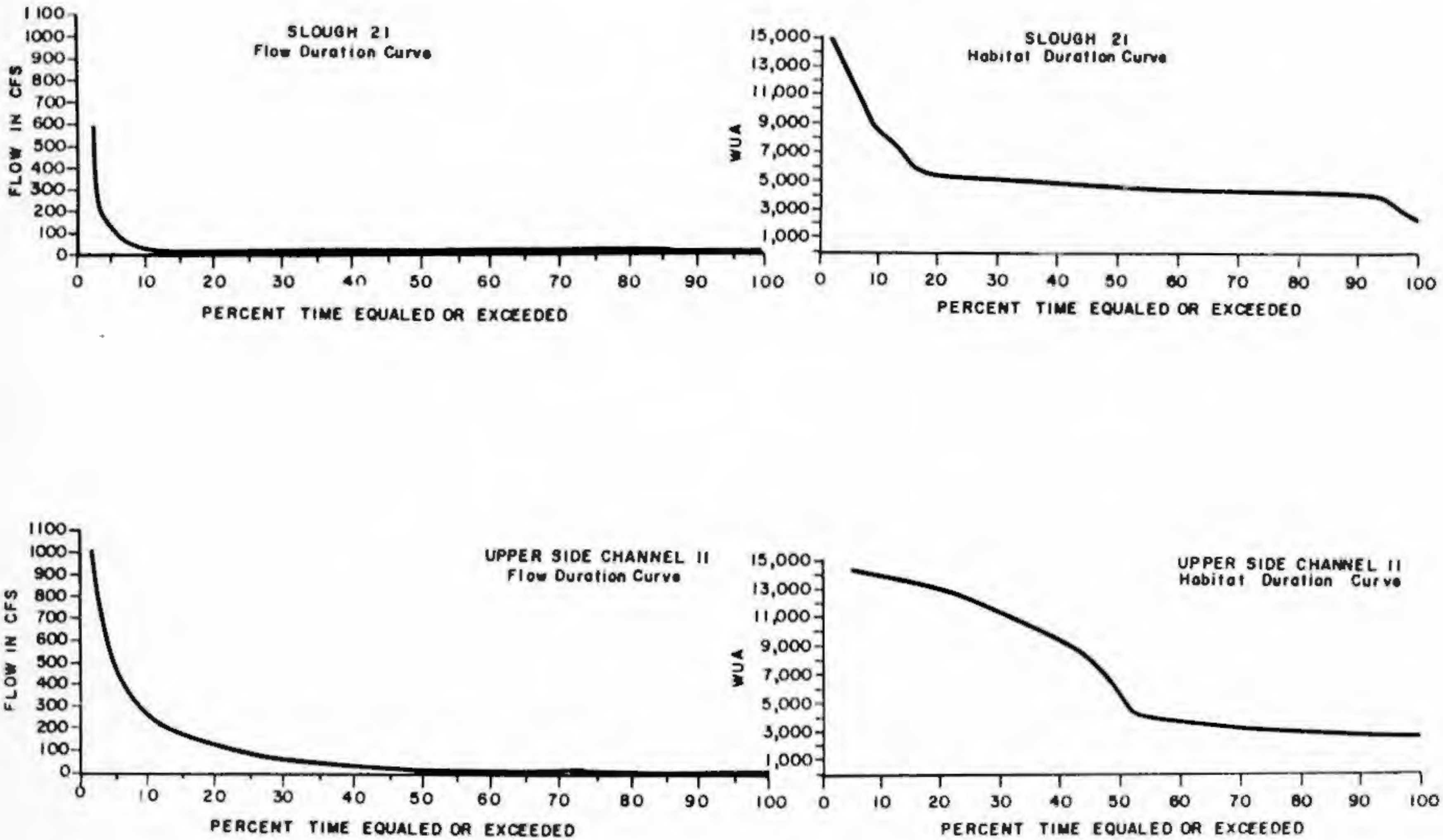

Figure V-11. Flow and habitat duration curves for spawning chum salmon by habitat categories.

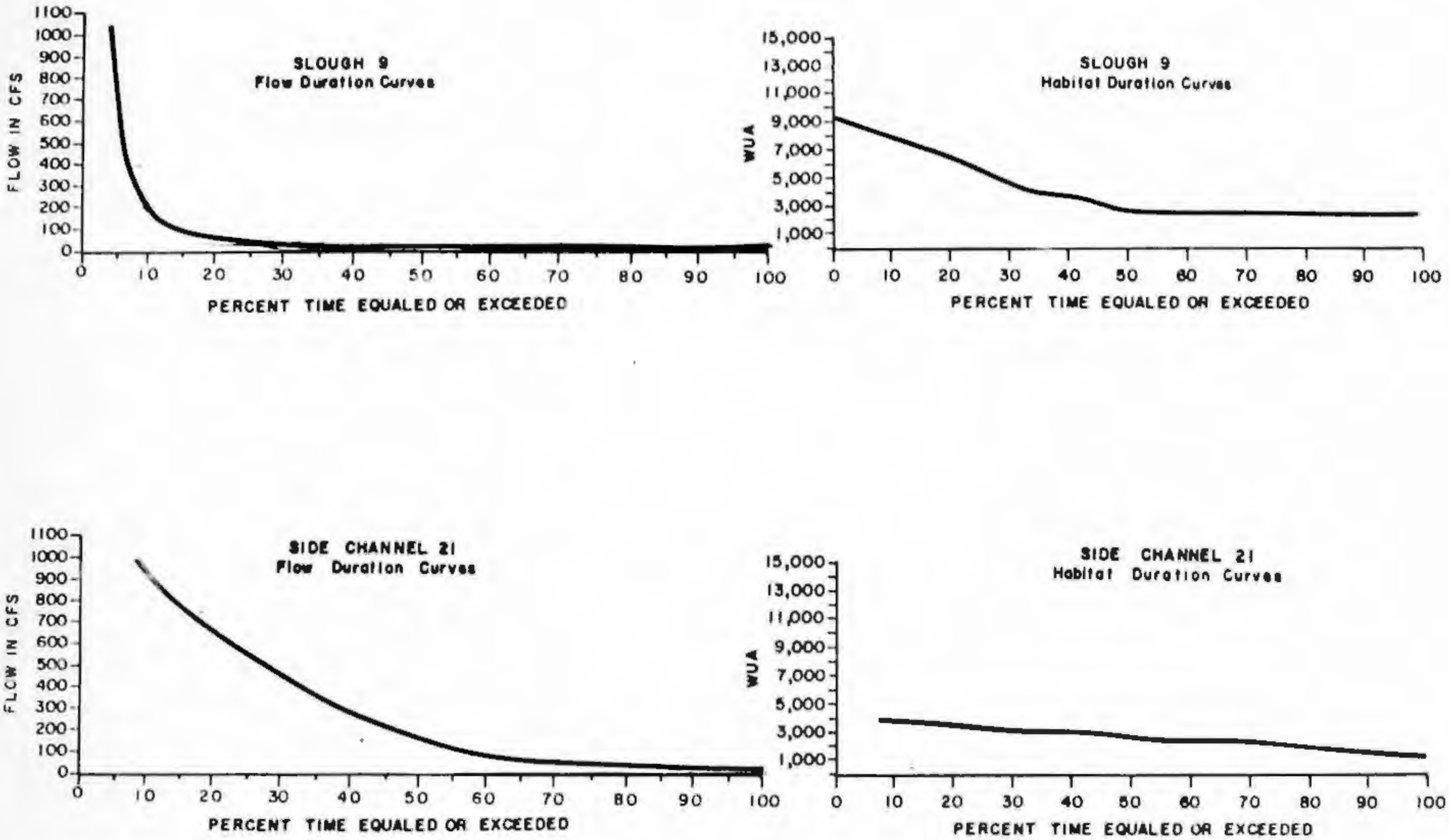

Figure V-11 (Continued).

changes in their respective WUA indices associated with the 30 and 70 percent exceedance values. Category III sites, which are generally breached at a mainstem discharge of 10,000 cfs, reflect the influence of mainstem discharge throughout the spawning period.

Rearing Salmon

Microhabitat Preferences. Field studies, conducted by ADF&G to determine the seasonal movement and habitat requirements of juvenile chinook, chum, coho, and sockeye salmon in the middle Susitna River, indicate that juvenile chum and chinook salmon are the most abundant salmon species that rear in side slough and side channel habitats. Juvenile coho salmon rear predominantly in tributary and upland slough habitats. The few sockeye juveniles rearing in the middle Susitna River are most commonly found in upland slough habitats. By early summer (end of June) most juvenile chum salmon have outmigrated from middle Susitna River habitats, and a large inmigration of chinook fry occurs from natal tributaries. These immature chinook redistribute into side channels and side sloughs during the remainder of the summer. With the onset of fall and colder mainstem and side channel water temperatures, chinook juveniles appear to move into the warmer water associated with upwelling areas in side slough habitats to overwinter (Dugan et al. 1984).

Rearing habitat is commonly evaluated using three variables: depth, velocity, and cover (Wesche and Rechard 1980; Bovee 1982). Habitat suitability criteria have been developed by ADF&G to describe the preferences of juvenile chum and chinook salmon for these microhabitat variables. Habitat suitability criteria developed by ADF&G indicate that water depths exceeding 0.15 feet provide optimal conditions for rearing chinook (Suchanek et al. 1984). This compares well with Burger et al. (1982), who found chinook using depths between 0.2 and 10 feet in the Kenai River.

Cover is used by juvenile salmon as a means of avoiding predation and obtaining protection from high water velocities. Instream objects, such as submerged macrophytes, large substrate, organic debris, and undercut banks provide both types of shelter for juvenile salmon (Bjornn 1971; Bustard and Narver 1975; Cederholm and Koski 1977; Burger et al. 1982). One significant finding of the ADF&G field studies is that juvenile chinook are apparently attracted to turbid water for cover. Juvenile chinook were commonly found in low-velocity turbid water (50-200 NTU) without object cover, but were rarely observed in low-velocity, clear water (under 5 NTU) without object cover[1] (Suchanek et al. 1984). The influence of turbidity on the distribution of juvenile chinook in side channel habitats was so pronounced that different habitat suitability criteria for velocity and object cover were developed by ADF&G for both clear and turbid water conditions (Figs. V-12 and V-13).

These criteria curves assign optimal suitability values to velocities between 0.05 and 0.35 fps for turbid water, and between 0.35 and 0.65 fps for clear water. Literature values typically indicate that optimal velocities for juvenile chinook in clear water are less than 0.5 fps (Burger et al. 1982; Bechtel 1983; P. Nelson, pers. comm. 1984). The criteria presented by both Burger et al. (1982) and Bechtel (1983) (Fig. V-14) can be considered comparable to ADF&G's criteria for juvenile chinook insofar as the Burger and Bechtel criteria were developed for juvenile chinook (under 100 mm) rearing in

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1 ADF&G selected 30 NTU to distinguish between clear and turbid water conditions (Suchanek et al. 1984). This is recognized as a reasonable preliminary threshold value. However, because of the limited number of data points that are available to define juvenile chinook behavior at turbidities between 5 and 50 NTU and above 200 NTU, turbidity ranges will be parenthetically expressed in our discussion of juvenile chinook behavior in clear (under 5 NTU) and turbid (50 to 200 NTU) water conditions. Turbidity ranges may be further defined in field studies.

