ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

FEDERAL ENERGY REGULATORY COMMISSION PROJECT NO. 7114

DRAFT

INSTREAM FLOW RELATIONSHIPS REPORT

TECHNICAL REPORT NO.3

A LIMNOLOGICAL PERSPECTIVE OF POTENTIAL WATER QUALITY CHANGES

OCTOBER 1985

PREPARED BY

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PREFACE

This text constitutes the third technical report of the Instream Flow Relationship Series (IFRS). Its primary purpose is to provide a limnologically oriented perspective for reviewing some important water quality issues associated with the Susitna Hydroelectric Project. This report will discuss certain characteristics of the reservoir innundation zones and the Susitna River "middle" reach which will affect their With-project aquatic biology. Qualitative and quantitative estimates of project-induced changes to selected water quality characteristics are discussed. Estimates of the With-project water quality and trophic status in the proposed reservoirs and the downstream Susitna River middle reach are included, particularly as they relate to fisheries biology.

The technical report series attempts to consolidate data presented in a variety of previously written reports by a variety of private, state and federal agencies and organizations. While the IFRS report series is not intended to be an impact assessment, it presents estimates of differences between the natural and regulated river which may be useful for project impact assessment.

Technical Report No.1. Fish Resources and Habitats of the Susitna Basin. This report consolidates information on the fish resources and habitats in the Talkeetna-to-Devil Canyon reach of the Susitna River available through January 1985.

Technical Report No.2. Physical Processes Report. This report describes such physical processes as reservoir sedimentation, channel morphology and stability and groundwater upwelling.

Technical Report No.3. Water Quality/Limnology Report. This report consolidates much existing information on water quality in the Susitna Basin. It addresses the potential for with-project leaching of heavy metals from the reservoirs inundation zones and their possible interactions with higher biological trophic levels; expected influences of the project on nitrogen gas supersaturation; expected project effects on hydrogen ion concentration and alkalinity; project-induced changes in plant macronutrients and their potential for influencing the trophic status of both of the project reservoirs and of the Middle river reach downstream of the reservoirs; and changes in the suspended sediment and turbidity regimes together with some potential biological effects related to these changes. This report will also discuss the estimated trophic status characteristics of the project reservoir(s) and the riverine habitats immediately downstream.

Technical Report No. 4. Instream Temperature. This report 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) evaluation of the influences of with-project stream temperatures on existing fish habitats and natural ice processes. A final report describing downstream temperatures associated with various reservoir operating scenarios and an evaluation of the effects of the these stream temperatures on fish was prepared in October 1984. A draft report addressing the influence of anticipated with-project stream temperatures on ice processes was prepared in November 1984.

Technical Report No.5. Aquatic Habitat Report. This report describes the availability of various types of aquatic habitats in the Talkeetna-to-Devil Canyon river reach as a function of mainstem discharge.

Technical Report No. 6. Ice Processes Report. This report will describe naturally occurring ice processes in the middle river, anticipated changes in those processes due to project construction and operation, and it will discuss the effects of naturally occurring and with-project ice conditions on fish habitat.

Aknowlegements

(To be written)

Executive Summary

Several water quality characteristics have been identified as potential environmental issues. Water quality characteristics for the proposed impoundment zones and the Susitna River "middle" reach have been examined and estimates of project-induced effects on some of the more important water quality issues are emphasized herein.

A moderate amount of water quality information has been collected, examined and narrowed to six sets of issues which may affect salmon and resident fish habitats and populations downstream of the proposed project. The six water quality issues discussed here are:

1) suspended sediments and turbidity,
2) pH,
3) heavy metals,
4) gas supersaturation,
5) plant macronutrients, and
6) dissolved oxygen and carbon concentrations.

Suspended Sediment and Turbidity

Suspended sediment and turbidity regimes have been examined with respect to project-induced alterations in their naturally cyclic regime. At present, estimates of project effects on the reservoir and river habitats and their biological inhabitants appear to be complex and mostly detrimental because of expected alterations to natural suspended sediment and turbidity regimes. Important fisheries habitats will be affected and mitigation presently appears to be necessary to balance some potentially detrimental effects. It is apparent that Alaska state water quality criteria regarding turbidity and suspended sediment will be exceeded during some temporal periods due to project construction and operations.

pH and Buffering System

Hydrogen ion concentrations and the buffering capacity of the aquatic ecosystem have been examined with respect to potential project effects. At present it is believed that the project effects on pH and buffering capacity will be minimal and biologically unimportant with respect to Susitna River fisheries ecology. No mitigation plans are proposed regarding this topic.

Heavy Metals

The potential for heavy metal leaching, downstream transport of toxic metals, and mobilization of toxic metals into the biological food chain has been investigated. Results from current literature research indicate that the project will substantially reduce the absolute quantities of most metals transported through the project to downstream areas. Literature research also indicates that the greatest potential for a problem regarding heavy metals will likely be the potential for biomagnification of mercury concentrations in organisms belonging to higher trophic levels in the reservoir and riverine aquatic ecosystems. Potentially useful mitigation measures have been briefly described. Other heavy metals besides mercury appear unlikely to cause biological problems. Pre-project and With-project monitoring of potentially toxic heavy metals have been proposed for both water and aquatic organisms.

Dissolved Gas Concentrations

Total dissolved gas concentrations, especially dissolved nitrogen, have been examined in the existing natural state. Analysis of the extant dissolved gas situations indicates that gas supersaturation conditions are naturally created by high volume flows through Devil Canyon rapids. Analysis of proposed project designs and operations and the watershed's hydrology result in conclusions that the project will minimize the chances for creating biologically harmful concentrations of supersaturated gases in aquatic habitats downstream of the project. Extensive mitigation measures are presently included in preliminary plans for design and operations of the Susitna Hydroelectric Project in order to minimize the potential for detrimental gas supersaturation and its effects on the aquatic ecosystem.

Macronutrients for Lower Trophic Level Organisms

Analysis of phosphorus and nitrogen concentrations found in the natural riverine habitat, together with estimates of the reservoir water quality conditions, indicates that both the proposed reservoirs and the Susitna River "middle" reach will be chronically light limited with respect to autochthanous primary productivity. Although the net downstream transport of both phosphorus and nitrogen will be substantially reduced by the project impoundments, both macronutrients should exist at concentrations in excess of their demand by photosynthetic microbial communities in both the reservoirs and the downstream riverine habitats directly affected by mainstem flows. Minimal rates and quantities of aquatic primary productivity are to be expected in the chronically turbid reservoir and mainstem riverine environments affected by project flows. Nutrient limitation of aquatic primary productivity is not expected to occur under with-project conditions.

Dissolved Oxygen, Organic Carbon and Project Effects

Concentrations of dissolved oxygen in the natural riverine habitat have been found to be moderately high to very high during all seasons. Chemical oxygen demands are naturally low to moderate and are expected to remain so. Limnological conditions in both project reservoirs are expected to minimize biological oxygen demands and to minimize formation of oxygen deficient waters at most depths. No detrimental environmental effects are expected in either the project reservoirs or in riverine habitats downstream due to project induced changes of dissolved oxygen concentration.

Dissolved and particulate organic carbon presently exists in low to moderately high concentrations in the Susitna River. Most of the organic carbon compounds are assumed to be of allochthonous origin, relatively refractory, and of low food quality. The project reservoirs will likely cause a short term increase in downstream organic carbon transport during each stage of filling, but as the reservoirs age this effect will decrease. In the long term, the project will cause a decrease in allochthonous carbon input into and transport through the Susitna River middle reach. Microbial processing of dissolved and particulate organic carbon within the reservoirs may enhance its food quality with regard to microbial and invertebrate organic carbon processors located downstream.

Reservoir and Riverine Productivity and Trophic Status

The productivity both project reservoirs is expected to be light limited and primarily dependent on microbial processing of allochthonously derived detritus. Both reservoirs are expected to have sparse populations of most organisms, including fish. Both reservoirs are expected to be classifiable as ultra-oligotrophic throughout their life expectancies.

The biological productivity of the middle reach riverine habitats which remain chronically turbid is expected to decrease with respect to the present conditions. More peripherial riverine habitats which are shallow, clear or intermittently turbid are expected to maintain or increase their biological productivity. Streambed substrate improvement is expected in some middle reach habitats.

1.0 INTRODUCTION

1.1 OBJECTIVES

The objectives of this report are multifold. One primary objective is to describe selected water quality characteristics of the unregulated middle reach of the Susitna River. A second objective is to estimate potential riverine water quality changes which may result from construction and operation of the proposed project. A third objective is to qualitatively and quantitatively describe selected aspects of the morphology and operation of the proposed project, especially with regard to potential project-induced water quality effects in both the reservoirs and the 52 mile river reach immediately downstream from the project. In this report, most limnological discussion will pertain to a fairly limited riverine reach primarily composed of the impoundment zone, located from river mile (RM) 240 downstream to RM 152, and to the "middle" river reach downstream of the project (i.e. RM 152 to RM 98.5 at the confluence of the Susitna and Chulitna Rivers).

An additional report objective is to generically describe the trophic status of the unregulated Susitna River "middle" reach as it now exists, and to provide discussion regarding the approximate trophic status and water quality characteristics of the project reservoirs and downstream riverine habitats especially as they relate to riverine fisheries.

1.2 BRIEF SUMMARY OF INFORMATION SOURCES

Information summarized or referenced in this report is derived in part from an assortment of published and unpublished reports produced by private organizations, and by agencies of the State of Alaska and the U.S. federal government. Many referenced documents were produced by private or public organizations under contract to the State of Alaska via the state's power development agency, the Alaska Power Authority. Additional sources of information are the project's official License Application to the Federal

Energy Regulatory Commission (FERC), the Draft Environmental Impact Statement produced by the FERC, published documents in peer reviewed scientific journals, and articles in popular publications available in the open literature. In addition, personnal communications with aquatic biologists and other professionals having personal experience within the Susitna River ecosystem as well as other similar and dissimilar riverine systems have been useful. Conceptualizations have been made about structural and functional relationships between abiotic and biotic entities which presently exist in Susitna River. Attempts have been made to describe trophic status changes which may result from an altered water quality regime associated with construction and operation of the proposed project.

2.0 THE SUSITNA RIVER WATERSHED - A LIMNOLOGICAL BACKGROUND

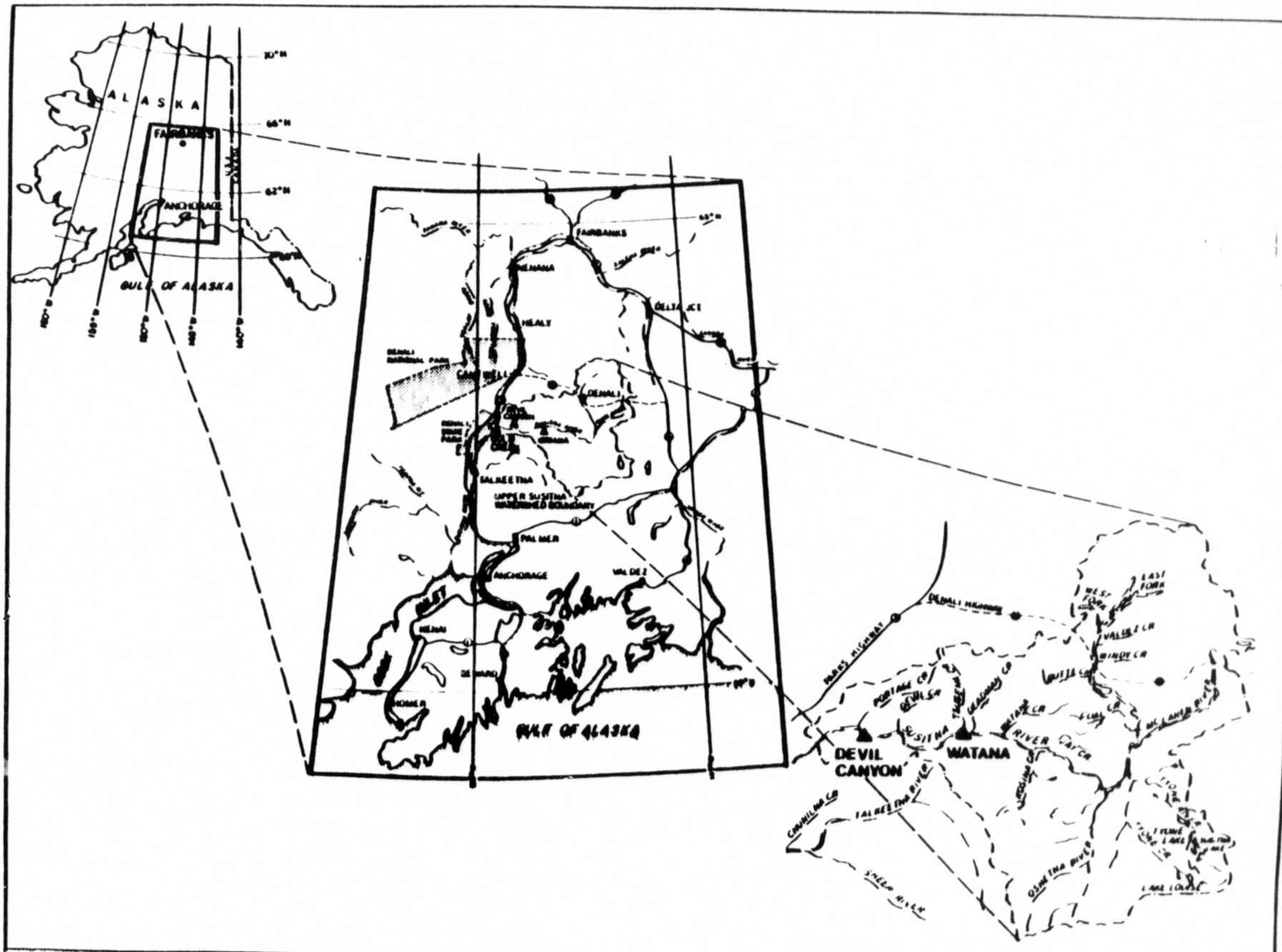
2.1 THE PROPOSED PROJECT

Application for a major hydroelectric project to be located on the Susitna River has been submitted by the State of Alaska. Primarily consisting of two reservoirs and electrical generating plants, the project will be located approximately 140 miles (220 km.) north - northeast of Anchorage, and 110 miles (180 km.) south - southeast of Fairbanks (Figure 2.1). The proposed system will consist of two dams, each with long, narrow and deep reservoirs, and underground powerhouses designed for a total combined generating capacity of 1,620 megawatts (MW). An annual average of approximately 6,570 gigawatt hours (Gwh) could potentially be produced by the system. The project is being proposed in order to supply the electrical power needs of customers in the south-central Alaska area known as the Railbelt. The project will non-comsumptively (except for small evaporation losses) utilize waters of the Susitna River for hydroelectric power production. All water will be reutrned directly to the river bed via powerplant tailraces, controlled releases via fixed-cone valves and, during rare high runoff events in the watershed, by spillway overflows (APA 1983 a,b).

2.2 THE PROJECT SETTING

2.2.1 Susitna River Watershed

The Susitna River watershed is the sixth largest river basin in Alaska with a total drainage area of 19,400 square miles (50,250 km^2), and is not ranked amongst the principal 50 rivers in the United States in terms of length (Todd 1970). The Susitna and its tributaries are free flowing rivers from their headwaters in the glaciers of the Alaska and Talkeetna mountain ranges to the river's mouth (Figure 2.2).



PROPOSED PROJECT LOCATION

FIGURE 2.1

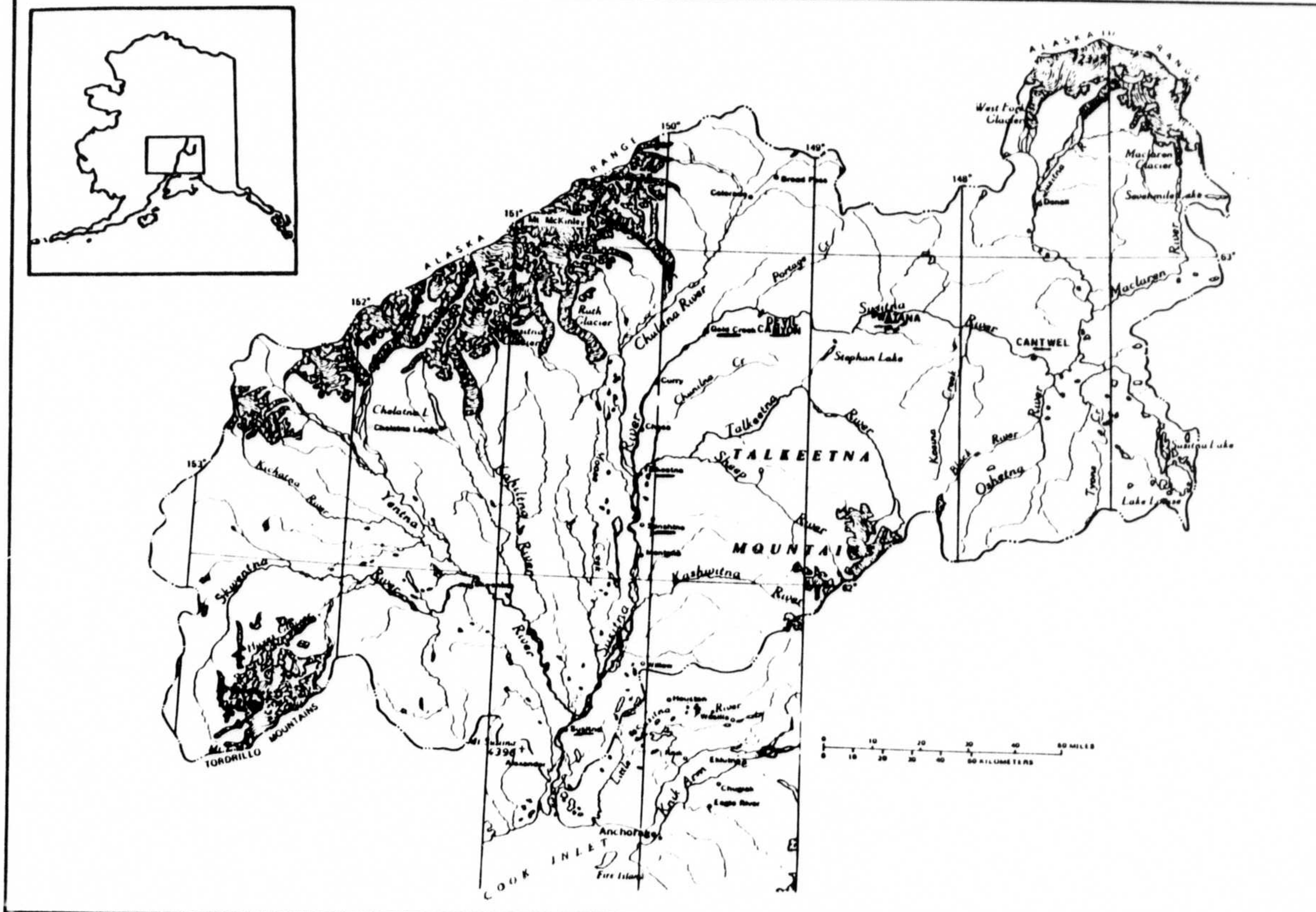
The Susitna River watershed is bounded by the Alaska Range of mountains to the north, west and southwest. To the east-southeast the river basin is bounded by the Talkeetna Mountains, while to the east - northeast the basin is bounded by the northern Talkeetna plateau and the Gulkana uplands. Elevations within the drainage basin range from 20,320 feet (6,194 meters) MSL at the south peak summit of Mt. McKinley, North America's highest peak, to sea level at the river's mouth in Cook Inlet, 320 miles downstream (AEIDC 1984, 1985).

Detailed riverine watershed and morphological descriptions are plentiful in several project documents (AEIDC 1985b, APA 1983a, FERC 1984, R&M Consultants, Inc. 1982) and need not be reiterated here in great detail. However, the fundamental climate, geology, morphology, hydrology, soils and vegetation will largely determine the water quality in the proposed reservoirs and the downstream "middle" river reach. Therefore, they merit some description and discussion in this report since they will limit and modify the ecosystem's limnological responses to the project. This document briefly discusses selected watershed features and aspects of the water quality expected in the project reservoirs and the 52 mile river reach immediately downstream of the proposed project, especially as the criteria relate to salmonid fishes. Limited discussion of lower river (downstream of the Susitna-Chulitna-Talkeetna confluence) water quality will be presented when appropriate.

2.2.2. The Geological Setting

Lithic materials from upper Paleozoic strata appear to be the oldest rocks known to be exposed in the watershed. They may be approximately 250 to 300 million years old, and appear to consist of sequences of volcanic flows which frequently contain interbedded limestones. Overlying the oldest rock sequence is another layer of volcanic and sedimentary rocks which consist of metabasalt flows interbedded with chert, argillite, marble, sandstone and shale of Triassic age (200-250 m. yr. ago).

FIGURE 2.2 SUSITNA RIVER WATERSHED INCLUDING MAJOR TRIBITARIES AND GLACIERS



During the Jurassic period the older more surficial rocks were intruded by diorite plutons. Subsequent uplift and erosion of the former strata was followed by marine deposition of a thick sequence of lower Cretaceous argillites and graywackes (Csejtey 1978). The aforementioned rock strata were subsequently faulted and folded during the late Cretaceous period (65-100 m.y. ago).

During the early Tertiary (40-65 m.y. ago) the area was again intruded by plutons of granitic and/or diorite composition and one of these diorite plutons lies under the Watana dam site. During these latter intrusions and following them, volcanic flows were extruded over the local area.

At least three major periods of tectonic deformation important to the project area have taken place. The first during the Jurassic (160-210 m.y.ago), the second during the late Cretaceous (65-110 m.y. ago), and the third which ocurred in the middle to late Tertiary (40 m.y. ago). Intrusions of plutons, crustal uplift, regional metamorphism, complex folding and faulting, and finally extensive uplift and erosion occurred during these three periods. Widespread erosion has removed much the volcanic and sedimentary rock which was thrust over this area 65-100 m.y. ago.

During the last few million years repeated glaciations have modified the Alaska and Talkeetna mountains and surrounding terrain into the basic topography which is apparent today. Glacial erosion has removed much of the soil at higher elevations, while the lower valleys and plains are covered by glacial drift of various thicknesses. At the Watana dam site bedrock is o overlain by up to 450 feet of glacial and fluvial deposits. Downstream, at the proposed Devil Canyon damsite, a thin layer of glacial drift covers the graywacke and argillite rocks which form the canyon's V-shaped, 600 foot high, sheer valley walls through which the Susitna River flows.

Ground up, eroded, pulverized, glaciated and otherwise weathered rock fragments from all of the forgoing lithic materials, soils and vegetation are the source of most of the mileau of water quality entities, both suspended and dissolved, which are found in the ground waters and surface waters of the Susitna River drainage. Suspended inorganic particulates sampled from the Susitna River are from weathering of watershed geological entities. Their generalized mineralogy has been analyzed by polarized light microscopy (R&M Consultants, Inc. 1984c, and 1982d) and are presented in Table 2.1. Petrographic analyses of these rock fragments is probably the simplest and best method for getting a representative sample of the fundamental mineralogy of the river's entire watershed and for assessing the potential of many minerals to influence and/or be a part of the Susitna River's water quality milieu. Analyses of these particulates (Table 2.2) indicates the mineral and elemental groups which will influence or be a part of the river's water quality.

2.2.3. Soils and Vegetation

The geological landscape of barren mountain peaks, glacial till covered plains, exposed bedrock cliffs, and steep, bedrock walled stream canyons with gravel beds, has characteristically poor soil development. The soils are typical of those developing in subarctic cold, wet climates on recent deposits of glacial till and outwash material. Spodzolic soils with a thin organic layer over a predominantly mineralized horizon are present in the majority of the proposed project drainage areas. The soil types include acidic often saturated, peaty soils of poorly drained areas; the acidic, relatively infertile forest soils; and the virtually inorganic gravels and sands along the river banks. Portions of the upper basin, including some limited areas around Watana Reservoir are underlain by layers of discontinuous permafrost. Permafrost has been primarily identified in localized pockets of fine grained glaciolacustrine and glacial till deposits (APA 1983a,e).

TABLE 2.1

SUSITNA HYDROELECTRIC PROJECT
APPROXIMATE MINERALOGY OF SUSITNA RIVER SUSPENDED SEDIMENTS
(MODIFIED FROM R&M CONSULTANTS, INC. 1982 d, 1984b)

Mineral	Percent Composition
Quartz	15-40
Feldspars (mixed)	15-30
Pyroxenes	10-15
Magnetite	10-15
Limonite	5-10
Clays	>5
Colloidal Silica	>5
Calcite	>2
Mica (Biotite & Muscovite)	5-20
Zircon	>1
Pyrite (FeS_2)	>5
Augite	5-10

TABLE 2.2

SUSITNA HYDROELECTRIC PROJECT
ELEMENT COMPOSITION OF MINERALS COMPARING COMMONLY ANALYZED SUSPENDED SEDIMENT PARTICLES FROM THE SUSITNA AND OTHER NEARBY GLACIAL RIVER DRAINAGES

Mineral	Elements
Pyrites (FeS_2)	Fe, S
Quartz (SiO_2)	Si, O
Alkali feldspar ($KAlSi_3O_8$ and $Na\ Al_2\ Si_3\ O_8$)	Na, Ca, Al, Si, O
Plagiocase feldspar ($Na\ Al\ Si_3\ O_8$ and $Ca\ Al_2\ Si_2O_8$)	Na, Ca, Al, Si, O
Pyroxenes ($Ca\ [Mg, Fe]\ Si_2\ O_6$)	Ca, Mg, Fe, Si, O
Iron and titanium oxides	
Magnetite (Fe_3O_4)	Fe, O
Hematite ($Fe_2\ O_4$)	Fe, O
Ilmenite ($Fe\ Ti\ O_3$)	Fe, Ti, O
Limonite ($2\ Fe_2\ O_3 \cdot 3\ H_2O$)	Fe, O
Biotite mica (complex K, Mg, Fe Al and Ti hydroxy fluo silicate)	K, Mg, Fe, Al, Si, O, F
Apatite [$Ca_5\ (OH, F, Cl)\ (PO_4)_3$]	Ca, F, Cl, P, O
Olivine $[Fe, Mg]_2\ Si\ O_4$	Fe, Mg, Si, O
Musovite (complex K, Al hydroxy fluo silicate)	K, Al, Si, O, F
Clays	
Illite ($K_x\ Al_4\ [Si_{2}\text{-}xAlxO_{20}]\ OH_4$)	K, Al, Si, O, H
Kaolinite ($Al_4\ [Si_4O_{10}]\ (OH)_8$)	Al, Si, O
Montmorillonite $(Na,K)_{x+y}\ (Al_{2-x}Mg_x)_2\ [(Si_{1-y}Al_y)_8O_{20}]\ OH_4 \cdot nH_2O$	Na, K, Al, Mg, Si, O
Chlorite $(Mg,Al)_{12}\ [(Si, Al)_8\ O_{20})\ (OH_{16})$	Mg, Al, Si, O
Calcite ($CaCO_3$)	Ca, C, O

Within the proposed Watana Reservoir inundation zone(i.e. 36,135 acres), more than 75 percent of the vegetated area is forested while most of the remaining area is shrubland (Table 2.3). The predominant forest types are black spruce and mixed conifer-deciduous forest containing black and white spruce, paper birch, trembling aspen, and balsam poplar. Most borrow sites are classified as shrubland or various forest types (APA 1983a,b). Bog-like areas with the proposed impoundment zones occupy less than one percent of the area.

Practically all of the area to be inundated by the Devil Canyon impoundment (i.e. 7,550 acres) is forested, and over 50 percent of that is of mixed conifer-deciduous type (Table 2.3). These forests and shrubland types are growing on fairly well drained and sometimes relatively warm south or southwest facing soils. Forests and shrubland are also present in areas of shallow peat, glacial till deposits, lowlands, and north facing slopes. The organic soil layer beneath them is often well developed, but generally not as extensive as in the Watana inundation zone (APA 1983a,b).

In the upper Susitna Basin a myriad of wet or poorly drained soils exists which are classified as wetlands. The wetlands on the upland plateaus include riparian zones, ponds and lakes which support sedge-grass tundra, low shrubland, and black spruce forest. These areas commonly consist of muskeg-bogs with thick mats of mosses, sedges, lichens and dwarfed shrubs, occassional black spruce, cotton grass tussocks, rushes, willows, labrador tea, Dwarf Arctic birch, blueberries, cranberries, bearberries, crowberries, bluejoint grass and polar grass. The underlying organic peat layer is often thick, slightly acidic and waterlogged (APA 1983a,f,g).

The riparian areas along the middle reach of the Susitna below the proposed dam sites (i.e. RM 150 downstream to RM 98) are characterized by pioneering communities of herbaceous and shrub species which are initially replaced by alder and then by balsam poplar and black cottonwood. The oldest and most stable areas are covered by mixed conifer-deciduous (white spruce and paperbirch) forest. However, physical disturbances such as ice jams,

TABLE 2.3

SUSITNA HYDROELECTRIC PROJECT
TYPE AND ACREAGE OF VEGETATION TO BE INUNDATED BY EACH IMPOUNDMENT OF THE SUSITNA HYDROELECTRIC PROJECT

Vegetation Type	Acreage for Each Impoundment		
	Watana I	Devil Canyon II	Watana III
Conifer Forest	6,639	1,048	8,523
Breadleaf Forest	720	393	332
Mixed Forest	5,741	3,996	4,493
Dwarf Tree Scrub	1,719	101	1,258
Tall Shrub	63	59	214
Low Shrub	308	9	1,308
Dwarf Shrub	0	0	0
Graminoid Herbaceous	25	0	225
Sparse Vegetation	14	0	21
Barren Ground	68	0	2
Water	4,146	1,944	586
Total Acreage	19,443	7,550	16,692

Source: APA 1985 Draft License Amendment (Table E.3.83) flooding events, bank erosion and sediment deposition have caused climax vegetation stages to be replaced by earlier seral stages along most middle reach riverine habitats (R&M Consultants, Inc. 1984a).

Plant and animal materials present in the drainage yield an additional spectrum of minerals and elements necessary for life. Thus, between abiotic (geological) and biotic sources of minerals and elements contributed to the Susitna River from its watershed, all the elements necessary for aquatic life exist in atleast moderate concentrations. The biological productivity of the Susitna River, however, appears to be somewhat limited. Some of the environmental variables which apparently retard riverine biological productivity and biomass production may include: low temperatures, light limitations by suspended particulates and/or ice and snow cover, high flow variability, high water velocity, particulate scour, unstable streambed substrate, and high concentrations of fine inorganic particulates within the streambed substrate interstitial spaces.

2.2.4. Mineral Resources and Human Influences

Few economically important mineral resources are currently known to exist in the immediate vicinity of the reservoirs or other proposed project features. Only a limited number of placer mines which are generally characterized by intermittent activity are known to exist in the drainage (FERC 1984).

2.2.5. Basic Watershed Climate

Alaska is divided into four major climatic zones on the basis of temperature and precipitation: arctic, continental, transitional and maritime. The upper Susitna River basin (including the proposed project reservoir zones) is predominantly in the continental zone, while the lower river basin extends into the more coastal, transition zone. Alaskan continental climate is characterized by extreme daily and seasonal temperature fluctuations and relatively low precipitation. Winds at the Watana dam site are predominantly from the southwest or northeast at approximately 20 mph (10 m.

per second) or less. The approximate range of temperatures within the reservoir impound zones is between -58°F and 95°F (-50°C to 35°) (APA 1983a). The lower river basin which is closer to the coastline is better buffured against extreme temperature fluctuations by the proximity of Cook Inlet marine waters, and also receives more precipitation than the reservoir zones within the upper river basin (APA 1983a).

2.2.6. Nutrient Limitation of Vegetation in Alaskan Soils

Terrestrial plant production in subarctic ecosystems like the Susitna River basin appears to be nutrient limited. Adequate nitrogen, phosphorus, potassium and micronutrients appear to be present in Alaskan soils for plant growth. However, the slow rate of recycling (rather than the total quantity) of nutrients in subarctic plant communities is currently thought to limit the availability of plant nutrients. The lack of available nitrogen is thought to be of primary importance in limiting terrestrial subarctic productivity. Nitrogen is present in adequate amounts in the ecosystem but appears to be strongly bound in the surficial organic soil layer and apparently under goes very slow recycling. Phosphorus utilization by subarctic tundra plants is thought to be limited by the turnover rate and supply of available nitrogen (Kubanis 1982; Laughlin 1973; McKendrick 1978; Chapin and Van Cleve 1978; Haag 1974). It may be reasonable to assume that more than adequate supplies of most plant nutrients will enter the reservoirs and downstream riverine habitats especially when the expected microbial demand for them is expected to be limited by other prevailing physical conditions (high turbidity, low temperatures, etc).

2.2.7. Basic Hydrologic Regime

The northernmost Susitna River headwaters originate at glaciers in the north eastern Alaska Range. The glaciers feed shallow, braided tributaries which are heavily laden with sand, silt and clay-sized outwash particulates. These tributaries flow southward for approximately 18 miles, converging just north of the Denali Highway bridge, and there join to form a shallow, single mainstem channel. The 950 square mile drainage above the Denali gauging station approaches maximal flows during the warmest days of the year which usually occur in July and August, and minimal winter flows during January and February of approximately 100-200 cfs. Mean annual discharge at Denali is approximately 2700 cfs. Between the Denali stream gauge and Vee Canyon the Susitna receives the glacial tributary MacLaren River (R.M. 259.8), the non-glacial, but humic acid stained Tyone River (R.M. 246.5), and the glacial river Oshetna (R.M. 233.4). The Susitna at Vee Canyon (R.M. 223) conveys a mean annual flow of approximately 6,404 cfs of water and approximately 6.5 million tons of suspended sediment (predominately during the periods May-September). From Vee Canyon, the Susitna flows westerly in a deep, narrow valley towards the Watana dam site while losing altitude from approximately 2000 feet MSL to 1,456 MSL. At the Watana dam site (RM 184.4) the Susitna drains an area of 5,180 sq. mi. and has a mean annual discharge of approximately 7986 cfs. From the Watana dam site through the upstream portion of Devil Canyon the Susitna River drops in altitude from 1,456 feet MSL to approximately 900 MSL at the Devil Canyon dam site (R.M. 152.2). The Susitna River's mean annual discharge at the Devil Canyon dam site is approximately 9084 cfs, and it drains a total area of 5810 square miles. The river drops precipitously through one-two miles of the lower Devil Canyon gorge to approximately 850 feet MSL at RM 150, and then flows more southerly to the Alaska Railroad bridge and the USGS gauging station near Gold Creek (RM 136.4). The total river drainage area at Gold Creek is approximately 6,160 sq. mi. and the mean annual discharge at the Gold Creek bridge is 9703 cfs.

The "middle" Susitna reach (RM 152 downstream to RM 98.5) extends from the downstream mouth of Devil Canyon to the confluence of the Susitna and Chulitna Rivers. The stream gradient of the middle reach is approximately 8-12 feet per linear mile (Figure 2.3) or approximately 500 feet in 52 miles.

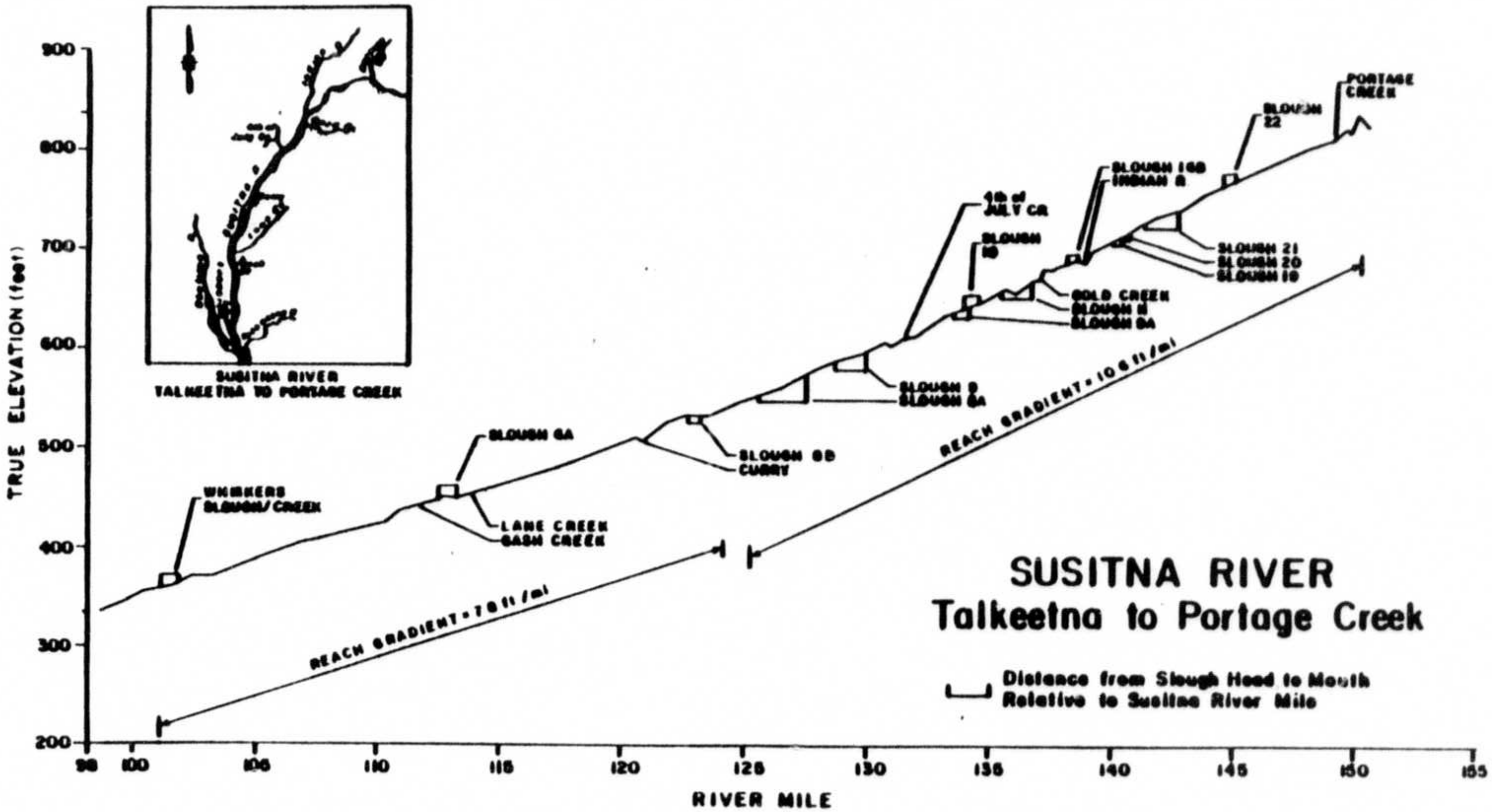


Figure 2.3 Gradient of the Susitna River from Talkeetna to Portage Creek.

Source: ADF&G 1982

The majority (approximately 90%) of the upper and middle Susitna River flow usually occurs during the May-September periods of each year (Figure 2.4). Peak flows at the Gold Creek monitoring station have varied from 20-50 x 10^3 cfs in fairly average years (Figure 2.4, 1970 hydrograph) to more than 85,000 cfs during maximal flood peaks corresponding to maximal freshet discharge composed of snowmelt and rainfall (Figure 2.4, 1964 hydrograph). Glacial melting, which usually reaches maxima in July and August, can contribute to high riverine discharges when combined with relatively large precipitation events in middle or late summer (Figure 2.4, 1967 hydrograph). Glaciers located on the south slopes of the Alaska Range occupy approximately 290 square miles of the Susitna River drainage basin. During drought years, such as 1969, it has been estimated that glacial melt waters may contribute approximately 30 to 50 percent of the Susitna's discharge at the Gold Creek gauging station (FERC 1984).

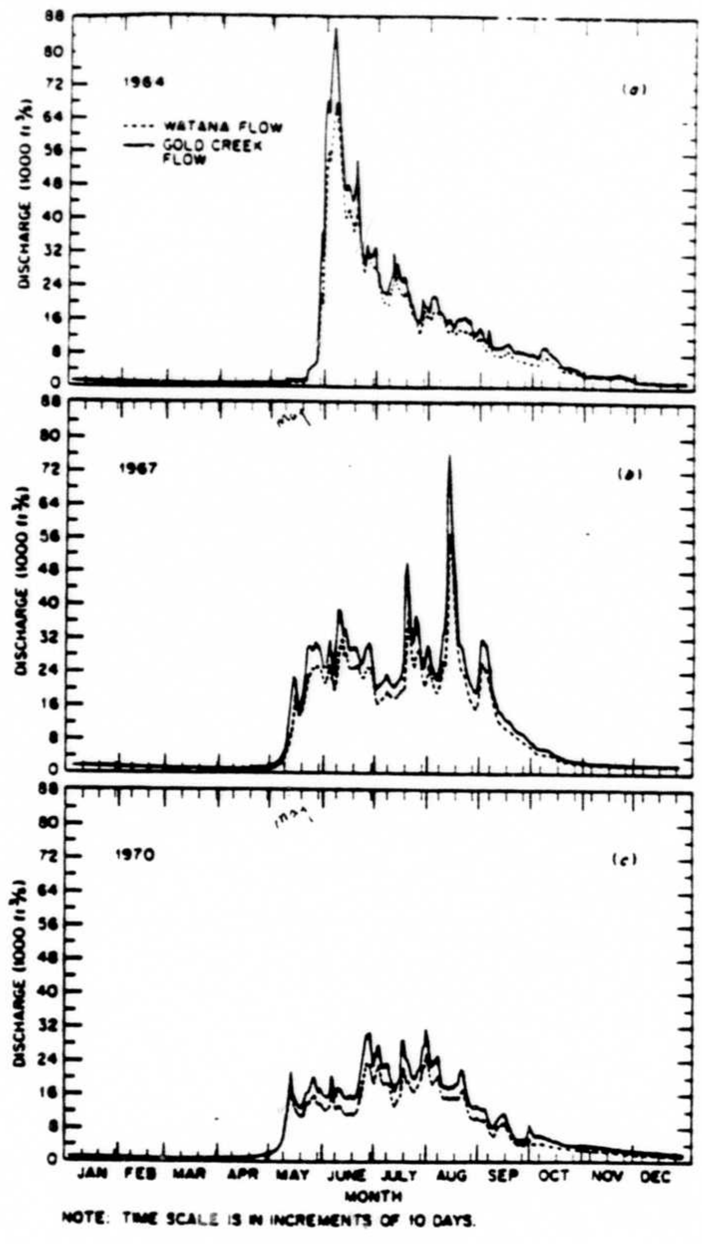


Figure 2.4 Representatiave annual hydrographs at the Watana dam site and the Gold Creek gaging station for two wet years with spring (1964) and fall (1967) floods and for one dry year (1970). Source: FERC 1984

3.0 GENERALIZED PROJECT DESCRIPTIONS: MORPHOLOGY AND FUNCTION

3.1 DAMS, RESERVOIRS AND BASIC CONSIDERATIONS

The basic development scheme for the project involves three separate construction and operation phases:

3.1.1 Watana Stage I

Watana Stage I is the initial project. It will have a normal operating level at el. 2,000 ft. MSL. At this level the reservoir will be approximately 39 miles long, with a maximum width of approximately three miles. the total volume will be 4.25 million acre-feet, and the surface area will be approximately 19,900 acres (Table 3.1). The maximum drawdown will be 150 feet, resulting in a minimum operating level of 1,850 ft. MSL. Watana Stage I provides 2.37 million acre-feet of active storage which corresponds to roughly 40 percent of the mean annual flow at the damsite, and while functioning alone, it will operate as a base load power plant.

The Watana Stage I power house will have four generators served by five multi-level intakes spaced between el. 1,800 and el. 1,980. In general, the uppermost intake level which is available for usage would be operated. Turbine tailrace waters will be discharged through two 34 foot diameter, concrete lined tunnels, each discharging beneath the surface of the river tailrace at the downstream toe of the dam.

Water for controlled spills will be withdrawn from the reservoir at el. 1,930 and discharged through any of six, 78 inch fixed-cone valves. These fixed-cone valves compose the terminal point of the outlet works and water discharged from these valves will form a spray while falling approximately 105 feet to the downstream tailwater elevation at 1,455 ft. MSL. Fixed-cone valves will be designed to dissipate the energy of the falling waters by creating spray over a relatively large surface area. Spray discharges are desired in order to avoid plunging and the potential for producing gas

Table 3.1

SUSITNA HYDROELECTRIC PROJECT
MORPHOLOGICAL AND HYDROLOGICAL FEATURES - WATANA RESERVOIR

	Watana Stage III	Watana Stage I
Elevation (maximum surcharge level)	2,201 MSL (671 m)	2,014 MSL
(normal maximum level)	2,185 MSL (666 m)	2,000 MSL
(minimum operating Level)	2,065 MSL (630 m)	1,850 MSL
Maximum Drawdown	120 feet (36.6 m)	150 feet
Live Storage	3.7 X 10^6 m) acre-ft. (4.6 X 10^9 m^3)	2.37x10^6 acre-ft
Maximum Surface Area	38,000 acres (60mi^2)	19,900 acres
Maximum Length	approx. 48 miles (77 km)	approx. 39 mi.
Maximum Width	approx. 8 miles (12.8 km)	approx. 3 mi.
Maximum Depth	735 ft. (223 m)	550 ft.
Mean Depth	250 ft. (76 m)	____
Gross Storage (total volume)	9.5 x 10^6 acre-ft. (11.7 X 10^9 m^3)	4.25x10^6 acre-ft
Shorline Length	183 miles (295 km)	____
Mean Hydraulic Residence Time	1.65 years	____
Drainage Basin	5,180 mi^2 (13,416 km)	5,180 $mi.^2$
Mean River Inflow	7,990 CFS (226 m^3s^{-1})	7,990 CFS
Peak Flood Inflows		
PMF	326,000 CFS (9,226 m^3s^{-1})	SAME
10,000 yr.	156,000 CFS (4,415 m^3s^{-1})	SAME
50 yr.	87,000 CFS (2,426 m^3s^{-1})	SAME
25 yr.	76,000 CFS (2,151 m^3s^{-1})	SAME
Tailwater Elevation	1,455 ft. MSL (443.5 m)	1,455 MSL
Area of Innundation - Stage I		19,443 acres
water and barren ground		4,146 acres
vegetation		15,297 acres
Area of Innundation - Stage III	16,692 acres additional	
water and barren	586 acres additional	
ground vegetation	16,106 acres additional	
Total Area of Innundation- Stage III1/	36,135 acres	

1/ Area approximated from topographic maps, not extrapolated to estimate of actual inundated surface area.

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supersaturation. Spillway usage is only expected to occur when riverine inflows exceeding the one in 50-year flood occur together with certain rare circumstances when the normal and surcharge storage capacity of the reservoir may be exceeded (APA 1983c,d).

The outlet works capacity at Watana Stage I is 24,000 cfs, while the powerhouse capacity is about 14,000 cfs. In the event that a flood could not be passed through the combined powerhouse and outlet works, because of energy demand and hydraulic capacity limitations, the reservoir will be allowed to surcharge to a maximum elevation of 2,014 ft. MSL. in order to avoid spillway usage.

3.1.2 Devil Canyon Stage II

Devil Canyon Stage II will be constructed next. It will have a normal operating level of 1,455 feet MSL., and a maximum planned drawdown of 50 feet. It will impound a reservoir approximately 26 miles long with a maximum surface area of 7,800 acres. Total volume impounded will be 1.1 million acre-feet while provisions are made for an active storage of 350,000 acre-feet (APA 1983c,d). Devil Canyon Stage II will be constructed in a long narrow gorge and will have little active storage. Its main function will be to develop high head for efficient power generation per unit of water discharge, and it will be used extensively to generate base load power and to reregulate peak water discharges released from Watana Stages I and III (Table 3.2).

During construction of Devil Canyon dam the river will be diverted into a 35.5 foot diameter concrete-lined tunnel located on the south river bank. The tunnel is designed to pass flood flows up to the 1:25-year summer flood routed through Watana Stage I. River diversion will allow dewatering of approximately 1,100 feet of the Susitna River between upstream and downstream cofferdams.

Devil Canyon dam will be a thin arch concrete structure constructed at RM 152, and will span a narrow portion of the gorge forming a downstream portion of Devil Canyon. The dam's crest elevation will be 1,463 ft. (446m)

Table 3.2

SUSITNA HYDROELECTRIC PROJECT
MORPHOLOGICAL AND HYDROLOGICAL FEATURES
DEVIL CANYON RESERVOIR - STAGE II

Elevation (maximum surcharge level)	1,466 MSL (446.8 m)
(normal maximum level)	1,455 MSL (443.5 m)
(Minimum operating level)	1,405 MSL (428.2 m)
Maximum Drawdown	50 ft. (15.2 m)
Live Storage	350,000 acre-ft. (432 $\times 10^6 m^3$)
Maximum Surface Area	7,800 acres (12 $mi.^2$)
Maximum Length	26 mi. (42 km)
Maximum Width	approximately 1 mile (1.6km)
Maximum Depth	565 ft. (171 m)
Mean Depth	140 ft. (42 m)
Gross Storage (total volume)	1.1×10^6 acre-ft.($1.4 \times 10^9 m^3$)
Shoreline Length	76 mi. (123 km)
Mean Hydraulic Residence Time	approx. 60 days
Drainage Basin	5,810 $mi.^2$ (15,048 km^2)
Mean River Inflow	9,080 CFS (256 $m^3 s^{-1}$)
Peak Flood Inflows	
PMF	345,000 CFS (w/Watana)
10,000 yr.	165,000 CFS (w/Watana)
50 yr.	39,000 CFS (w/Watana)
25 yr.	37,800 CFS (w/Watana)
Tailwater Elevation	850 ft. MSL
Area of Innundation-Stage II[1/]	7,550 acres total
Water and Barren Ground	1,944 acres
Vegetation	5,606 acres

1/ Area approximated from topographic maps, not extrapolated to estimate of actual inundated surface area.

MSL with an actual height of 646 ft.(197m) above its foundation. Large concrete thrust blocks on each valley wall abutment will help support the structure. The dam itself will be composed of approximately 1.3 million cubic yards of concrete (APA 1983c,d).

Four 20 foot diameter concrete-lined intake structures on the north end of the dam will draw water from two near surface depths between el. 1,455 and el. 1,405 MSL into concrete-lined penstock tunnels. These tunnels will conduct water to the underground powerhouse where four 150 MW turbine generators will be located. Each turbine will be rated for a maximum discharge of 3,680 CFS (i.e. 14,700 CFS total potential discharge from all four turbines combined). Tailrace waters exiting the turbines will be routed downstream approximately 6,800 feet through a single 38 foot diameter concrete-lined tunnel. Thus tailrace waters from Devil Canyon turbines will be discharged under the river surface and downstream of nearly all the violent lower Devil Canyon rapids (APA 1983c,d). This long tailrace tunnel discharge will help dilute any flows still discharged through Devil Canyon outletworks and/or spillways and will thereby help avoid any downstream gas supersaturation conditions.

Auxiliary outlet facilities of Devil Canyon Dam will consist of seven fixed-cone valves located in the lower portion of the dam. The seven fixed-cone valves will have a combined maximal discharge capacity of approximately 42,000 CFS when the reservoir pool level is at el. 1,455. Four 102 inch, and three 90 inch diameter valves will be installed at dam elevations of 1,050 ft. MSL and 930 ft. MSL respectively. The fixed-cone valves at Devil Canyon dam, opposed to those at Watana dam, will not draw water from the reservoir surface. Instead, the cone valves at Devil Canyon dam will draw water from deep within the reservoir's hypolimnion at depths of 405 ft. (123m) and 525 ft. (160m) (APA 1983 c,d).

Controlled releases from Devil Canyon dam's fixed-cone valves, as at Watana, will be in the form of a spray from the downstream face of the dam. Sprays from the more shallow valves will be discharged from an elevation of 170 feet above tailwaters, while sprays from then deeper valves will be discharged approximately 50 feet above downstream tailwaters. The tailwater surface elevation downstream of Devil Canyon dam will be approximately 900 feet MSL, and from there, discharged waters will enter the remaining one to two mile stretch of Devil Canyon rapids before mixing with tailrace discharges and then passing downstream through the middle reach (APA 1983c,d).

3.1.3 Watana Stage III

Watana Stage III involves raising the Stage I structure by 180 feet to its original planned height. Watana Stage III will have a normal operating level at el. 2,185 and a planned maximum drawdown of 120 feet. At el. 2,185 the reservoir would cover 38,000 surface acres, be approximately 48 miles long and have a live storage 3.7×10^6 acre-feet (APA 1983c,d) (Table 3.1). In the final planned configuration Watana Stage III would be utilized as peaking power plant with the more downstream Devil Canyon Reservoir used to reregulate its downstream discharges.

In general, neither reservoir will have an extensive littoral zone since the topography within each impoundment zone is characterized by relatively steep valley walls. Average hydraulic residence time will be relatively short for Watana and very short for Devil Canyon Reservoir. Both reservoirs will be relatively deep and cold, and both will have relatively great maximum and mean depths. Both reservoirs will have relatively small surface area to water volume ratios and will have very shallow euphotic zones. Each reservoir is expected to remain relatively unproductive (biologically speaking) based on the morphological and hydrological characteristics alone (Wetzel 1975).

During construction of Watana Stage III, the dam would be raised and two additional power units added to the four previously existing ones. These two additional units would have water intakes at four levels between el. 2,000 and el. 2,170. Four additional intakes for withdrawals between el. 2,000 and el. 2,170 will also be added to the existing intakes for the four generators originally installed during Watana Stage I. Thus Watana Stage III will have six generators, four of which may be able to draw water from as many as nine depths between el. 1,800 and el. 2,170.

Watana Stage III powerhouse hydraulic capacities total approximately 22,000 cfs with an additional outlet works total capacity of approximately 30,000 cfs.

3.2 GENERALIZED RESERVOIR OPERATIONS AND DOWNSTREAM FLOWS

Reservoir operation simulations have been conducted in order to optimize the project benefits with respect to power production, while simultaneously conforming to environmental constraints specified for protection of certain habitat features downstream. Key constraints on the reservoir operation simulations are the operating guide and the minimum and maximum instream flow requirements at Gold Creek which must be satisfied each week. The system operating guide governs the release for power while the total powerhouse releases are restricted by the discharges required to meet the system power demand. Any additional flow required to meet downstream environmental flow requirement is released through the outlet works of the appropriate dam(s). Flood releases to maintain dam safety requirements are first made through the outlet works and, additionally if necessary, through the appropriate spillway(s).

Case E-VI is the Applicant's selected best flow case for optimizing power generation and downstream environmental habitat protection. Detailed discussion of E-VI and other flow regime considerations are contained in another project document (Harza-Ebasco 1984f). Basically, Case E-VI flow requirements maintain summer minimum discharges (at Gold Creek) of 8-9,000 cfs, while allowing summer maximum discharges of no more than 35,000 cfs (except during the rare event of large flooding with a return period of greater than 1 in 50 years). Winter time flows will be constrained between 3,000 and 16,000 cfs and will be allowed to vary within certain bounds in order to satisfy certain water quality constraints while still meeting the system power demand. Approximate streamflows simulated to be exceeded 50 percent of the time for the staged hydroelectric project in 1996 (Stage I), 2007 (Stage II), 2008 (Stage III), 2020 (Stage III) have been displayed in Figures 3.1, 3.2, 3.3, and 3.4 respectively.

3.2.1 Watana Stage I Operation Alone

A minimum instream flow requirement is prescribed at Gold Creek to ensure that the project will release flows for environmental purposes. The historical intervening flow between Watana and Gold Creek is assumed to be available to supplement the project releases to meet the minimum flow requirement. If the flow prescribed by the operating guide does not meet the environmental requirement, the operation program will attempt to release more water through the powerhouse in order to meet the requirement. If the release required to meet environmental flow requirements exceeds the maximum powerhouse flow to meet the energy demands, the difference between the required outflow and the maximum power discharge is released through the outlet works. This outlet works release is called an environmental release since it is made only to meet the environmental flow requirement and is not used for power generation.

The outlet works capacity at Watana Stage I is 24,000 cfs, while the powerhouse capacity is about 14,000 cfs. In the event that a flood could not be passed through the powerhouse and outlet works, because of energy demand and hydraulic capacity limitations, the reservoir is allowed to surcharge above the normal maximum water surface elevation. This surcharging is done to avoid the use of the spillway for floods less than the 50-year event. A maximum surcharge level of el. 2,014 ft. is permitted before the spillway operates.

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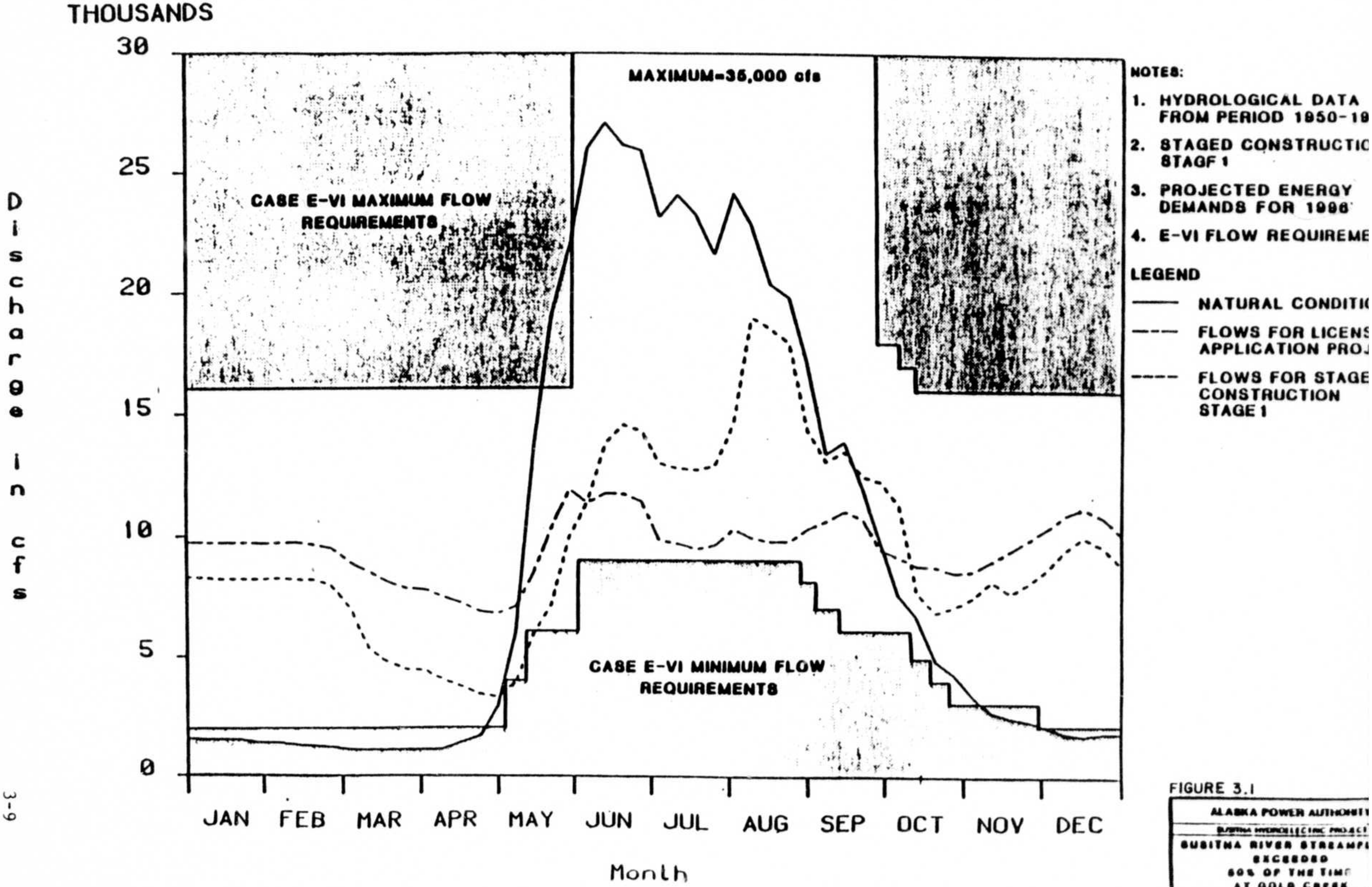
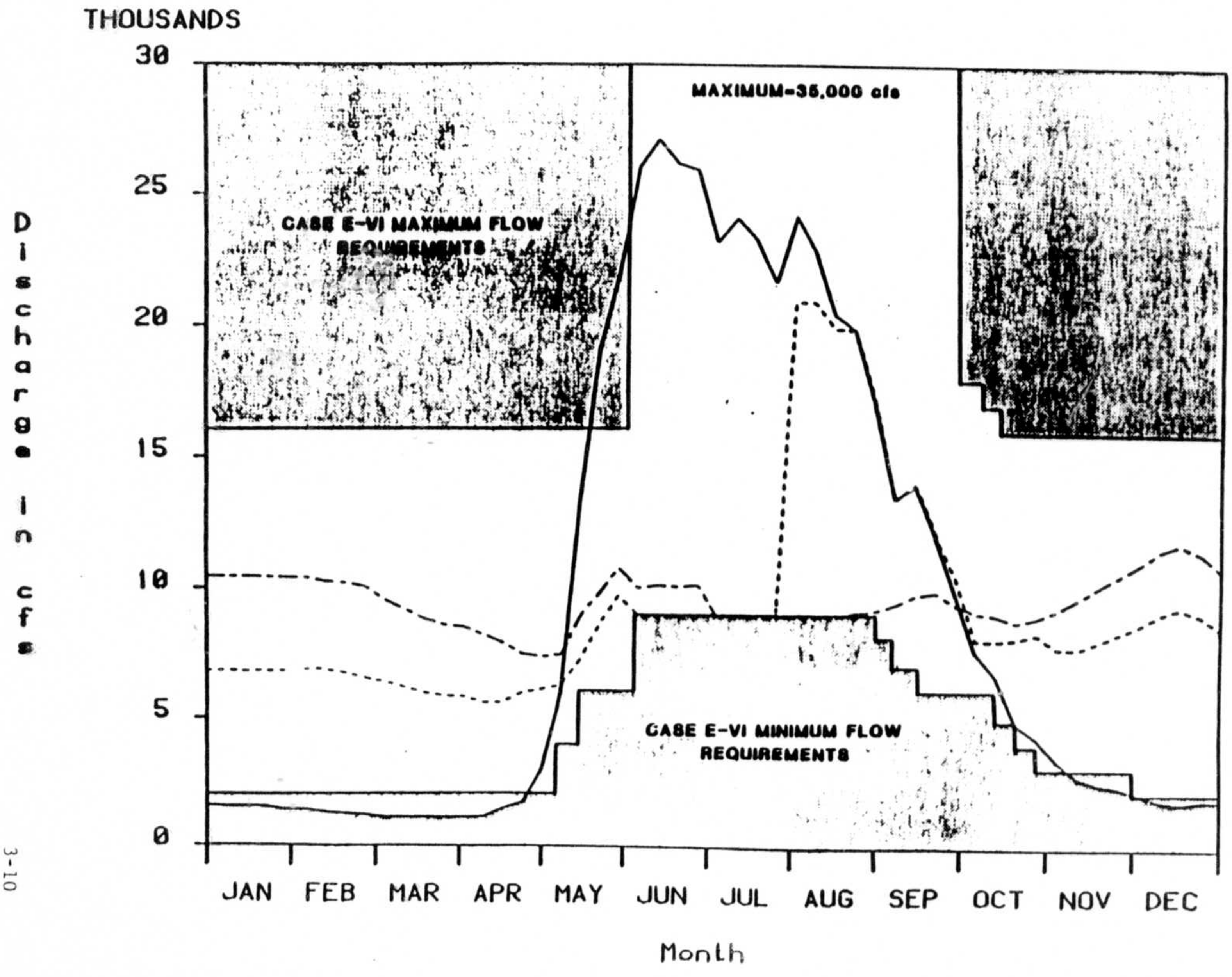


FIGURE 3.1

ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
SUSITNA RIVER STREAMF
EXCEEDED
50% OF THE TIME
AT GOLD CREEK



NOTES:

1. HYDROLOGICAL DAT FROM PERIOD 1950-
2. STAGED CONSTRUCT STAGE 2
3. PROJECTED ENERGY DEMANDS FOR 2007-
4. E-VI FLOW REQUIRE

LEGEND

——— NATURAL CONDI

– – – FLOWS FOR LICE APPLICATION PR (2020 ENERGY DEM

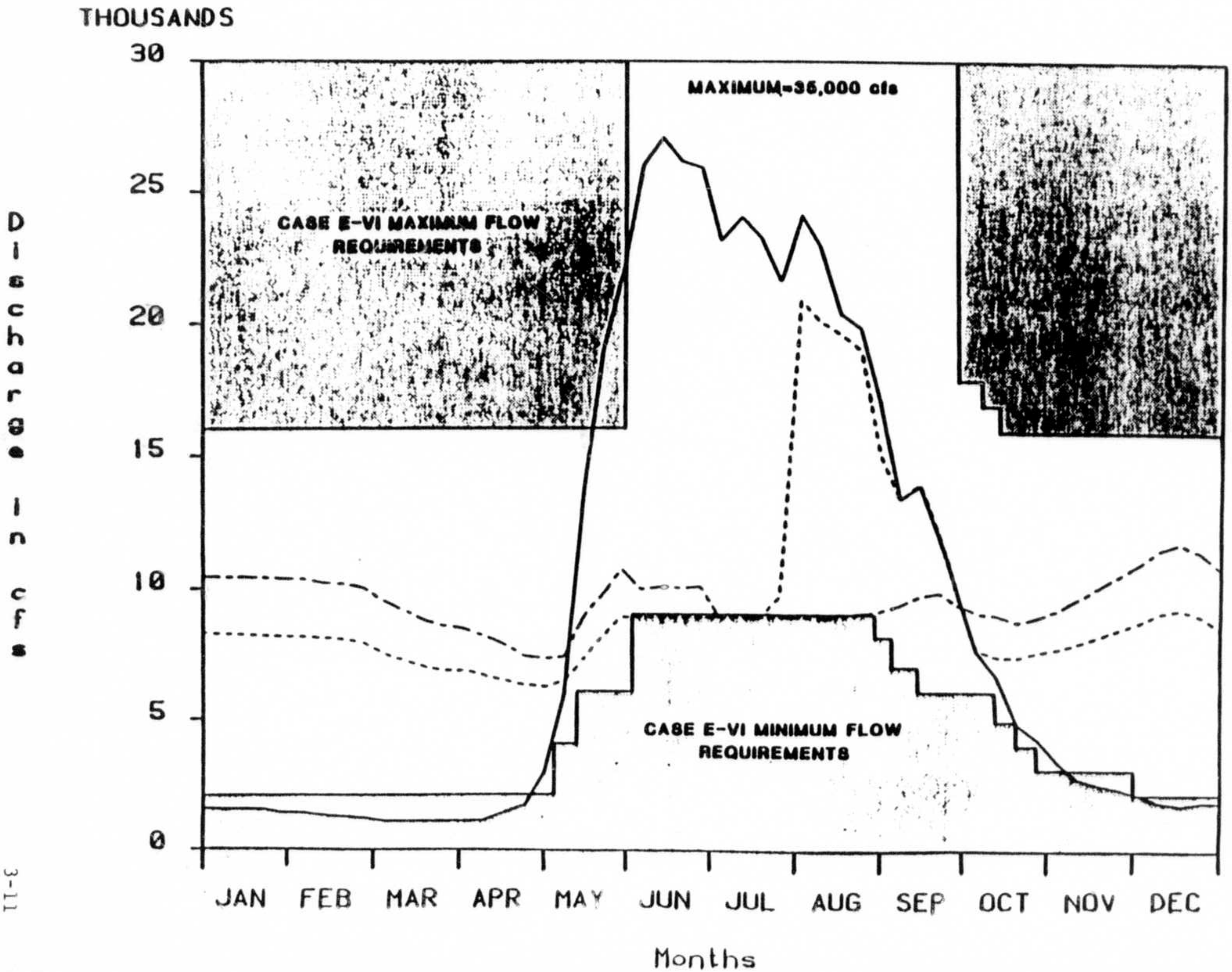
- - - - FLOWS FOR STA CONSTRUCTION (2007 ENERGY DE

FIGURE 3.2

ALASKA POWER AUTHORI

SUSITNA HYDROELECTRIC PROJEC

SUSITNA RIVER STREAMF EXCEEDED 50% OF THE TIM AT GOLD CREEK



NOTES:

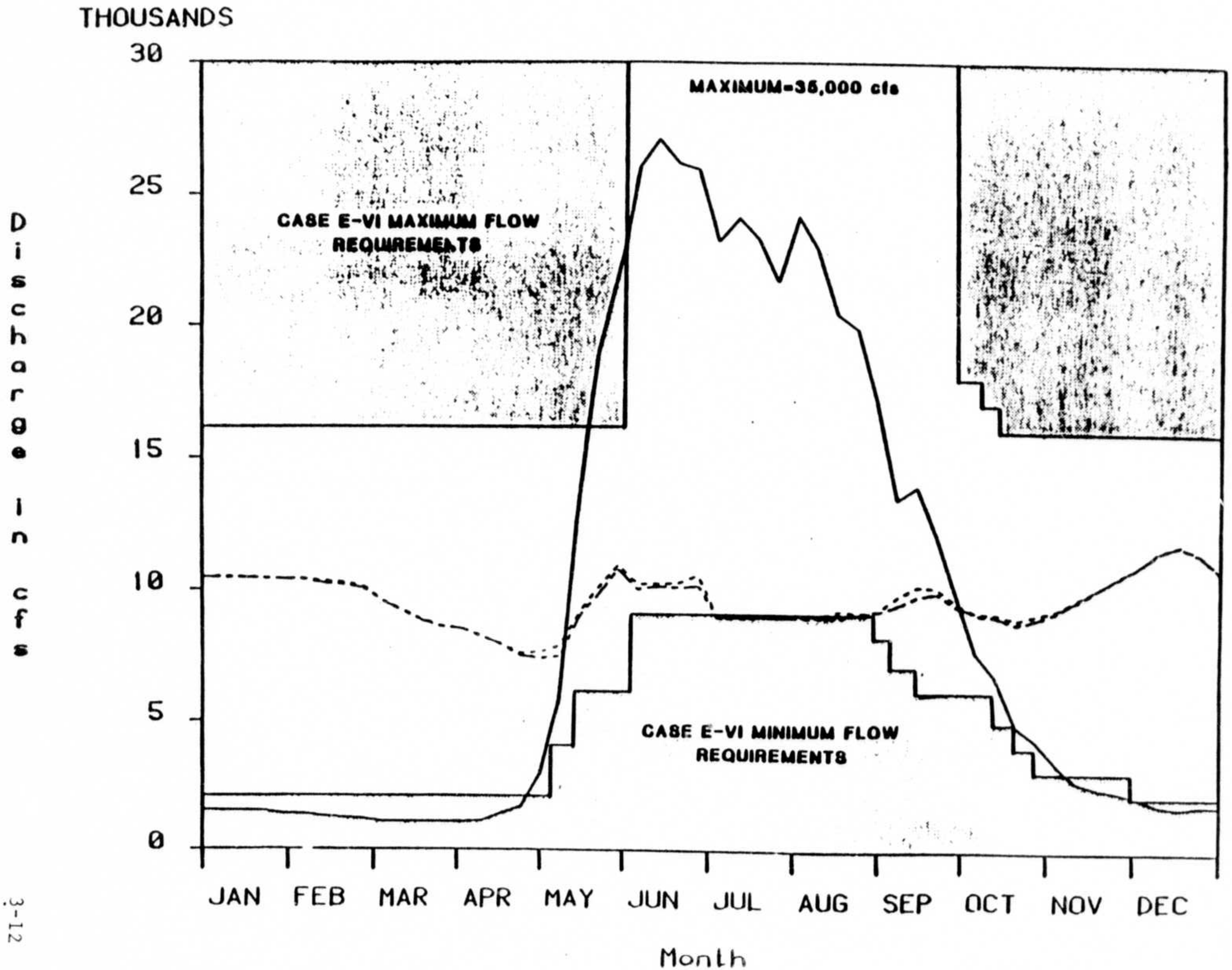
1. HYDROLOGICAL DATA FROM PERIOD 1950-
2. STAGED CONSTRUCT STAGE 3
3. PROJECTED ENERGY DEMANDS FOR 2008
4. E-VI FLOW REQUIREM

LEGEND

——— NATURAL CONDIT
— — — FLOWS FOR LICE APPLICATION PR (2020 ENERGY DEM
- - - - FLOWS FOR STAG CONSTRUCTION (2008 ENERGY DEM

FIGURE 3.3

ALASKA POWER AUTHORI
SUSITNA HYDROELECTRIC PROJEC
SUSITNA RIVER STREAM EXCEEDED 50% OF THE TIM AT GOLD CREEK



NOTES:

1. HYDROLOGICAL DATA FROM PERIOD 1950-1
2. STAGED CONSTRUCTI STAGE 3
3. PROJECTED ENERGY DEMANDS FOR 2020
4. E-VI FLOW REQUIREM

LEGEND

—— NATURAL CONDITI

- - - FLOWS FOR LICEN APPLICATION PRO

--- FLOWS FOR STAGI CONSTRUCTION STAGE 3

FIGURE 3.4

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUSITNA RIVER STREAMFL EXCEEDED 50% OF THE TIME AT GOLD CREEK

3.2.2 Operation of Either Watana Stage I or Stage III with Devil Canyon Stage II

For double reservoir operation, Devil Canyon operates as a run-of-river facility as long as the reservoir is full. The Devil Canyon Reservoir is to be refilled if the reservoir is not full, if the total inflow is greater than the release required to meet the environmental flow requirement. The total energy generated at Watana and Devil Canyon is compared to the system energy demand and adjusted in successive iterations by increasing or decreasing powerhouse discharges to meet system energy demands.

An operating guide is developed and applied to optimize the Watana powerhouse releases for power generation. Minimum instream flow requirements and constraints on rate of change of discharge are also applied.

The intervening flow between Devil Canyon and Gold Creek is assumed to be available to supplement the project releases to meet the minimum flow requirements. If the environmental flow requirement is not met by powerhouse discharges, more water is released through the Devil Canyon powerhouse in order to meet the requirement and the Devil Canyon Reservoir will drawn down. If the increased release through the Devil Canyon powerplant would cause the total energy generation to be greater than the system demand, the release from the Watana powerplant is reduced. This is done to minimize Devil Canyon outlet works releases which may result in reduced temperatures downstream.

If the release required to meet environmental flow requirements exceeds the Devil Canyon powerhouse discharge to meet energy demands, then the difference is released from the Devil Canyon outlet works. In the summer of dry years when the system energy demand is low and the downstream flow requirement is high, Devil Canyon may be drawn down continuously. If the water level at Devil Canyon reaches the minimum operating level of el. 1,405 ft, Watana must then release water to satisfy the minimum flow requirement. If the release from Watana for the minimum flow requirement would generate more energy than the required amount part of the release would be diverted to the outlet works.

The powerhouse hydraulic capacities are about 14,000 cfs at both Watana Stage I and Devil Canyon. The capacity is about 22,000 cfs for Watana Stage III. The outlet works capacity at Devil Canyon is 42,000 cfs while the capacity at Watana is 24,000 cfs in Stage I and 30,000 cfs in Stage III. In the event that a flood could not be passed through the powerhouse and outlet works, because of energy demand and hydraulic capacity limitations, Watana is allowed to surcharge above its normal maximum level. The maximum surcharge level is el. 2,014 ft. for the Watana Stage I Dam and el. 2,193 ft, for the Stage III Dam.

4.0 BASELINE WATER QUALITY AND EXPECTED WATER QUALITY CHANGES

4.1 BASELINE WATER QUALITY - THE MIDDLE RIVER REACH

The unregulated Susitna River exhibits continuously changing water quality characteristics. As the continuum of climatological characteristics gradually shifts through annual and seasonal changes the riverine water quality follows suit. For the sake of limnological simplicity, we can briefly describe the two most contrasting periods of water quality which constitute the "summer" or open water season and the "winter" or ice covered season. The spring and fall transition periods between characteristic summer and winter water quality period vary with respect to their duration and annual timing. Preliminary observation of limnological phenomena in the middle river reach, however, indicates that spring and fall water quality transition periods may have substantial biological importance.

The ice covered season is characterized by relatively low and stable flows, as is the case for many subarctic rivers (N.O.A.A 1982). It is characterized by relatively high dissolved solids content and low concentrations of suspended particulates, and both of these characteristics are due to the dominant influences of gound water on the river's winter surface flows. Low and stable winter surface flows are primarily due to intersection of mainstem river channels with the surface of the ground water table in the valley's subsurface aquifer. The acidic nature of atmospheric precipitation some of which percolates through the watershed soils and subsurface lithic materials is partially responsible for the dissolution of minerals and elements resulting in the ground waters's relatively high dissolved solids content. Biological catabolism of organic soil materials together with abiotic chemical reactions often add to the dissolved solids content of ground water but may also reduce its concentration of dissolved oxygen and change concentrations other dissolved gases. Carbon dioxide contents of Susitna River ground water, for example, are often relatively high while dissolved oxygen contents are relatively low compared to surface waters which are more nearly equilibrated with atmospheric gas concentrations.