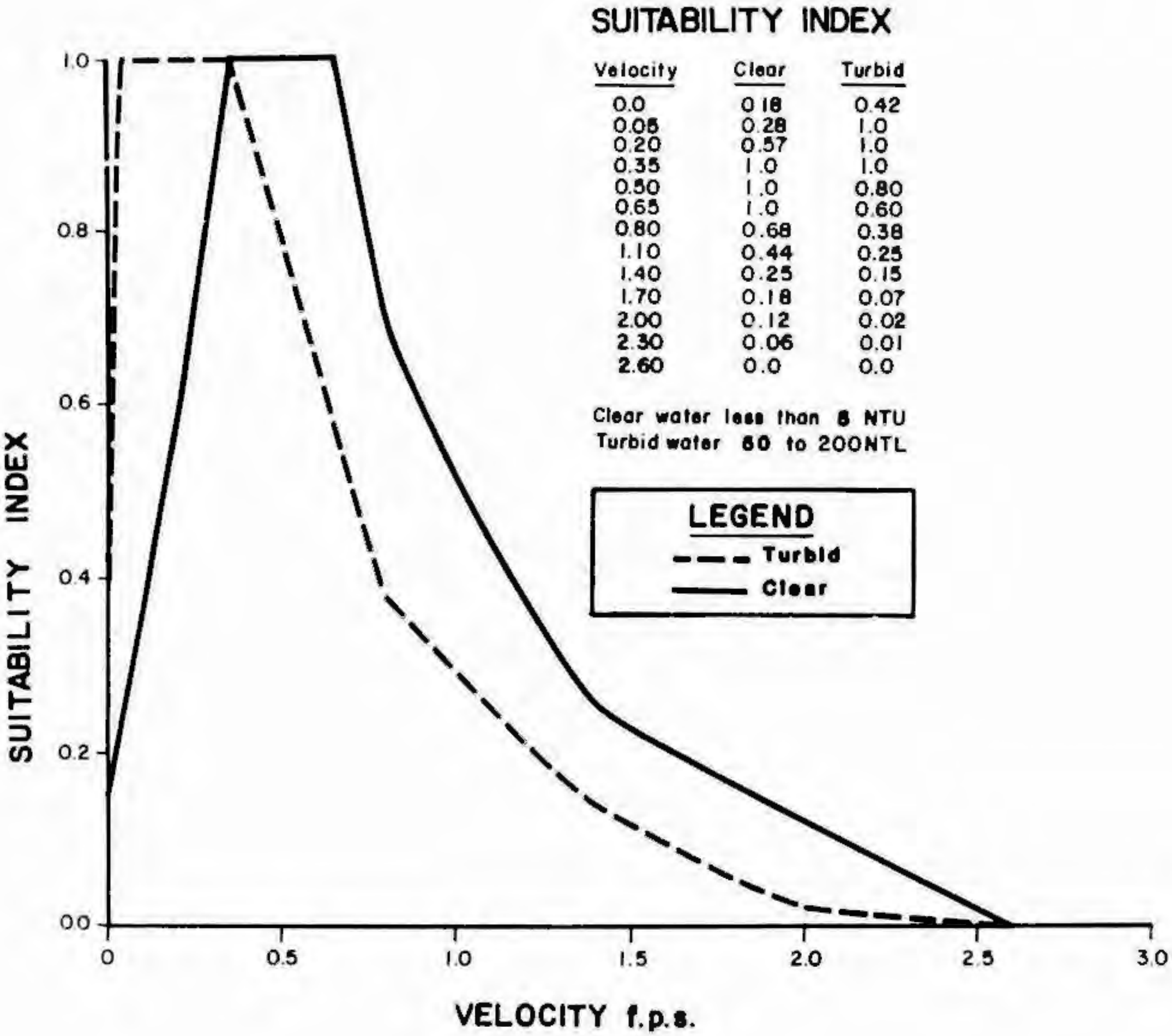


Figure V-12. Velocity criteria for juvenile chinook in clear and turbid water.

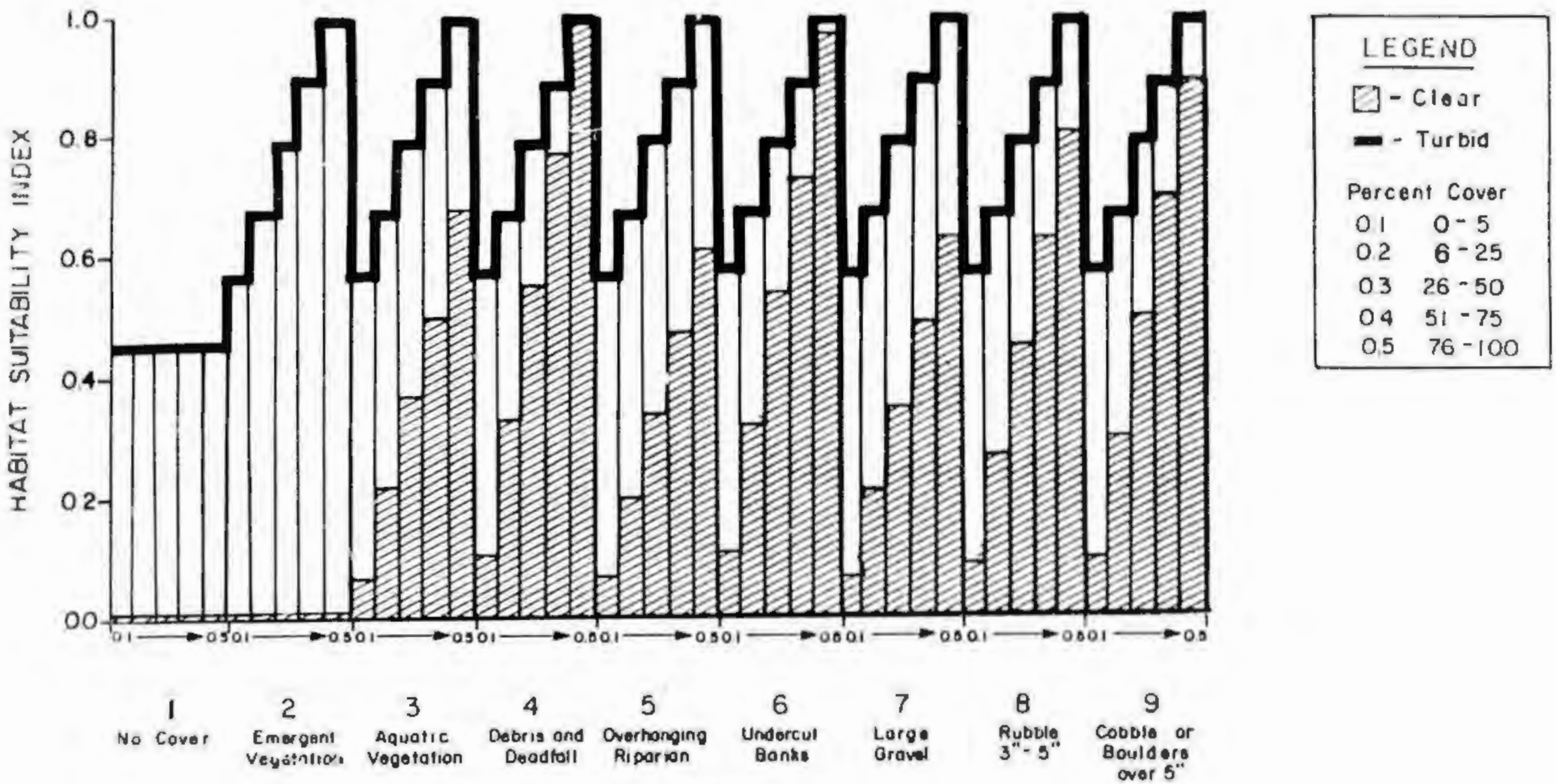


Figure V-13. ADF&G cover criteria for juvenile chinook in clear and turbid water conditions.

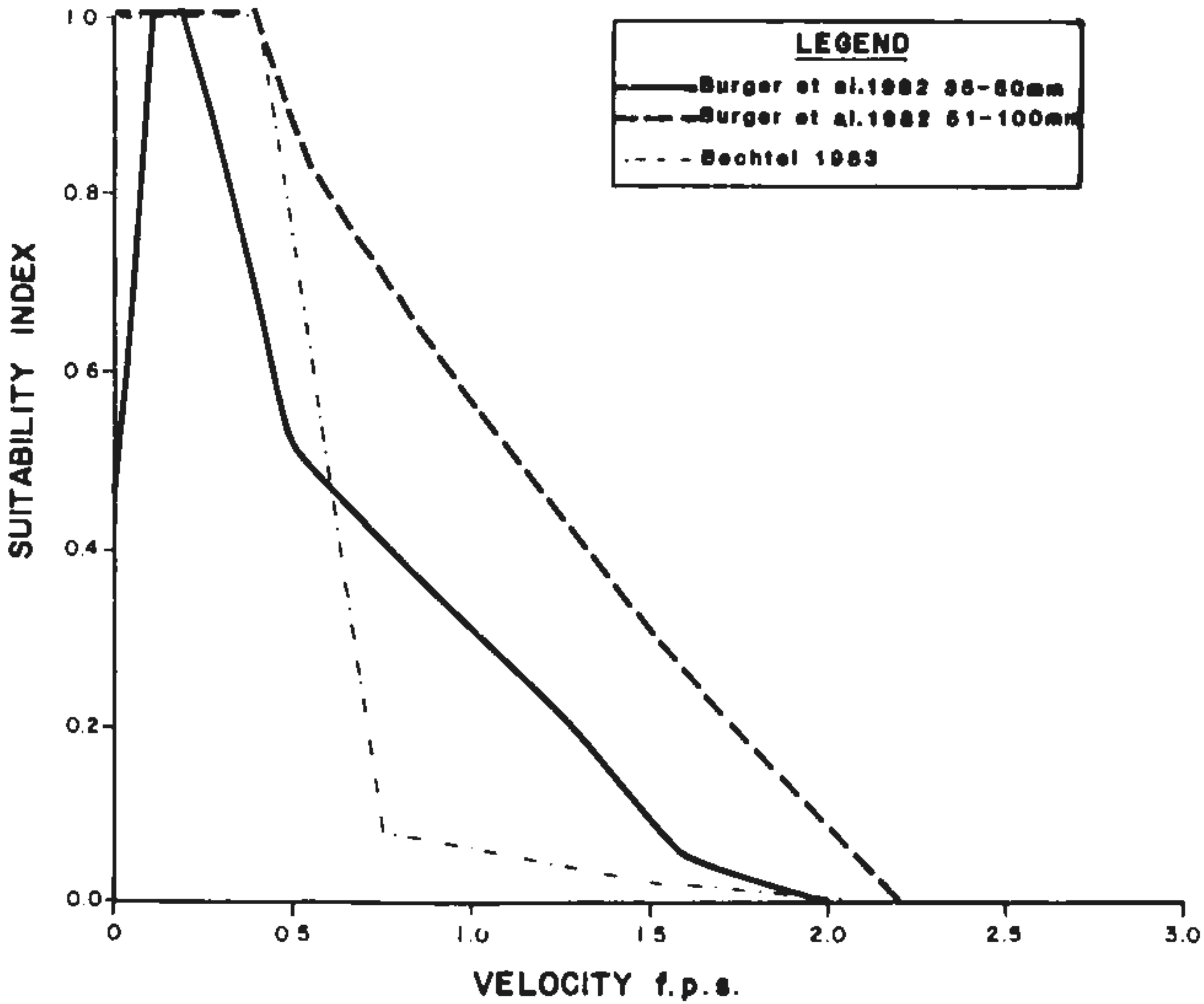


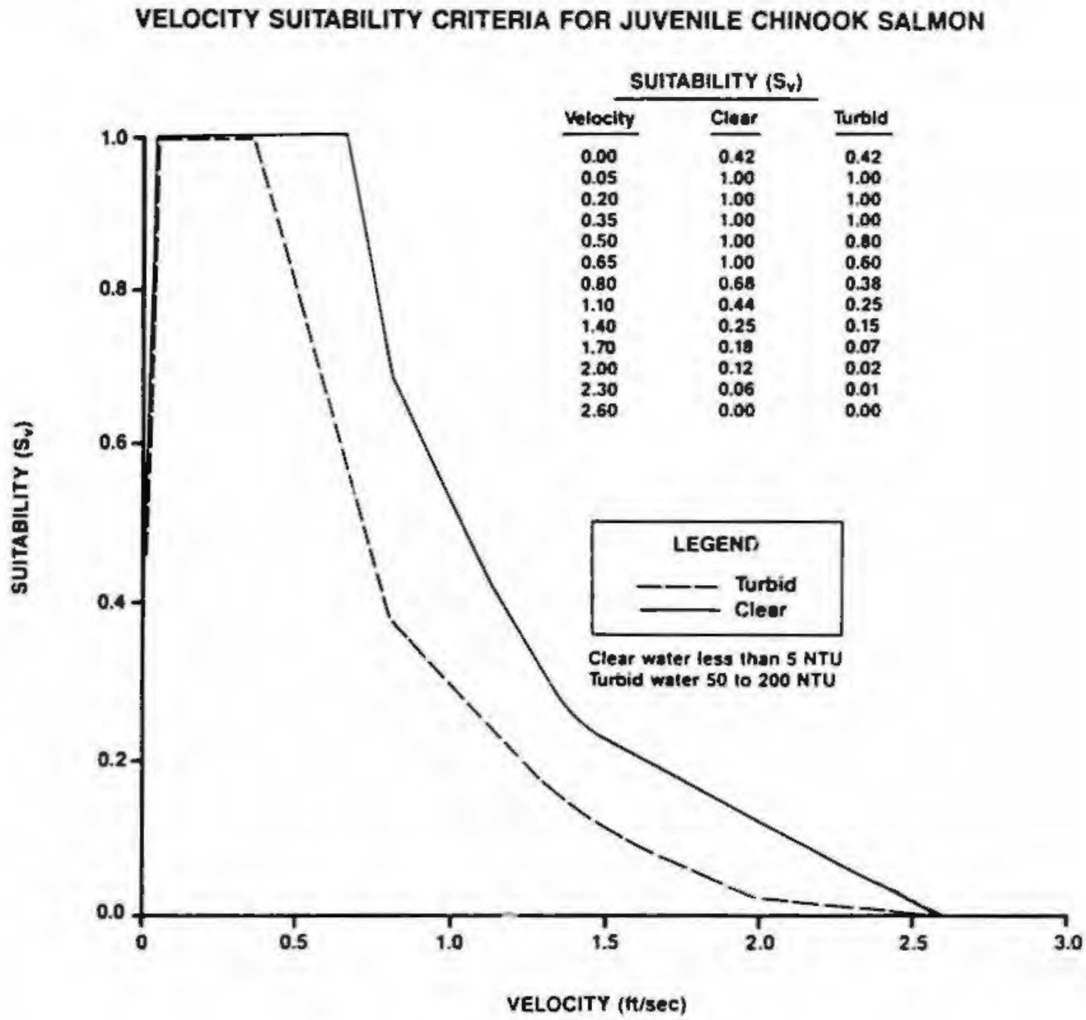
Figure V-14. Velocity suitability criteria for juvenile chinook in the Kenai and Chakachamna rivers, Alaska (Burger et al. 1982 and Bechtel Civil and Minerals 1983).

large glacial rivers in Alaska. Although the chinook criteria from the literature were developed from data collected in clear water (less than 30 NTU), they are more similar to the Susitna River velocity criteria for turbid water (50-200 NTU). The apparent reason for this discrepancy is the difference in field methods used by ADF&G and the other investigators.

Mean column velocities were measured by both ADF&G and other investigators to develop habitat suitability curves for juvenile chinook. However, the location at which the mean column velocity was measured relative to the apparent locations of juvenile chinook were different. ADF&G reported the mean column velocity at the midpoint of a six-foot by 50-foot cell (mid-cell velocity) regardless of the location of fish within the cell. The velocity criteria developed by Burger and Bechtel are based on mean column velocities measured in the immediate vicinity of individual fish observations or captures (point velocities).

Assuming that immature fish in clear water are more likely to be found along stream banks (where lower velocities and cover are generally more available), the practice of measuring mid-cell velocities a minimum distance of three feet (one half the width of the ADF&G sample cell) from the streambank would result in slightly higher mean column velocities being measured than if point velocities had been measured. It is understandable that the 0.35 to 0.65 fps velocity range selected by ADF&G as being optimal for juvenile chinook is slightly higher than the 0 to 0.5 fps velocity range selected by other investigators. However, it should not be assumed that low velocities (less than 0.35 fps) are unimportant to rearing chinook salmon. Consequently, the optimum velocity range of the IFR clear water suitability criteria were extended to include velocities between 0.05 and 0.65 fps (Fig. V-15).

Juvenile chinook do not associate with object cover in turbid water (50-200 NTU) as much as they do in clear water (Suchanek et al. 1984). Rather, they are randomly distributed in low velocity areas with



	SUITABILITY (S_v)	
Velocity	Clear	Turbid
0.00	0.42	0.42
0.05	1.00	1.00
0.20	1.00	1.00
0.35	1.00	1.00
0.50	1.00	0.80
0.65	1.00	0.60
0.80	0.68	0.38
1.10	0.44	0.25
1.40	0.25	0.15
1.70	0.18	0.07
2.00	0.12	0.02
2.30	0.06	0.01
2.60	0.00	0.00

Figure V-15. Velocity suitability criteria used to model juvenile chinook habitat (WUA) under clear and turbid water conditions in the middle Susitna River (Steward 1985).

little or no object cover. In these low-velocity turbid areas, it is quite likely that mid-cell velocities measured three feet from the streambank differ little from point velocities measured in microhabitats along the shoreline that would be inhabited by juvenile chinook in a clearwater stream. Therefore, it is not surprising that the 0 to 0.4 fps velocity range selected by ADF&G as being optimum for juvenile chinook in turbid water differs little from the 0 to 0.5 fps velocity range selected by other investigators using point velocity measurements rather than mid-cell velocities as their data base.

It can be inferred from the ADF&G habitat suitability criteria that in low-velocity water (<0.4 fps) juvenile chinook do not require protection from water currents and are more likely to be found within the water column away from object cover if the water is turbid (50 to 200 NTU) than if it is clear (less than 5 NTU). At velocities greater than 0.4 fps, the distribution of juvenile chinook in turbid water is more strongly influenced by velocity. When velocities exceed 1.0 fps, object cover is probably as important to juvenile chinook in turbid water as it is in clear water. However, since these young fish probably cannot visually orient in turbid water, they cannot make use of object cover that may be available and are, therefore, redistributed in microhabitats by velocity currents.

Whenever mainstem discharge recedes sufficiently for side channels to become nonbreached and the turbid water to clear (due to the influence of local runoff and/or groundwater inflow), juvenile chinook often move from formerly occupied low-velocity turbid water pools to small clearwater riffles near the upstream end of the site. Given the high suspended sediment concentrations that occur naturally in side channel habitats, interstitial spaces between streambed particles in low velocity areas are generally filled with fine glacial sands. Thus, at low mainstem discharges when these side channels are not breached and water at the site has cleared, the most likely place to find interstitial spaces not filled with fine sediments is in riffle areas that were subjected to relatively high velocities when the site was breached. Such riffle areas generally occur near the head of the side channel.

From the preceding discussion, it can be concluded that velocity and cover are the two most important abiotic microhabitat variables influencing juvenile chinook rearing habitat. Of the two, cover appears more influential. Although offering no protection from velocity, turbid water appears to provide juvenile chinook adequate cover if velocities are less than 0.4 fps. In clear water, juveniles generally seek concealment within interstitial spaces among streambed particles. These interstitial spaces also provide enough protection from velocity that juveniles are frequently found in areas possessing velocities between 0.35 and 0.65 fps (Suchanek et al. 1984).

Based on the foregoing discussions, the clearwater cover and depth criteria developed by ADF&G for chinook have been adopted for use in the IFR analysis. However, the ADF&G velocity criteria for juvenile chinook in clear water have been modified such that the optimal velocity range extends from 0.05 to 0.65 fps rather than 0.35 to 0.65 fps (refer Fig. IV-15). As velocity increases above 0.65 fps, the habitat suitability decreases in accord with the ADF&G clearwater criteria.

In turbid water habitats, the ADF&G depth and turbid water velocity criteria are applied. However, the ADF&G turbid water cover criteria were modified by multiplying the clearwater cover suitability values for each cover type by a turbidity factor. This turbidity factor is the ratio between the fitted mean catch per cell in turbid and clear water for corresponding cover categories (Table V-3).

Table V-3. Calculation of turbidity factors for determination of the influence of turbidity on clearwater cover criteria for juvenile chinook salmon (Suchanek et al. 1984).

Percent Cover	Number of Fish Per Cell		Turbidity Factor
	Clear	Turbid	
0-5%	.8	3.5	4.40
6-25%	2.4	4.2	1.80
26-50%	4.0	4.8	1.20
51-75%	5.6	5.5	1.00
76-100%	7.3	6.2	0.80

Application of these turbidity factors increases the suitability of a microhabitat area if 50 percent or less of its surface area has object cover. Turbidity has no discernible influence on cover if 51 to 75 percent of the microhabitat area possess object cover and slightly decreases habitat suitability if more than 76 percent object cover is present (Fig. V-16). The decrease in suitability of the higher percent cover categories in turbid water is considered to reflect the inability of juveniles to visually orient themselves in turbid water (>50 NTU) and fully utilize the available cover.

Because the turbid water suitability values calculated for the "emergent streambank vegetation" and "no-cover" types were unrealistically low (approximately 0.04), the value, 0.30, was chosen for these cover types under turbid water conditions. This seemed appropriate because 0.30 was the value calculated for the majority of other cover types under turbid water conditions when zero to 5 percent object cover was available under clearwater conditions.

Habitat Availability. Figure V-17 compares WUA indices forecast using both the ADF&G and the modified velocity criteria for juvenile chinook rearing at Side Channel 21 and Upper Side Channel 11. Increasing the range of low velocities suitable for juvenile chinook in clear water at these study sites did not significantly affect the shape of the WUA response function previously forecast by ADF&G. This is attributable to the poor cover conditions associated with low-velocity areas in these sites under natural conditions. The most notable changes occurred where low-velocity water is more likely associated with larger substrates in the mid-channel zone or with streambank cover at high flows (Upper Side Channel 11).

Figure V-18 presents WUA indices forecast for juvenile chinook using cover criteria for low and high turbidity conditions. Identical habitat response curves are forecast under low-turbidity conditions because the ADF&G clearwater cover criteria remains unchanged.