The open water season is characterized by relatively high and variable surface flows. It is also characterized by a more dilute chemical milieu and by higher suspended particulate concentrations in the Susitna River. Approximate water quality characteristics of both the winter and summer season may be compared and contrasted (Table 4.1). Concentrations of selected metals, which have the potential to be toxic in some chemical states, are discussed in greater detail in another section of this report which deals primarily with heavy metals (eg. Ch. 7).

Freshet runoff, atmospheric precipitation, glacial melt, and most other tributary runoff dilute river surface flow concentrations of many dissolved chemical entities during the open water season. Higher riverine discharges during the open water season also erode and resuspend bed load and stream bank particulates resulting in large and variable concentrations of riverine suspended sediments.

Table 4.1

SUSITNA HYDROELECTRIC PROJECT
APPROXIMATE WATER QUALITY CHARACTERISTICS OF THE SUSITNA RIVER
AT GOLD CREEK DURING MAY-OCTOBER VS. NOVEMBER-APIIL.

Parameter	May-October		November - April	
	Range	Mean	Range	Mean
Mean Flow (cfs)	4,000-50,000	26,000	700-4,000	1,600
Total Suspended Sediments (mg/l)	10-2,600	700	0-8	<8
Turbidity (NTU)	20-740	200	0-5	0
Total Dissolved Solids (mg/l)	50-150	90	100-180	150
Conductivity (umhos/cm^2)	80-225	145	80-300	240
Color (platinum cobalt units)	0-110	15	0-40	5
ph (ph units)	6.5-8.0	7.3	7.0-8.0	7.5
Alkalinity (mg/l as $CaCO_3$)	25-85	50	45-90	70
Hardness (mg/l as $CaCO_3$)	30-110	60	60-120	100
Total Organic Carbon (mg/l)	1-3	3	1-5	3
Chemical Oxygen Demand (mg/l)	2-22	11	2-16	9
Total Phosphorus (ug/l)	10-400	120	10-50	30
Total Nitrogen (ug/l)	200-900	600	500-1000	750
Temperature (°C)	2-13	9	0-2	0
Chloride (mg/l)	1-15	5	7-35	22
Calcium-dissolved (mg/l)	10-38	19	18-40	29
Sulfate (mg/l)	1-30	16	10-38	20
Dissolved Oxygen (mg/l)	8.5-13.5	12	11.0-16.0	14
Dissolved Oxygen (% of Saturation)	80-110	102	76-110	98
Phosphate - ortho (ug/l)	0-100	<10	10-30	20
Magnesium - dissolved (mg/l)	1-8	3	3-10	5
Sodium - dissolved (mg/l)	2-10	4	5-21	13
Potassium - dissolved (mg/l)	1-5	2	1-5	2

Source: R and M Consultants, Inc. and L.A. Peterson and Assoc. 1982; APA 1983; R and M Consultants, Inc. 1982.

4.2 EXPECTED WATER QUALITY CHANGES -GENERALIZED

Construction and operation of the proposed project will alter most water quality characteristics in the reservoirs and in downstream riverine habitats which are directly inundated by mainstem flows. Impoundment of the river will reduce the frequency and the amplitude of the annually cyclic water quality fluctuations observed in the unregulated river. Project operation will also cause a temporal phase shift of many naturally occuring water quality regimes. Maximum suspended sediment concentrations, for example, will probably occur in the late summer, fall, and early winter seasons, instead of during the late spring and summer which is when natural maxima occur.

Water quality and quantity changes induced by the project are not expected to cause either the reservoirs or downstream riverine habitats to be uninhabitable by most naturally occurring flora and fauna. It is expected, however, that project induced water quality changes in the reservoirs and in downstream riverine habitats will affect biomass production at all trophic levels, especially in the aquatic habitats which are constantly turbid. Reduced biological productivity at most trophic levels may be the effect if chronically high turbidity levels prevail. Mitigation measures are being proposed, however, to help maintain natural levels of fish productivity.

Several commonly measured water quality characteristics have been examined in order to estimate the approximate values and/or concentrations at which they will exist in the project reservoirs and downstream mainstem channels of the middle river reach (Table 4.2). Most project induced changes in water quality are expected to cause relatively unimportant environmental effects with respect to aquatic biology in both the reservoirs and downstream riverine habitats in the middle river.

4.3 SELECTED WATER QUALITY ISSUES

Certain expected water quality changes have been labeled as environmental "issues" and, as such, have been more thoroughly examined with regard to potential environmental effects. More detailed discussions of these water quality entities and their potential environmental effects are found in the following chapters of this text (eg. Chapters 5, 6, 7, 8, 9, 10 and 11.

TABLE 4.2

ESTIMATED APPROXIMATE WATER QUALITY CHARACTERISTICS OF THE S.H.P. RESERVOIRS AND DOWNSTREAM RELEASE WATER

Parameter	Estimated Value
True Color	<100 pcu
Trophic Status	Ultra-oligotrophic
Mean Annual Primary Productivity(Reservoirs)	1-20 g Carbon m^2/yr.
Mean Annual Primary Productivity (Susitna River Middle Reach)	Unknown
Maximal Euphotic Zone Tempertures	<15 °C
Phytoplankton Standing Crop (Reservoirs)	<1.0 gm/m^3 (wet weight)
Phytoplankton Volume (Reservoirs)	<1.0 cm^3/m^3
Dominant Phytoplankters (Reservoirs)	Chlorophyceae Bacillariophyceae, Chrysophyceae, Dinophyceae, Cyanophyceae
Dominant Periphyton (Susitna River Middle Reach)	Cyanophyceae, Chlorophyceae, Bacillariophyceae
Dominant Zooplankters (Reservoirs)	Rotifera and Copepoda
Dominant Macroinvertebrates (Susitna River Middle Reach)	Chironomidae
Total Dissolved Solids	≃100 mg/l
Euphotic Zone (to 1% of PAR)	0.1 - 3.0 meters (fluctuating)
Total Organic Carbon	<5 mg/l
Particulate Organic Carbon	<0.5 mg/l
Dissolved Organic Carbon	<5.0 mg/l
Alkalinity	60-100 mg/l as $CaCO_3$
pH	6.0 - 8.0 range; 7.0+ mean
Conductivity	100-150 umhos/cm^2
Dissolved Oxygen	8.0+ mg/l; 80+% Saturation
Hardness	70-100 mg/l as $CaCO_3$
Total Filterable Sediments (0.45 u filters)	0-200 mg/l
Total Suspended Sediments (centrifuged)	5-200 mg/l
Turbidity	100-400 NTU
Total Organic+$NO_3^=$+NH_4 Nitrogen	<1000 ug/l
Total Bioavailable P	<20-30 ug/l

5.0 AN ALTERED SUSPENDED SEDIMENT AND TURBIDITY REGIME

The significance of changes in the natural regime of suspended sediments and turbidity on salmon and resident fish habitats has been identified as a fisheries issue for this project. The following text summarizes the current status of our knowledge regarding this topic.

5.1 INTRODUCTION

All rivers tend to establish a dynamic equilibrium with respect to sediment transport and channel morphology. Sediment swept downstream from one reach during degradation tends to be replaced, on the average, by sediment inputs from some other upstream reach (Leopold et al. 1964, Morisawa 1968, Fan 1976, Simmons 1979). Dams disturb the natural dynamic equilibrium of riverine sediment transport by stopping most downstream sediment transport and replacement.

Most sediments which presently depend upon the river's tractive force for downstream movement are expected to be trapped upstream of the dams (R & M Consultants, Inc. 1982c; Peratrovich, Nottignham and Drage, Inc. and I.P. Hutchinson 1982; FERC 1984; Harza-Ebasco Susitna Joint Venture 1984). Suspended particulates passing downstream through the project structures will be fewer, smaller, and their average mineral composition and three-dimensional shapes will be altered from the natural conditions (Anderson et al. 1972; Ostrem 1975; Ostrem et al. 1970; R & M Consultants, Inc. 1982a; R & M Consultants, Inc. 1982d; R & M Consultants, Inc. 1985). The present temporal regimes of bedload transport, suspended sediment transport, turbidity and streambed substrate sedimentation are seasonally dichotomous and variable. River regulation will make these regimes more seasonally continuous and less variable.

Extensive modeling efforts utilizing DYRESM[1/] and especially created sub-

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[1/] DYRESM: Dynamic reservoir simulation model (Patterson, Imberger, Hebbert and Loh 1977) routines dealing with suspended sediments (TSS) have been used to estimate the size characteristics and mean monthly concentration of particulates which will exit the project reservoirs during operational phases of Stage I, II and III. Sedimentation column studies using Susitna River water samples have been made to investigate settling patterns of particulates and the characteristics of "suspendable" particles. Review of other settling column studies together with study of data from existing glacial lake and glacial river ecosystems has been used to establish the best approximate relationship between suspended sediments and turbidity for use with this project.

Because of the basic interaction between biological activity and light it seemed appropriate to examine and attempt to calibrate an approximate relationship between turbidity and light transmission. An approximate relation between turbidity and the maximum depth of the euphotic zone was developed. This relationship gives us a coarse tool for use in estimating the maximum volume and/or area of the most biologically active sites which will receive incident light in both the reservoir and riverine aquatic habitats.

To date, only generalizations can be made about the interactions between the altered sediment regime, the expected With-project flushing of existing fine sediments from some streambed substrates, and the sedimentation dynamics associated with the Project's estimated operational sediment regime. Project induced alterations of the sediment and turbidity regime are expected to minimize potential biological productivity in both reservoirs and in some downstream riverine habitats. We are presently unable to quantitatively estimate the Susitna River Middle Reach productivity changes to be expected at the microbial detritovore, primary producer and macroinvertebrate trophic levels when compared to natural conditions. However, a limited perspective of water quality characteristics estimated for downstream discharges together with limited familiarity with various other riverine characteristics indicates that:

- o chronically turbid riverine habitats may have their biological productivity reduced when compared to the natural conditions because of high turbidity and reductions of allochthanous organic detritus inputs from upstream;

- o clear and intermittently turbid habitats may experience the same or increased biological productivity when compared to the natural conditions because of the fertilization capabilities of sedimented glacial flour juxtapositioned with epilithon, and improvements of the condition of some streambed substrates.

Extensive literature reviews have indicated that the estimated With-project suspended sediment and turbidity regime will have negligable direct affects on adult and juvenile resident fish and salmon. Direct affects on the fish are expected to result in sublethal stress, but should not result in mortality. Although direct evidence is lacking of the effects of long-term exposure to the expected With-project levels of suspended sediments and turbidity under the expected environmental conditions, indirect evidence implies that most middle reach fish may survive if forced to overwinter in turbid mainstem habitats.

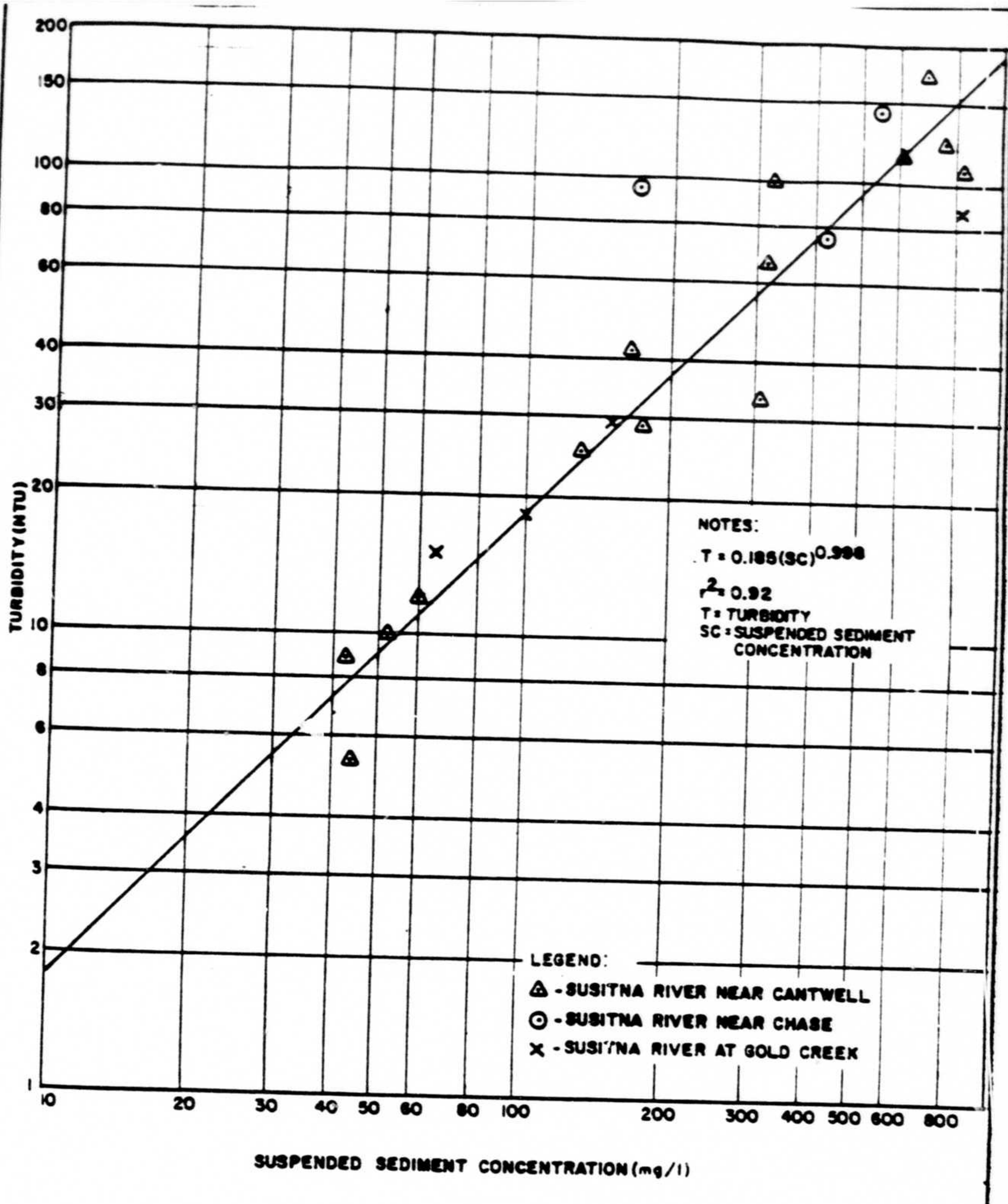
Approximate levels of suspended sediment and turbidity which are generally associated with various levels of aquatic habitat protection are presented.

5.2 SUSPENDED SEDIMENT AND TURBIDITY RELATIONSHIPS

Turbidity should be clearly distinguished from a mass or concentration of suspended particles in a liquid. Turbidity is an expression of the optical property of a sample which causes light (generally white light) to be scattered and absorbed rather than transmitted in straight lines through the sample (Austin 1973, Gibbs 1974, A.P.H.A. 1980). The particulates suspended in a sample which contribute the greatest turbidity per unit weight are generally larger than 1.0 micron mean data diameter but less than 10 micronsmean beta diameter (Gibbs 1974, Hecky and McCulloughj 1984, Peterson et al. 1985a). The light scattering and absorbing properties of inorganic particulates suspended in water are influenced not only by their size and concentration, but also by their elemental chemistry and mineralogy. In the Susitna River it is believed that the turbidity will be influenced to a relatively minor degree by dissolved and colloidal inorganic and organic entities, such as colloidal silica and dissolved humic compounds.

The relationships between suspended sediment concentration and turbidity (NTU's) have been investigated in both large and small lotic environments in Alaska (R & M Consultants, Inc. 1982c, e, 1984b, 1985; Peratrovich, Nottingham and Drage, Inc. and I.P. Hutchinson 1982; Lloyd 1985; Peterson et al. 1985a). Most data from lotic, glaciated habitats or from placer mine sluice box effluents (neither of which had lakes, reservoirs or settling basins upstream) show that the calculated ratio of NTU/TSS is less than 1:1. In fact, the middle reach of the Susitna River and other large Alaskan rivers draining glaciated watersheds have generalized NTU/TSS ratios approximating 1:4 or 1:5. Wide variances among these ratios exist (Figures 5.1; 5.2). In relatively small glacial streams, ratios of NTU/TSS may also be highly variable, and may sometimes average slightly greater than the ratios found in large glacial rivers (i.e. >1:1)(Figure 5.3 and 5.4). Lloyd (1985), reviewed data gathered from relatively small, non-glacial streams in interior Alaska. Some of these streams were receiving placer mine wastes while others were not. Samples from these streams were also found to have ratios of NTU/TSS with great variability, but had an average ratio of approximately 1:1 (Figure 5.5).

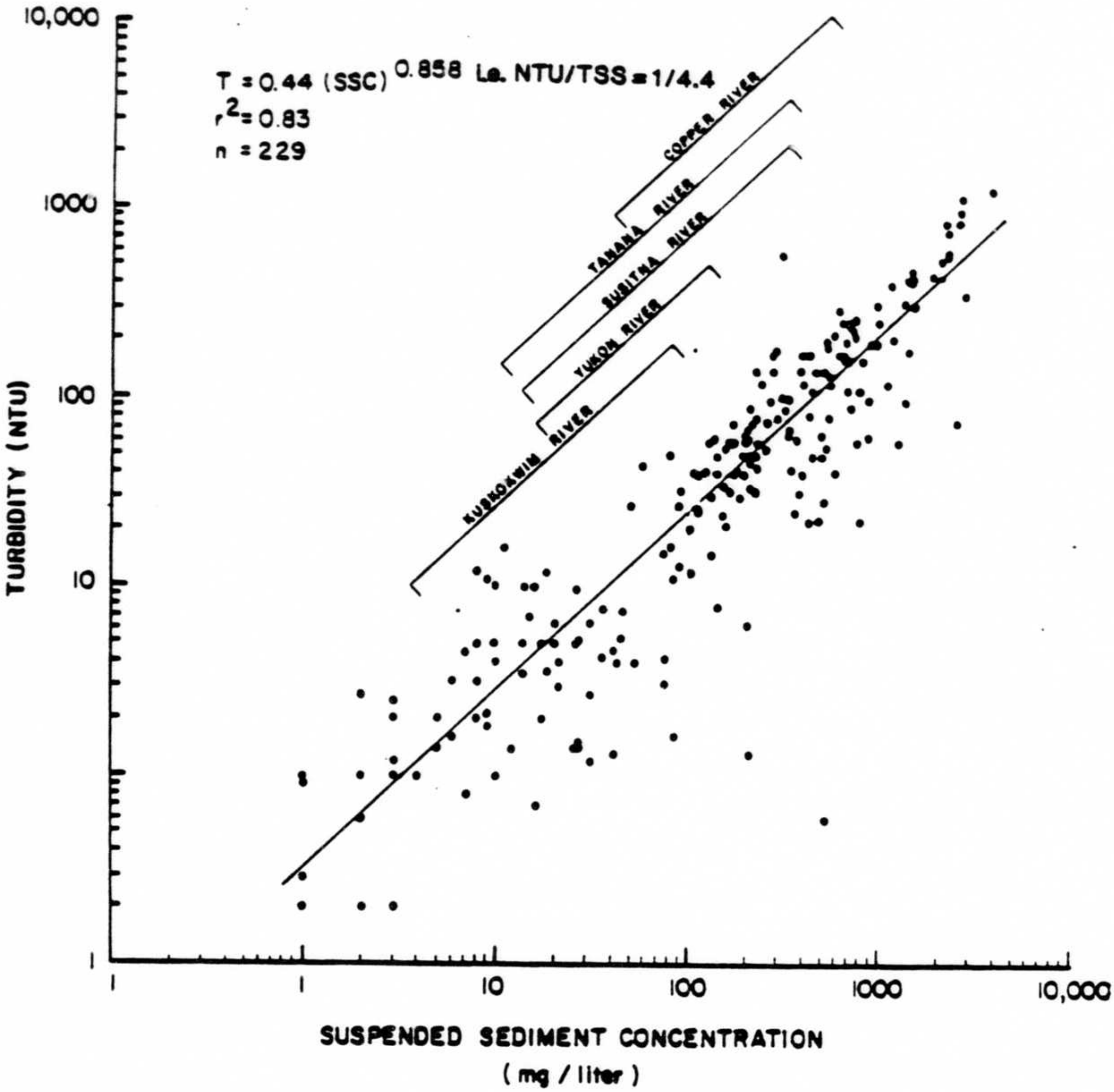
Llyod (1985), using data from another study on wastewater discharge from sixteen placer mines in interior Alaska (R & M Consultants, Inc. 1982e), drew a figure relating turbidity and suspended sediment concentrations at unaffected upstream sites and at sites downstream of mining wastewater effluents. Examination of Lloyd's plot (Figure 5.6) demonstrates that the ratio NTU/TSS again has wide variances and that the naturally clear streams generally exhibited NTU/TSS ratios <1:1 while the same stream influenced by



TURBIDITY VS. SUSPENDED SEDIMENT CONCENTRATION SUSITNA RIVER

SOURCE PERATROVICH, NOTTINGHAM AND DRAGE 1982

FIGURE 5.1



TURBIDITY VS SUSPENDED SEDIMENT CONCENTRATION IN SEVERAL ALASKAN RIVERS

Figure 5.2 Empirical relationship of naturally occurring turbidity versus suspended sediment concentration for rivers and streams in Alaska, sampled during May-October, 1976-1983 (derived in this report from data provided by USGS, 1984).

SOURCE: LLOYD 1985

FIGURE 5.2

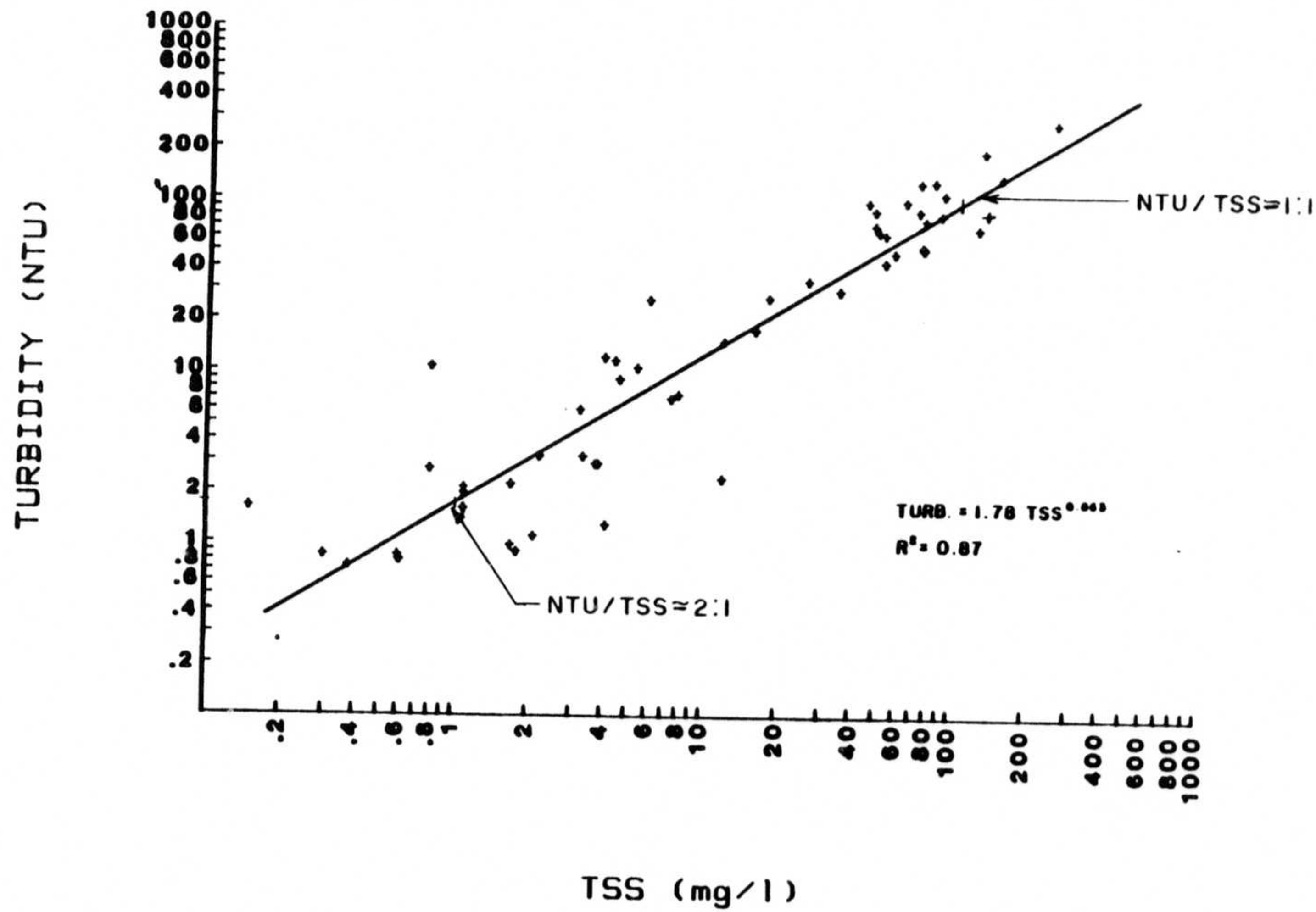


FIGURE 5.3

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	1984 EAST FORK DATA: TURBIDITY VS. TOTAL SUSPENDED SOLIDS FOR LOTIC INFLUENTS TO EKLUTNA LAKE	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

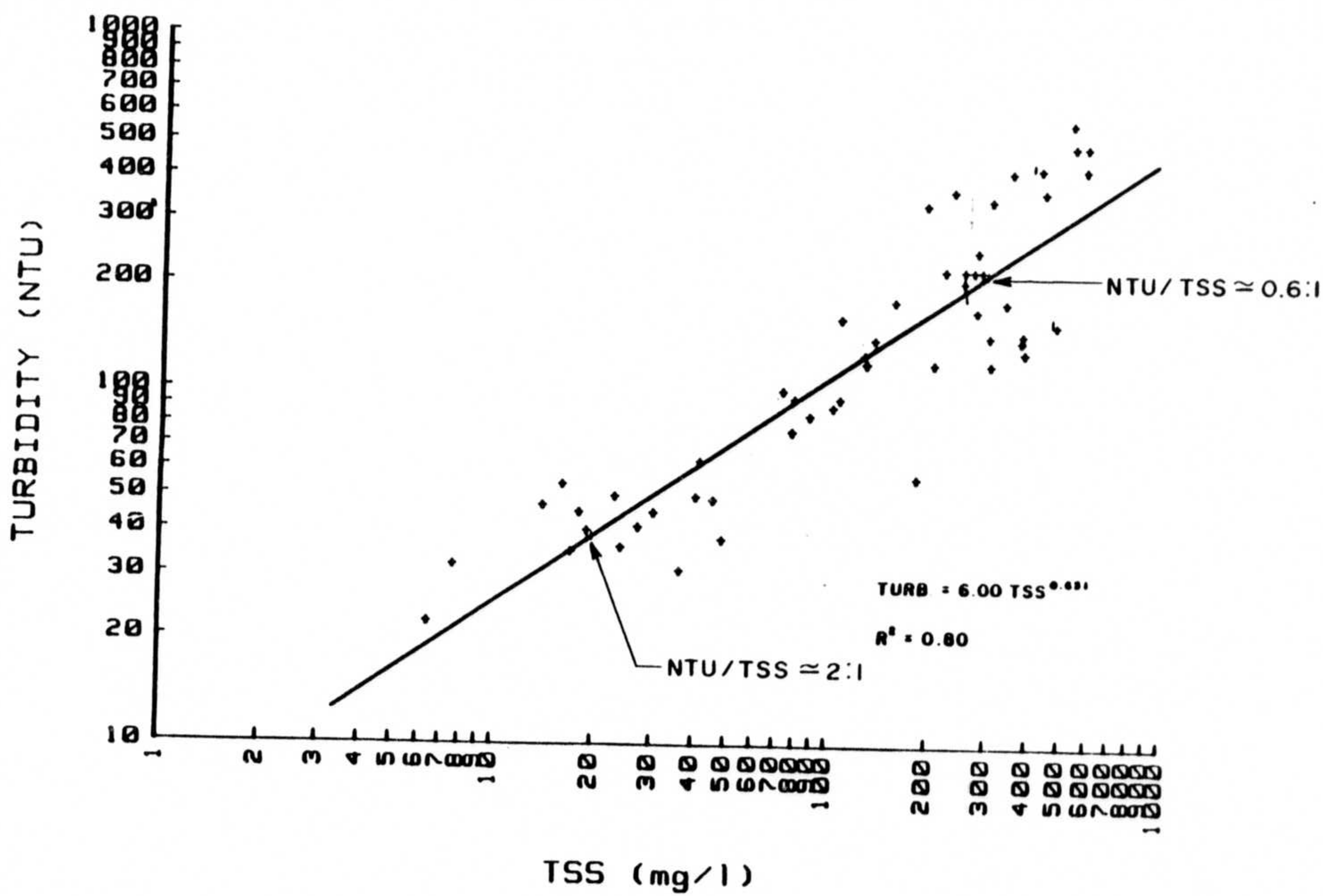


FIGURE 5.4

PREPARED BY:

R&M CONSULTANTS, INC.

ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

1884 GLACIER FORK DATA:
TURBIDITY
VS.
TOTAL SUSPENDED SOLIDS
FOR LOTIC INFLUENTS TO EKLUTNA LAKE

PREPARED FOR:

HARZA-EBASCO

SUSITNA JOINT VENTURE

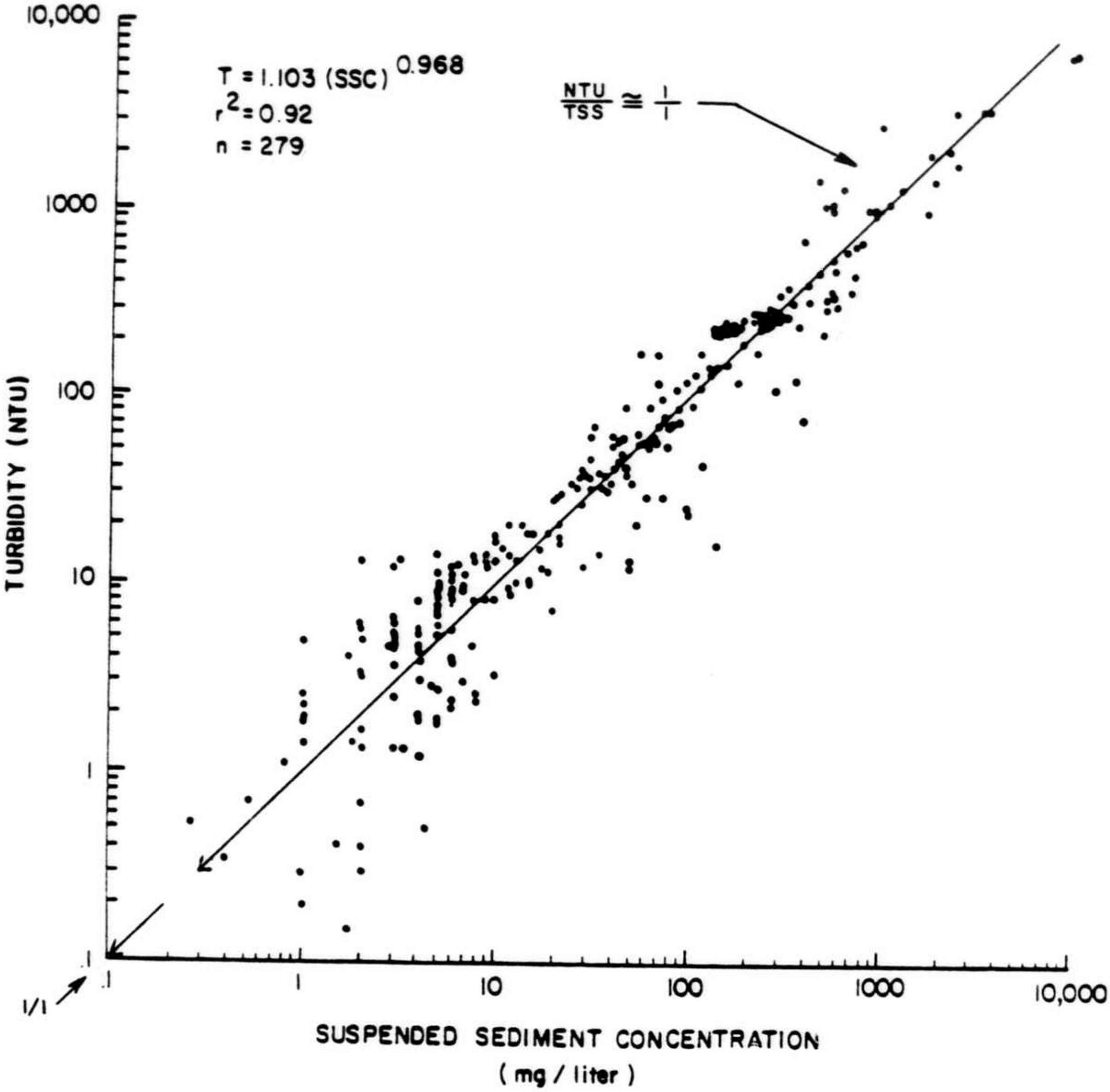


Figure 5.5 Empirical relationship of turbidity versus suspended sediment concentration for placer-mined and neighboring unmined streams in interior Alaska, sampled during summer, 1983-1984 (derived in this report from data provided by Post, 1984; Toland, 1984). (Adapted From Lloyd 1985)

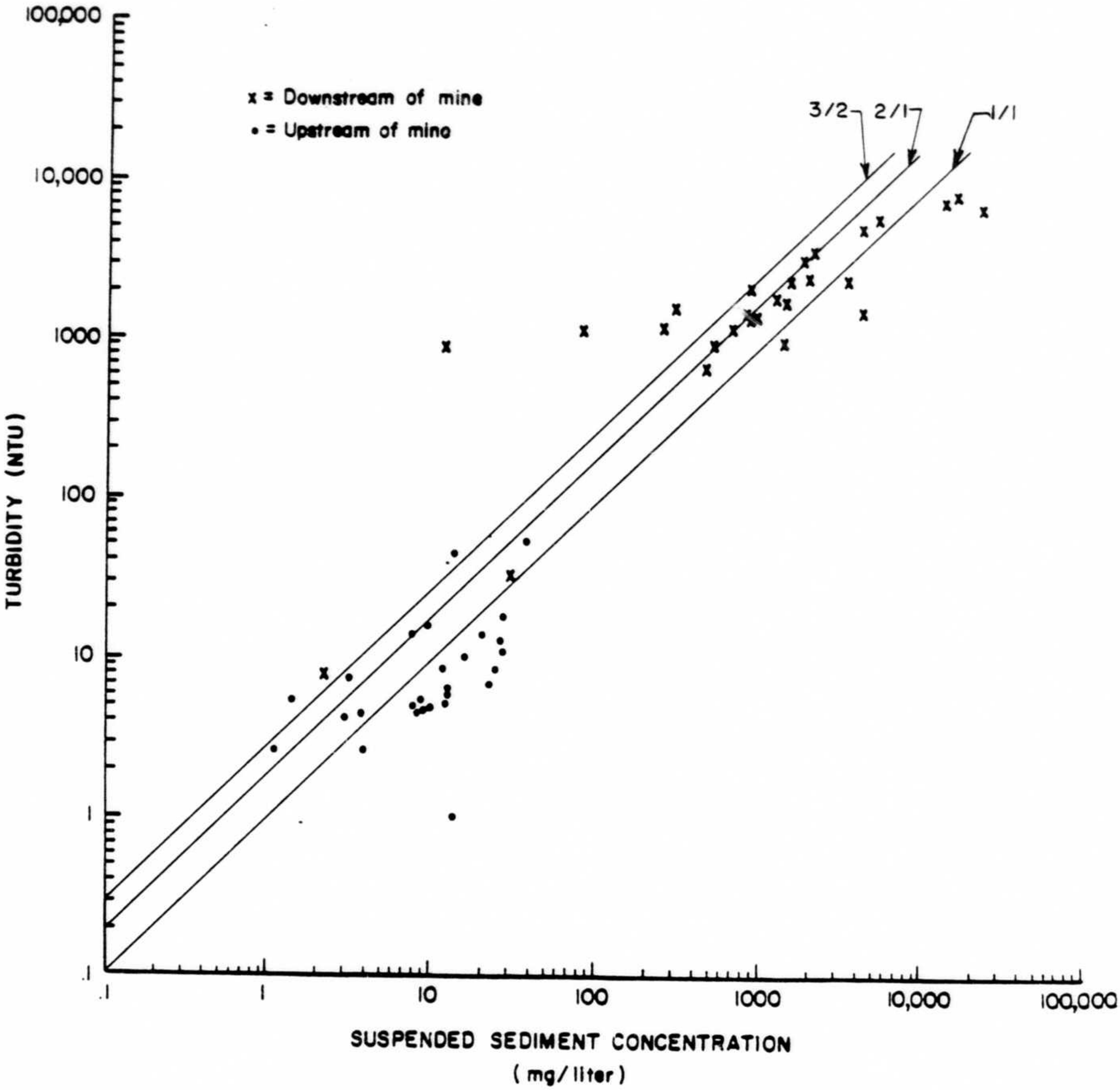


Figure 5.6 Plot of turbidity and suspended sediment concentration for certain placer-mined streams in Alaska (plotted in this report from data presented in R&M Consultants, 1982a). (Adapted From Lloyd 1985)

mining wastewater effluents tended to exhibit NTU/TSS ratios >1:1. An obvious cause of such results is that treatment of mining wastewater removes the coarser, heavier particles while leaving the smaller, lighter particles in suspension. Such treatment could obviously shift the ratio of NTU/TSS to a greater value.

Examination of settling column data from 15 separate placer mine sluice box effluents (R & M consultants, Inc. 1982e) and from two separate settling columns utilizing water samples form the Susitna River (R & M Consultants, Inc. 1984b) indicates that the ratio NTU/TSS changes through time from <1:1 to >2:1 after 72 to 96 hours of relatively quiescent settling (Tables 5.1, 5.2, 5.3).

Plots of the NTU vs. TSS data pairs in the three former tables indicate that, under the relatively quiescent conditions existing in the settling columns, the ratio of NTU/TSS may ultimately have approached values >2:1 (Figures 5.7, 5.8, and 5.9). If a continuous and unchanging ratio were to exist between turbidity and the suspended sediment concentration, then the slope of the lines in the three former figures would be exactly 45° from horizontal. And if turbidity were entirely caused by TSS then regression analyses would predict that zero turbidity would result from zero suspended solids. The three formerly depicted figures do not support either of these relationships. All three relationships do, however, indicate that the amount of turbidity produced per unit of suspended sediment (i.e. the ratio NTU/TSS) increased as: 1) more settling time elapsed, and 2) the larger and heavier particles precipitated out of suspension leaving progressively less weight of suspended particles.