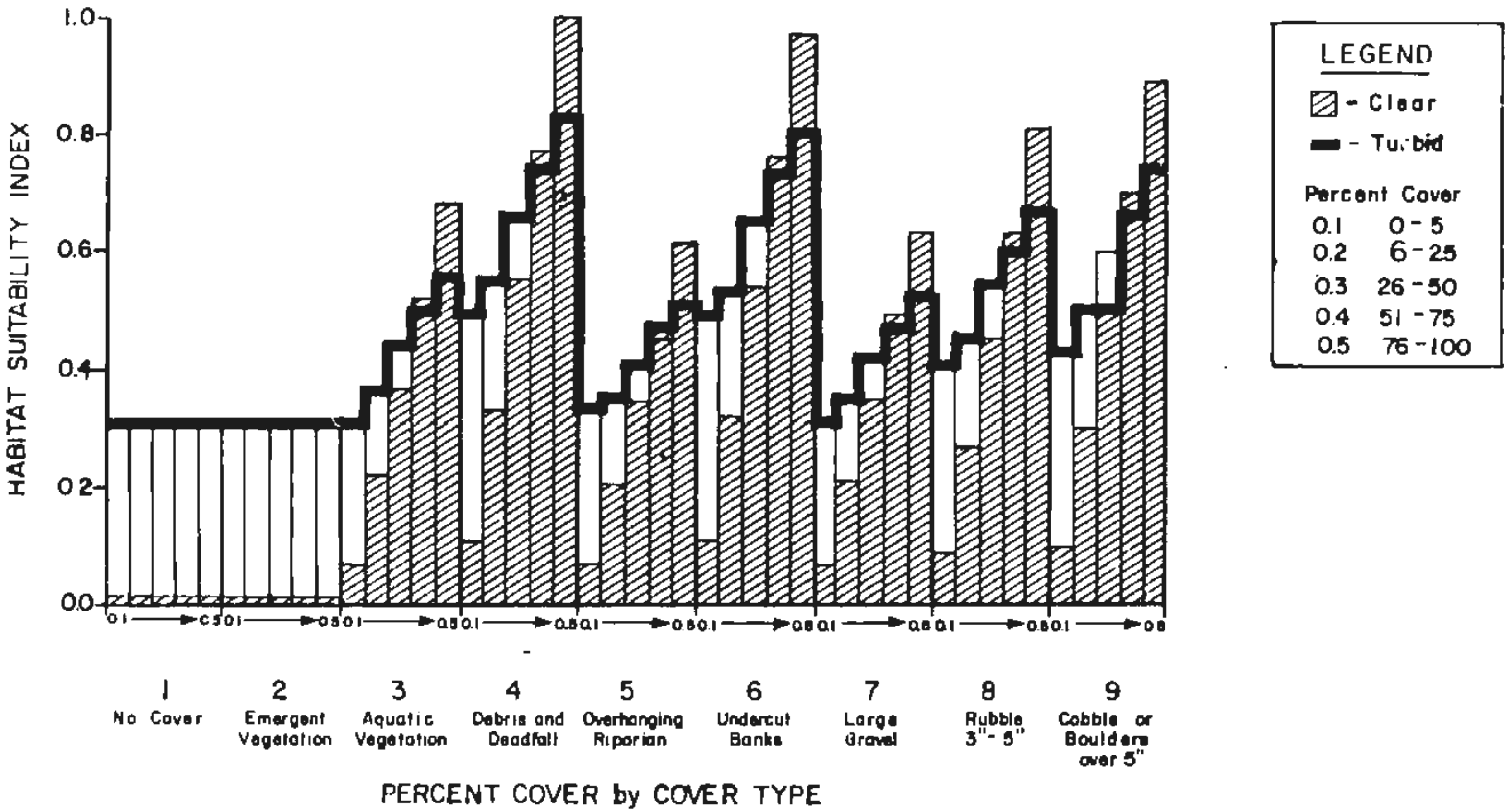


Figure V-16. Revised cover criteria for juvenile chinook in clear and turbid water.

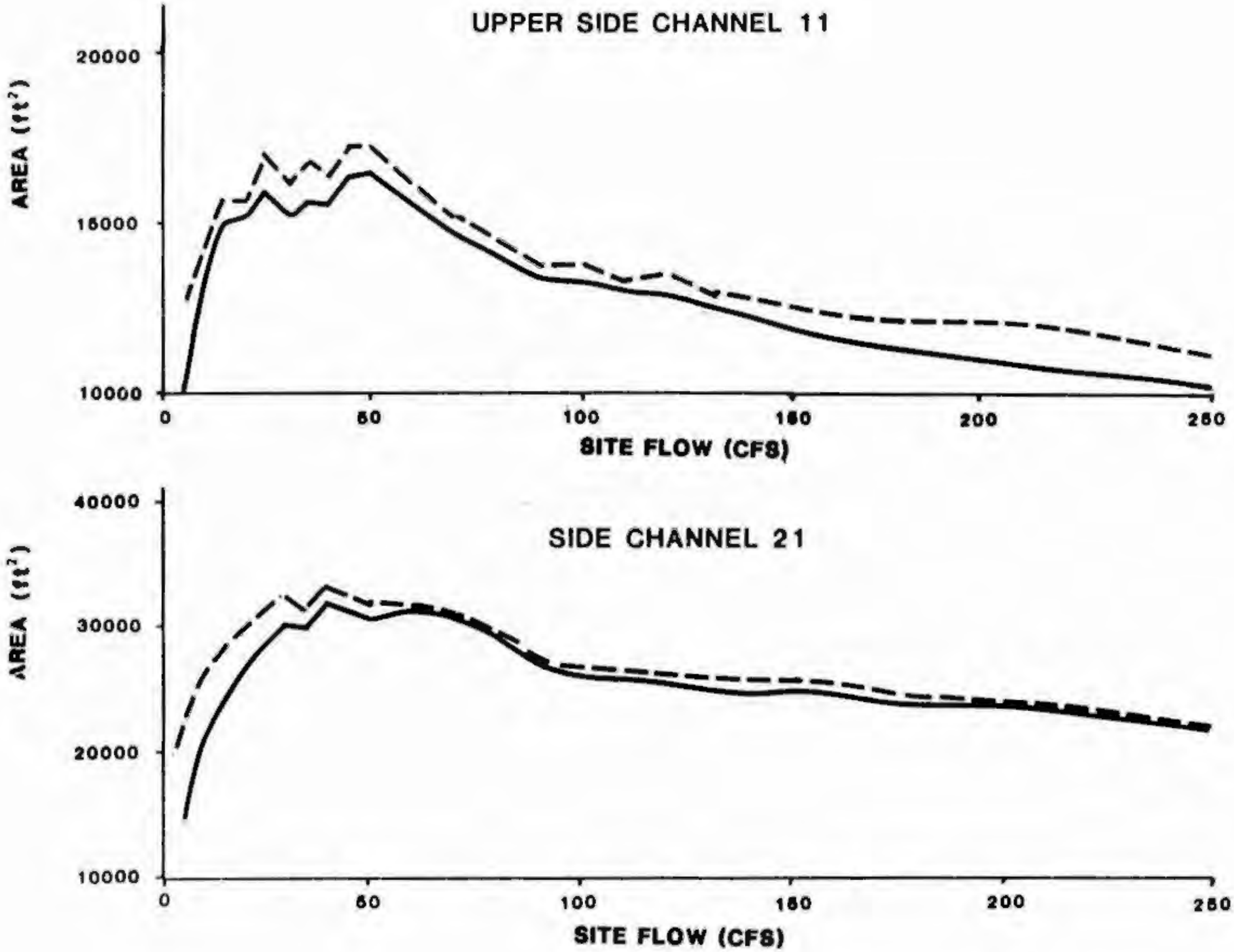


Figure V-17. Comparison between WUA forecasts using ADF&G low turbidity velocity criteria (solid line) and modified low turbidity velocity criteria (dashed line).

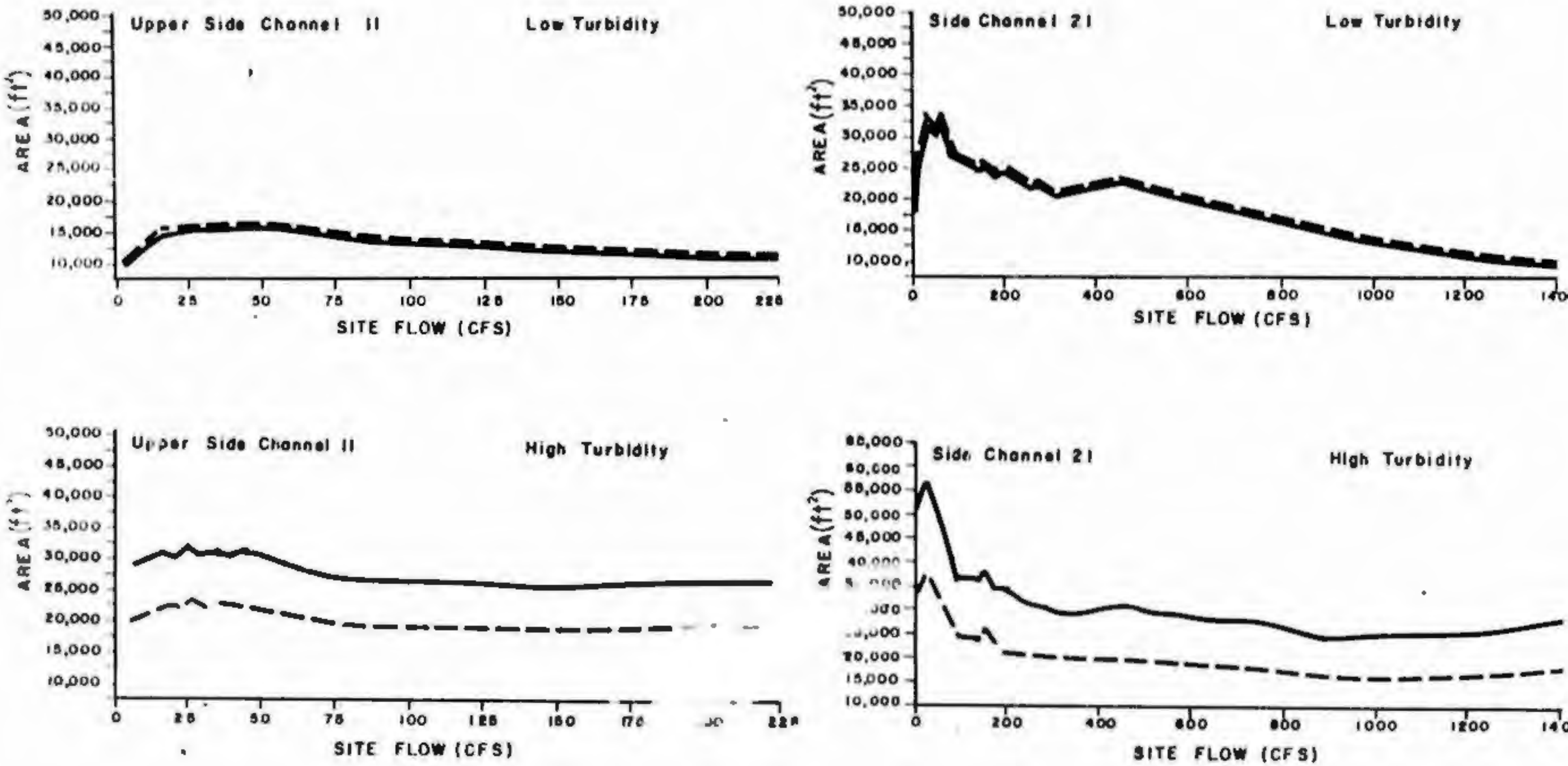


Figure V-18. Comparison between WUA forecasts using ADF&G (solid line) and modified cover criteria (dashed line) for juvenile chinook.

Application of the modified turbid water cover criteria results in approximately a 25 percent reduction in WUA indices from the ADF&G forecasts. However, the basic shape of the habitat response curves remains unchanged.

Under project operation, the larger suspended sediments (sands) that are currently transported by the river are expected to settle out in the reservoirs. Without continual recruitment of these sediments into habitats downstream of the reservoirs it is anticipated that the finer material presently filling interstitial spaces among larger streambed particles will be gradually removed. The effect of an increase in cover suitability resulting from the removal of these sediments was simulated by increasing the percent cover at two study sites one percentage category and recalculating WUA indices for juvenile chinook. This simulation provided increased WUA indices at Upper Side Channel 11 and Side Channel 21 of approximately 40 to 60 percent depending upon whether the clear or turbid water suitability criteria were applied (Fig. V-19).

Rearing habitat for juvenile chinook under low-and high-turbidity was forecast for Side Channel 21 and Upper Side Channel 11 using a combination of the modified velocity, and cover criteria in conjunction with ADF&G criteria for depth, velocity and cover (Table V-4). The respective WUA forecasts are compared to total surface area in Figure V-20. The upstream berms at these sites are overtopped by mainstem discharges of 9,200 and 13,000 cfs, respectively. Low turbidity exists at these sites whenever the mainstem discharge is insufficient to overtop the upstream berms. The same relationship exists between WUA indices and mainstem discharge when low turbidity prevails. Whenever the sites are overtopped and high turbidity exists the revised model forecasts less WUA. Turbidity has a lesser effect on increasing WUA indices at the Side Channel 21 site than the Upper Side Channel 11 site because less favorable velocities typically exist at the Side Channel 21 site.