Analysis of both Susitna River settling column experiments indicates that both turbidity and suspended sediment concentrations decline rapidly in the initial hours of the experiments and that their rate of decline decreased with increasing settling time (Figure 5.10 and 5.11). Particle size analysis indicated that relatively smaller particles (with greater surface area and consequently greater light scattering capabilities per unit weight)

TABLE 5.1 AVERAGE TOTAL SUSPENDED SOLIDS AND TURBIDITY VALUES SETTLING COLUMN TESTS

MINE SITE	0 HOUR TSS mg/1	0 HOUR Turb NTU	6 HOUR TSS mg/1	6 HOUR Turb NTU	12 HOUR TSS mg/1	12 HOUR Turb NTU	24 HOUR TSS mg/1	24 HOUR Turb NTU	48 HOUR TSS mg/1	48 HOUR Turb NTU	72 HOUR TSS mg/1	72 HOUR Turb NTU	72 HOUR NTU/TSS Ratio
1	6,280	3,200	2,310	2,900	2,060	2,200	1,260	1,900	1,240	1,500	780	1,500	1.94
2	53,800	14,200	5,300	7,100	14,100	5,400	1,800	2,900	800	1,700	620	1,200	1.94
3	11,200	6,700	3,410	6,500	4,080	5,300	3,600	5,200	3,400	4,700	2,800	3,700	1.32
4	33,500	10,700	5,310	6,800	2,690	4,000	1,430	2,300	540	1,300	190	1,400	7.37
5	5,480	5,300	3,990	4,200	3,260	2,900	1,840	2,900	1,280	2,300	1,000	1,700	1.70
6	8,100	3,100	4,250	2,300	1,850	1,600	1,410	1,300	1,130	1,100	810	1,200	1.48
7	17,200	6,300	2,760	2,800	1,730	2,200	1,320	2,000	1,030	1,600	1,160	1,980	1.71
8	13,700	6,100	2,900	3,600	2,290	2,500	1,850	2,500	1,590	1,900	1,130	1,200	1.06
9	12,700	7,900	2,710	4,800	1,130	2,100	700	1,280	330	600	180	420	2.33
10	18,100	7,400	4,950	5,600	3,700	5,100	3,480	5,100	2,430	3,600	2,290	3,000	1.31
11	3,030	2,700	1,780	2,400	1,470	1,700	1,280	2,000	1,350	2,600	1,170	2,000	1.77
12	20,700	8,500	6,550	6,800	4,180	5,300	2,180	4,300	1,840	3,100	1,110	2,400	2.16
13	27,900	10,200	1,470	1,800	490	680	200	330	52.3	180	42.9	110	2.56
14	25,600	11,100	0,400	6,800	1 534	630	232	370	68.8	130	35.2	45	1.28
Porcupine	8,610	4,300	2,830	2,800	1,630	2,300	873	1,500	740	1,400	651	1,300	2.0
													$\overline{X} = 2.1$

Note: The values listed above are average values of the column ports sampled.
Average values for Porcupine Creek listed under 6 hour and 12 hour were sampled at 4 and 7 hours, respectively.
Total Suspended Solids and Turbidity values for Porcupine Creek after 528 hours (22 days) are 120 mg/l and 390 NTU, respectively.

Table 5.2
Settling Column Run #1
Total Suspended Solids and Turbidity

	TSS (mg/l)	Avg TSS	Avg* Percent Remaining	Turbidity (NTU)	Avg Turbidity
Susitna River (7/31/84)	181	-	-	-	-
0 Hours					
Top	117			172	
Middle	146	124	100	174	165
Bottom	108			148	
3 Hours					
Top	120			134	
Middle	115	119	96	154	141
Bottom	122			136	
6 Hours					
Top	63			144	
Middle	105	93	75	125	138
Bottom	111			144	
12 Hours					
Top	49			100	
Middle	85	78	63	118	115
Bottom	100			126	
24 Hours					
Top	34			90	
Middle	64	57	46	108	101
Bottom	74			104	
48 Hours					
Top	32			90	
Middle	59	52	42	110	104
Bottom	66			112	
72 Hours					
Top	34			76	
Middle	48	50	41	112	103
Bottom	69			120	
96 Hours					
Top	38			90	
Middle	49	48	39	94	96
Bottom	56			104	

$$\text{* Average Percent Remaining} = \frac{\text{Average TSS at Time (T)}}{\text{Average TSS at Time 0}} \times 100$$

NTU/TSS
3.00
1.92
1.86
X = 2.26

(Source: R & M Consultants, Inc. 1984c)

Table 5.3

Settling Column Run #2

Total Suspended Solids and Turbidity

	TSS (mg/l)	Avg TSS	Avg* Percent Remaining	Turbidity (NTU)	Avg Turbidity	
Susitna River (8/6/84)	410	-	-	-	-	
0 Hours						
Top Part	320			308		
Middle Part	355	342	100	308	304	
Bottom Part	350			296		
3 Hours						
Top	230			304		
Middle	300	283	83	280	300	
Bottom	320			316		
6 Hours						
Top	190			280		
Middle	260	243	71	316	291	
Bottom	280			276		
12 Hours						
Top	160			232		
Middle	245	215	63	240	228	
Bottom	240			212		
24 Hours						
Top	145			244		
Middle	220	190	55	280	268	
Bottom	205			280		
48 Hours						
Top	155			240		
Middle	175	167	49	244	241	
Bottom	170			240		
72 Hours						
Top	93			220		
Middle	122	112	33	268	247	
Bottom	120			252		
96 Hours						NTU/TSS
Top	78			204		2.62
Middle	106	101	30	208	210	1.96
Bottom	119			220		1.85
						$\overline{X} = 2.14$

$$\text{* Average Percent Remaining} = \frac{\text{Average TSS at Time (T)}}{\text{Average TSS at Time 0}} \times 100$$

(Source: R & M Consultants, Inc. 1984c)

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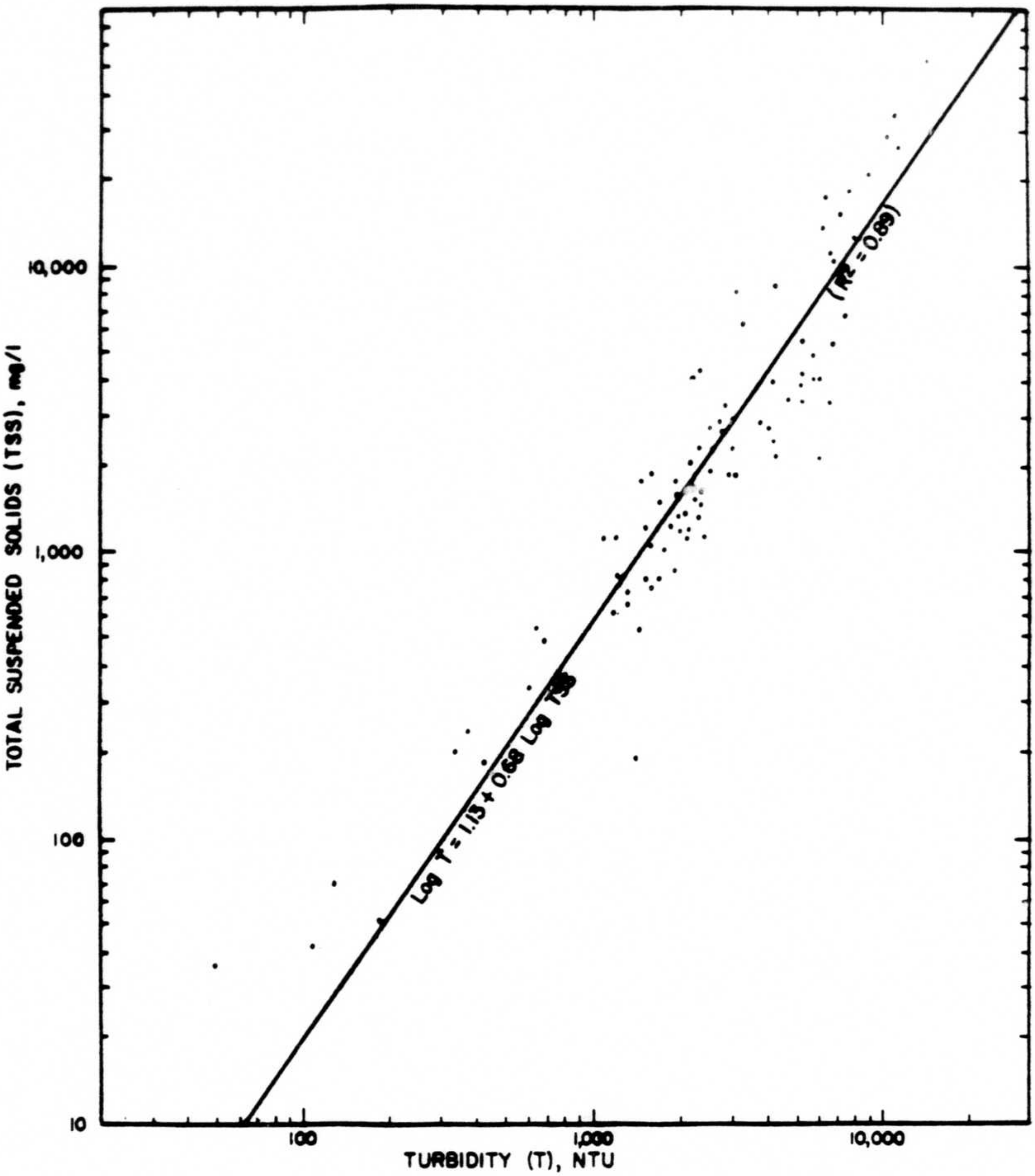


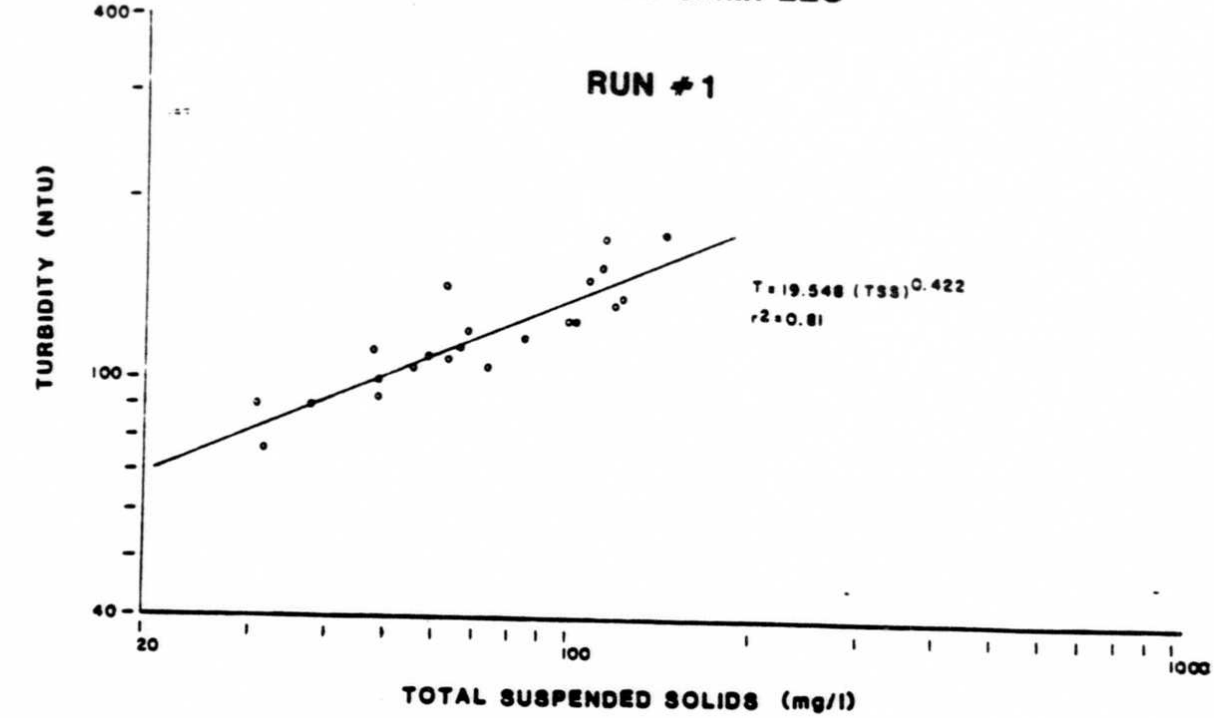
Figure 5.7

RELATIONSHIP BETWEEN TURBIDITY AND TOTAL SUSPENDID SOLIDS

SETTLING POND DEMONSTRATION PROJECT

DATE	SCALE	DRAWN BY	CHECKED BY	PROJECT NO.	DRAWING NO.
6-6-82	AS SHOWN	LDS	JHW	013104	5

TURBIDITY vs. SUSPENDED SOLIDS
FROM SETTLING COLUMN
SUSITNA RIVER SAMPLES



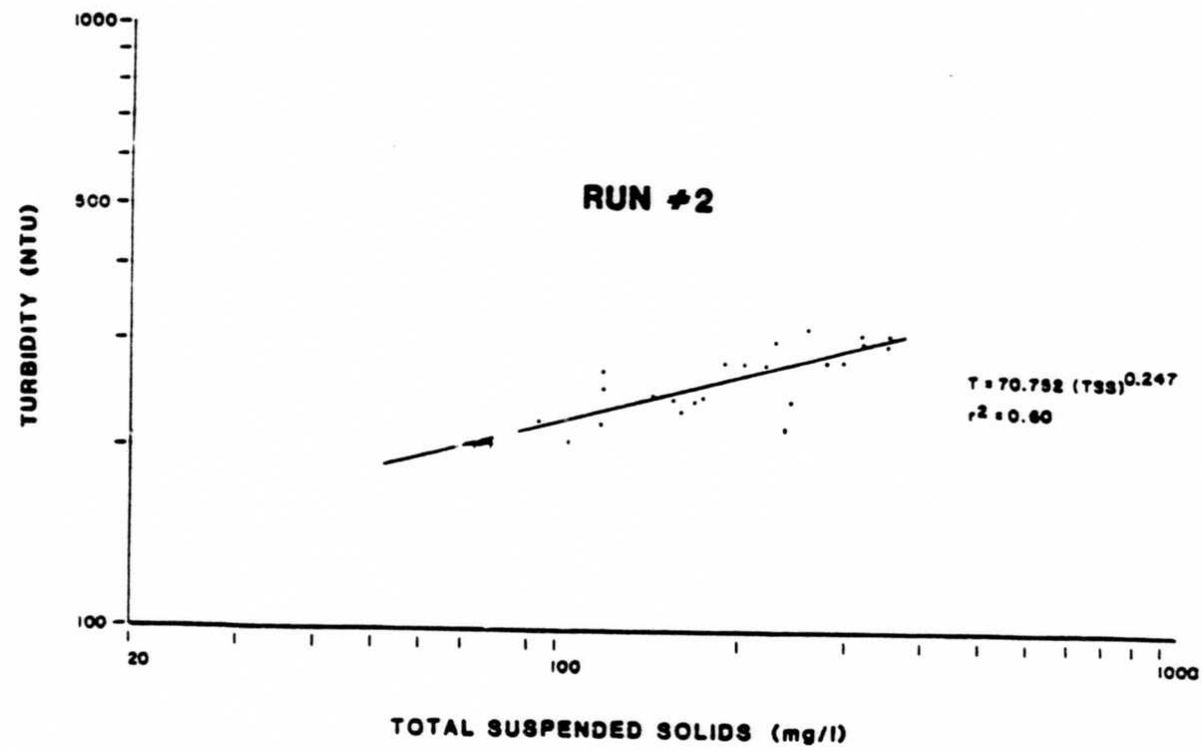


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FIGURE 5.8

HARZA-EBASCO
SUSITNA JOINT VENTURE

SUSITNA RIVER SAMPLES
TURBIDITY vs. SUSPENDED SOLIDS
FROM SETTLING COLUMN RUN 1 and 2
COMBINED

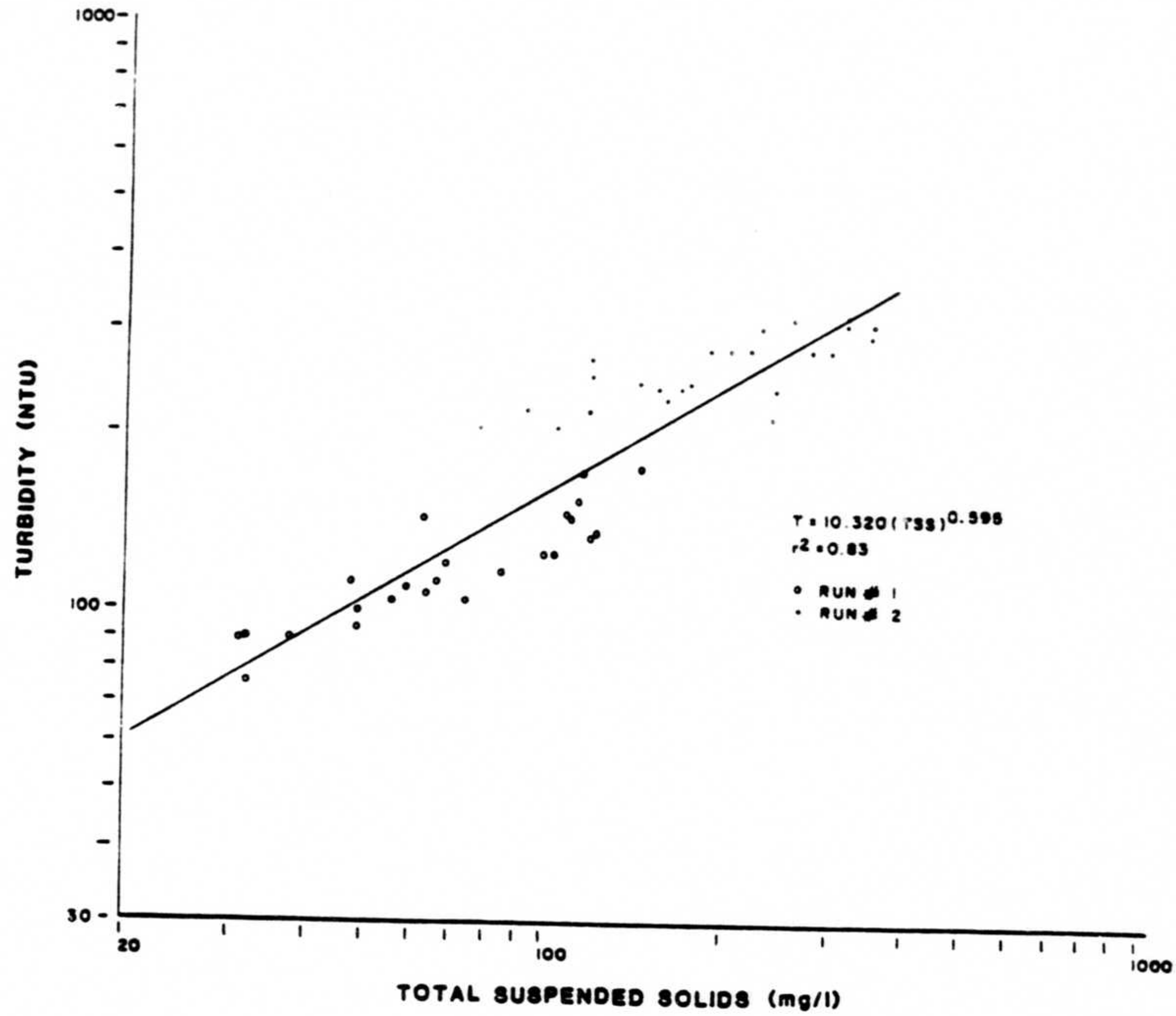

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FIGURE 5.9

HARZA-EBASCO
SUSITNA JOINT VENTURE

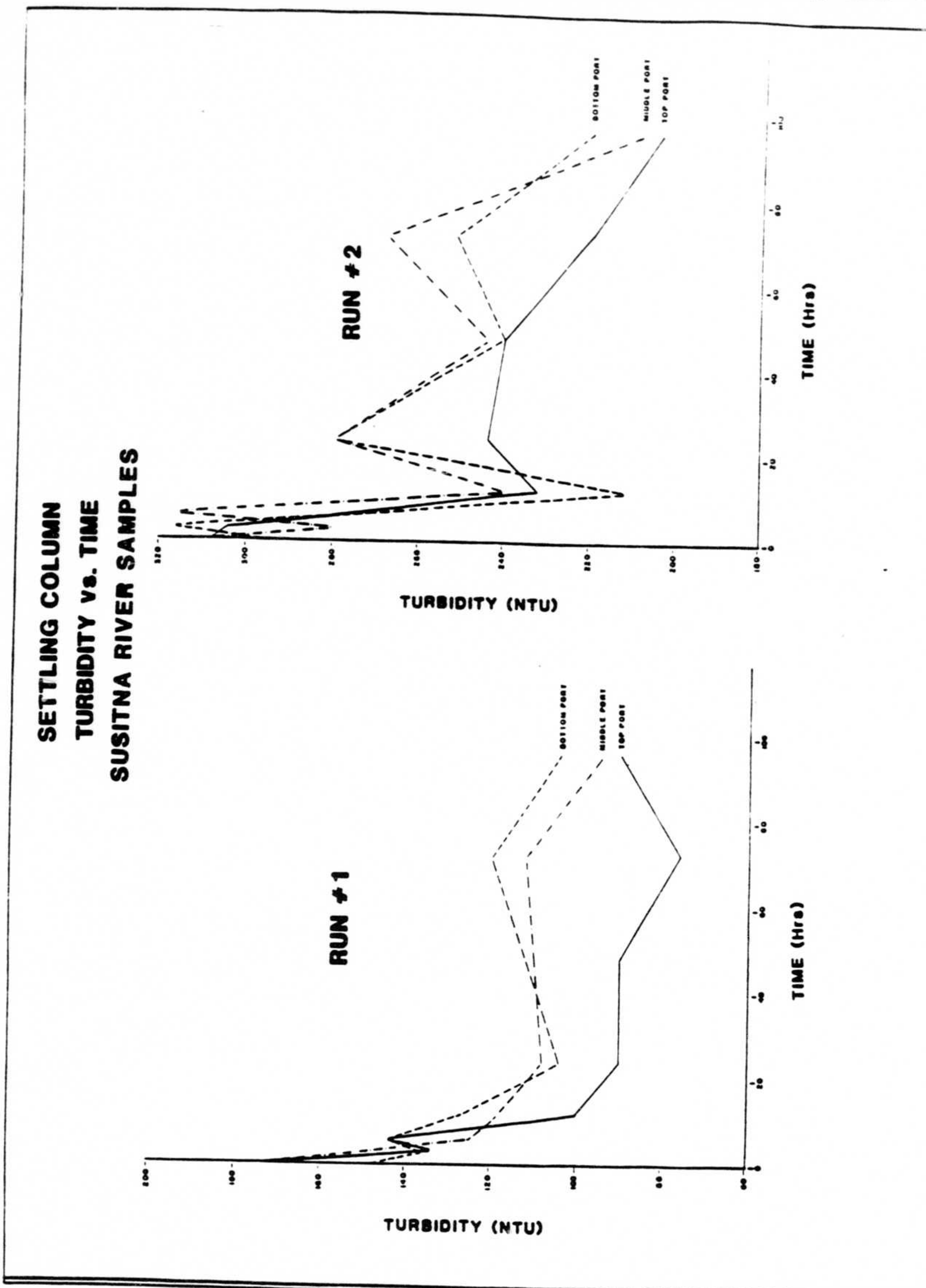

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FIGURE 5.10

HARZA-EBASCO
SUSITNA JOINT VENTURE

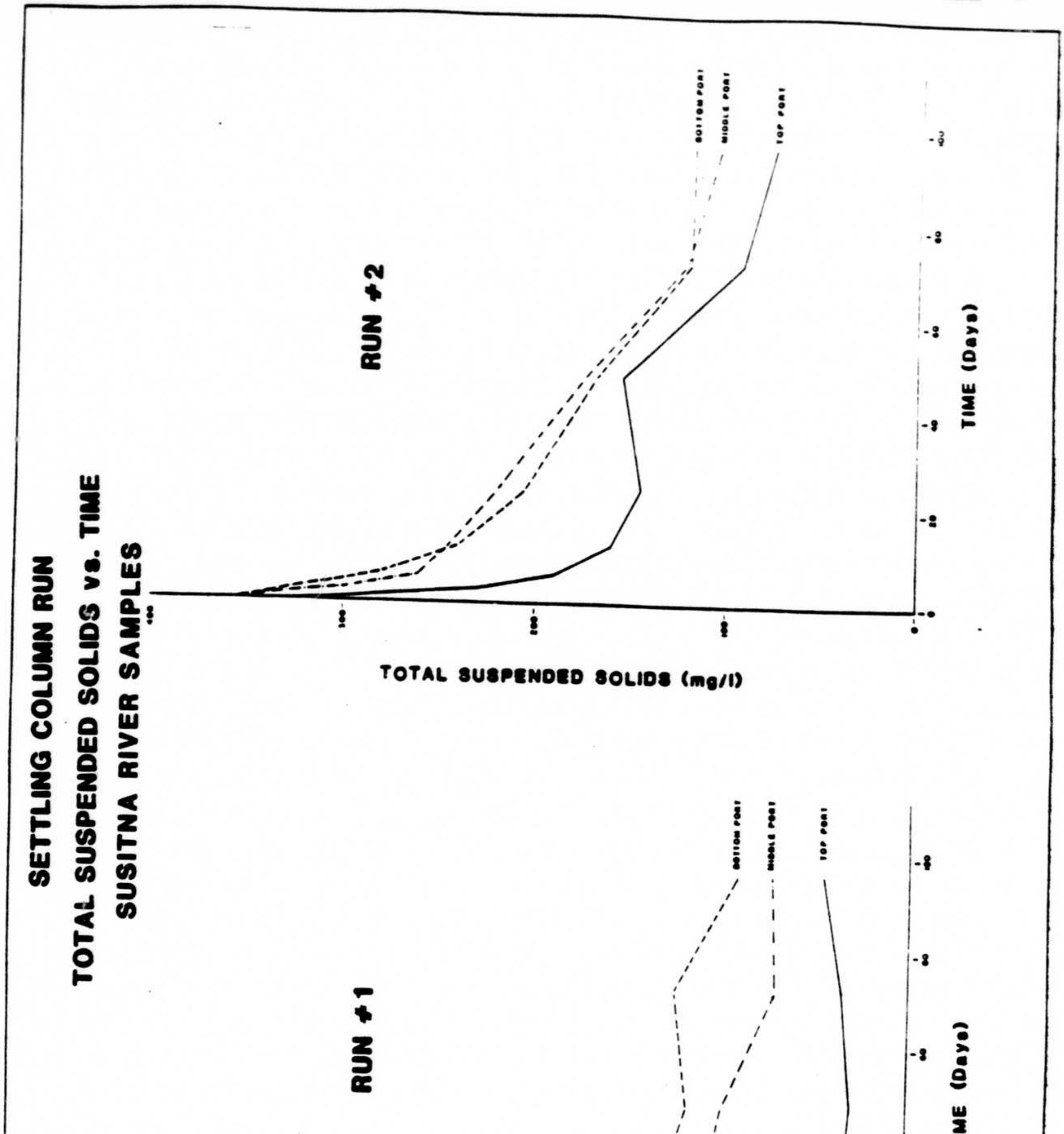

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FIGURE 5.11

HARZA-EBASCO
SUSITNA JOINT VENTURE

remained in suspension in greater concentration after 96 hours of settling (R & M Consultants, Inc 1984b).

It may be reasonable to deduce that the ratio NTU/TSS may have increased with increasing time elapsed in the settling columns. At some point, however, had the experiments continued, the ratio NTU/TSS would have altered its rate of change from that shown in Figures 5.7, 5.8, and 5.9. This alteration would not be predictable in time and would ultimately depend on the miniscule changes (in turbulence, biology, and chemistry, etc.) which would occur within the settling columns. Prolonged rates of settling in large and relatively turbulent reservoirs experiencing hydrologic, climatic, geochemical and biological changes would also be expected to produce relatively large and variable ratios of NTU/TSS with little predictablity as to absolute value or times of change. It may be hypothesized that ratios of NTU/TSS in a large reservoir like Watana and in its discharges may be ≥2:1 and highly variable in time.

More than 200 NTU/TSS data pairs were collected in Eklutna Lake (Figure 5.12) and more than 50 similar data pairs were collected in the Eklutna Lake tailrace (Figure 5.13) during 1984 (R & M Consultants, Inc. 1985). Ratios of NTU/TSS in the reservoir tailrace varied from <1:1 to >20:1 with a mean value of 3.62:1. Ratios of NTU/TSS in Eklutna Lake acturally varied from <0.6:1 to >50:1, with a mean value of 4.38:1. These data may be interpreted as supportive of a hypothesis that glacial sediments settling for prolonged time periods in large lake/reservoirs in south central Alaska will produce highly variable and largely unpredictable values for the ratio NTU/TSS, and that the ratios of NTU/TSS will generally be ≥2:1, and will probably average closer to 2-4:1.

Analysis of all the preceding data together with limited data from two other chronically turbid lakes in south central Alaska indicates that large, glacially affected lotic systems will generally exhibit NTU/TSS ratios of approximately 1:4-5, while large, glacially affected lentic systems will generally exhibit NTU/TSS ratios of approximately 2-4:1 (Figure 5.14).

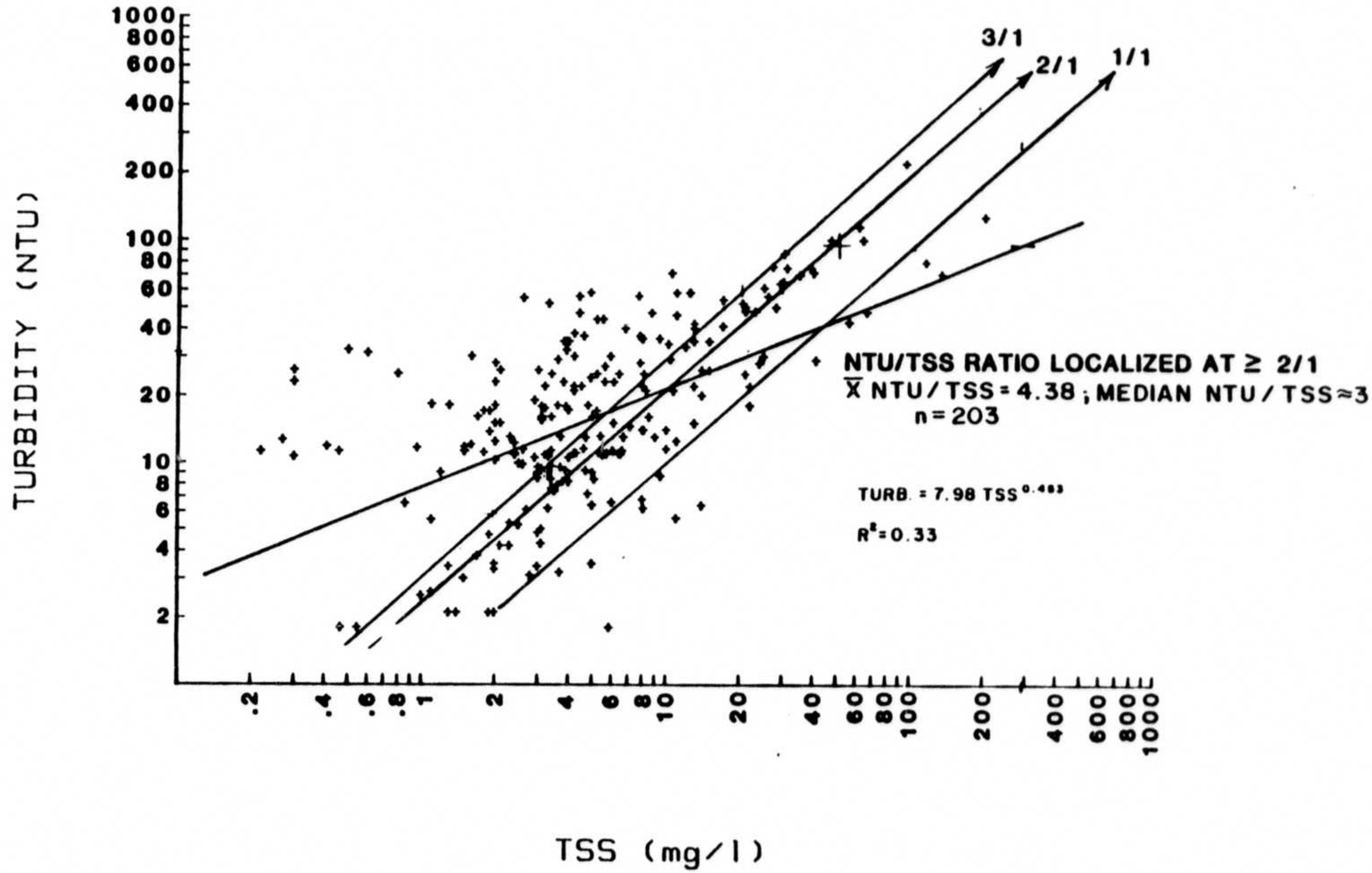


FIGURE 5.12

PREPARED BY: R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS	EKLUTNA LAKE DATA: TURBIDITY VS. TOTAL SUSPENDED SOLIDS	PREPARED FOR: HARZA-EBASCO SUSITNA JOINT VENTURE

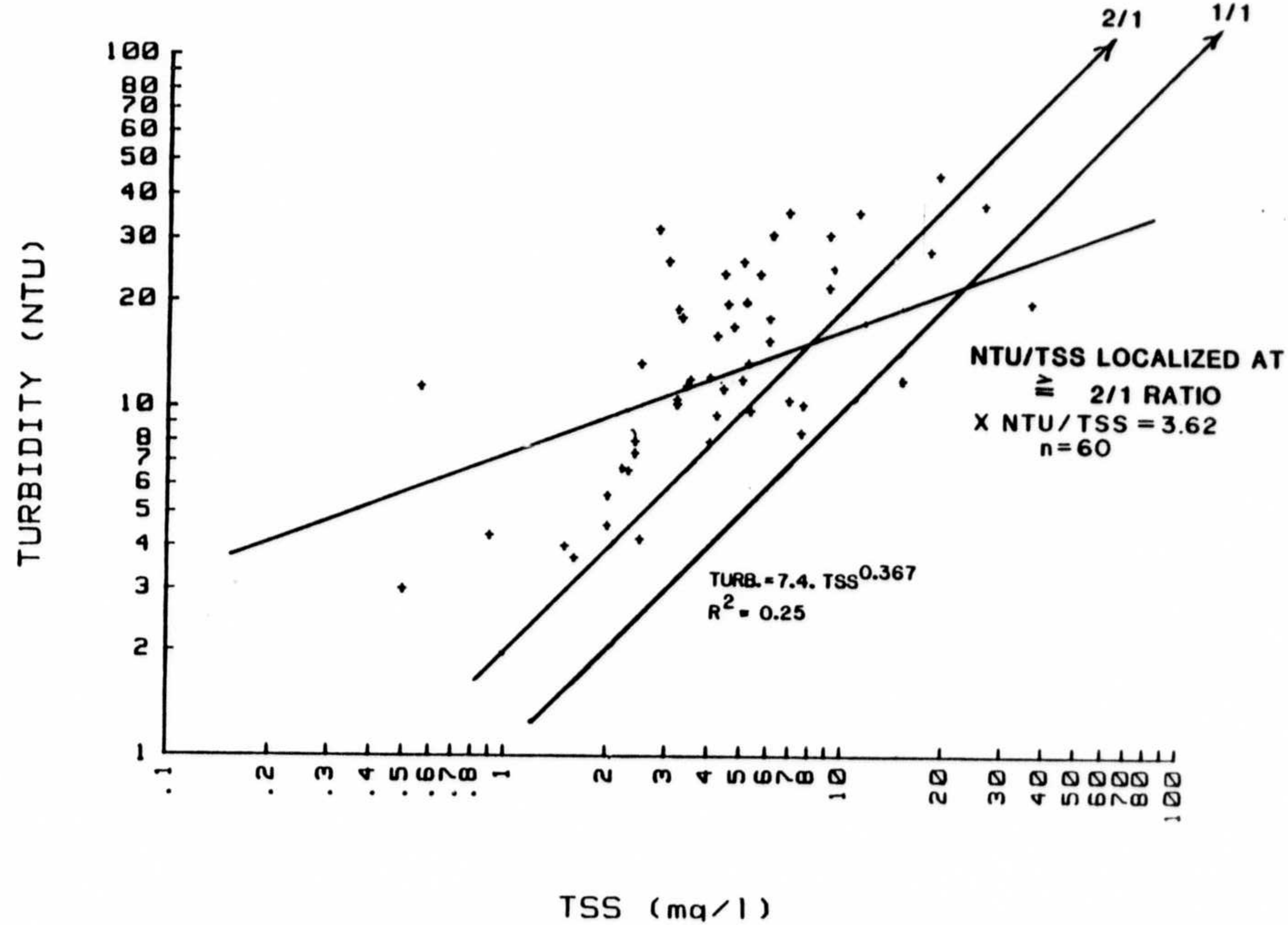
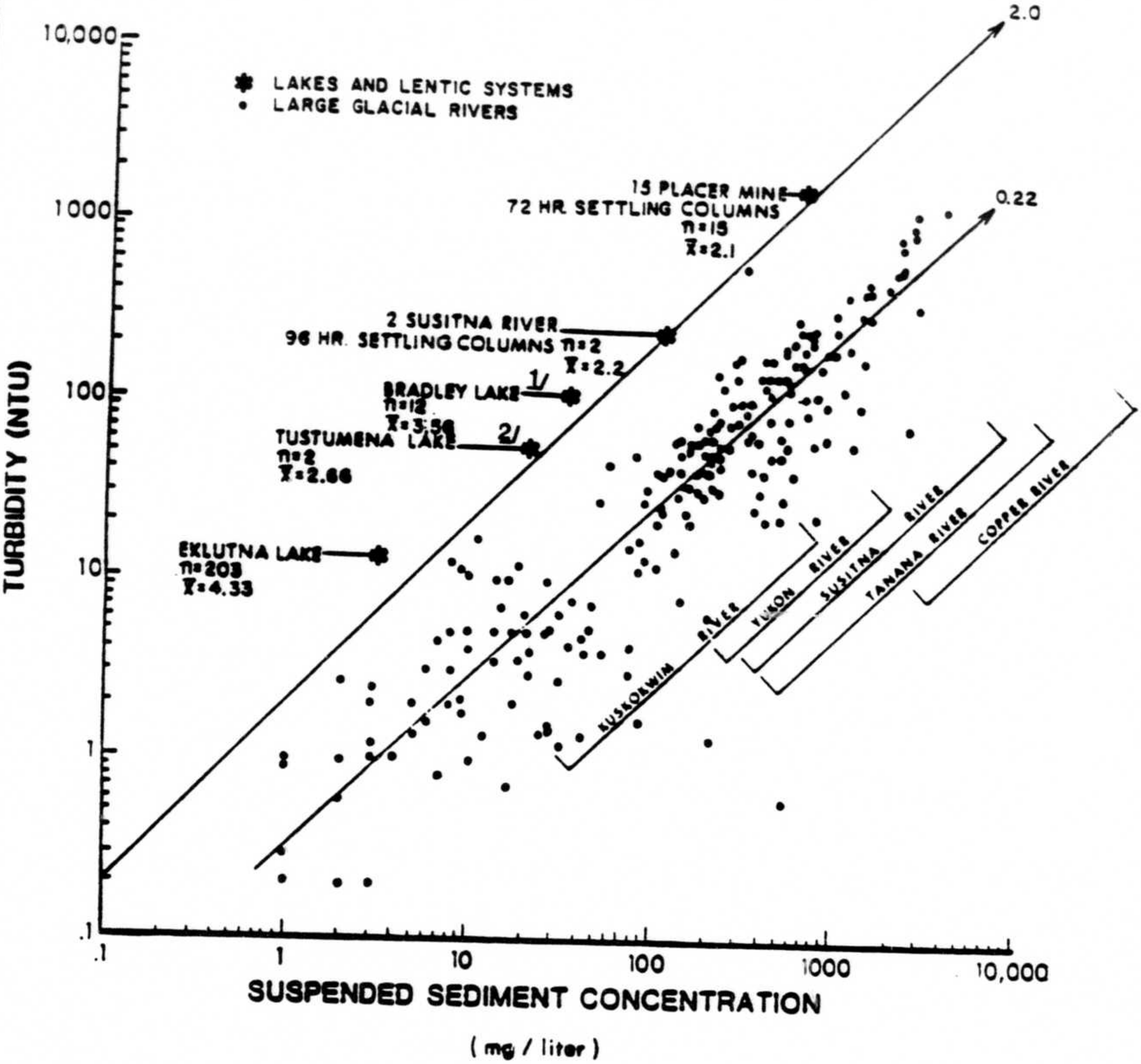


FIGURE 5.13

PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

1984 TAILRACE DATA:
TURBIDITY
VS.
TOTAL SUSPENDED SOLIDS

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE



EMPIRICAL RELATIONSHIPS OF TURBIDITY VERSUS SUSPENDED SEDIMENT CONCENTRATION FOR RIVERS AND LAKES IN ALASKA (MODIFIED AFTER LLOYD 1985)

1/ Ott Water Engineers, Inc. 1981

2/ Scott, K. M. 1982, and Koenings, J. 1983

FIGURE 5.14

5.3 THE DYRESM MODEL AND ITS USE FOR ESTIMATING THE WITH-PROJECT SEDIMENT REGIME CHANGE

Predictions of reservoir thermal stratification, ice cover and outflow thermal and hydraulic characteristics have been made using a numerical model developed by Imberger, et al. (1978). Vertical distribution and outflow concentrations of suspended sediment have also been estimated for both Watana and Devil Canyon reservoirs using modifications of DYRESM subroutines. The following summary provides a concise, simplified description of how the model operates, including a brief description of model calibration using data from Eklutna Lake.

In the formulation of the modeling strategy of DYRESM, the principle physical processes responsible for the mixing of heat and other water quality components have been parameterized. This contrasts with other simulation models which are largely empirically based. The modeling philosophy employed in DYRESM requires a reasonable understanding of the key processes controlling water quality, so that they may be parameterized correctly. This process related approach to modeling has the advantage that the resulting model may require less calibration and is more generally applicable than the empirically based methods. A second consideration in model formulation has been to keep the computational costs as low as possible in order to keep running costs within reason. This allows for a greater number simulation runs to test the sensitivity of outflow characteristic predictions to major variables, such as intake operating policy and environmental flow requirements, than if more time consuming models were used. This has necessitated the restriction of spatial variability to one dimension (in the vertical) and the adoption of a fundamental time increment of one day. Certain physical processes require time steps shorter than one day. In this case the model allows for subdaily time intervals as small as one quarter hour.

The following discussion demonstrates that the principle processes responsible for reservoir mixing may be adequately parameterized and satisfactorily represented within a one-dimensional framework.

First the reservoir or lake in question is subdivided into a series of horizontal slabs of varying thickness, volumes and cross-sectional areas in accordance with the prescribed reservoir geometry. The number of layers is allowed to vary as required to represent the vertical distribution of heat and salt to within a specified accuracy. The uppermost layer may be thought of as corresponding to the lake's surface layer or epilimnion with its base being located at the thermocline depth and its top at the lake surface. This layer is the most important as it receives the direct input of atmospheric forcing and is usually associated with the largest gradients in water quality properties. As discussed later this layer receives special attention in the model compared to other layers. Within each layer the variables are considered to be uniform. Heat in the form of solar radiation is input to each layer according to the physics of absorption of short wave radiation (Beer's Law).

The transfer of heat between all the layers (other than the upper two layers) is determined by the vertical turbulent fluxes as specified by the turbulent eddy diffusivity and the differences in properties between the layers. The value of the vertical diffusivity is not set empirically but follows the energy arguments of Ozmidov. In this way the vertical mixing process responds to changes in the level of energy available for mixing caused by storms (wind stirring) and also by the potential energy released from inflowing rivers. In addition, this internal mixing formulation includes the inhibiting effect of local stratification rates on the mixing process.

Experience has shown that it is necessary to consider the individual processes controlling the mixing in the uppermost layer, known as the upper mixed layer, in a more detailed manner than in the deeper layers. These processes are wind stirring, convective cooling, the shear across the base of the mixed layer, the stabilizing effects of the absorption of short wave radiation and the density gradient at the base of the layer. The method involves the consideration of three conservation equations within the layer, the conservation of heat, salt and turbulent kinetic energy. Solution of these equations provides an estimate of the energy available for mixing the upper layer with lower layers. One unique feature of this upper mixed layer formulation is that it allows for the influence of strong internal motions known as seiches, on the mixing and deepening of the upper layer to be taken into account.

A brief explanation of wind generation of these internal motions or seiches provides an example of how a two and three-dimensional process occurring in a reservoir is treated within the context of a one-dimensional model. When the wind starts to blow along the longitudinal axis of the lake that is initially at rest, the shearing motion at the base of the upper layer is considered to grow at a constant rate until either the wind ceases or reverses in direction, a period of time equal to one quarter the period of the natural seiche has elasped, or the earth undergoes a period of revolution on its axis. When any one of these limits is attained the shear is set to zero and the build-up of internal motion recommences. Not only does the shear influence the deepening of the thermocline or the upper layer thickness but also the shear may destabilize the stratification. In this latter case the temperature profile is then smoothed to the point where it remains stable with respect to shearing motion of the wind forced seiche.

Another two-dimensional process is the river inflow dynamics. If the river water is lighter than the uppermost layer of the lake it forms a new upper layer over the old one which may ultimately be amalgamated into the former upper layer. Conversely, for an underflowing river an entrainment coefficient for the incorporation of the surrounding lake water into the descending river plume is computed from the river discharge, the density constrast between lake and river water, the slope of the bottom and the geometry of the river bed. The volumes of the layers are then decremented according to the computed daily entrainment volumes at the same time as the inflowing river water is diluted by lake water until it either reaches the deepest layer or the dam. Another possibility is that the density of the plunging river plume may be reduced to that of the adjacent layer density whereupon the inflow begins to intrude into the main body of reservoir. Whether this intrusion process is dominated by viscous-buoyancy forces or by an inertia-buoyancy balance is determined by the computation of a non-dimensional parameter depending on the discharge, the local density gradient and the mixing strength at the level of insertion. This parameter then sets the overall thickness of the inflow and therefore how the inflowing volume is subdivided among the existing layers surrounding the inflowing depth.

Similarly, outflows at a surface level and up to two subsurface levels are governed by the same parameter which determines the amounts to be withdrawn for each of the layers in the vicinity of the outflow points. To illustrate how this may work in practice, it is useful to consider two extreme cases. In one case the outflow volume is large relative to the stabilizing effect of the ambient stratification (inertia-buoyancy balance) and the outflow is withdrawn nearly uniformly from all the layers. In the second case, when a weak outflow obtains a viscous-buoyancy balance, the density gradient severely confines the vertical range of outflow layers to those in the immediate vicinity of the offtake.

The model has been extended to include the influence of ice and snow cover, and suspended ice concentration in the inflowing rivers. The conduction of heat and the penetration of solar radiation across a composite of two layers, one composed of snow and the other of ice, is computed from their physical properties, namely, thermal conductivities, extinction coefficients for solar radiation and densities, and from the energy transfers at the surface with the atmosphere. Components of the surface energy budget, as in the case of an ice-free surface, are the incoming and outgoing longwave radiation, solar radiation, the sensible heat transfer and latent heat exchanges. Several cases may be distinguished. If more heat flows upward through the ice than can be supplied by the turbulent and molecular transfers of heat from the water to the ice, ice is created and added to the existing ice cover. Conversely, the ablation of ice at the base of the ice sheet occurs when an excess of heat is present. Similarly the snow or upper surface of the ice as the case may be is melted when sufficient heat is present to elevate the surface temperature above the freezing point.

An additional physical process incorporated in the model with ice cover is an allowance for partial ice cover either during the freeze-up or break-up period. Partial ice cover accounts for the wind action in dispersing thin sheets that might be formed and is based on an assumed minimum ice thickness of 10 cm. Furthermore, the thickness of the snow cover on the ice is limited by the supporting buoyancy force associated with a given thickness and density of ice. Finally the amount of solar radiation transmitted through the snow layer depends on the thickness, age and temperature of the snow cover. Frazil ice input from the inflowing rivers is either used to cool the upper layers if an ice cover is not present or is added to the fraction of partial ice cover or to the thickness of the full ice cover.

A more detailed discussion of DYRESM is provided in Imberger and Patterson (1980).

5.3.1 Testing of DYRESM model (Eklutna Lake Study)

The DYRESM program has been used extensively in Australia and Canada to predict hydrothermal characteristics within lakes and reservoirs. To test DYRESM in predicting the thermal structure in glacially fed reservoirs, a data collection program was established in 1982 to obtain data on the thermal structure of Eklutna Lake located approximately 30 miles (50 km) north of Anchorage, Alaska. A weather station was also established to provide the necessary meteorological input to DYRESM.

Detailed daily simulations were made of Eklutna Lake from June 1 to December 31, 1982 for the 1983 License Application (APA 1983a, b) and from June 1, 1982 to May 31, 1983 for the studies made after submittal of the License Application (Harza-Ebasco 1984g). These established the adequacy of the DYRESM model.

Simulated and measured vertical temperature profiles at a station in the approximate center of the lake were made. In general, most profiles are modeled to within 0.5°C (1°F). This is well within the observed variation of temperature at the data collection stations throughout the lake. Deviation in measured and simulated profiles can be explained through an assessment of the meteorological variables used and the reliability of the measurement of these variables. However, even with errors due to estimating weather data from sources other than that of the station at Eklutna Lake, the temperature profiles are reasonably modeled.

Outflow temperatures from Eklutna Lake for the period June 1982 through May 1983 were compared to simulated values. In general, for the entire simulated period of June 1982 through May 1983, simulated and measured outflow temperatures show excellent agreement. Deviations of up to 2.8°C occur between measured and simulated temperatures in late June and early July, 1982. This is believed to be the combined result of the approximate nature of the initial condition specified at the beginning (June 1, 1982) of the simulation, and, possible underestimation of wind speed.

The simulated vertical temperature profiles in the reservoir indicate reasonable agreement with measured profiles. This indicates that although average meteorological conditions over the entire period were suitably measured, conditions on a daily basis may be in error. Wind speed, in particular, would have the major influence since an overestimation of wind speed would result in deepening of the epilimnion which would result in warmer outflow temperatures in summer.

Field observations in the winter of 1982-1983 and 1983-1984 indicate that the ice cover formation on Eklutna Lake would begin during the latter part of November with a full ice cover formed by mid-December. In the 1982-1983 ice season, DYRESM estimated ice cover formation to begin on December 2, with a full ice cover on December 20. Measurements made on January 11 and 13, 1983 and February 18, 1983 indicate an ice cover thickness of 13 to 18 inches and 21 to 25 inches respectively. This compares favorably with a predicted ice thickness of 16.5 and 21.7 inches respectively.

The study of Eklutna Lake as described above, has demonstrated the ability of the DYRESM model to predict the hydrothermal condition of a glacial lake under Alaskan meteorological and hydrological conditions.

5.3.2 Suspended Sediments

The concentration and distribution of suspended sediment in the project reservoirs and in the downstream river is an important water quality parameter affecting fishery resources. Two other water quality parameters, turbidity and vertical illumination, are related to the concentration and size of suspended material. Additionally, the settling of material in the reservoir may affect the storage capacity and thus, the energy production of the project. Therefore, refined analyses were made using two methods to estimate the concentration, distribution and size of material suspended in the reservoir and its outflows, and to estimate the amount of material which, over time, could settle in the reservoir. The first of these analyses was made by extending the capability of the DYRESM model to include suspended sediment modeling capabilities, testing it with Eklutna Lake data and then applying it to Watana. The second analysis was made using generalized trap efficiency estimates.

In general, when the Susitna River enters the Watana Reservoir, the river velocity will decrease, and the larger diameter suspended sediments will settle and form a delta at the upstream end of the reservoir. The delta formation will adjust to the changing reservoir water level. Some sediment will pass through channels in the delta to be deposited further downstream in the reservoir. Depending on the relative densities of the reservoir water and the river water, the river water containing the finer unsettled suspended sediments will either enter the reservoir as an overflow, interflow, or underflow.

To estimate the maximum amount of sediment deposition in the reservoir affecting storage capacity, generalized trap efficiency envelope curves developed by Brune (1953) were used. These indicated that 90-100 percent of the incoming sediment would be trapped in a reservoir the size of Watana.

The results of the analysis using Brune's curves indicate sediment deposition will not affect the operation of any stage of the Project. A conservative assumption of a 100 percent trap efficiency was used to estimate the amount of time to fill the reservoir with sediment.

The sediment deposited over the short operating period of Watana Stage I would be about 25,000 acre-feet, or less than two percent of the dead storage volume. The result showed the deposition of 410,000 acre-feet of sediment after 100 years (HE 1984a). The 100-year deposit is approximately 22 percent of the Stage I dead storage volume or 10 percent of the total Stage I volume.

Sedimentation studies at glacial lakes indicate that the Brune curve may overestimate sediment deposition and would thus provide a conservatively high estimate of storage lost due to deposition. These studies have shown that the fine glacial sediment (flour) may pass through the reservoir. Some lakes immediately below glaciers have been reported to have trap efficiencies of 35-80 percent (Ostrem, et al. 1969; Andersson, et al. 1970; Ostrem, et al. 1970; Ostrem 1975; Kjeldsen and Ostrem 1975). Hydroelectric reservoirs on three large rivers in Sweden exhibited sediment trap efficiencies of 50-66 percent (Nilsson 1976). Kamloops Lake, British

Columbia, a deep glacial lake on the Thompson River, retains an estimated 66 percent of the incoming sediment (Pharo and Carmack 1979). Kluane lake, Yukon Territory, a deep glacial lake on the Slims River, apparently retains an estimated 90 to 100 percent of its suspended sediment inflow (Bryan 1974a, 1974b, 1974c, Fahnesstock 1974, Barnett 1974).

All studies examined have shown that particle sizes of sediments leaving glacial lakes are smaller than those entering (R & M Consultants, Inc. 1982d, 1985; Ostrem, et al. 1969; Andersson, et al. 1970; Ostrem, et al. 1970; Ostrem 1975; Kjeldsen and Ostrem 1975). The same studies indicate that quartz, and orthoclase and plagioclase feldspars dominate the mineralogy of glacial lake inflow sediments, while mica, chlorite, and amphibole show increasing percent compostion in glacial lake effluents. Studies of Eklutna Lake effluents and Susitna River samples analyzed after settling column experiments indicate that colloidal silica, calcite, magnetite, clays and small, platy shaped quartz and feldspar particles may be more prominant in the effluents from the project reservoirs than they are in the influents (R & M Consultants, Inc. 1982d, 1984b, 1985).

Because the Brune curves may overestimate suspended sediment settling in the reservoir the DYRESM model was extended. The extended model includes the simulation of suspended sediment in the reservoir in order to refine the estimates of suspended sediment concentration and turbidity. This version of the DYRESM model was tested using suspended sediment data collected at the Eklutna Lake (R & M 1985) from November 1983 to October 1984. Good agreements on outflow suspended sediment concentration were obtained. The following sections described the model, the testing on Eklutna Lake and the application to Watana and Devil Canyon Reservoirs.

5.3.3 DYRESM Model

The ice-covered version of the dynamic water quality simulation model, DYRESM, was extended to include the modeling of horizontally averaged profiles of suspended sediment. A number of key processes are modeled as follows:

- meteorological forcing,
- turbulent mixing,
- suspended sediment induced vertical mixing, and
- winter ice cover and reduced vertical mixing.

The model uses daily time steps and vertical settling velocities are specified externally. As with temperature and total dissolved solids, a suspended sediment profile is prescribed initially from field data or from estimation. The daily inflow values of suspended sediment concentration are also input. The distribution of suspended sediment in the reservoir is changed by three processes; by mixing, by convective overturn, and by settling. The convective adjustment considers the density distribution in the reservoir, including the contribution to water density of the suspended sediment. A check is made for density inversion, and unstable layers are mixed.

A method was developed to handle the changes in suspended sediment concentration due to settling of the suspended sediment. In pre-determined time intervals, the vertical distance a sediment particle sinks at a prescribed velocity is compared to the minimum simulated layer thickness, then the subdaily time step is divided by a factor of two until the distance the particle sinks in the time step is less than the thickness of the layer it has entered. In each subdaily time step, the suspended sediment entering and leaving each layer is computed and added or removed from the layer. The portion of this sediment which falls into the layer below is added to that layer.

5.3.4 Eklutna Lake Modeling

To test this version of the DYRESM model for its applicability to predict suspended sediment concentrations in the project reservoirs, the updated model was applied to Eklutna Lake, near Anchorage, a glacial lake hydraulically, climatologically and morphologically similar to the reservoirs. Watana and Eklutna lakes have similar average percentages of their drainage areas covered by glaciers, similar average residence times, similar climatological conditions, and are operated or to be operated for hydroelectric power production. The hydrological and meteorological data collection program at Eklutna was continued with emphasis on suspended sediment sampling from May to November 1984.

Measured suspended sediment concentrations ranged from 0.15 to 570 mg/l in the inflow streams, form 0.1 to 200 mg/l in the lake, and from 0.56 to 36 mg/l in the outflow. Peak values in the inflow occurred in late July or early August, in the lake in about September, and in the outflow in late July to mid-August. During the winter, inflow, lake and outflow suspended sediment concentrations were on the order of 1-10 mg/l. During the summer, the average suspended sediment concentrations were substantially higher than winter values and were increased further following large rainfall events or periods of significant glacial melt. Turbidity values generally followed the trends in the suspended sediment concentration, dropping off in the winter at inflow, lake, and outflow sites and peaking in mid-to-late summer. Values observed ranged from 0.5 to 580 NTU in the inflow streams, from 1.8 to 220 NTU in the lake, and from 3.0 to 46 NTU in the outflow.

The determinations of total incoming suspended sediments to the lake were based on the total suspended sediments measured for Glacier Fork and East Fork tributaries. To simulate the suspended sediment profile in the lake, the suspended sediments were divided into three particle size groups: 0-3 microns, 3-10 microns and greater than 10 microns. Test runs indicated that particles greater than 10 microns would settle rapidly to the bottom of the lake and contribute little to the suspended sediment profiles. Therefore they were not considered further in the study.

The estimates of the total incoming suspended sediments of each group were based on the weighted particle size distributions. These distributions were determined from samples taken from East Fork and Glacier Fork obtained during field trips made on July 20, August 28, and October 23, 1984. The daily particle size distributions were interpolated from these three basic distributions.

Application of the extended DYRESM model requires the specification of an initial distribution of settling velocity and the density of the sediment. In the study, the settling velocity of a particle size range was determined in accordance with Stoke's Law. A settling velocity of 1.53x10-6th meter per second was used for the 0-3 micron sediments and 2.00x10-5th meter per second for the 3-10 micron sediments. A particle density of 2.60 was used in the study, to represent the measured density of from 2.50 to 3.00.

The DYRESM simulations for the 0-3 micron sediments and 3-10 micron sediments were made separately. The resulting outflow suspended sediments of these two studies were then combined to indicate the total outflow suspended sediment concentrations.

The predicted Eklutna outflow suspended sediment concentrations agree with data obtained from the powerhouse tailrace, and the model is therefore considered applicable to the Susitna Project reservoirs. On two occasions, the field data show temporary increases in tailrace suspended sediment concentrations not predicted by the DYRESM model. The temporary deviations are probably due to locally strong winds near the powerhouse intake, and, hence, more concentrated wind energy available for mixing the water and sediments near the intake. It is not possible to account for these temporary local fluctuations in the model since the weather stations is located on the opposite end of the lake and can not register such local variation in winds.

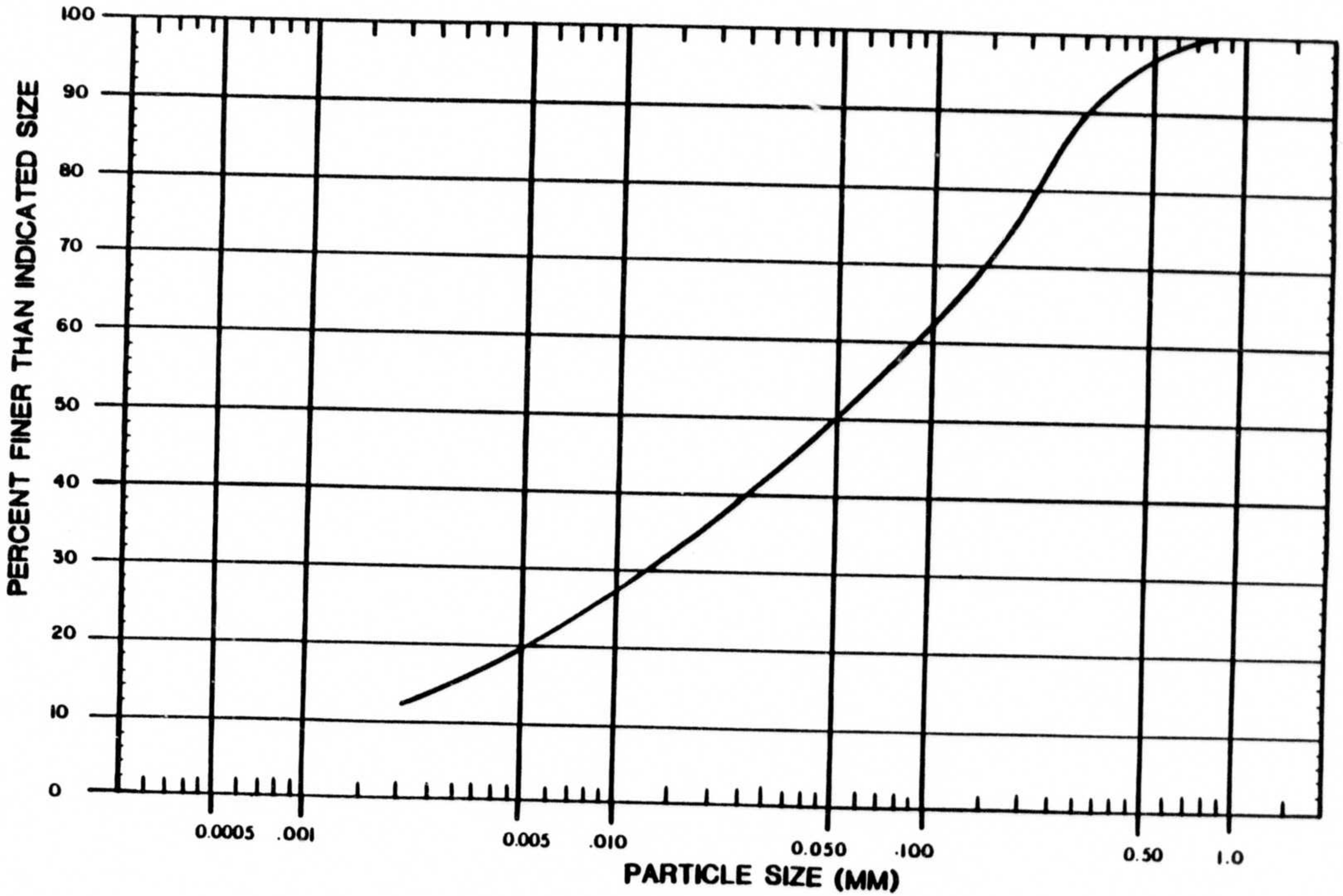
An additional reason for these deviations may be short-term fluctuations in incoming sediment concentrations or size distributions as a result of meteorological or hydrological events. These short-term fluctuations would not be accounted for by sampling the inflow at monthly intervals.

5.3.5 Susitna Reservoir Modeling

The extended DYRESM model was applied to simulate the suspended sediments in the Project reservoirs and in the project outflows. Case E-VI flow requirements and 1970 and 1981-82 meteorological conditions were considered. Data on the suspended sediment concentration and size in the Susitna River are available at Cantwell and Gold Creek. The particle size distribution of the suspended sediments at Cantwell is shown on Figure 5.15.

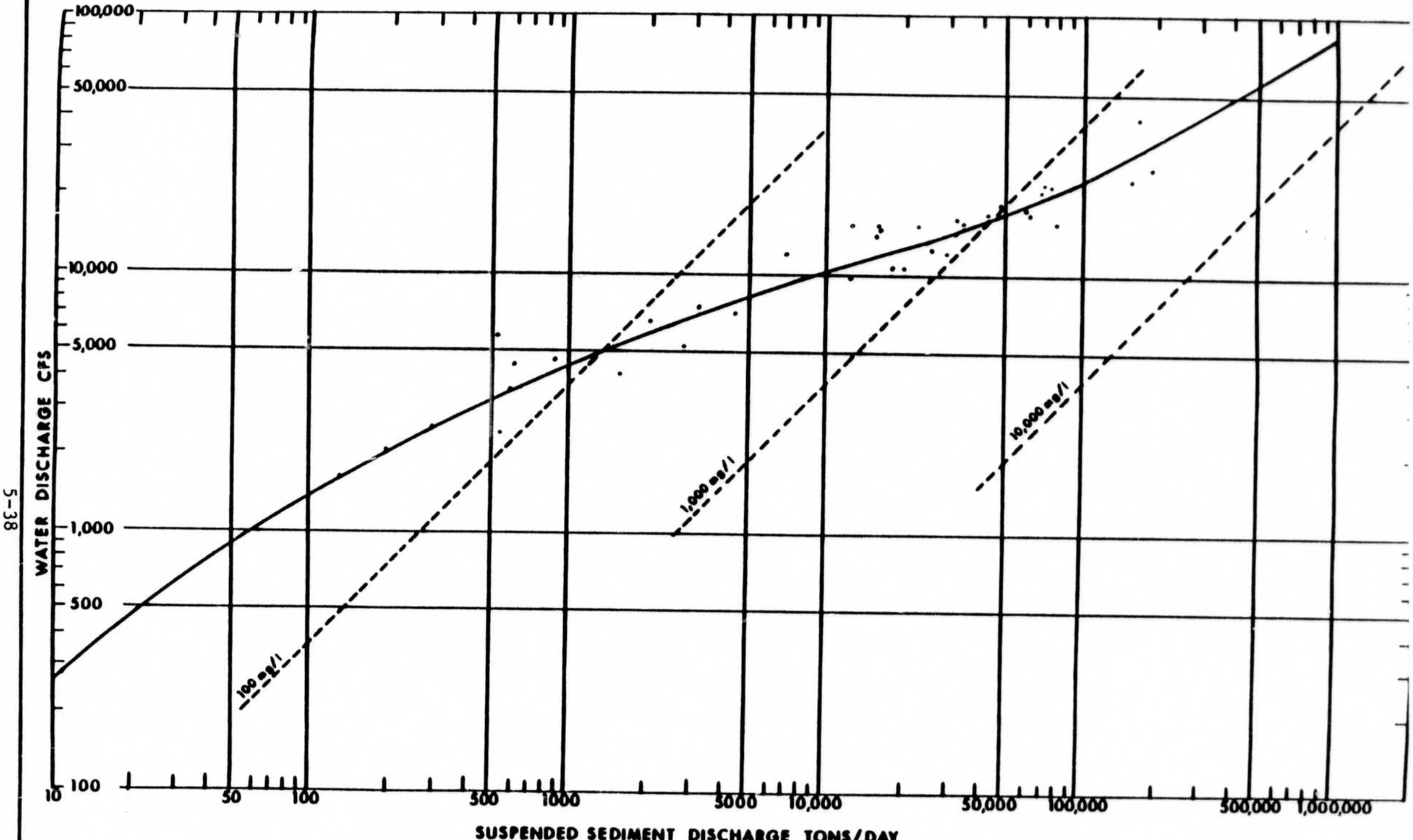
Based on the Eklutna Lake study, the suspended sediment in the Watana Stage I Reservoir outflow is expected to be comprised primarily of particles of 3-4 microns or less. Larger particles will generally settle out rapidly without significantly affecting the average suspended sediment levels in the reservoir and outflow. Therefore, settling of sediments of up to 10 microns has been studied. The incoming suspended sediments of up to 10 microns were divided into two particle size ranges and an average settling velocity was assigned to represent each size range. The 0-3 and 3-10 micron particles were represented by an average settling velocity of 1.5×10^{-6} m/sec and 2.0×10^{-5} m/sec respectively.

The total amount of sediment influent to the reservoir was estimated form the USGS observations at the gaging station near the upstream end of the reservoir. Figure 5.16 shows the estimated relationship between discharge and sediment load at the USGS gaging station on the Susitna River near Cantwell. Based on this relationship the total amounts of sediment influent to the reservoir for 1970, 1981 and 1982, representing years of near minimum, maximum and average sediment inflow to the project were computed to be 4,200,000, 8,500,000 and 5,600,000 tons, respectively. Additional sediment load for the drainage area between the gage and the damsite was computed based on the drainage area ratio. The amount of sediment influent of each particle size range was determine from the suspended sediment particle size distribution curve of samples taken near Cantwell as shown in Figure 5.15. Fifteen percent of the total sediment influent was assigned to the 3-10 micron range and 12 percent to the 3-10 micron range.



SUSPENDED SEDIMENT SIZE DISTRIBUTION
SUSITNA RIVER NEAR CANTWELL

FIGURE 5.15



SUSPENDED SEDIMENT RATING CURVE
AT USGS GAGING STATION
SUSITNA RIVER NEAR CANTWELL, ALASKA

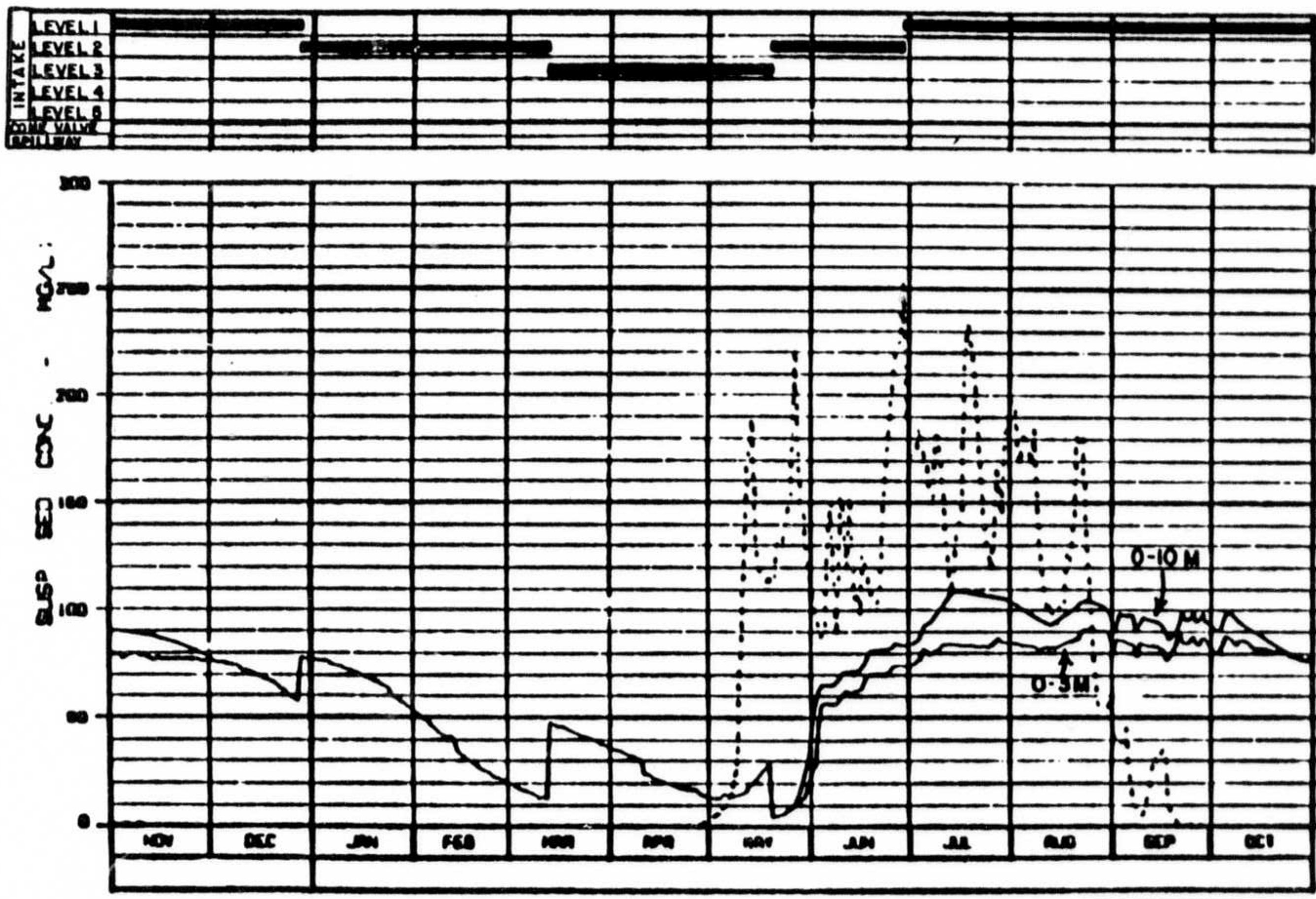
FIGURE 5.16

The suspended sediment concentrations in the reservoir and the outflows were simulated for the 1970, 1981, 1982 flow conditions with Case E-VI downstream flow requirements and 2001 energy demand. The outflow suspended sediment concentrations for these cases are shown in Figures 5.17, 5.18, and 5.19 respectively. These results show that 3 to 10 micron particles will generally settle out in the reservoir. The results also indicate that the outflow suspended sediment concentration and, hence, the turbidity level, would be more uniform throughout the entire year than for natural conditions. The outflow suspended sediment concentration in the "average" year would reach its lowest level of about 10 to 20 mg/l in early May and increase its level toward a maximum of about 150 mg/l in July or August, while the mainstem river sediment inflow may vary from about 2-180 mg/l in October to April to as much as 200 to 2,200 mg/l in July to September.

During the winter months, because of the relatively long reservoir residence time, a large portion of the 0-3 micron sediments will remain in suspension for a relatively long period of time and continue to affect the suspended sediment level of the reservoir outflow. As shown in Figure 5.19, the outflow suspended sediment concentration would approach some what of an equilibrium level of about 100 mg/l near the end of October, and then gradually decrease toward a minimum of about 10 to 20 mg/l in early May.

In summary, the downstream suspended sediment condition near the project site will be affected by the operation of Watana Stage I Reservoir. The summer suspended sediment level will be decreased from about 60-3000 mg/l to about 60-150 mg/l and, in the winter, the suspended sediment level will be increased from about 1-8 mg/l to about 20 to 100 mg/l.