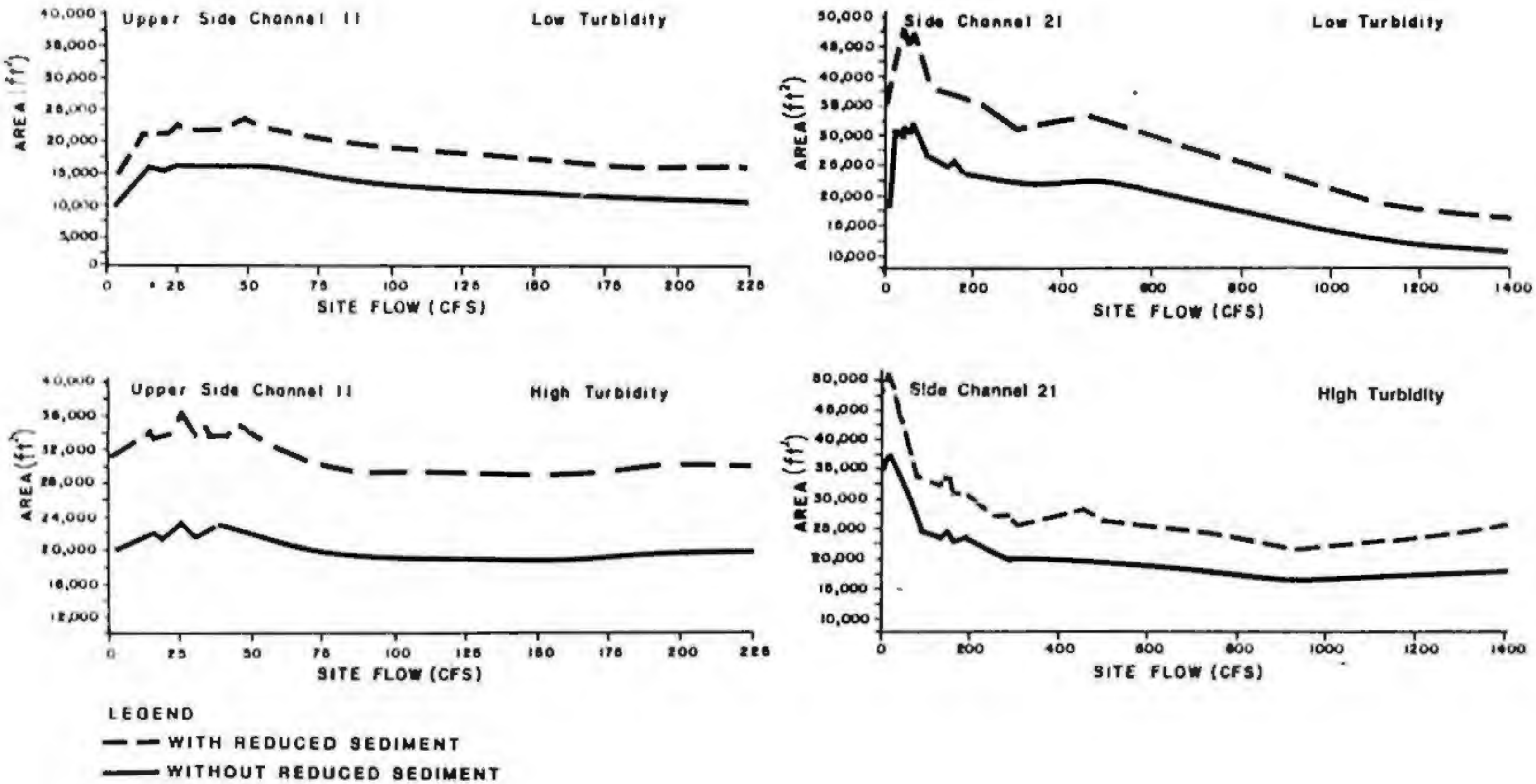


Figure V-19. Simulated effect of reducing fine sediment deposition at two study sites.

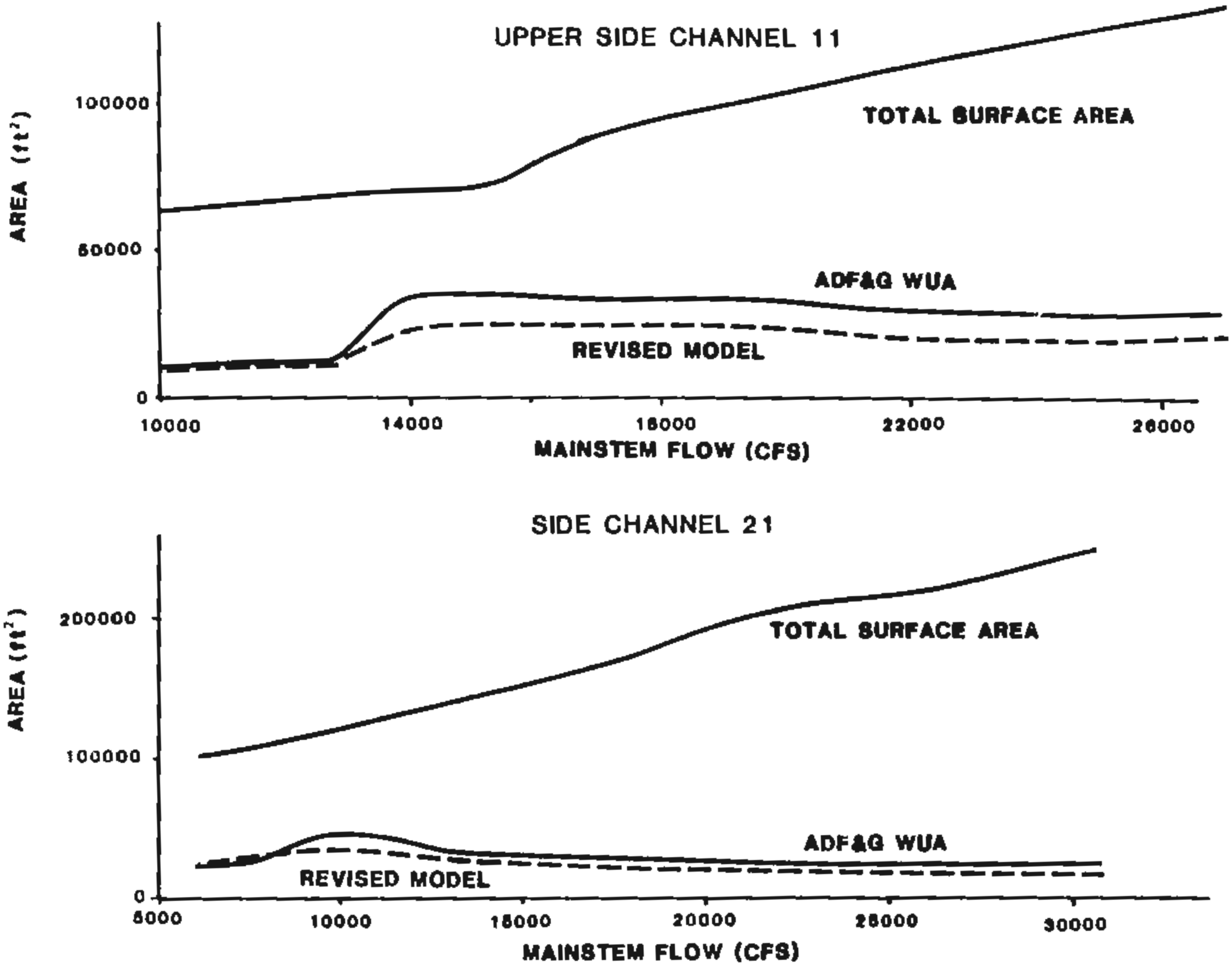


Figure V-20. Comparison between WUA forecasts using ADF&G and revised rearing habitat model.

Table V-4. Habitat suitability criteria used in revised model to forecast WUA for juvenile chinook salmon under low and high turbidities.

Low Turbidity (<30 NTU)	High turbidity (> 30 NTU)
ADF&G Cover Criteria	ADF&G Depth Criteria
ADF&G Cover Criteria	Modified Cover Criteria
Revised Velocity Criteria	ADF&G Velocity Criteria

Given the habitat suitability criteria developed for juvenile chinook and typical middle river conditions, depth of flow is a relatively inconsequential microhabitat variable unless it is less than 0.15 feet. Thus, the general shape of habitat response curves for juvenile chinook is determined primarily by the interaction between cover and velocity. Because juvenile chinook salmon in the middle Susitna River use naturally occurring turbidity levels as a form of cover, notable increases in WUA are caused by the breaching of a clearwater study site by turbid mainstem flow. The magnitude of the WUA increase is proportional to the increase in wetted surface area possessing suitable velocities.

The relationship between WUA and wetted surface area is plotted as a flow dependent percentage in Figure V-21. At higher mainstem discharges a lesser percentage of the total wetted surface area is available as rearing habitat. This is attributable to wetted areas with suitable velocities for rearing fish becoming available at a lesser rate as discharge continues to increase; a common occurrence in well-defined steep gradient channels. The most efficient use of streamflow to provide rearing habitat appears to occur immediately following overtopping of the site when the flow is turbid and a large percentage of the total wetted surface area is associated with low velocity flow.

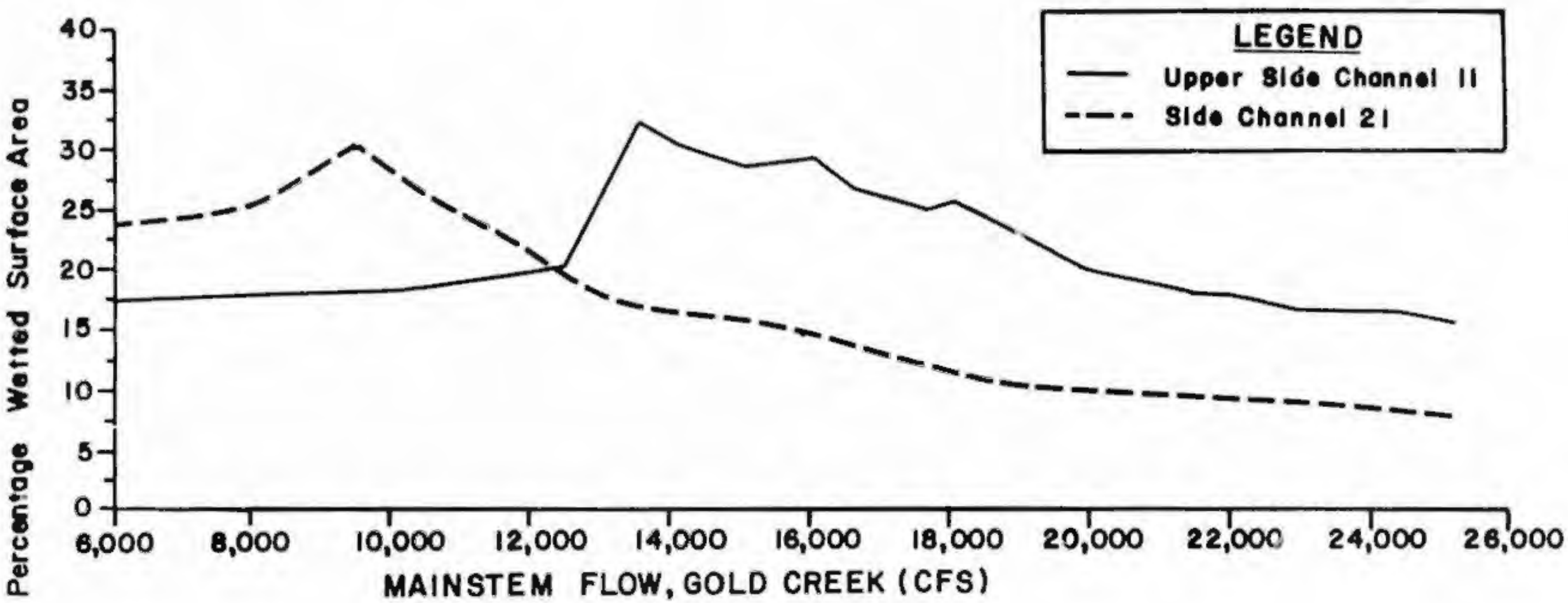


Figure V-21. Percent of total wetted surface area providing WUA for rearing chinook at Side Channel 21 and Upper Side Channel 11.

VI. SUMMARY

This section summarizes the relative importance of the various physical processes and habitat variables discussed in Sections IV and V with regard to the primary evaluation species and evaluation periods identified in Section III. The major conclusions obtained from a subjective evaluation of naturally occurring physical processes is presented, as well as, a discussion of some inherent project-induced changes to these processes. Understanding the nature and general magnitude of these project-induced changes should provide a sound technical basis for selecting streamflow and stream temperature regimes to avoid or minimize negative effects, and maximize beneficial effects, of the proposed Susitna Hydroelectric Project on fish habitats within the Talkeetna-to-Devil Canyon river segment.

Influence of Streamflow on Habitat Types and Other Variables

Six aquatic habitat types have been identified based on similarities in morphologic, hydrologic, and hydraulic characteristics (ADF&G, Su Hydro 1983a; Klinger and Trihey 1984). The surface area of some habitat types such as upland sloughs, tributaries and tributary mouths are relatively insensitive to variations in mainstem discharge. However, both the wetted surface area and habitat quality of other habitat types such as the mainstem and side channels, respond directly to variations in mainstem discharge. In addition, the type of aquatic habitat which occurs at some locations (specific areas) is also a function of mainstem discharge. Such an example is the transformation of turbid water side channel habitat to clear water side slough habitat as mainstem discharge decreases (Klinger and Trihey 1984).

Because of these marked responses of aquatic habitats to changes in mainstem discharge, the streamflow regime of the middle Susitna River is considered the primary driving variable that controls habitat availability. Important descriptors of mainstem discharge are the magnitude, frequency, duration, and seasonality of streamflow events. Microhabitat variables, which respond to variations in streamflow, and which influence the quality of fish habitat are depth, velocity, channel structure, substrate composition, upwelling, water temperature, suspended sediment, turbidity, and dissolved organics and inorganics. Many of these variables are themselves interrelated. Understanding the cause-effect relationships between these variables and quantifying the magnitude of project induced changes to them provides a technical basis for estimating both the beneficial and adverse effects of the proposed project on fish habitat and populations.

Regional climate causes seasonal and annual variations in streamflow and stream temperature. Basin topography and geology in concert with regional climate determine runoff and water quality patterns, channel morphology, and streambed composition. For the middle Susitna River channel morphology and, to a large degree, streambed composition can be considered constants (R&M 1982a; Univ. of Alaska, AEIDC 1985b) but streamflow, stream temperature and water quality vary both seasonally and annually.

The relationship between air temperature and water supply determines the seasonal response of streamflow, water temperature and water quality. Annual variations in basin precipitation and climate account for year-to-year fluctuations with cyclic variation of air temperature being the primary cause of seasonal differences. Summer drought is usually moderated by streamflow originating from glaciers (which cover about 290 square miles of the upper Susitna Basin) and from three large lakes in the Tyone River drainage. Because glacial flow results in high turbidities and suspended sediment concentrations during summer, the water quality of mainstem influenced habitats changes markedly with the seasons.

High streamflows reshape channel geometry, which at lower discharge levels controls site-specific hydraulic conditions. Median summer streamflows typically exceed the mean annual discharge by a factor of two and transport large amounts of suspended sediment. The associated high velocities, turbidities, and abrasive action of the suspended sediments are considered limiting to the colonization of the streambed by algae and aquatic insects, which generally provide an important food source for fish.

Streamflows and stream temperatures during winter play an integral role in middle Susitna River ice processes which directly affect channel structure, shoreline stability, and the general quality of winter fish habitat. River ice also affects instream hydraulics, most notably by constricting the channel, reducing velocity, and increasing river stage. This increase in water surface elevation during winter has both positive and negative effects on fish habitat. Higher water surface elevations during winter are considered important for raising local groundwater elevations, thereby maintaining upwelling in slough an side channel areas. These upwellings provide a source of relatively warm water (2-3°C) throughout winter (Trihey 1982; ADF&G, Su Hydro 1983c) which is considered essential for the survival of incubating salmon eggs and overwintering fish. However, if river stage increases enough to overtop the upstream berm of the slough or side channel, then near 0°C water would flow from the mainstem into these sites, negating the thermal effect of upwelling and greatly reducing the value of upwelling areas as winter habitat.

River stage (discharge) is important during summer with regard to controlling access to fish habitat in side channels and sloughs located along the flood plain margin. Because of the complex multi-thread channel pattern of the middle Susitna River, changes in mainstem water surface elevation strongly influences the amount of watered and dewatered channel area as well as the relative percentages of clear and turbid water surface area (Klinger and Trihey 1984).

Seasonal Utilization of Middle River Habitats

Mainstem and side channel habitats are predominantly used as migrational corridors by adult and juvenile salmon. Adult inmigration begins in late May and extends to mid-September. Juvenile outmigration occurs from May through October. A limited amount of chum salmon spawning occurs at upwelling areas along shoreline margins in these habitats (Barrett et al. 1984), and chinook juveniles use low-velocity areas for rearing (Suchanek et al. 1984). Several species of resident fish also use mainstem and side channel habitat during both summer and winter (Sundet and Wenger 1984). The more important species appear to be rainbow trout, Arctic grayling, and burbot.

Side sloughs provide important spawning, rearing, and overwintering habitat. One prominent physical characteristic of this habitat type is the influence of upwelling groundwater, which maintains clear water flow in these habitats during periods of low summer mainstem discharge and open leads during winter. Approximately half of the chum salmon (5,000) and all of the sockeye salmon (1,500) that spawn in the middle Susitna River do so in side slough habitats (Barrett et al. 1984). Most chum and sockeye spawning activity occurs between mid-August and mid-September. Upwelling attracts spawning salmon and provides incubation conditions that result in high survival rates (Vining et al. 1985). Fry begin to emerge in April, and rear near these natal spawning areas until June (ADF&G, Su Hydro 1983e). Chum fry outmigrate to marine habitats during June and early July. Juvenile chinook enter side slough habitats in August and overwinter until late spring, when they begin their outmigration to marine habitats.

Upland sloughs provide summer rearing and overwinter habitat for juvenile coho and chinook salmon (Dugan et al. 1984). Sockeye juveniles generally move into upland sloughs during June, but many leave prior to the onset of freeze-up. A limited amount of spawning by chum salmon also occurs in this habitat type (Hoffman 1985; Barrett et al. 1984). Tributary mouths provide a small amount of spawning, rearing and overwintering habitat. Small numbers of pink, chum, and chinook salmon have been observed spawning in tributary mouth habitats (Barrett et al. 1984) and juvenile chinook and coho salmon may be found in these habitats throughout the year (Dugan et al. 1984).

Evaluation Species and Periods

Seasonal habitat requirements are species- and life stage-specific. Evaluation species were selected on the basis of their importance to commercial and sport fisheries (refer Section III), and the potential for project construction and operation substantially altering their existing habitat. The primary evaluation species and life stages are chum salmon spawning and incubation, and juvenile chinook salmon rearing. Since biological activity, physical processes, and habitat conditions vary seasonally, the year was divided into four evaluation periods. These periods were selected to best accommodate the natural timing of the four principal freshwater life stage activities of Pacific salmon (spawning, incubation, overwintering, and summer rearing) in the middle Susitna River (Fig. VI-1).

Although portions of the evaluation periods overlap, the habitats occupied by overlapping life stages as well as their habitat requirements differ sufficiently to warrant separate analyses. To facilitate integrating periods of biologic activity with the standard time step used in the reservoir operation and various streamflow models, evaluation periods are defined coincident with water weeks (Table VI-1). Water weeks begin October 1 and consist of 51 consecutive 7-day periods. The fifty-second week (September 23-30) contains eight days, and February 29 is omitted.

Table VI-1. Evaluation periods as defined by water weeks.

Species	Life stage	Evaluation period	Water Weeks
Chum	Spawning	August 12 to September 15	45 through 50
Chum	Incubation	August 12 to March 24	45 through 25
Chinook	Overwintering	September 16 to May 19	51 through 33
Chinook	Summer rearing	May 20 to September 15	34 through 50

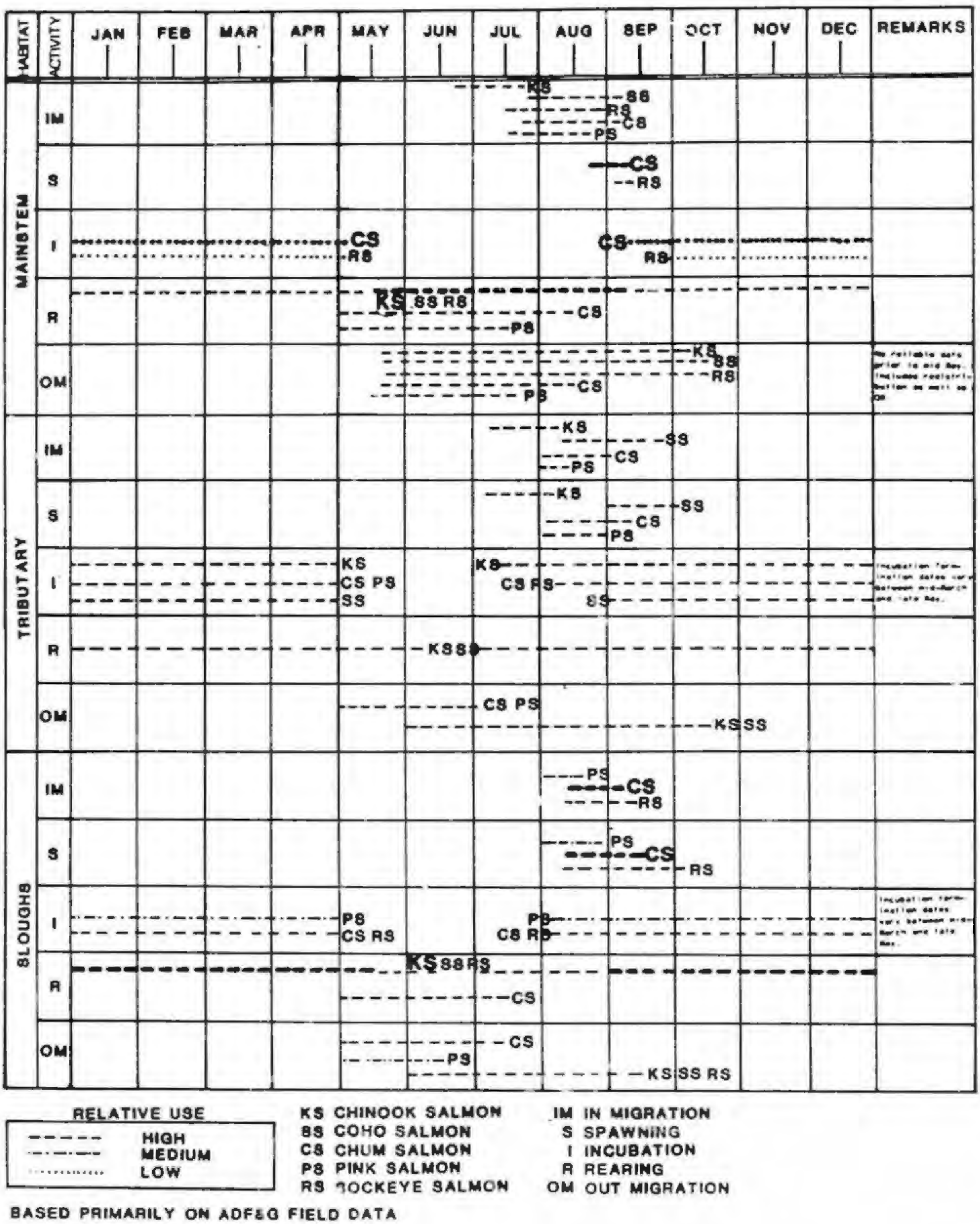


Figure VI-1. Phenology and habitat utilization of middle Susitna River salmon in mainstem, tributary, and slough habitats (adapted from Woodward-Clyde and Entrix 1985).