Modeling techniques similar to those used for Watana Stage I have been used to estimate outflow sediment concentrations for Watana and Devil Canyon Stage II, using average year sediment inflow conditions and Case E-VI flows with 2002 Energy Demands (Figures 5.20 and 5.21). Using late Stage III energy demands, average year sediment inflows and Case E-VI flows, estimates



LEGEND:

——— PREDICTED OUTFLOW SUSP. SED. CONCENTRATION (MG/L)

- - - - - INFLOW SUSP. SED. CONCENTRATION (MG/L) (0-3 MICRONS ONLY)

NOTES:

1. SSC INFLOW VALUES REPRESENT THE 0-3 MICRON RANGE AND ARE 15% OF TSS

FIGURE 5.17

ALASKA POWER AUTHORITY
SUSITNA PROJECT
WATANA RESERVOIR OUTFLOW (0-10) SUSPENDED SOLIDS LOW INFLOW YEAR
HARZA-EBASCO JOINT VENTURE

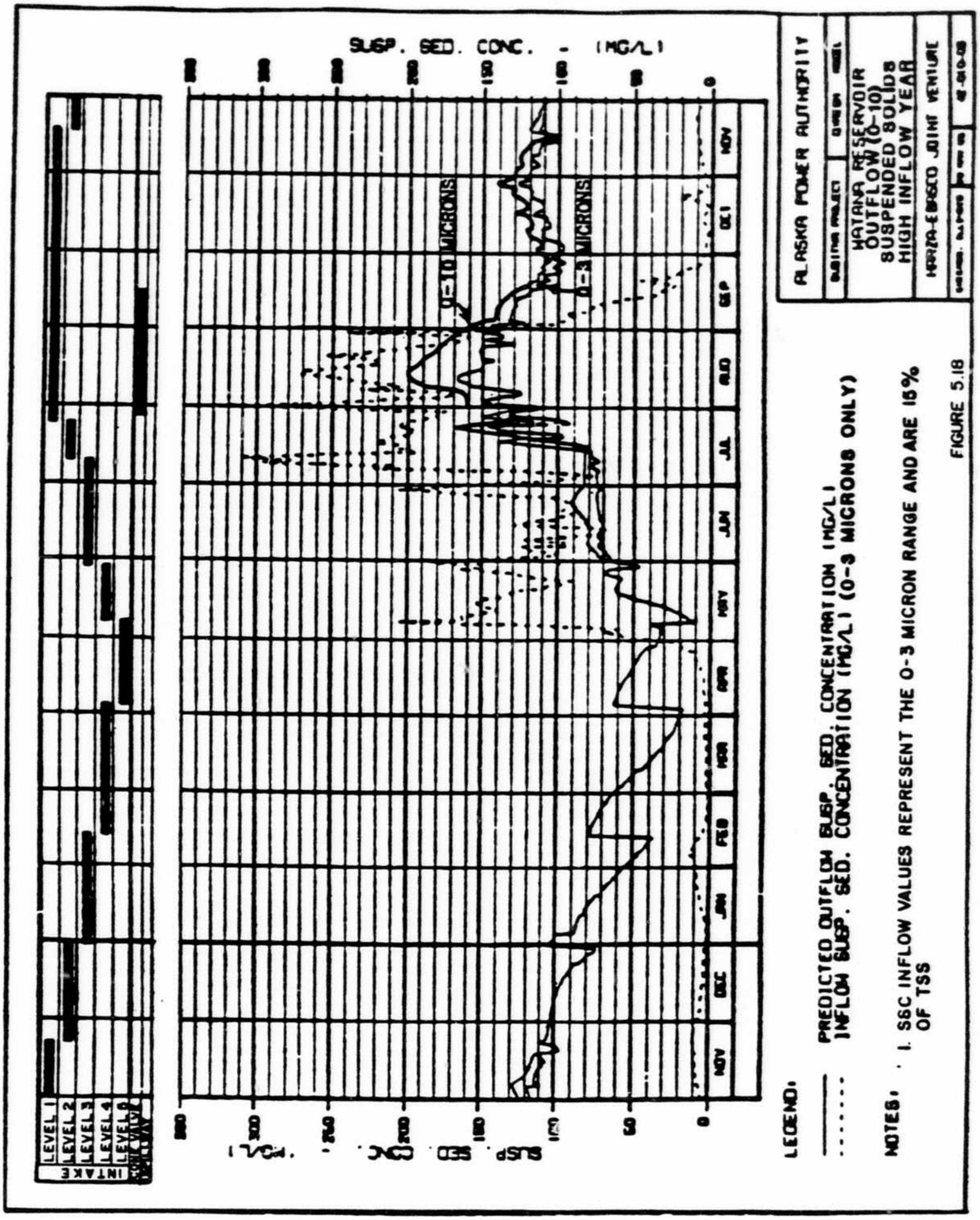
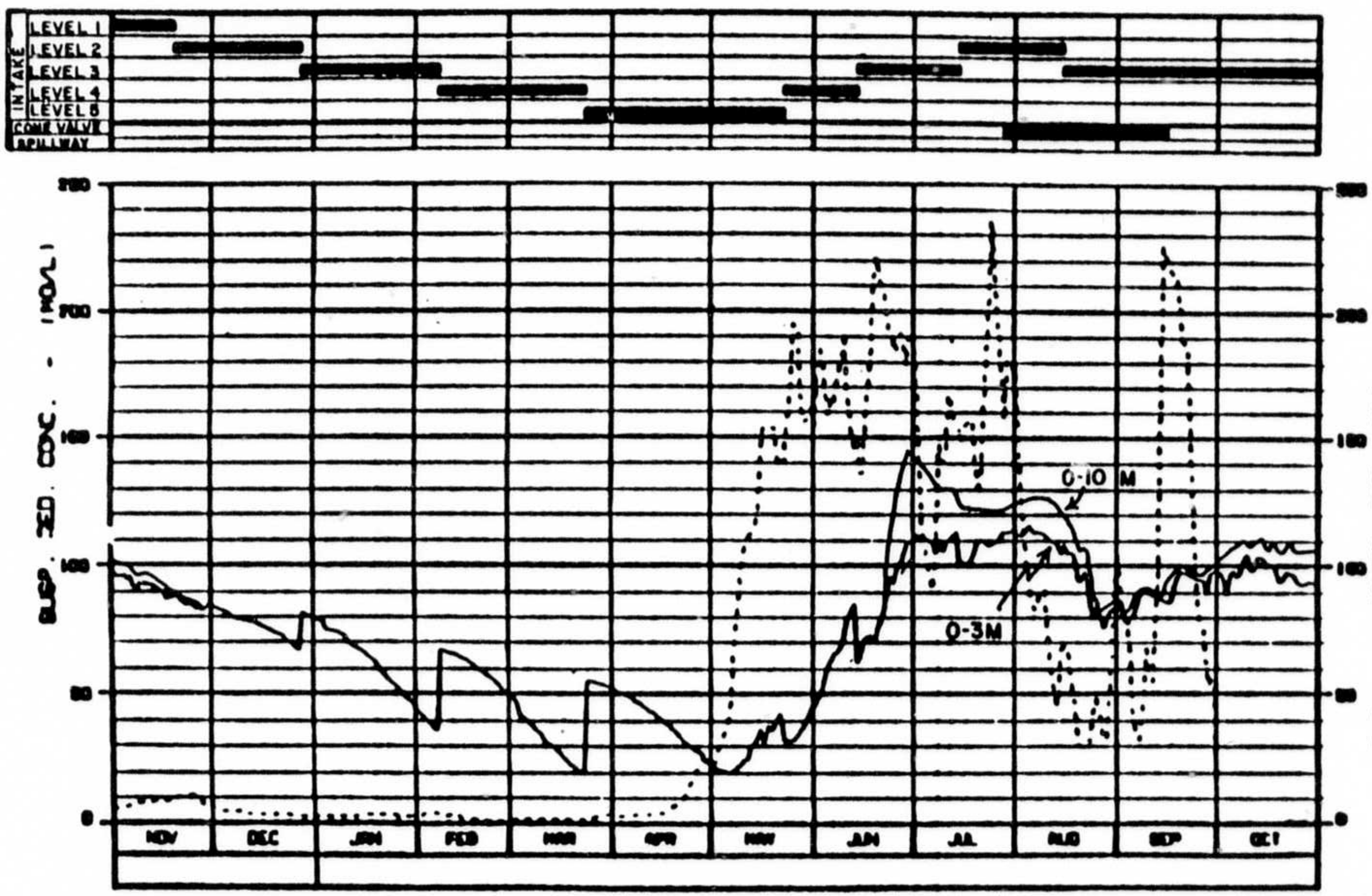

SUSP. SED. CONC. - (MG/L)
0
50
100
150
200
250
300
350
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
0-10 MICRONS
0-3 MICRONS
INTAKE
LEVEL 1
LEVEL 2
LEVEL 3
LEVEL 4
LEVEL 5
CONE VALVE
LEGEND:
PREDICTED OUTFLOW SUSP. SED. CONCENTRATION (MG/L)
INFLOW SUSP. SED. CONCENTRATION (MG/L) (0-3 MICRONS ONLY)
NOTES:
1. SSC INFLOW VALUES REPRESENT THE 0-3 MICRON RANGE AND ARE 15% OF TSS
ALASKA POWER AUTHORITY
SUSITNA PROJECT
WATANA RESERVOIR
OUTFLOW (0-10)
SUSPENDED SOLIDS
HIGH INFLOW YEAR
HARZA-EBASCO JOINT VENTURE

FIGURE 5.18



LEGEND:

——— PREDICTED OUTFLOW SUSP. SED. CONCENTRATION (MG/L)

- - - - INFLOW SUSP. SED. CONCENTRATION (MG/L) (0-3 MICRONS)

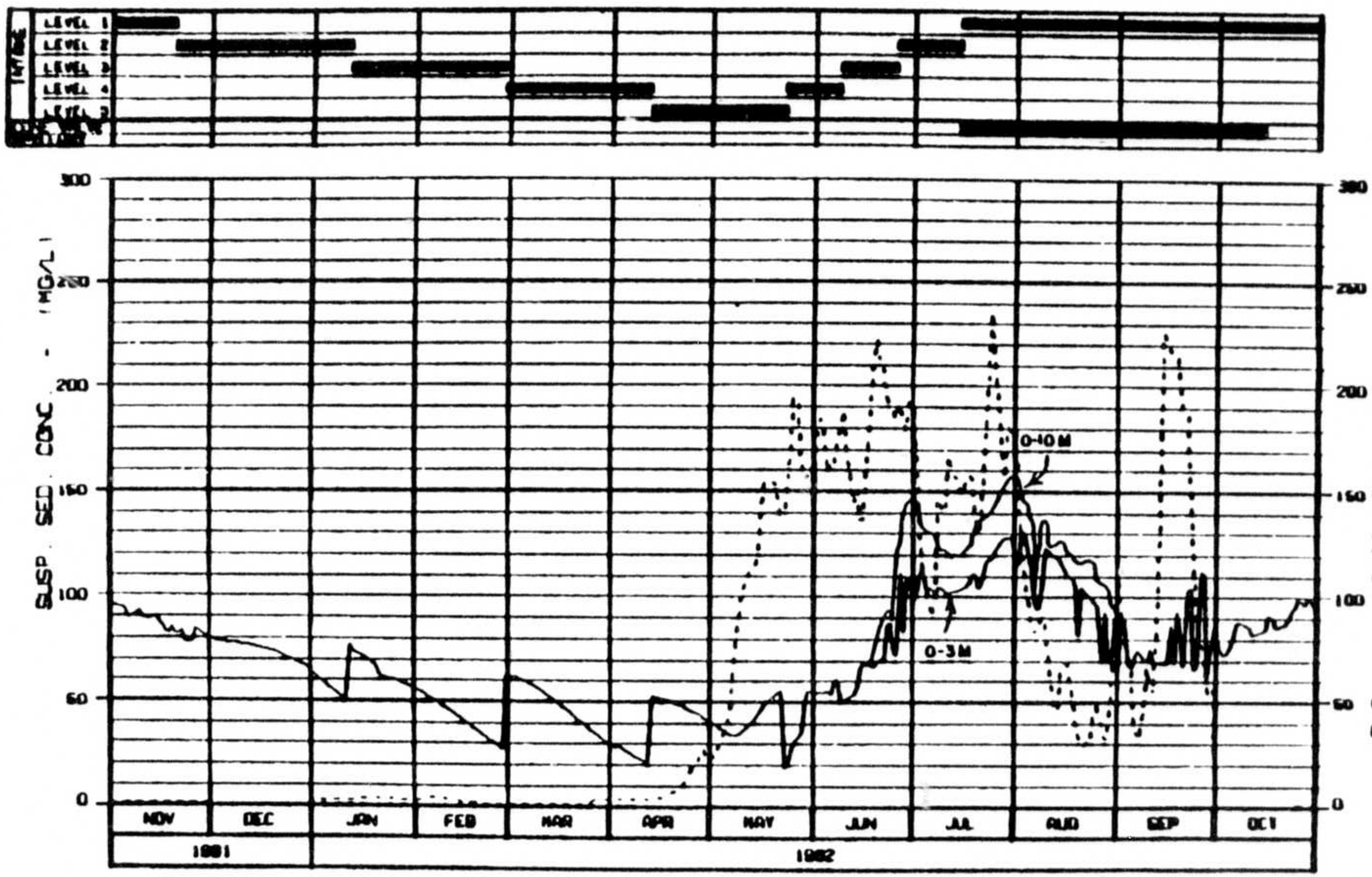
NOTES: 1. SSC INFLOW VALUES REPRESENT THE 0-3 MICRON RANGE AND ARE 15% OF TSS

FIGURE 5.19

ALASKA POWER AUTHORITY

WATANA RESERVOIR OUTFLOW (0-10 MICRONS) SUSPENDED SOLIDS AVERAGE INFLOW YEAR

HARZA-EBASCO JOINT VENTURE



LEGEND:

——— PREDICTED OUTFLOW SUSP. SED. CONCENTRATION (MG/L)

- - - - INFLOW SUSP. SED. CONCENTRATION (MG/L) (0-3 MICRONS ONLY)

NOTES:

1. SSC INFLOW VALUES REPRESENT THE 0-3 MICRON RANGE AND ARE 15% OF TSS

ALASKA POWER AUTHORITY

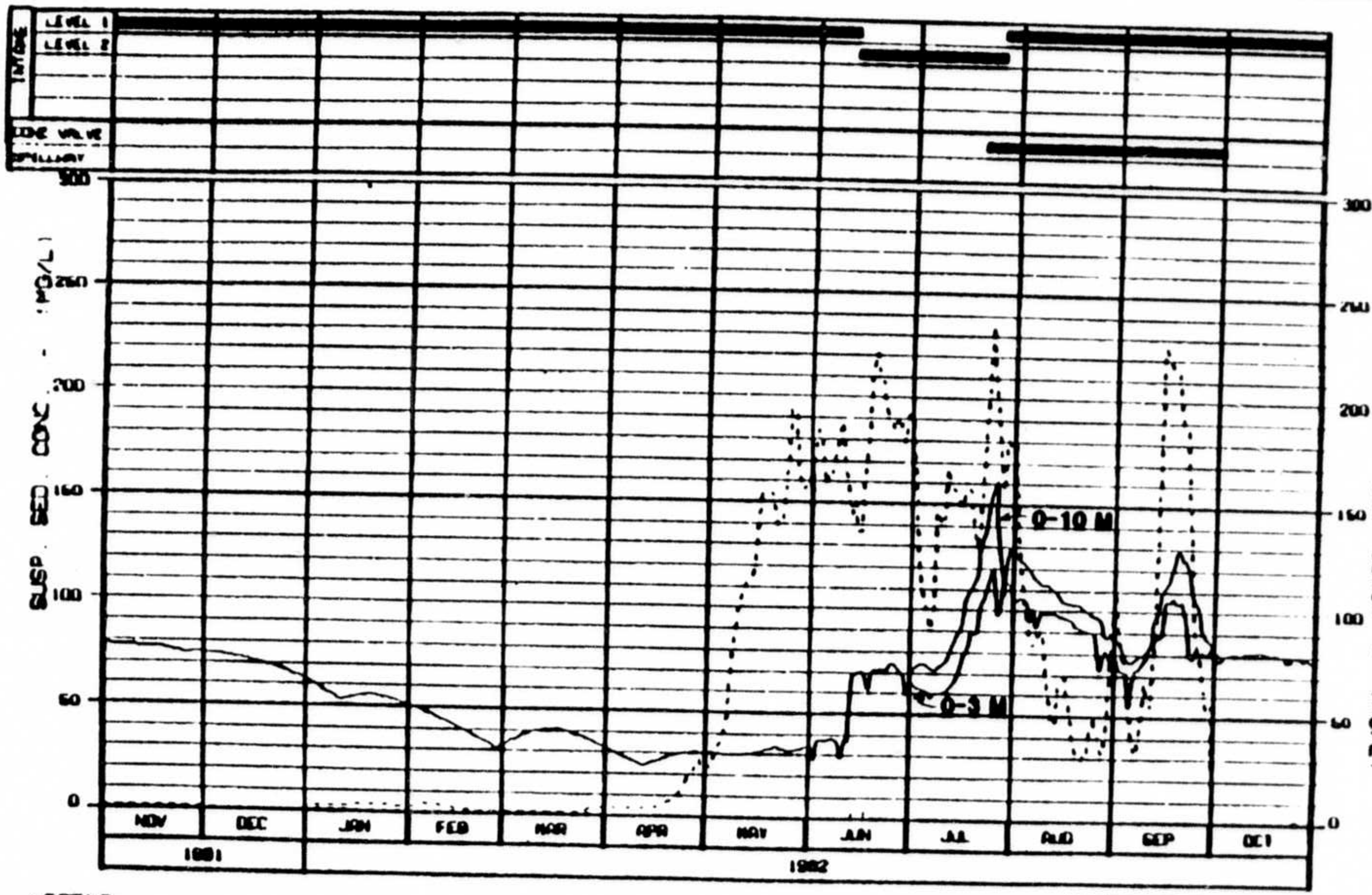
SUSITNA PROJECT | ORIGIN NODE.

WATANA RESERVOIR
OUTFLOW SUSPENDED SOLIDS
STAGE II AVERAGE YEAR

HARZA-EBASCO JOINT VENTURE

CHICAGO, ILLINOIS | 10 JAN 85 | 42-010-05

FIGURE 5.20



LEGEND:

——— PREDICTED OUTFLOW SUSP. SED. CONCENTRATION (MG/L)

- - - - INFLOW SUSP. SED. CONCENTRATION AT WATANA (MG/L)(0-3 M)

NOTES:

1. SSC INFLOW VALUES REPRESENT THE 0-3 MICRON RANGE AND ARE 15% OF TSS.

ALASKA POWER AUTHORITY	
SUSITNA PROJECT	DYRESM MODEL
DEVIL CANYON OUTFLOW (0-10) SUSPENDED SOLIDS STAGE II AVERAGE YEAR	
HARZA-EBASCO JOINT VENTURE	

FIGURE 5.21

of sediment discharges from Devil Canyon and Watana Reservoirs have been modeled (Figure 5.22 and 5.23).

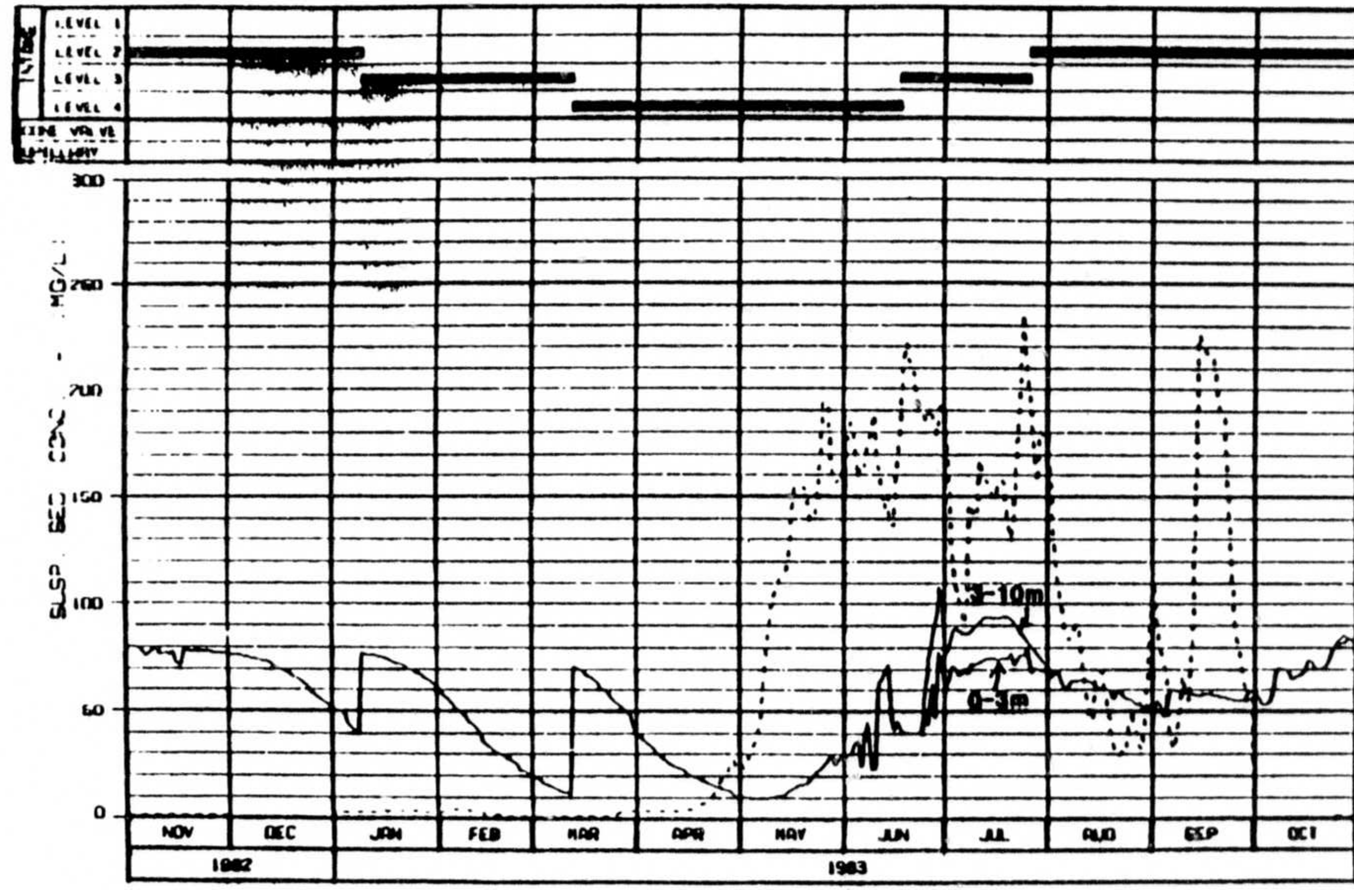
Graphically displayed and tabularized results indicate that the average monthly sediment concentration estimated to exist in the project discharges will be decreased during each successive project stage (Figure 5.24, and Tables 5.4, 5.5, 5.6). The results also indicate the expected decrease in sediment concentrations during summer, and expected increase in sediment concentrations in winter. Winter increases in sediment concentrations may exceed the applicable state water quality standard (A.A.C. 1984).

5.3.6 Other sources of Sediment

Shoreline erosion will occur as a result of two geologic processes: beaching and mass movement. Through mass movement processes, an undetermined amount of material will be introduced into the reservoir as a consequence of skin and bimodal flows, and shallow rotational and block slides. As a result of the slope instability along the shoreline, an indeterminate amount of material will be come suspended in the reservoir.

The Watana Stage I Reservoir normal pool level of el. 2,000 is generally within the confines of the river valley. As a result, the overburden thickness along the shoreline which could be exposed to sliding would be less than during Stage III. Additionally, the reservoir shoreline length is less than during Stage III and would also contribute to a smaller amount of slides.

It is not possible to accurately estimate the amount of material which will become unstable or suspended in the reservoir nor the amount which will pass through the reservoir and contribute to suspended sediment in the river. The shoreline deposits are primarily glacial till comprised of sitly-sands (SM) but including some sandy clays (SC). Geotechnical investigations near



LEGEND:

——— PREDICTED OUTFLOW SUSP. SED. CONCENTRATION (MG/L)

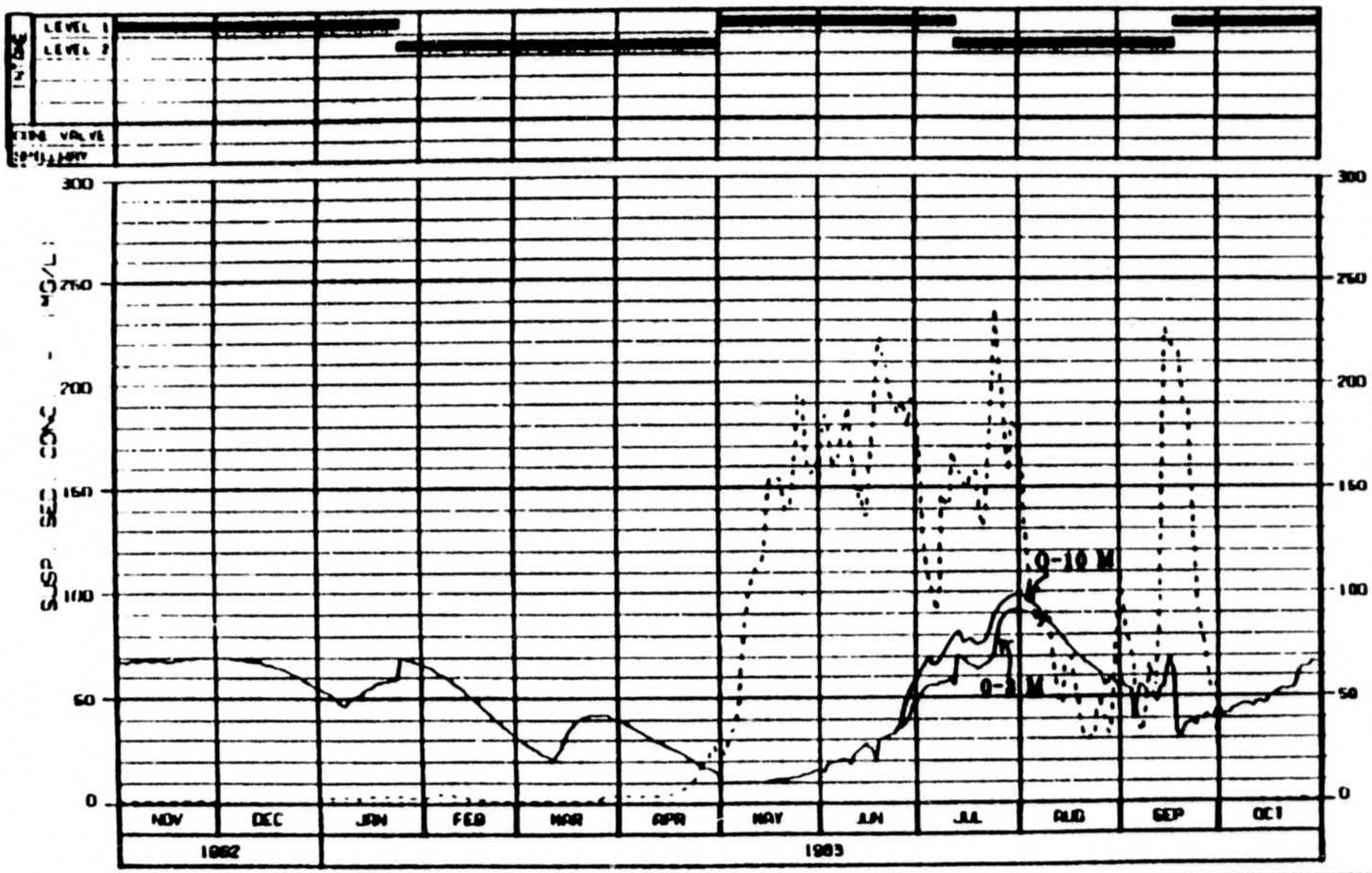
- - - - INFLOW SUSP. SED. CONCENTRATION (MG/L)

NOTES:

1. SSC INFLOW VALUES REPRESENT THE 0-3 MICRON RANGE AND ARE 15% OF TSS

ALASKA POWER AUTHORITY	
SUSITNA PROJECT	DYRESM MODEL
STAGE III WATANA OUTFLOW SUSPENDED SOLIDS (0-10 MICRONS) AVERAGE YEAR	
HARZA-EBASCO JOINT VENTURE	

FIGURE 5.22



LEGEND:

——— PREDICTED OUTFLOW SUSP. SED. CONCENTRATION (MG/L)

- - - - INFLOW SUSP. SED. CONCENTRATION AT WATANA (MG/L) **(0-3 M ONLY)**

NOTES:

1. **SUSPENDED SEDIMENT INFLOW VALUES REPRESENT THE 0-3 M RANGE AND ARE 15% OF THE TOTAL SUSPENDED SEDIMENT INFLOW**

ALASKA POWER AUTHORITY	
SUSITNA PROJECT	DYRESM MODEL
STAGE III DEVIL CANYON OUTFLOW SUSPENDED SOLIDS (0-10 MICRONS) AVERAGE YEAR	
HARZA-EBASCO JOINT VENTURE	
CHICAGO, ILLINOIS · 10 JAN 86	42-010-06

FIGURE 5.23

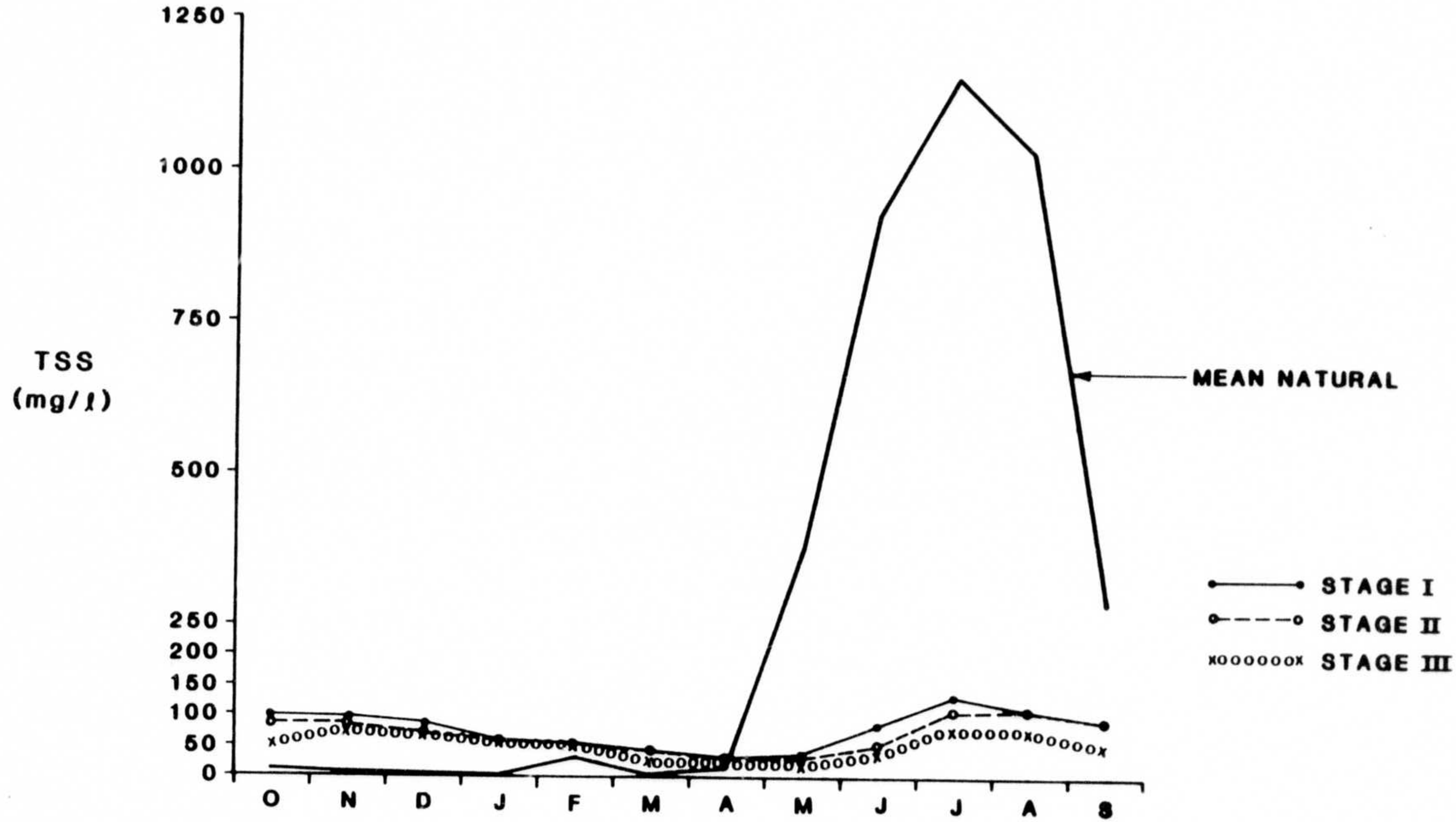


FIGURE 5.24 ESTIMATED MEAN MONTHLY SUSPENDED SEDIMENT CONCENTRATIONS FOR PROJECT DISCHARGES

the dam site indicate that, of the material smaller than three inches in size, less than 15 percent is smaller the five microns. The reservoir suspended sediment modeling indicates that material of 3-4 microns or less will generally comprise the material which remains in suspension. Therefore, most of the material which may become unstable and may potentially slide, will settle out in the immediate vicinity of the slide and not contribute to reservoir sediment concentrations. Only a small portion of the material along the surface of a slide may become suspended. The bulk of the material may be expected to remain in a mass and not become entrained. It is believed that shoreline instability and erosion will contribute most significantly to suspended sediment concentrations in the most surficial layers of the reservoirs.

Although the time period during which bank instability would occur is unknown, slope failures are expected to be highest early in project operation and to decrease with time. Any resulting increase in suspended sediment concentration would follow the same pattern.

5.4 STUDIES OF THE EXISTING TURBIDITY REGIMES IN THE SUSITNA RIVER MIDDLE REACH, IN EKLUTNA LAKE, AND ESTIMATES OF THE WITH-PROJECT TURBIDITY REGIME

Turbidity is a water quality characteristics important to all forms of aquatic life. for this reason relatively extensive surveys of turbidity regime patterns have been made in the Susitna River middle reach, and in Eklutna Lake. By using knowledge about the existing turbidity regimes and comparing them to estimated With-project conditions, it is hoped that some qualitative estimates of project effects can be made.

5.4.1 Existing Middle Reach Turbidity Regime

As discussed previously, the natural turbidity regime is highly variable and seasonally dichotomous. During the 6 month winter period turbidity values are extremely low (0-10 NTU). During the open water season (May-October) turbidity values at Gold Creek have been measured from 0 to as high as 740 NTU, with average values of approximately 200 NTU. Frequent turbidity values were recorded during the open water seasons of 1983 and 1984 at various sampling stations (Figures 5.25; 5.26; 5.27; and 5.28). Analysis of the 1983 and 1984 data confirms the high variability and approximate average turbidity values which had been recorded from previous, less frequent sampling.

5.4.2 Eklutna Lake Turbidity Regimes

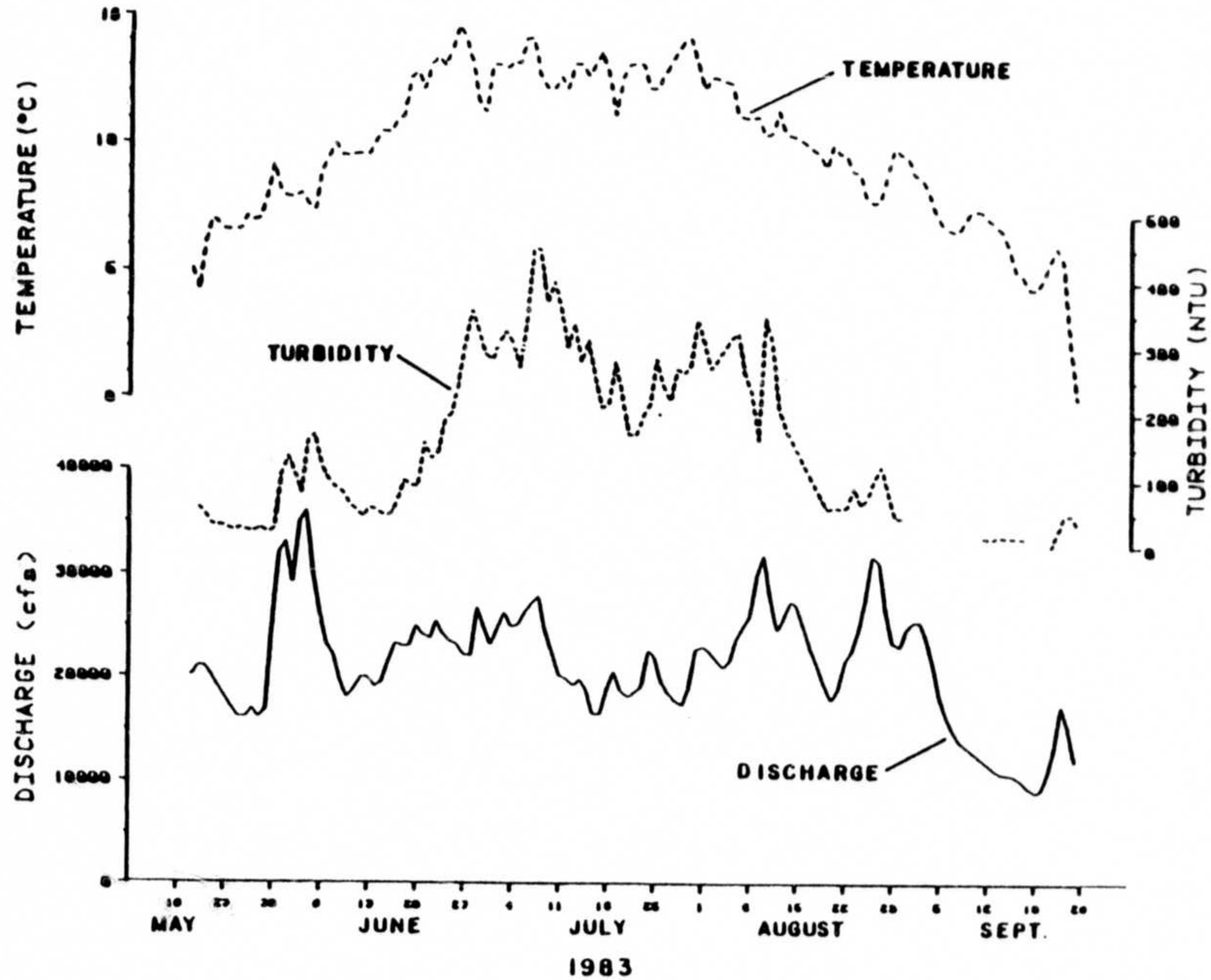
Turbidity in a large environment is a function of thermal structure, wind-mixing, re-entrainment of fine particulates along shoreline boundaries, aeolian input of particles, the concentration and duration of tributary influent of particulates and the hydraulic and hydrologic characteristics of the system. The prevailing biogeochemical processes as well as the elemental and mineralogic characteristics of the particulates also contribute to turbidity regime patterns.

Turbidity regime behavior patterns observed in Eklutna Lake provide a physical model which may be used to estimate generalized turbidity patterns in Watana Reservoir.