Relative Ranking of Physical Habitat Variables

Table VI-2 presents the results of subjectively evaluating the technical information presented in Sections III through V within the analytic structure of the IFRS model introduced in Section II. This table summarizes the relative degree of influence that individual physical habitat variables exert on aquatic habitats in the middle Susitna River during each of the evaluation periods identified above.

The habitat- and evaluation period indices provided in Table VI-2 only consider physical aspects of habitat quality and do not reflect the important synergistic influences that biologic processes have on the quality and productivity of aquatic habitats. Therefore, these index values should not be used to rank habitat types or evaluation periods in terms of their productivity.

The presence of upwelling water is the most important habitat variable influencing the selection of spawning areas by chum salmon and it significantly affects egg-to-fry survival rates (ADF&G, Su Hydro 1983c; Vining et al. 1985). Upwelling's importance is derived from its associated thermal and water quality characteristics which provide life support for the aquatic community during winter and to a large extent influence habitat quality during the remainder of the year.

Table VI-2, Parts A and B summarize the influence of this physical habitat variable on spawning and incubation for each habitat type. Use of upwelling areas in mainstem and side channel habitats by spawning salmon is limited by several factors. High sediment concentrations result in large volumes of sand being transported in close proximity to the streambed, and mainstem and side channel streambeds generally consist of large particles which are well-cemented by silts and sands (R&M 1982a; ADF&G, Su Hydro 1983a). During August mainstem stage is usually adequate to provide adult spawners access to upwelling areas in mainstem and side channel habitats (Harza-Ebasco 1984g; Klinger and Trihey 1984), but, naturally declining water

Table VI-2. Relative degrees[1] of influence that physical habitat variables exert on the suitability of middle Susitna River habitat types during the four evaluation periods.

Habitat Variable*	Mainstem	Side Channel	Side Slough	Upland Slough	Tributary Mouth
	PART A: Spawning (August 12 - September 15)				
Mainstem flow	-3	-2	+2	0	-1
Upwelling	+1	+2	+3	+3	+2
Substrate composition	-3	-2	0	-2	+2
Suspended sediment	-1	-1	0	0	0
Turbidity	0	0	0	0	0
Water Temperature	0	0	0	0	0
Habitat Index	-6	-3	+5	+1	+3
	PART B: Incubation (August 12 - March 24)				
Mainstem flow	-3	-2	+2	0	-1
Upwelling	+1	+2	+3	+3	+2
Substrate composition	-1	-1	+1	-1	+1
Suspended sediment	-1	-1	0	0	0
Turbidity	0	0	0	0	0
Water temperature	-3	-3	+2	+2	-2
Ice processes	-2	-2	-1	0	-2
Habitat Index	-9	-7	+7	+4	-2
	PART C: Overwintering (September 16 - May 19)				
Mainstem flow	-2	-2	+2	0	-1
Upwelling	+1	+1	+3	+3	+1
Substrate composition	-2	-2	+2	-1	+2
Suspended sediment	0	0	0	0	0
Turbidity	0	0	0	0	0
Water temperature	-3	-3	+2	+2	+1
Ice processes	-3	-3	-2	-1	-2
Habitat Index	-9	-9	+7	+3	+1
	PART D: Summer Rearing (May 20 - September 15)				
Mainstem flow	-3	-2	+2	0	-2
Upwelling	0	+1	+2	+2	0
Substrate composition	-2	-2	+2	+1	+2
Suspended sediment	-3	-2	-1	-1	0
Turbidity	+2	+2	0	0	0
Water temperature	0	0	0	0	0
Habitat Index	-6	-4	+5	+2	0

[1] Evaluation scale

- +3 extremely beneficial
- +2 moderately beneficial
- +1 slightly beneficial
- 0 no effect
- -1 slightly detrimental
- -2 moderately detrimental
- -3 extremely detrimental

* Typical conditions for the habitat type during the season evaluated.

surface elevatins during September limit spawning habitat quality in some mainstem upwelling areas. Mainstem and side channel habitats are are generally limited by velocity, except in isolated backwater locations along streambank margins. These locations usually possess low quality spawning substrates because of their tendency to accumulate relatively deep deposits of fine sediments.

Exclusive of the major clearwater tributaries, spawning most frequently occurs in side slough habitats where upwelling is prevalent and other physical habitat conditions are suitable. Naturally occurring velocities seldom limit spawning in side slough habitats. However, side slough habitats are often limited by shallow depths, and poor quality streambed composition. Shallow depths also cause passage problems which inhibit spawning salmon from using upwelling areas in upstream portions of the side sloughs. Periodic short-term increases in slough flow are important for improving passage conditions (Trihey 1982; Estes and Vincent-Lang 1984c). These increases are principally caused by overtopping events or by rainfall runoff.

Both incubation and overwintering are adversely influenced by naturally occurring cold water temperatures, river ice, and low streamflows (refer Table VI-2, Part B and Part C). The presence of upwelling groundwater creates favorable incubation conditions in slough habitats and resulted in egg-to-fry survival rates up to 35 percent in 1983-1984 (Vining et al. 1985). Pools within the sloughs generally provide adequate depth and water temperatures for juvenile fish to overwinter. At times, side sloughs are overtopped during winter as a result of the mainstem ice cover formation (refer Section IV). The influx of cold mainstem water into side slough habitats may reduce intragravel water temperatures and adversely affect incubation rates and embryo growth. Overtopping also adversely affects overwintering fish.

The adverse influence of cold water temperatures is most pronounced in mainstem and side channel habitats where near 0°C water temperatures exist for approximately seven months. Upwelling exists in mainstem and side channel areas but its thermal value is significantly reduced due to the large volumes of 0°C water in these channels. Shorefast and slush ice form along channel margins filling low-velocity areas, where fish might otherwise overwinter, with ice. Mid-channel velocities generally exceed those considered suitable for over-wintering habitat. In addition large volumes of anchor ice and a thick ice cover (4-6 ft) form over mainstem and side channel habitats (R&M 1983a).

Much of the main channel and side channel surface areas possess high velocities and suspended sediment concentrations which are not suitable for small fish (refer Table VI-2, Part D). In portions of these habitats where streambed materials are large enough to provide juvenile fish refuge from high velocities, interstitial spaces are generally filled by densely packed glacial silts and sand, thereby preventing fish from burrowing into the streambed. Rearing areas associated with mainstem and side channel habitats are typically located in low velocity areas along the shoreline margin, or in backwater areas. Shoreline gradients are often mild, hence seasonal variations of streamflow can cause large changes in wetted surface area (Klinger-Kingsley 1985).

Although turbidity has some value to juvenile chinook for cover (Suchanek et al. 1984) high turbidity also limits light penetration and reduces primary production levels in mainstem and side channel habitats. Low primary production levels result in a low aquatic food base for rearing fish. Thus, turbidity has both beneficial and detrimental effects on rearing habitats in the middle Susitna River. Side sloughs and side channels that fluctuate between clear and turbid water habitats in response to streamflow variations, appear to provide better conditions for primary and secondary production than areas that remain turbid throughout summer. While the area is clear, primary production rates would be high, stimulating production of benthic prey. Under higher turbidities, the young chinook could move into these areas and feed without unduly exposing themselves to predation.

However, if these areas remain turbid continuously, aquatic food production would likely be reduced.

The most important variables affecting fish habitat in the middle Susitna River are streamflow, upwelling, temperature, turbidity, and suspended sediment. Streamflow and upwelling are most influential for determining habitat availability, where as temperature, suspended sediment, and turbidity are the primary regulators of habitat quality. The relative importance of these habitat variables changes with the season, species, life stage and habitat type being considered. The habitat index values (column totals) appearing in Table VI-2 are listed in Table VI-3 to identify the evaluation periods and habitat types most limited by natural conditions.

Table VI-3. Summary of habitat and evaluation period indices for the middle Susitna River as derived in Table VI-2.

Evaluation Period	Mainstem	Side Channel	Side Slough	Upland Slough	Tributary Mouth	Evaluation Period Index [1]
Spawning	-6	-3	+5	+1	+3	0
Incubation	-9	-7	+7	+4	-2	-7
Overwintering	-9	-9	+7	+3	+1	-7
Summer Rearing	-6	-4	+5	+2	0	-3
Habitat Index [2]	-30	-23	+24	+10	+2	

[1] Row total

[2] Column total

The information summarized in Table VI-3 reflects the detrimental influences of high mainstem discharges and sediment concentrations during summer and of low streamflows and stream temperatures during winter. Review of the habitat- and evaluation period indices in Table VI-3 indicate that the most stressful period of the year for fish occurs during fall and winter. Naturally occurring physical habitat conditions are least limiting to spawning and most limiting to incubation and overwintering. It is also evident that mainstem and side channel habitats are more adversely effected by the natural streamflow, stream temperature and sediment regimes of the Susitna River than are slough and tributary mouth habitats.

Influence of Project Design and Operation on Downstream Physical Processes and Fish Habitats

Construction and operation of the proposed Susitna Project would alter the natural streamflow, sediment, and thermal regimes of the middle Susitna River. These changes would affect, to varying degrees, instream hydraulic conditions, turbidity, ice processes, streambed composition, upwelling, and stream channel geometry, all of which influence the availability and quality of fish habitat. Using this opportunity to: (1) improve incubation and overwinter conditions, (2) reduce high summer streamflows and sediment concentrations, and (3) maintain or improve existing clearwater spawning and rearing habitats appears to be a reasonable goal when establishing instreamflow requirements for the middle Susitna River. However, attainment of this goal depends upon understanding the degree of control alternative design and/or operation criteria might exert on downstream physical processes and habitat variables.

Some project-induced changes, such as to the natural sediment and turbidity regimes, are inherent with project construction and offer a very limited opportunity to be influenced by project design or operation. Other project-induced changes, such as to the natural streamflow and stream temperature regimes are also inherent, but these changes may be moderated or controlled through project design or operation. Understanding the degree of control project design and operation might have over changes to natural processes and physical habitat variables can provide an effective means of developing measures to avoid or minimize negative effects and maximize beneficial effects project operation on downstream fish habitats.

Alternative design considerations and operating policies will afford varying degrees of control over the natural streamflow, stream temperature and sediment regimes of the river. Based on information provided in Section IV and other project reports, the degree of control over aquatic habitat variables afforded by alternative design or operating criteria can be ranked in ascending order of effectiveness according to: (1) control over downstream sediment concentrations and turbidities, (2) control over the magnitude and variability downstream temperatures and ice processes and (3) control over downstream flow. Each of these topics are discussed separately below.

Sediment and Turbidity

The 8.6 million acre-foot impoundment behind Watana dam will trap the sand and larger sediments currently being transported from upstream sources (R&M Consultants 1982d; Harza-Ebasco 1984e). This reduction in sediment load is expected to result in some degradation of the main channel downstream from the reservoirs (Harza-Ebasco 1985e). A general coarsening of streambed materials should occur within the middle Susitna River as sand and other fine sediments are eroded from the streambed and transported downstream.

However, not all suspended sediment would settle out in Watana Reservoir. Very fine sediments (< 5 microns) are expected to remain in suspension throughout the year, causing streamflows downstream of Watana Reservoir to change from highly turbid in summer and clear in winter to moderately-turbid throughout the year (Peratrovich et al. 1982; Harza-Ebasco 1984e).

Alternative design or operating criteria for Watana or Devil Canyon Dams affords a very limited degree of control over downstream suspended sediment concentrations and turbidities. Both these habitat variables are far more influenced by reservoir size and retention time, and particle size and light refraction than by the manner in which the dams would be operated. The reduction in mid-summer suspended sediment concentrations is expected to have an unquantifiable but beneficial influence on habitat conditions for aquatic insects and immature fish. Both have been found to respond favorably to reduced sediment transport rates in other systems (Bjornn et al. 1977). At present, project-induced changes in natural turbidity levels are not sufficiently understood to forecast the net effect of project altered turbidities on food production and fish habitat in the middle Susitna River. However, work is under way which should improve the level of understanding by early 1986.