When comparing the two reservoirs, however, at least the following facts should be kept in perspective:

- The drainage area for Eklutna is less than 3 percent that of Watana;

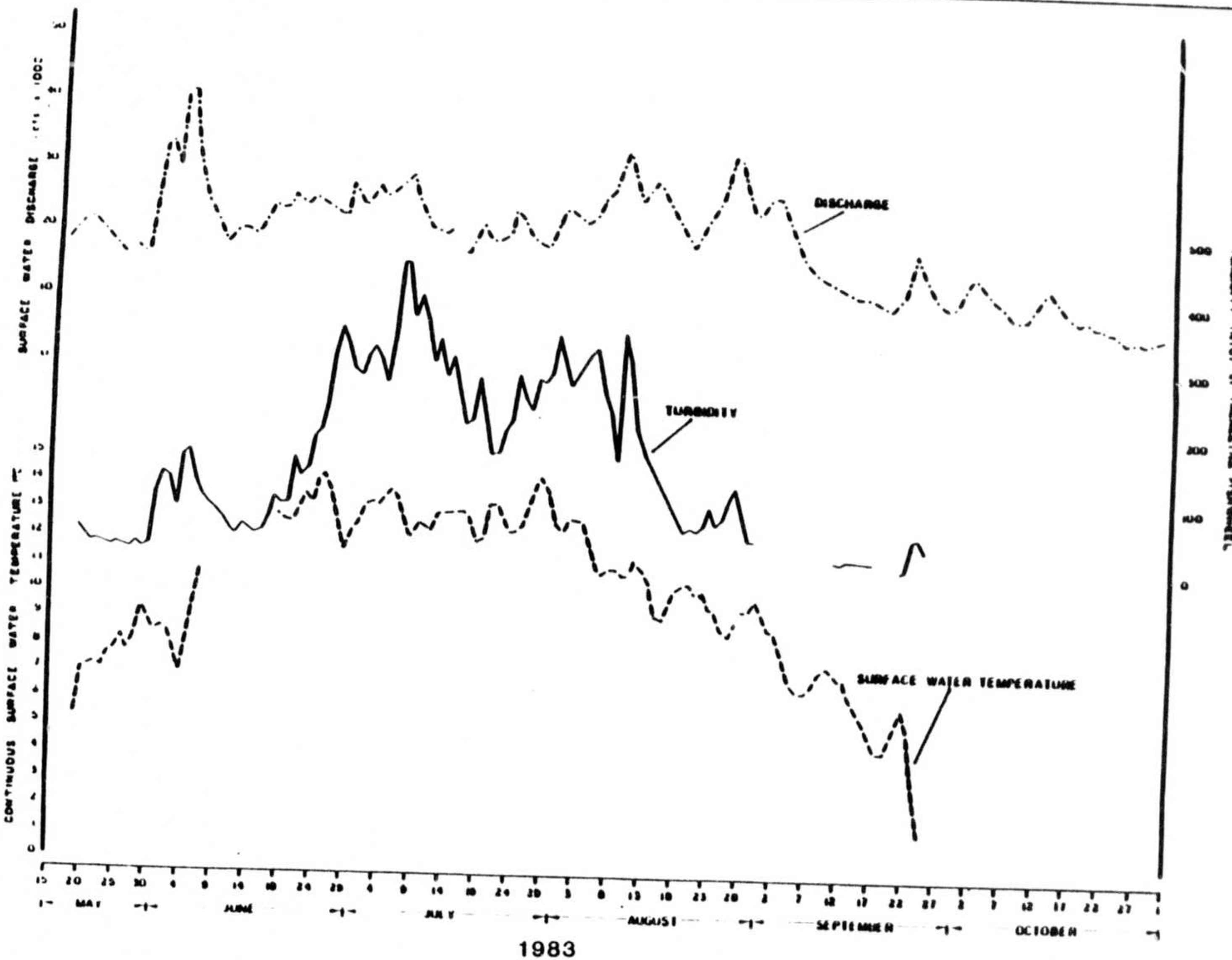
- The glaciated area of Eklutna Lake is approximately 5.2 percent of its total watershed area, which is comparable to the 5.9 percent glacially covered watershed of Watana. The actual areas of glacial ice in Eklutna and Watana watersheds are 6.2 miles^2 and 290 miles^2, respectively;



MAINSTEM DISCHARGE, WATER TEMPERATURE, AND TURBIDITY RECORDED AT THE GOLD CREEK STATION, SUSITNA RIVER

SOURCE: ADF & G 1984c

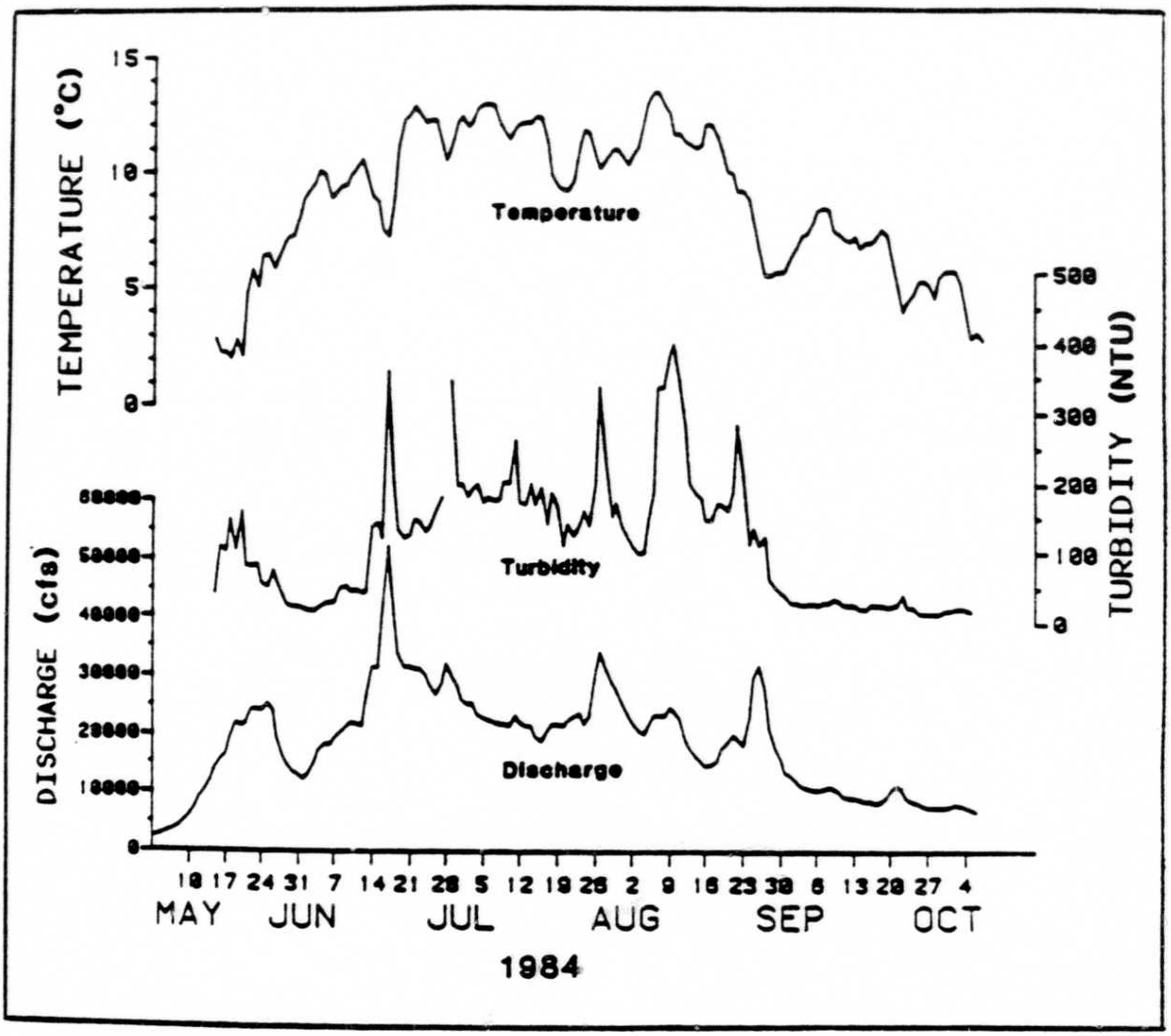
FIGURE 5.25



TURBIDITY, WATER TEMPERATURE, AND SUSITNA RIVER DISCHARGE VERSUS TIME AT THE TALKEETNA FISHWHEEL CAMP.

SOURCE: ADF&G 1984c

FIGURE 5.26



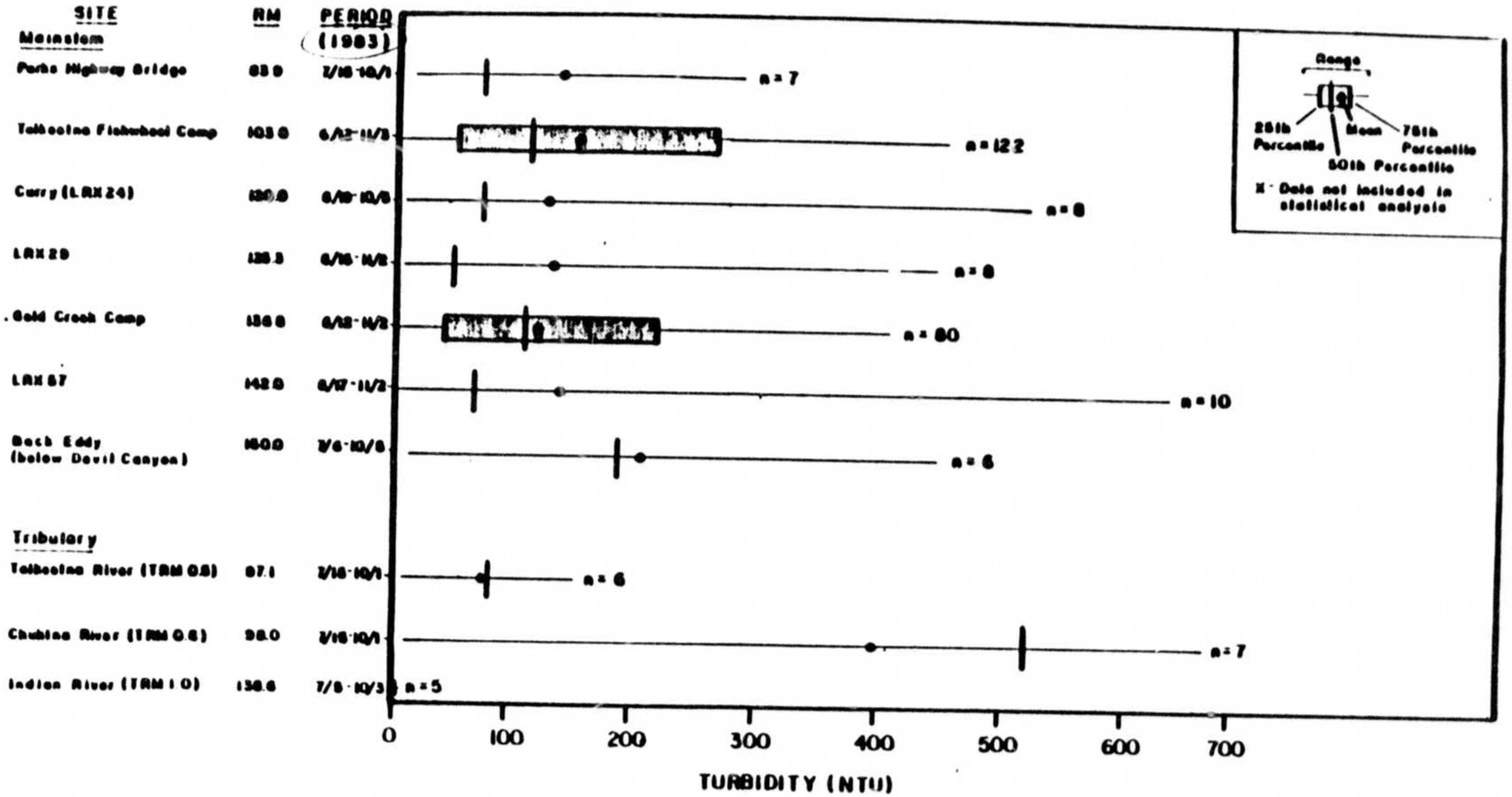
NOTES:

1. DISCHARGE WAS MEASURED AT THE USGS GAGING STATION AT GOLD CREEK
2. WATER TEMPERATURE AND TURBIDITY WERE MEASURED AT TALKEETNA STATION

MAINSTEM DISCHARGE, WATER TEMPERATURE, AND TURBIDITY IN THE MIDDLE REACH OF THE SUSITNA RIVER, 1984.

SOURCE: ADF & G 1985

FIGURE 5.27



TURBIDITY DATA SUMMARY SHOWING RANGE, 25th, 50th (MEDIAN), AND 75th PERCENTILE FOR MAINSTEM AND TRIBUTARY STUDY SITES.

SOURCE: ADF & G 1984c

FIGURE 5.28

- Ekłutna Lake has approximately 10 percent (3,420 acres) of the surface area of the proposed Watana Reservoir (38,000 acres);

- Maximum depth of Eklutna Lake (200 ft.) is less than one third that for Watana Reservoir (735 ft.);

- Mean depth of Eklutna Lake (121 ft.) is less than one half that for Watana Reservoir (250 ft.);

- Maximum length of Eklutna Lake (7 miles) is less than one sixth that of Watana Reservoir (48 miles);

- Maximum width of Eklutna Lake (0.7 miles) is less than one tenth that of Watana Reservoir (8 miles);

- Mean width of Eklutna Lake (0.6 miles) is less than one half that of Watana Reservoir (1.5 miles);

- Hydraulic residence time for Eklutna Lake (1.77 yr.) is very similar to that of Watana Reservoir (1.65 yr.);

- Annual water inflow to Eklutna Lake (234,300 acre feet) is less than 5 percent that for Watana Reservoir (5,750,263 acre feet). The maximum storage capacity for Eklutna Lake (415,000 acre ft.) is also less than 5 percent than for Watana (9.5 million acre ft.);

- Annual water inflow to Eklutna lake and Watana Reservoir is approximately 60 percent of their respective storage capacities; and

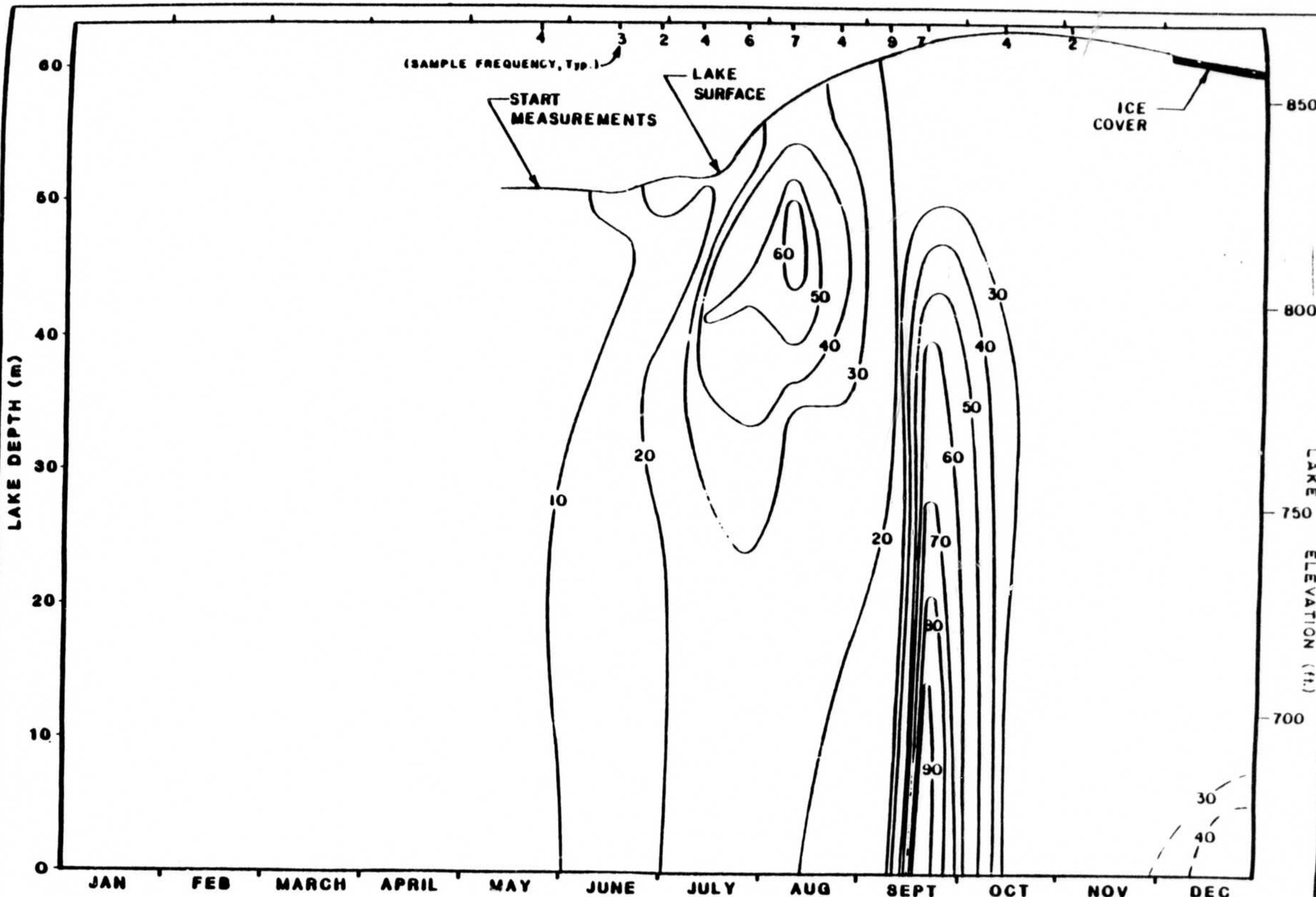
- Estimated annual sediment inflow to Eklutna Lake (less than 100,000 tons) is less than 2 percent of the estimated annual sediment inflow to Watana Reservoir (approximately 6.5 million tons).

Because of these disparities between Eklutna and Watana it can be expected that the annual turbidity patterns of the two lentic systems would be similar. However, the turbidity levels and sediment concentration are expected to be higher in Watana than what has been observed in Eklutna.

Data collected at the approximate centER of Eklutna Lake from March 1982 through June 1984 (R&M 1982d, 1985) demonstrate patterns of turbidity behavior which may be expected at Watana. In March 1982 (Figure 5.29, March, April and May 1983 (Figure 5.30), and March, April, May and June 1984 (Figure 5.31), turbidity beneath the Eklutna Lake ice cover decreased to its annual minimum of less than 10 NTU. Shortly after the lake surface ice melted in April or May, but before significant glacial melt had commenced, turbidity was 7-10 NTU throughout the water column. Usually by June, the turbidity had begun to increase, but no distinct surface turbidity plume was evident. This increase in turbidity was probably due to windmixing and/or vernal lake turn-over, and influent turbidity. By mid-summer, slight increases in turbidity were noted at the lake bottom near the river inlet or in the lake water column. Distinct turbidity plumes were evident as interflows, overflows, or underflows in the lake from late July through mid-September. Turbidity values had significantly decreased by the time the plume had traveled 5 miles down the lake. In late September of 1982 and 1984, a turbid layer was noted at the bottom of the lake as river water entered as underflow. By mid-October, the lake was usually either in its fall overturn period or had progressed through it, with near-uniform temperatures at approximately 7°C (44.6°F) and turbidities of less than 30-35 NTU.

5.4.3 Watana Reservoir

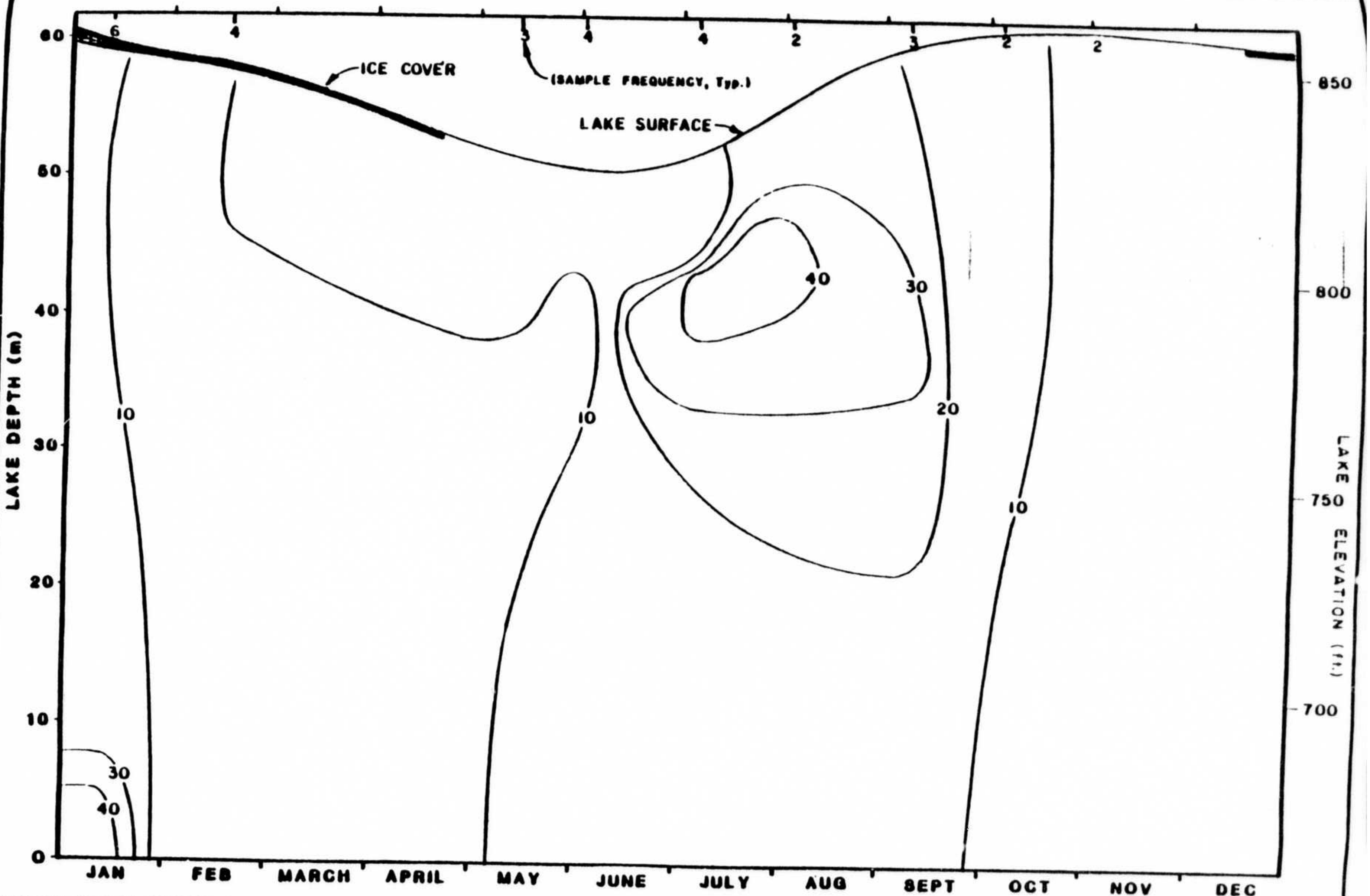
The results of the suspended sediment modeling of Watana Reservoir may be used to estimate sediment concentrations and turbidities in the upper layers of the main body of the reservoir. These simulations indicate that the reservoir will be generally uniform in suspended sediment concentration in November at a value of approximately 100 mg/l as a result of isothermal



PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

ISO-TURBIDITY vs. TIME
EKLUTNA LAKE at STATION 9
1982

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE
FIGURE 5.29

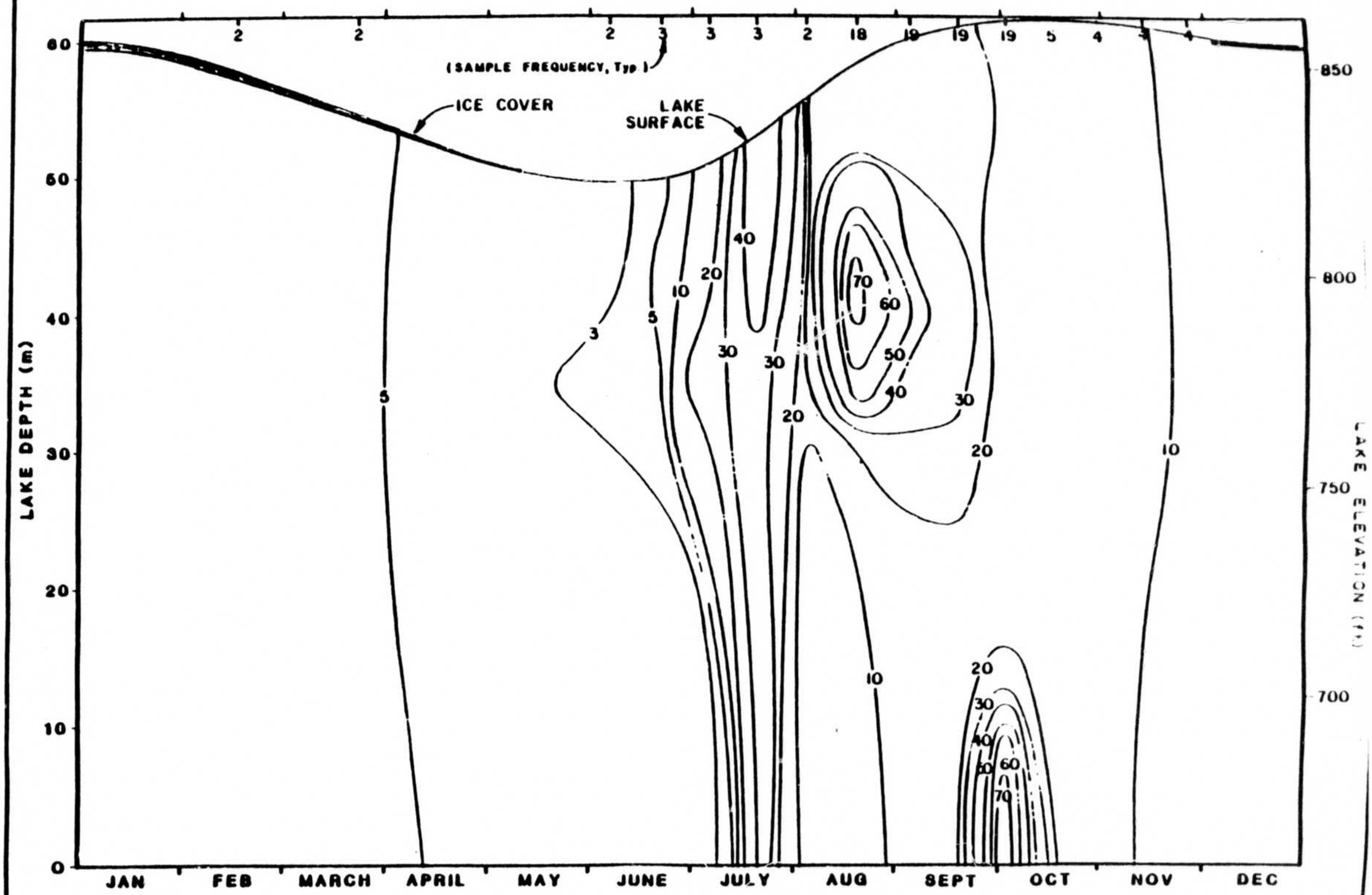


PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

ISO-TURBIDITY vs. TIME
EKLUTNA LAKE at STATION 9
1983

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

FIGURE 5.30



PREPARED BY:
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS HYDROLOGISTS SURVEYORS

ISO-TURBIDITY vs. TIME
EKLUTNA LAKE at STATION 9
1984

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE
FIGURE 5.31

conditions and a fall overturn induced by winds. When the reservoir ice cover forms in mid to late November it minimizes windmixing of the upper layers of the reservoir. As clear, incoming river water enters the reservoir near the surface, and as suspended glacial material settles, the sediment concentration near the surface will decrease. By January, concentrations near the surface may be approximately 10 mg/l. Sediment concentrations will increase with depth in the reservoir. This pattern will be essentially unchanged throughout the ice cover period. However, concentrations near the surface may decrease to a low of 5 mg/l later in the winter, just prior to ice cover melt-out or break-up.

Beginning in May, the influx of suspended material caused by snowmelt runoff and precipitation will increase suspended sediment concentration near the surface. Flows will also enter the reservoir below the surface and concentrations may increase throughout the reservoir depth. Concentrations near the surface are simulated to increase from 70 mg/l to 110 mg/l by July 1 and to remain at these levels through early August. These concentrations are simulated to increase to a maximum of approximately 200 mg/l at a depth of approximately 100 feet. The concentration near the surface generally decreases to approximately 70 mg/l by October, and the concentration at the 100-foot depth generally decreases to 150 mg/l at the same time.

Turbidity levels in the main body of the reservoir will generally follow the same pattern as the suspended sediment concentration but may be 2-4 times greater. As discussed earlier, turbidity can be related to the suspended sediment concentration by multiplying the sediment concentration, in mg/l, by at least two to get the turbidity in NTU. Thus, turbidities near the surface may be expected to be at least 200 NTU in November, decrease to 10-20 NTU by January, remain at that level throughout winter, increase between May and July to 200-300 NTU and remain at that level until November. Average monthly sediment concentrations and estimated minimal turbidities in With-project discharges have been calculated (Tables 5.4, 5.5, 5.6, and Figure 5.32).

TABLE 5.4

SUSITNA HYDROELECTRIC PROJECT
NATURAL AND ESTIMATED MEAN MONTHLY SUSPENDED SEDIMENT CONCENTRATIONS AND MINIMAL TURBIDITY VALUES EXPECTED TO EXIT WATANA RESERVOIR DURING STAGE I OPERATIONS

		STAGE I OPERATION	
Month	Observed Suspended Sediment Concentrations1/	Estimated Mean Suspended Sediment Concentrations1/	Estimated Minimal Turbidity
	(mg/l)	(mg/l)	NTU2/
January	<1-8	65	130
February	N.A.	55	110
March	1-6	43	86
April	N.A.	30	60
May	65-1,110	35	70
June	151-1,860	85	170
July	100-2,790	130	260
August	158-1,040	110	220
September	23-812	90	180
October	7-140	100	200
November	N.A.	95	190
December	N.A.	83	166

1/ Data derived from Table E.2.4.28; from Exhibit E, Chapter 2 data.

2/ Turbidity estimated by using factor of (2x) times TSS concentrations (See discussions in Exhibit E, Chapter 2).

TABLE 5.5

SUSITNA HYDROELECTRIC PROJECT
NATURAL AND ESTIMATED MEAN MONTHLY SUSPENDED SEDIMENT CONCENTRATIONS AND MINIMAL TURBIDITY VALUES EXPECTED TO EXIT DEVIL CANYON RESERVOIR DURING STAGE II OPERATIONS

Month	Observed Suspended Sediment Concentrations[1]	STAGE II OPERATION: Estimated Mean Suspended Sediment Concentrations[1]	STAGE II OPERATION: Estimated Minimal Turbidity
	(mg/l)	(mg/l)	NTU[2]
January	<1-8	60	120
February	N.A.	45	90
March	1-6	40	80
April	N.A.	30	60
May	65-1,110	28	56
June	151-1,860	55	110
July	100-2,790	110	220
August	158-1,040	110	220
September	23-812	90	180
October	7-140	80	160
November	N.A.	80	160
December	N.A.	73	146

N.A. = Not Available.

1/ Data derived from Table E.2.4.60; (in Exhibit E, Chapter 2).

2/ Turbidity estimated by using factor of (2x) times TSS concentrations (See discussions in Exhibit E, Chapter 2).

TABLE 5.6

SUSITNA HYDROELECTRIC PROJECT
NATURAL AND ESTIMATED MEAN MONTHLY SUSPENDED SEDIMENT CONCENTRATIONS AND MINIMAL TURBIDITY VALUES EXPECTED TO EXIT DEVIL CANYON RESERVOIR DURING STAGE III OPERATIONS

Month	Observed Suspended Sediment Concentrations1/	STAGE III OPERATION: Estimated Mean Suspended Sediment Concentrations1/	STAGE III OPERATION: Estimated Minimal Turbidity
	(mg/l)	(mg/l)	NTU2/
January	<1-8	55	110
February	N.A.	50	100
March	1-6	25	50
April	N.A.	25	50
May	65-1,110	17	34
June	151-1,860	35	70
July	100-2,790	75	150
August	158-1,040	75	150
September	23-812	55	110
October	7-140	50	100
November	N.A.	70	140
December	N.A.	68	136

N.A. = Not Available.

1/ Data derived from Table E.2.4.85; (in Exhibit E, Chapter 2)

2/ Turbidity estimated by using factor of (2x) times TSS concentrations (See discussions in Exhibit E, Chapter 2).

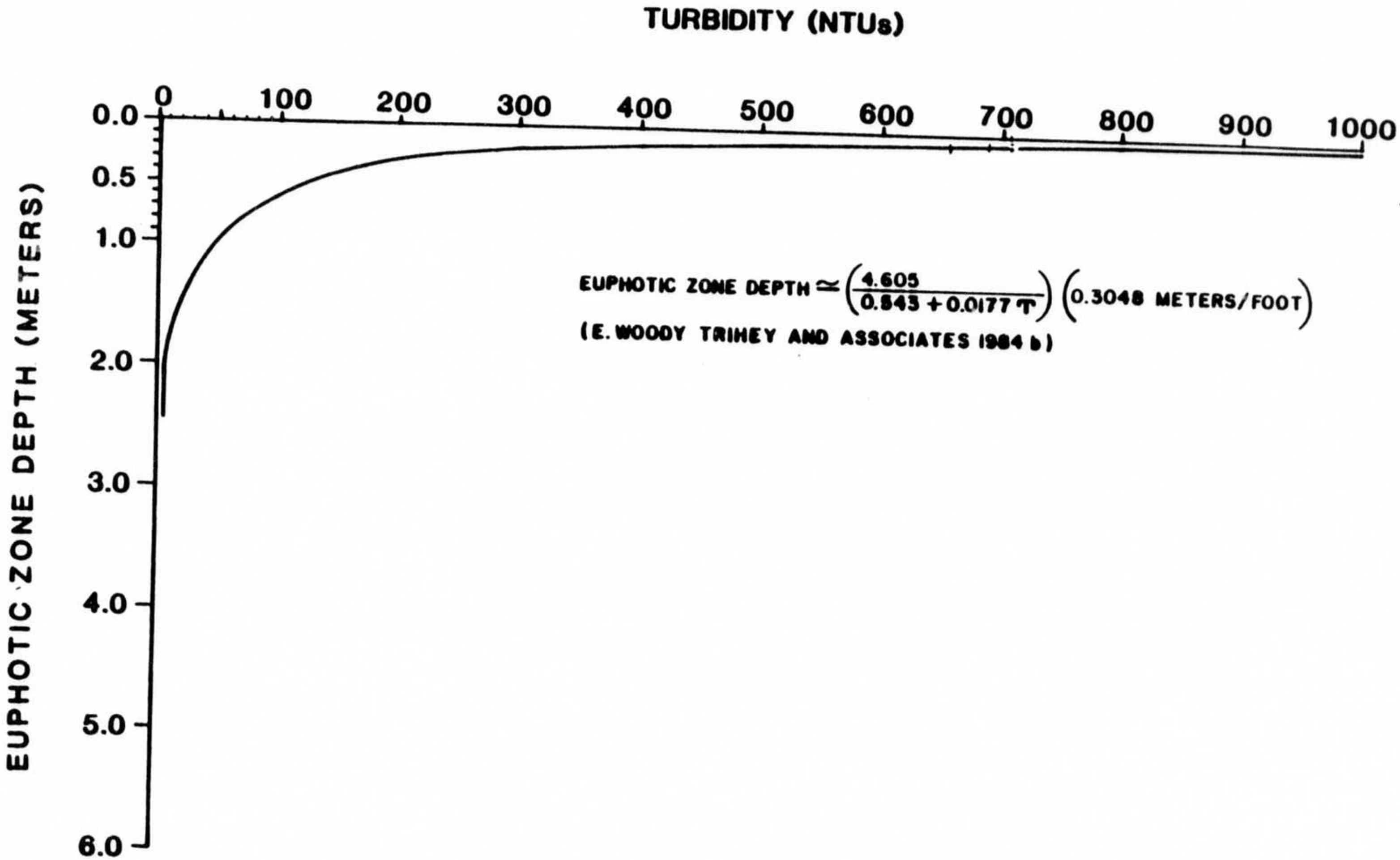
vertically transmitted PAR per unit of turbidity. For this relationship data collected in the glacial flour impacted Eklutna Lake, from undisturbed and placer-mine affected streams in interior Alaska, from various sampling points in the Susitna River drainage basin, and from Knik Arm have been pooled for use in synthesizing a model relating turbidities and maximum euphotic zone depths (i.e. the depth to 1 percent PAR). This empirically derived relationship has been graphically represented (Figure 5.33). It may may be expressed as the relation between maximum euphotic zone depth in feet (Z ft.) and turbidity (T) in nephelometric turbidity units (NTU) as follows:

$$Z\ \text{ft.} = \frac{4.605}{(0.543 + 0.0177\ T)}$$

5.6 ESTIMATED FISHERIES IMPACTS OF AN ALTERED SEDIMENT AND TURBIDITY REGIME IN THE MIDDLE REACH

Organisms existing in rivers, whether glacially influenced or not, are likely to be specialized to exist in lotic environments (Lagler et al. 1962; Gill 1971; Hynes 1970, 1973; Merrit and Cummins 1978). Salmon, both Salmo sp. and Onchorhyncus sp., have probably evolved through at least four major ice ages, several minor ice ages, and interglacial periods which took place during the Pleistocene (Flint and Skinner 1977; Netboy 1974 and 1980; Dott and Batten 1981). During their natural dispersions and speciations in European, Asian and North American waters between 35° and 70° North latitudes salmon have undoubtedly encountered and endured highly varied riverine sediment regimes. All existing species of salmon have evolved behavioral and presumably genetic adaptations for selecting and surviving in aquatic environments which are subject to variable amounts of suspended sediment, turbidity and sedimentation.

Most researchers have concluded that the productivity, biomass and health of most aquatic organisms (including most salmon life cycle stages) in cold



AN EMPIRICALLY DERIVED, GENERALIZED RELATIONSHIP BETWEEN TURBIDITY AND THE MAXIMUM EUPHOTIC ZONE DEPTH (1.0 % P.A.R)

FIGURE 5.33

water, lotic habitats are inversely related to the mass of small particulates in suspension or settled in the interstices of the streambed substrate (Shaw and Maga 1942; Stuart 1953a, 1953b and 1954; Cordone and Kelley 1961; Cooper 1965; Einstein 1968 and 1972; Gibbons and Salo 1973; Nat. Acad. Sciences 1973; Hynes 1970 and 1973; Brusven and Prather 1974; Bjornn, et al. 1977; Iwamoto, et al. 1978; Sorenson, et al. 1977; Ward and Stanford 1979; Muncy et al. 1979; Reiser and Bjorn 1979; Alabaster and Lloyd 1980; Bell 1980; McClelland and Brusven 1980; Wilber 1983; Lloyd 1985; Peterson et al. 1985a). Acute affects of suspended sediments on either rearing juvenile or migrating adult salmonids are usually not detectable at concentrations less than multi-hundreds or even multi-thousands of milligrams per liter (Noggle 1978; Smith 1978; Ross 1982; Gibbons and Salo 1973; Bjornn, et al. 1977; Iwamoto et al. 1978; Bell 1980; Lloyd 1985; Peterson et al. 1985a). Chronic effects of inorganic suspended sediments at concentrations between 0 and 100 milligrams/liter on rearing juvenile and adult salmonids are usually noted as either negligable or as slightly reducing their health and survivability. Chronic exposure to fine sediments of freshly fertilized eggs, incubating eggs and developing alevins is frequently noted as stressful if not lethal.