Temperature and Ice Processes

Downstream water temperature would be altered by impounding the natural flow of the Susitna River. The reservoirs will attenuate the annual variation in stream temperature by storing heat energy during spring for redistribution during fall and winter. With-project mainstem water temperatures are expected to be cooler during summer and warmer during fall and early winter. Mid summer and mid winter stream temperatures are not expected to change appreciably from natural (Univ. of Alaska, AEIDC 1984). Alternative multi level intake designs and operating criteria can provide only a moderate degree of control over mainstem water temperatures because of the overriding influence of air temperature (APA 1984a).

Dewatering and freezing of streambeds and a prolonged period of near zero degree water temperature appear to be the most critical habitat conditions affecting natural fish populations in the middle Susitna River (refer Table VI-2). An increase in mainstem water temperature over natural stream temperatures during fall and early winter would extend the period of biologic activity, delay the onset of winter ice processes and possibly improve overwinter survival in the affected habitats. Were water temperatures sufficient to prevent formation of an ice cover, it is expected that terrestrial vegetation would become better established along shorelines and on partially vegetated gravel bars. This change would improve streambank stability and provide fish greater access to streambank cover and terrestrial insects. Lack of an ice cover would also preclude staging, thereby reducing the frequency at which side slough habitats are overtopped during winter.

Streamflow

Streamflow is the primary driving variable which either directly or indirectly effects all aquatic habitat variables (Fig. VI-2). In the middle Susitna River, different aspects of streamflow are important at different times of the year and to different habitat types. Mainstem water surface elevations and site specific depths are of greatest concern in side channel and slough areas where the highest degrees of habitat utilization have been observed (ADF&G, Su Hydro 1983e). These habitats are the most vulnerable to dewatering by abnormally low summer streamflows (Klinger-Kingsley 1985) or to overtopping during winter because of abnormally high discharges and enhanced river ice conditions (Harza-Ebasco 1985d).

Velocity appears to be of secondary or tertiary importance depending upon the species and habitat type being evaluated. Habitat response curves (Section V) for both spawning and rearing fish in side slough and side channel habitats are more significantly influenced by increases in depth resulting from overtopping (a water surface elevation phenomena), than by site specific velocity conditions. Analyses of hydraulic conditions in shoreline margins of the mainstem and large side channels (Williams 1985) indicate that flow velocity often suppresses rearing conditions for juvenile salmon. Shoreline margins are usually devoid of cover objects and stream channel and streambank gradients are often too steep to provide any significant change in the amount of wetted surface area possessing suitable rearing velocities unless mainstem discharge was reduced to the range of 5,000 cfs.

Project operation could provide a considerable degree of control over the magnitude and variability of streamflows in the middle Susitna River (Harza-Ebasco 1984g). During the open water season, streamflow could be regulated to provide relatively stable depths and velocities in side channel and slough habitats, or could be intentionally fluctuated during early summer to flush undesirable sediments from the

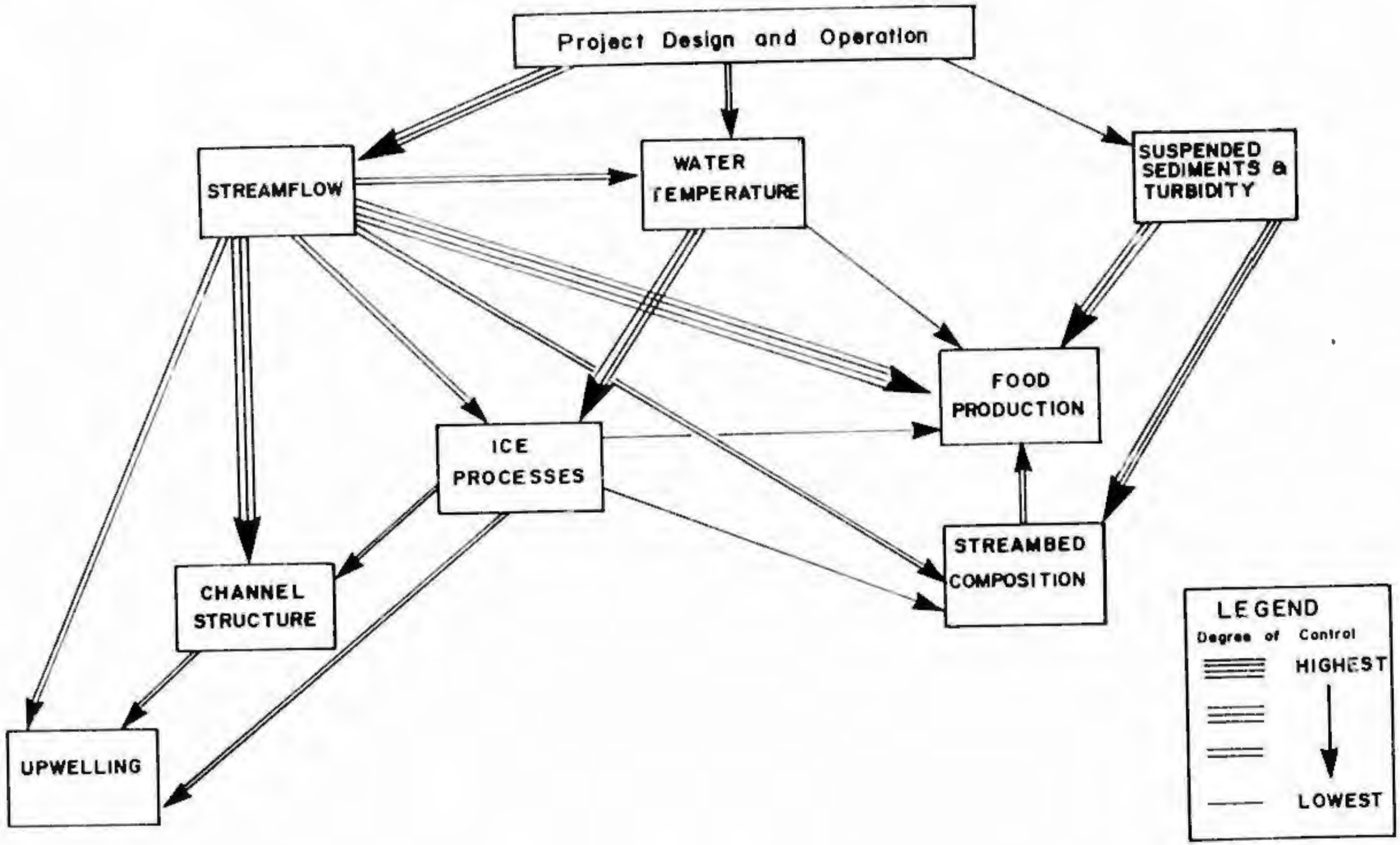


Figure VI-2. Ranking of habitat component in accord with the degree of control project design and operation might provide them.

streambed. Streamflow fluctuations during late summer and fall could assist adult salmon gain access to side slough spawning habitats. However, persistent cyclic fluctuations (such as those associated with hydropower peaking) would likely be detrimental to fish and fish food organisms in mainstem and side channel habitats. During winter, higher than natural, but stable, streamflows would likely improve habitat conditions in mainstem and side channel habitats presently influenced by river ice or dewatering and freezing. Higher than natural water flow would contribute to improved upwelling in the side sloughs which would likely benefit incubation and overwintering conditions. However, if mainstem water surface elevations associated with higher winter streamflows were sufficient to cause recurrent mid-winter overtopping of slough habitats the inflow of cold mainstem water would adversely affect incubation and overwintering conditions in the side sloughs.

Fish Habitats

The relative degree of influence that with-project physical habitat variables might exert on the suitability of aquatic habitats in the middle Susitna River is summarized by Table VI-4. These subjective index values are based upon the assumption that the with-project physical habitat conditions implied by preceding discussions do occur: sediment transport rates are expected to be significantly reduced, turbidities decreased in summer and increased during winter, stream temperatures increased during winter, and ice processes moderated upstream from RM 125. In addition it is assumed that streamflows would be in the range of 12,000 to 14,000 cfs during summer and 8,000 or 9,000 cfs during winter.

The index values in Table VI-4 may be used to evaluate the relative degree of influence with-project physical habitat variables might exert on each of the habitat types at different times of the year. These indices do not reflect the important synergistic influence of biologic processes on habitat quality and therefore, do not

Table VI-4. Relative degrees[1] of influence that estimated with-project physical habitat variables might have on the suitability of middle Susitna River habitat types during the four evaluation periods.

Habitat Variable*	Mainstem	Side Channel	Side Slough	Upland Slough	Tributary Mouth
	PART A: Spawning (August 12 - September 15)				
Mainstem flow	-1	+1	+1	0	+2
Upwelling	+2	+3	+2	+2	+2
Substrate composition	-1	+1	+1	-2	+2
Suspended sediment	0	0	0	0	0
Turbidity	0	0	0	0	0
Water Temperature	0	0	0	0	0
Habitat Index	0	+5	+4	0	+6
	PART B: Incubation (August 12 - March 24)				
Mainstem flow	+1	+1	+2	0	+1
Upwelling	+1	+2	+3	+3	+1
Substrate composition	-1	-1	+1	-1	+1
Suspended sediment	0	0	0	0	0
Turbidity	0	0	0	0	0
Water temperature	-1	-1	+2	+2	-1
Ice processes	-1	-1	-1	0	-1
Habitat Index	-1	0	+7	+4	+1
	PART C: Overwintering (September 16 - May 19)				
Mainstem flow	+1	+1	+2	0	+1
Upwelling	+1	+2	+2	+2	+1
Substrate composition	+1	+2	+2	-1	+2
Suspended sediment	0	0	0	0	0
Turbidity	+1	+1	0	0	0
Water temperature	-1	-1	+2	+2	-1
Ice processes	-1	-1	-1	-1	-1
Habitat Index	+2	+4	+7	+2	+2
	PART D: Summer Rearing (May 20 - September 15)				
Mainstem flow	+2	+2	+2	0	+2
Upwelling	0	0	+1	+1	0
Substrate composition	+1	+1	+2	+1	+2
Suspended sediment	0	0	0	0	0
Turbidity	+2	+2	0	0	0
Water temperature	0	0	0	0	0
Habitat Index	+5	+5	+5	+2	+4

[1] Evaluation scale
- +3 extremely beneficial
- +2 moderately beneficial
- +1 slightly beneficial
- 0 no effect
- -1 slightly detrimental
- -2 moderately detrimental
- -3 extremely detrimental

* Anticipated with-project conditions for the habitat type during the season evaluated based on information contained in the draft license amendment (APA 1985a).

necessarily define any particular increase or decrease in fish populations.

However, were the proposed project designed and operated with the intent of ameliorating the more stressful naturally occurring physical habitat conditions, a considerable degree of improvement appears to be attainable in mainstem and side channel areas (Table VI-5). Through project-induced reductions of high summer streamflows and sediment transport rates, and an increase in winter streamflow and temperatures, a considerable degree of improvement in both summer and winter physical habitat conditions appears to be attainable. The successful completion of IFR Volume 2 and the Comparisons Process will provide the necessary technical information to define the most practical streamflow and stream temperature regimes for attaining the beneficial physical habitat conditions implied by the habitat and evaluation period indices in Table VI-5.

Table VI-5. Comparison between habitat and evaluation period indices for natural (N) and with-project (P) conditions.

Evaluation Periods	Mainstem		Side Channel		Side Slough		Upland Slough		Tributary Mouth		Evaluation Period Index[1]	
	N	P	N	P	N	P	N	P	N	P	N	P
Spawning	-6	0	-3	+5	+5	+4	+1	0	+3	+6	0	+15
Incubation	-9	-1	-7	0	+7	+7	+4	+4	-2	+1	-7	+11
Overwinter	-9	+2	-9	+4	+7	+7	+3	+2	+1	+2	-7	+15
Summer Rearing	-6	+5	-4	+5	+5	+5	+2	+2	0	+4	-3	+21
Habitat Index[2]	-30	+6	-23	+14	+24	+21	+10	+8	+2	+13		

[1] Row total

[2] Column total

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