Studies have not yet been found which have investigated and reported the effects of chronic exposure to suspended sediments which have lasted more than 9-10 months, and most experiments lasted for only a few days to a few months (Iwamoto et al. 1978; Bell 1980; Lloyd 1985; Peterson et al. 1985a). No experimental results have been located to date which examine the effects of continuous exposure of rearing salmonids to the expected With-project winter conditions in mainstem affected channels (i.e. 0-2°C, <less than 150 milligrams per liter of predominately small suspended sediments; and less than 300 NTU). The evidence which has been examined, however, suggests that the effects of overwintering in chronic suspended sediment levels such as those expected in the mainstem habitats might be stressfull but probably survivable. It should also be remembered that many clear water peripheral habitats, and clear water upwellings and tributary inflows may provide

numerous suitable niches for middle reach fishes during all periods of the annual cycle.

Any Project-induced detrimental impacts which may occur in chronically turbid channels would likely result from sedimentation effects on streambed substrate habitat, on early fish life cycle stage (egg and alevin incubation), and on optically related fish behavior. These effects may largely result from intrusion of fine particulates into interstial spaces of some streambed substrates and to relatively high turbidity (Stuart 1953a and 1953b; Cooper 1965; Einstein 1968; Alabaster and Lloyd 1980; Beschta and Jackson 1979; Iwamoto et al., 1978; Carling 1984; Bell 1980; Bisson and Bilby 1982; Milhous 1982; Sigler et al. 1984; Lloyd 1985; and Peterson et al. 1985a).

Cursory information about the suspended sediment concentration and turbidity levels in two other glacially affected rivers in south central Alaska have been assembled. With-project conditions in mainstem affected channels of the Susitna River middle reach are expected to be more biologically detrimental than either the Kenai or Kasilof Rivers (Table 5.7).

5.6.1 Recommended Criteria

Recommendations for the upper tolerable limit of chronic exposure to TSS which can support good fisheries are approximately 25 mg/l (Alabaster and Lloyd 1980; Bell 1980; Wilber 1983). Chronic exposure to concentrations of 25-80 mg/l TSS are commonly expressed as being potentially hazardous and detrimental, or providing only good-to-moderate protection for fresh water aquatic life (Hynes 1973; National Academy of Science 1973; Alabaster and Lloyd 1980; Wilber 1983). Chronic exposure to TSS concentrations of 80-400 mg/l is reported to be considered "not good', "poor", providing only "low levels of protection" and being "possible lethal" to aquatic organisms (Gibbons and Salo 1983; Alabaster and Lloyd 1980; Bell 1980; and Wilber 1983). Chronic exposure to TSS concentrations in excess of 400 mg/l should be considered extremely bad and potentially lethal (Gibbons and Salo 1983; Alabaster and Lloyd 1980; Bell 1980; and Wilber 1983).

TABLE 5.7

SUSITNA HYDROELECTRIC PROJECT
APPROXIMATE ANNUAL RANGE AND MEAN VALUES OF TSS AND TURBIDITY IN SELECTED REACHES OF TWO SOUTH CENTRAL ALASKAN GLACIAL RIVERS COMPARED TO WITH-PROJECT ESTIMATES FOR THE SUSITNA RIVER MIDDLE REACH

River	Reach	TSS/Turbidity	Observation Period
Kenai	below Kenai Lake	Range 2-26mg/l; mean N.A.1/ 0-32 NTU2/	1956-1974 1979-1981
Kenai	at Soldotna Bridge	Range 1-151mg/l; mean<40mg/l1/ 0-32 NTU2/	1967-1979 1979-1981
Kasilof	below Tustumena Lake	Range 15-45mg/l; mean N.A.1/ 38-60 NTU3/	1953-1968 1983-1985
Susitna	Watana Discharge	Range 30-130mg/l; mean=77mg/l 60-260 NTU (minimum)	Stage I Mean Annual Estimate
Susitna	Devil Canyon Discharge	Range 28-110mg/l; mean=62mg/l 56-220 NTU (minimum)	Stage II Mean Annual Estimate
Susitna	Devil Canyon Discharge	Range 17-70mg/l; mean=50 34-150 (minimum)	Stage III Mean Annual Estimate

1/ Source: Scott 1982
2/ Source: Burger, et al. 1982
3/ Source: Pers. comm.: Koenings, J. 1983-1985; Van Nieuwenhuyse, E. 1985

5.6.2 Present Conditions

Pre-project water quality conditions in the mainstem Susitna River channels (regarding suspended sediments) range from extremely poor during much of the open water season to excellent during the winter season. Nevertheless, some rearing juvenile salmon survive the high suspended sediment concentrations and high turbidity levels during portions of the summer diel cycles. Some Susitna specific data indicates that a limited portion of the middle reach juvenile salmon (especially chinook) may even prefer the high suspended sediment concentrations and turbidity of mainstem affected habitats (ADF&G 1984b and 1985a, c).

It is well known that intermittent high TSS Concentrations, and darkness each seem to be causally related to benthic invertebrate drift (Hynes 1970; Muller 1974; Rosenberg and Wiens 1978). In fact chronically high turbidity, with its attendent reduction of vertical ligh penetration, may help stimulate fairly continuous drift during summer in certain habitats in the Susitna River middle reach. Artificial darkness has been known to enhance daytime drift under experimental conditions (Hynes 1970; Muller 1974).

One possible explanation for the apparent preference of some rearing juvenile chinook for relatively turbid waters documented during Susitna River studies is that they were permanently or transiently selecting turbid waters to take advantage of a relatively good drifting food supply. Much evidence supports the concept that feeding juvenile chinook are opportunistic feeders specializing in drifting, autochthonously produced invertebrates (mostly Chironomidae) (Becker 1973; Dauble et al. 1980; Burger et al. 1983; ADF&G 1985b). A second, but not mutually exclusive explanation of the apparent juvenile chinook preference for relatively high turbidity, is that they employ the turbidity as cover.

5.6.3 With-project Turbidity Regime

The biological significance of chronic exposure to high turbidity is likely to be minimzation of riverine biomass production at all trophic levels. Autochthonous primary productivity may begin to be reduced at approximately 25 NTU (Bell 1980; Van Nieuwenhuyse 1983; Lloyd 1985), but stream depth will be an important factor in determining the amount of PAR reaching the streambed substrate. Even highly turbid glacial streams may have moderate or high autochthonous productivity at subvertebrate trophic levels in sufficiently shallow habitats (Milner 1983). At low turbidity (0-25 NTU), disregarding other environmental limiting factors, it may be surmized that authochthonous primary productivity and perhaps productivity at higher trophic levels would be enhanced by the fertilizing effects of nutrients associated with the suspended inorganic particulates.

The upper tolerable limit of chronic turbidity to which all stream habitats and inhabitants may be exposed while still maintaining a self sustaining salmon population has not been established. It is likely that each riverine habitat type would respond to different turbidity exposures (different turbidity levels; intermittent versus chronic, etc.) in different ways. Very coarse estimates of the maximum tolerable chronic turbidity for maintaining a viable salmonid fishery in subarctic Alaska may be within the 100-200 NTU range for streams with mean depths of 0.5 feet or greater. The Kasilof River, which is one of the more chronically turbid rivers in south central Alaska known to maintain a self sustaining salmonid fishery probably rarely exceeds 15-45 mg/l TSS (Scott 1982) and probably rarely exceeds 100 NTU (Koenings, J. 1983, Lloyd 1985).

6.0 HYDROGEN ION CONCENTRATION AND ALKALINITY

The significance of potential changes in pH on salmon and resident fish habitats due to inundation of soils, organic detritus and lithic materials in the project reservoirs has been identified as a fisheries issue. This chapter examines the current status of our knowlege on the subject.

6.1 Discussion

The physical, chemical and biological characteristics of a water body (including its pH and alkalinity) will reflect the basic climatic, hydrologic, and biogeochemical regimes of its entire drainage basin, and not merely the small portion of the drainage which is under water (Welch 1952, Hutchinson 1967, 1973, 1975, Wetzel 1975, Vollenweider and Kerekes 1980). The pH of upstream and downstream mainstem Susitna riverine habitats is presently regulated by the carbon dioxide-bicarbonate-carbonate and aluminum silicate dissolution buffering systems (Wetzel 1975, Stumm and Morgan 1970). These two buffering systems maintain pH values between 6.0 and 8.3 in most fresh water ecosystems of North America including the Susitna River.

The drainage basin of the Susitna River upstream of the proposed Devil Canyon dam site encompasses approximately 5,810 square miles of unvegetated mountains and subarctic tundra. The watershed's bedrock, glacial till and glacial outwash materials contain alkalinity-producing carbonate and silicate minerals (APA 1983a, R&M Consultants Inc. 1982a,b). Overlying the watershed's lithic material is a substantial area of tundra consisting of saturated, peaty soils, which may be acidic in nature. Sphagnum bogs are frequent on the tundra and they commonly have a pH less than 4.5. Despite sustantial inflow from tributary drainages with acidic soils and acidic bogs, the ionic composition of the mainstem river is presently sufficient to buffer tributary acidity and maintain low to moderate alkalinity values. Changes in mainstem pH values are seasonally variable but remain between 6.0 and 8.1. The mean annual pH is greater than 7.0 in the mainstem water of the Susitna river watershed (Figure 6.1). The pH of intragravel waters of

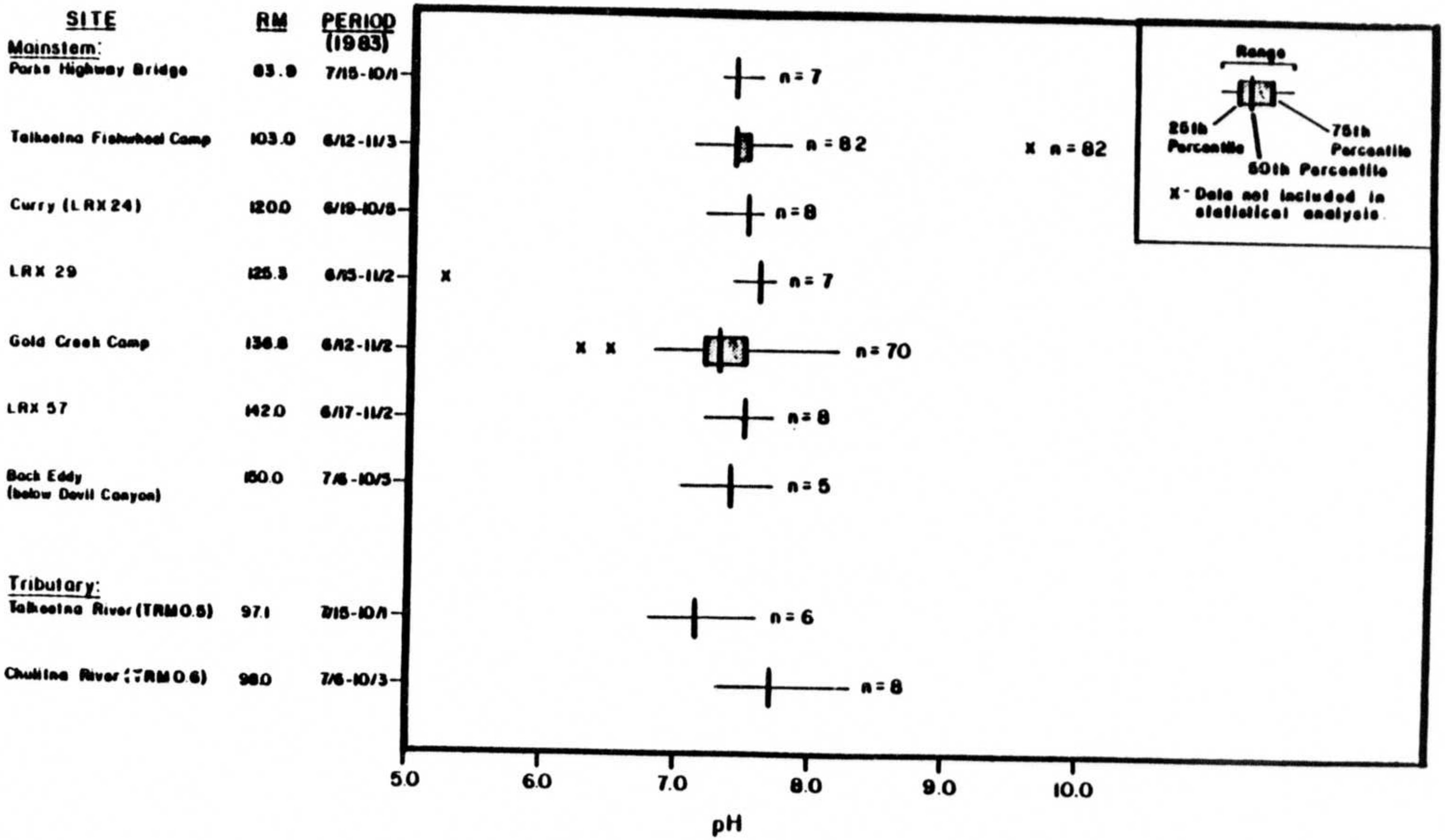


Figure 6.1 pH data summary showing range, 25th, 50th (median), and 75th percentile for mainstem and tributary water quality study sites (Source: ADF & G 1984c)

tributary, peripheral and mainstem habitats is similar to that of mainstem surface waters (Figures 6.2, 6.3).

A wetlands mapping project has been completed by the USFWS in order to quantify the amount of different wetland types in both Watana and Devil Canyon impoundment zones. The estimated total of vegetated areas which are classifiable as wetlands equals 8,316 acres or 18.8 percent of the combined impoundment areas. The estimated total of all "bog-like" wetlands equals 1,182 acres or approximately 2.7 percent of the combined impoundment zone areas. The pH of the proposed reservoirs and downstream riverine habitats under with-project conditions will be regulated by the same chemical buffering system existing at present. Flooding of the small area of bog habitats is not anticipated to cause a biologically significant change of pH in riverine habitats downstream of the proposed project or in the reservoirs. The overall effect of the project will be to buffer the amplitude of pH changes in both the reservoirs and in the downstream riverine habitats, just as the project will buffer the amplitude of changes in the flow, temperature and TSS regimes.

A large number of references, including review articles, research reports and texts have been reviewed for any discussion of pH changes in reservoirs or their downstream habitats due to bog inundation (See reference section of this text). No documentation of such a problem has been located in the open literature dealing with lake or large reservoir limnology in subartic environments. No pH problems due to bog inundation are expected to be associated with this project.

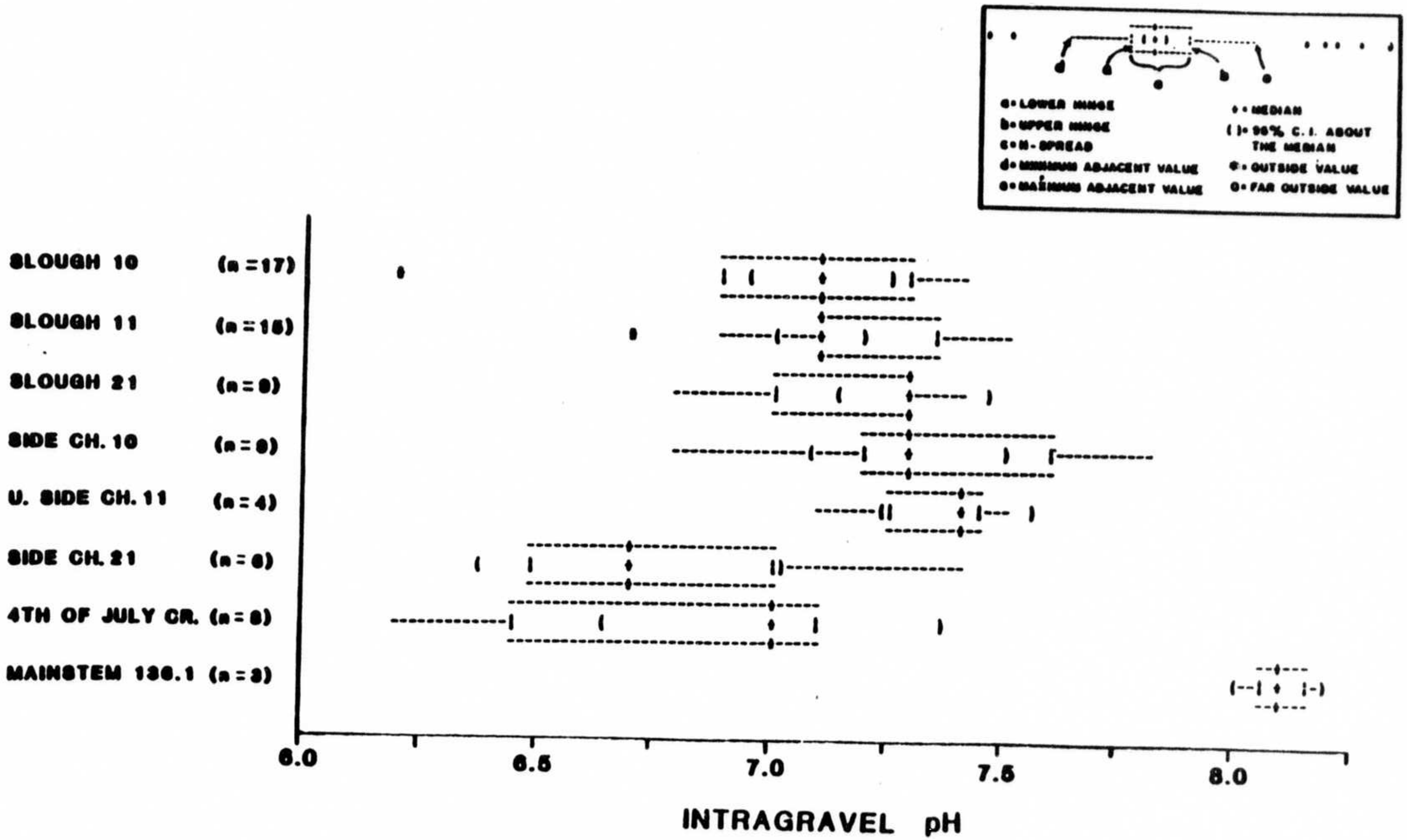


Figure 6.2 Summary, by study site, of the intragravel pH data periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (Source: ADF & G 1985 d)

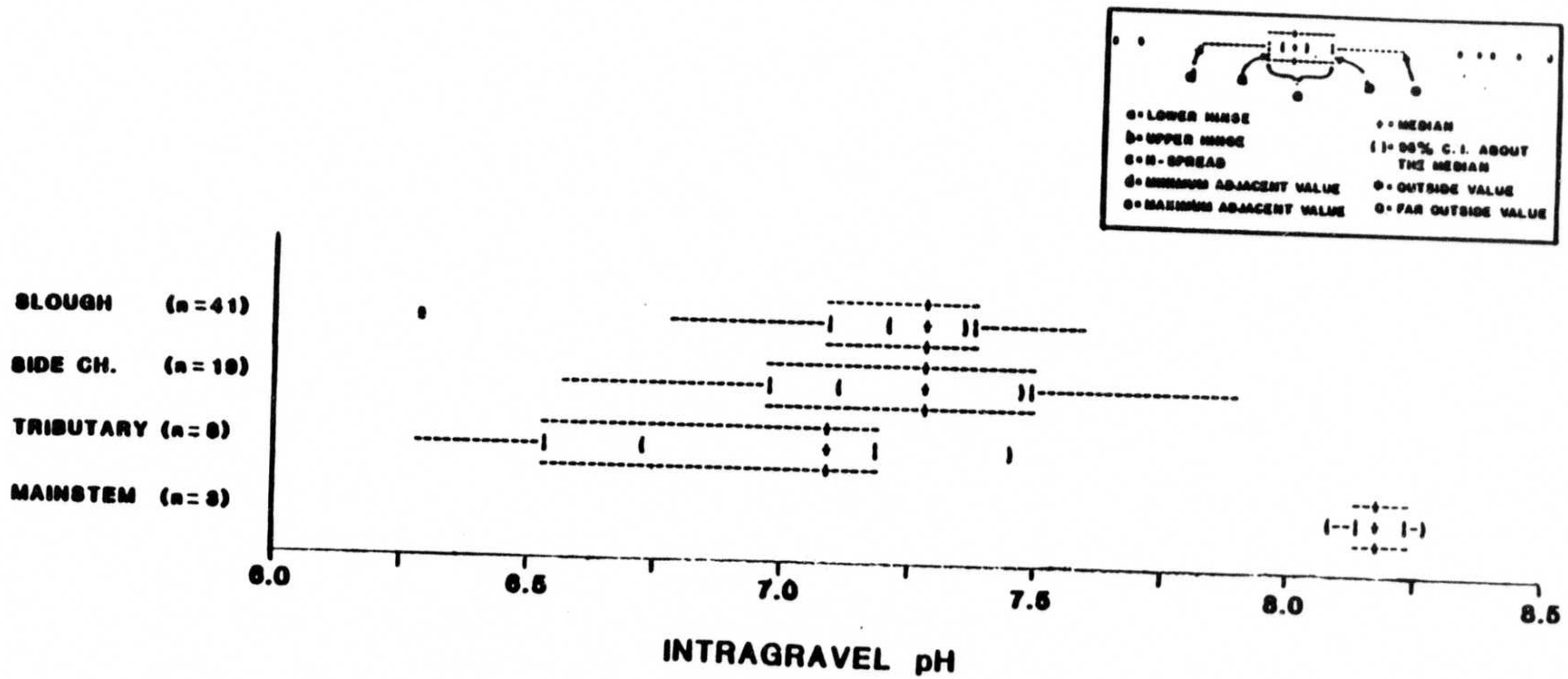


Figure 6.3 Summary, by habitat type, of the intragravel pH data periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (Source: ADF & G 1985 d)

7.0 GENERALIZED INFORMATION REGARDING PROJECT EFFECTS ON HEAVY METALS

7.1 INTRODUCTION

Leaching of potentially toxic heavy metels from newly inundated reservoir vegetation and soils may occur during the early life of any reservoir. In the Susitna River some trace metals presently exist in concentrations higher than agency limits for protection of freshwater organisms (APA 1983a, b). Knowledge of the potential for the project reservoirs to create toxic metal problems is useful for addressing public and agency concerns. The purpose of this chapter is to summarize the potential for leaching of heavy metals from soils and organic matter within the newly impounded reservoirs, and the potential project induced biological effects to be expected, if any, due to heavy metal probilization.

Literature on the subject was searched by both manually and electronically1/. There are few cases studies. Most water quality studies of newly impounded reservoirs have been related to trophic status, not metal dynamics. The studies we found focused upon mercury bioaccumulation, as mercury is the only heavy metal known to enter the food chain as a direct result of river impoundment. (Abernathy and Cumbie 1977; Bodaly et al. In press; Meister et al. 1979).

1/ DIALOG ® databases searched included Pollution Abstracts, Aquatic Sciences and Fisheries Abstracts, and Water Resources Abstracts. Cold Regions database, maintained by the Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire, was also searched.

The original License Application (1983a, b) reviews the concentrations of metals in Susitna River water and evaluates them using published criteria and guidelines (AAC 1984; EPA 1976; McNeely et al. 1979; Sittig 1981). Many metals violated these criteria and guidelines. As stated in the original License Application, the measured levels of heavy metals in the Susitna River represent natural conditions. With the exception of some placer mining operations, the water shed supports no significant industries, agriculture, or urbanization. Consequently, it was concluded that the violations of water quality criteria represent a naturally affected aquatic ecosystem. Nevertheless, the high levels of certain heavy metals warrant further investigation. Metals which exceeded applicable criteria included both dissolved and total recoverable aluminum (Al), cadmium (Cd), copper (Cu), manganese (Mn), mercury (Hg), and zinc (Zn). In addition, the dissolved fraction of bismuth and the total recoverable quantities of iron (Fe), lead (Pb), and nickel (Ni) also exceeded the criteria[2/].

2/ In this report, total recoverable metal is used synonymously with total metal. Total recoverable is the amount of a given constituent that is in solution after a representative water-suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of only readily soluble substances. Complete dissolution of all particulate matter is not achieved by the digestion treatment, and thus the determination represents something less than the "total" amount (that is, less than 95 percent) of the constituent present in the dissolved and suspended phases of the sample. Dissolved metals are operationally defined as those that pass through 0.45 um pore filters

As soils weather and undergo development, water transports materials from upper alluvial horizons to lower alluvial horizons. The migration of ions, molecules, and particles from rock surfaces and through soil material is a very important process of soil development; water is the essential transport vehicle. As rainwater drains over rocks and percolates through the soil, its chemistry is very dynamic and the percolating water reaching each soil horizon has a composition determined by its previous path. In a reservoir, the same processes occur but downward transport of solutes from soil and rock surfaces may no longer be the dominant direction of solute transport. Rather, the materials may be carried up into the water column by advective forces, and be reflected in the limnology of the reservoir.

Geochemical weathering is accelerated by organic ligands[3/], particularly humic substances[4/] (Baker 1973; Schalscha et al. 1967; Singer and Navrot 1976; Huang and Keller 1970). Humic substances and their abilities to complex trace metals are well studied (Schnitzer and Khan 1972; Christman and Gjessing 1983). Humic substances are mild leaching agents. they have the ability to mobilize a wide variety of metal ions in rock weathering processes. Their metal leaching ability is due to their role as a ligand in natural solutions. Metal complexing capacities of humic substances vary with the sources of humus as well as the metal (Jackson, et al. 1978; Pott

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3/ In coordination chemistry, the metal cation is called the central atom. The ligands are anions or molecules which donate electrons to form a coordinate bond (Stumm and Morgan 1981).

4/ Humic substances encompass a heterogenous polymer system composed of complex organic molecules, usually with molecular weights of 300-200,000; some of which are insoluble (humins), base soluble (humic acid), or acid soluble (fulvic acid); and all of which are derived from the decomposition of vegetable or animal materials.

el al. In press; Schnitzer and Khan 1972; Singer and Navrot, 1976). Humic substances are common throughout the soils of the Watana and Devil Canyon Reservoir watersheds.

Another geochemical process that will influence metal concentration in the proposed Susitna reservoirs is ion exchange. Sorption and desorption of metal cations at the solid-solution interface will strongly influence prevailing metal speciation in the reservoirs (Stumm and Morgan 1981). As the reservoir fills, the metal ions available for sorption will adsorb onto the suspended solids until the sorption capacity or the sorbate limit is reached. If the sorbate (metal ion) concentration is limiting, then free metal concentrations will be generally low after sorption equilibrium is reached. If the sorbant (suspended solids) concentration is the limiting factor, then the equilibrium free metal concentrations will be higher. The former case, sorbate limiting, will likely be dominant in the proposed Susitna Reservoirs due to the tremendous suspended solids load in the river (APA 1983a, b).

7.2 MERCURY

OCCURRENCE IN THE SUSITNA RIVER

The U.S. Geological Survey (USGS) has monitored dissolved and total recoverable mercury at various points in the Susitna River. These data were presented in the original License Application as Figures E.2.115 and E.2.116. The detailed mercury data, taken directly from the annual USGS Water Resource Data reports, are shown in Table 7.1.

Total recoverable Hg averaged 0.2 ug/L and ranged from zero to 0.8 ug/L. Dissolved Hg averaged 0.06 ug/L, ranging from zero to less than 0.5 ug/L. The levels of dissolved Hg shown in Table 7.1 are on the high end of the range of Hg concentrations typically found in unpolluted North American surface waters (Moore and Ramamoorthy 1984). The Hg concentrations probably

TABLE 7.1
SUSITNA HYDROELECTRIC PROJECT
AVAILABLE USGS DATA - METAL ANALYSES 1/

Date d-m-y	Discharge (cfs)	Suspended Solid (mg/L)	Dissolved Organic C (mg/L)	Aluminum Total	Cadmium Total	Cadmium Dis-solved	Copper Total	Copper Dis-solved	Iron Total	Iron Dis-solved	Lead Total	Manganese Total	Manganese Dis-solved	Mercury Total	Mercury Dis-solved	Nickel Total	Zinc Total	Zinc Dis-solved
Station: Susitna River at Gold Creek (152920900)																		
140677	52,000	915	-	14,000	<10	-	50	-	20,000	100	100	370	40	0.2	-	50	80	-
100877	20,000	656	-	13,000	<10	-	50	-	18,000	-	<100	320	180	0.3	-	<50	80	-
041077	8,500	22	-	500	<10	-	<10	-	850	40	<100	20	0	0.2	-	<50	30	-
230681	17,500	327	2.8	-	0	<1	31	4	15,000	90	18	250	4	0.4	0	23	60	6
210781	42,600	680	18.0	-	5	1	190	5	19,000	120	47	320	10	0.3	0.2	29	120	10
300382	1,520	8	1.6	-	< 1	<3	2	1	40	15	3	10	3	<0.1	<0.1	2	10	<12
010782	24,500	303	2.0	-	1	1	23	3	12,000	140	<1	210	7	<0.2	<0.1	22	50	14
160982	34,600	812	-	-	1	<1	56	7	14,000	120	15	280	8	<0.2	<0.1	36	90	5
Station: Susitna River at Sunshine (15292780)																		
250381	3,800	2	2.6	-	0	<1	5	4	160	40	0	10	4	0.1	0.1	18	20	30
250681	55,000	735	-	-	0	<1	52	4	26,000	190	25	550	7	0.6	0	52	200	6
230781	86,300	713	4.7	-	1	0	42	3	23,000	250	21	450	10	0.3	0.1	29	90	20
020782	58,700	659	4.7	-	<1	<1	30	5	20,000	220	<1	400	10	0.2	<0.1	33	80	9
150982	70,100	1,620	-	-	<1	<1	75	12	29,000	200	41	620	14	0.2	0.1	40	130	17
Station: Susitna River at Susitna Station (15294350)																		
031075	47,500	159	-	-	10	0	20	5	3,800	120	<100	110	10	0.2	0.2	-	10	10
170376	5,380	2	-	-	10	0	10	2	240	60	<100	30	30	0	0.1	-	30	0
280576	67,900	257	-	-	2	1	40	10	3,300	140	16	100	0	<0.5	<0.5	-	20	0
260776	99,100	785	-	-	<10	0	50	0	26,000	30	<100	540	0	0.3	0	-	100	0
061076	30,600	191	-	-	<10	0	<10	1	5,400	40	<100	130	0	0.3	0.4	-	30	10
090377	6,790	-	-	-	<10	0	<10	2	560	90	<100	40	30	0	0	-	20	10
230577	86,800	378	-	-	<10	0	20	1	10,000	150	<100	230	8	0	0	-	50	20
190877	148,000	1,490	0.1	-	10	1	90	1	42,000	70	<100	870	20	0.2	0	-	180	4
131277	7,020	10	0.7	-	0	0	7	4	360	60	3	20	20	0	0	-	20	10
050478	6,420	2	-	-	1	1	3	1	230	60	7	20	20	0	0	-	10	10
240578	55,300	-	1.8	-	0	1	24	4	5,600	110	10	120	10	0.1	0	-	30	10
170778	120,000	773	2.3	-	2	1	45	1	24,000	20	27	500	0	0.2	0.1	-	90	10
150179	9,890	3	9.3	-	0	1	3	2	490	90	11	40	10	0.1	0	-	10	3
140579	86,800	683 2/	6.8	-	1	0	25	4	14,000	170	60	10	10	0.2	0	-	50	10
190679	95,200	416	0.9	-	1	1	29	1	12,000	0	12	250	10	0.1	0	-	60	10
170979	87,700	901	0.6	-	0	<1	37	1	26,000	40	16	580	4	0.1	0	-	80	<3
120380	9,360	3	-	-	0	0	5	2	450	150	2	30	30	0.1	0	4	20	<3
160680	144,000	458	5.9	-	0	-	26	2	16,000	20	4	270	5	0.1	0	19	50	<3
300780	207,000	1,490	3.7	-	0	0	75	3	38,000	140	16	700	10	0.1	0	40	140	7
090481	7,780	4	2.1	-	0	<1	3	0	390	160	1	30	20	0.1	0	6	60	<3
120681	88,600	326	3.4	-	2	<1	28	7	15,000	90	33	410	6	0.3	0	22	50	20
150781	173,000	920	2.9	-	0	<1	90	5	28,000	50	96	580	7	0.8	0.2	36	160	6
090482	4,000	9	-	-	<1	<3	2	1	320	65	<1	30	17	<0.1	<0.1	1	10	<12
190582	54,800	526	-	-	<1	<3	28	5	9,900	190	14	240	11	0.1	<0.1	17	60	<12
140782	103,000	797	-	-	1	<1	32	3	7,900	69	5	570	6	0.2	0.2	53	110	5

1/ All concentrations are in micrograms per liter unless otherwise indicated.
2/ Estimated

425832/7/18

reflect the natural mercury deposits in south central Alaska (Johasson and Boyle 1972 as cited by Moore and Ramamoorthy 1984).

Twenty-five to fifty percent of the total mercury in the Susitna River occurs as the dissolved species. Published investigations generally show less than ten percent of the total mercury is dissolved Hg. Mercury is usually associated with suspended particles (Jackson et al. 1978; Lockwood and Chen 1973; McNeely et al. 1979; Moore and Ramamoorthy 1984; Rudd et al. 1983).

A bivariate correlation analysis was performed to elucidate phenomena controlling Hg (and other metals) speciation in the Susitna River (see Appendix 7.20). Total recoverable Hg was significantly correlated with total recoverable Zn (r=0.5471) at least to the 0.01 level and with total recoverable lead (r=0.5538) and total recoverable copper (r=0.3936) at or beyond the 0.05 level. Dissolved Hg was not significantly correlatd with any other variable included in the analysis. Neither total nor dissolved Hg were significantly linked with river discharge, total suspended solids, or dissolved organic carbon.

POTENTIAL FOR LEACHING AND BIOACCUMULATION OF MERCURY - A LITERATURE REVIEW

Research has shown that mercury levels in aquatic biota can increase following impoundment and reservoir formation (Abernathy and Cumbie 1977; Bodaly et al. In press; Cox et al. 1979; Meister et al. 1979). The source of the mercury is the inundated soils. Bodaly et al. (In press) implicated organic topsoil horizons as the major source of accumulated mercury. Rudd et al. (1983), studying industrially produced mercury pollution in a northwest Ontario river system, reported that most mercury in the system was buried below surficial sediments (in organic-poor sediments). They found that this Hg probably did not contribute substantially to mercury bioaccumulation, which was found to occur primarily in the water column and surficial organic sediments.

Mercury is generally bioaccumulated in the methylated form (EPA 1980). Methlyation occurs by microbial action on the Hg(II) ion in both aerobic and anaerobic environments. In general, conditions enhancing the metabolism of soil and aquatic microorganisms will enhance mercury biomethylation. Rudd and Turner (1983b) demonstrated increased mercury bioaccumulation in fish was related to increased primary productivity. Wright and Hamilton (1982) showed that an increase in microbial nutrients in sediments resulted in higher rates of mercury methylation upon addition of microbial nutrients to the water column, indicating that methylation occurs primarily at the sediment- water interface.

In contrast to methylmercury's tendancy to bioaccumulate, inorganic mercury strongly favors association with particulate phases (Cranston and Buckley 1972; Hannan and Thompson 1977; Lockwood and Chen 1973; Moore and Ramamoorthy 1984). In fact, application of organic-poor sediments to <u>in situ</u> enclosures in a mercury contaminated system in Ontario resulted in decreased rates of Hg bioaccumulation (Rudd and Turner 1983a). Laboratory tests by Jernelov and Lann (1973) showed that Hg biomethylation was reduced to less than 0.1 percent after treatment with freshly ground silica. The sediments apparently bound the mercury, making it less available for bio-methylation and/or accumulation. In their mercury amelioration study, Rudd et al. (1983) concluded that elevated concentrations of suspended sediments substantially reduced methylmercury accumulation in fish, while stimulation of primary productivity increased methylmercury bioaccumulation. This concept has direct implications for assessing the potential bioaccumulation of Hg in the proposed Susitna reservoirs.

Bioaccumulation is a function of an organism's rates of uptake versus elimination. The bioaccumulation factor for mercury is high because its uptake is relatively fast, but its elimination relatively slow. High temperature accelerates the uptake of mercury compounds by accelerating the metabolic and respiratory rates of the organisms and increasing the need for food (EPA 1980; Wright and Hamilton 1982; Shin and Krenkel 1976). Similarly, low temperatures depress the rate of Hg bioaccumulation.

Mercury levels in organisms seem to vary directly with trophic position. Piscivorous fish and fish predators generally have the highest concentrations (Phillips et al., 1980; Potter et al., 1975; O'Conner and Nielson 1981; Kucera 1982). Work by Fimreite et al. (1971) in Canada showed the magnification of mercury from fish to fish-eating birds. Swedish research (Skerfving et al. 1970) has demonstrated the transference of methylmercury to humans eating contaminated fish; this same research showed a statistically significant ($r=0.6$; $P<0.05$) correlation between mercury concentrations and the frequency of and chromosome breaks in red blood cells.

Implications for the Susitna Hydroelectric Project

Data on mercury occurrence in the Susitna watershed in insufficient to make conclusive statements on Hg speciation and present levels in the watershed biota. However, this review of relevant literature supports the following conclusions regarding the potential bioaccumulation of mercury in fishes in the Susitna Reservoirs.

Soils in the project impoundment zones are fairly typical of those formed in cold, wet climates on glacial till or outwash. They include acidic, saturated, peaty soils of wet areas; acidic, relatively infertile soils of the forests; and raw gravels and sands along the river. After inundation, microbiological methylation of mercury from the organic soil horizons of Watana and Devil Canyon Reservoirs is likely to result in mercury levels in the reservoir fish higher than current concentrations.

Environmental conditions at the sediment-water interface in Watana and Devil Canyon Reservoirs will tend to minimize biomethylation and subsequent bio-accumualtion of natural mercury in the reservoirs. Methylmercury release from sediments at 4°C has been found to be 50 to 70 percent of that at 20°C, in laboratory studies (Wright and Hamilton 1982). Biomethylation is directly related to microbiological activity in sediments (Bisogni and

Lawrence, 1975; Shin and Krenkel 1976; Wright and Hamilton 1982). This implies that biomethylation will be low in the oligotrophic Susitna Reservoirs. Additionally, the high inputs of inorganic suspended sediments (glacial flour) may scavenge mercury from the water column. Much of the suspended solids will settle to the floor of the reservoir and blanket the inundated soils and vegetation. This will tend to isolate the organic matter reported to be the major source of mercury for methylation and bioaccumualtion.

Thus, even though there will likely be some detectable increases of mercury in reservoir fishes in both impoundments, natural conditions may tend to keep these increases low. Furthermore, fish populations in the reservoirs are not expected to be high, nor are they expected to be significantly harvested by man (APA 1983a, b; FERC 1984).

Bioaccumulation of mercury occurs rapidly, within one to three years of impoundment. Abernathy and Cumbie (1977) showed that mercury bioaccumulation by fish in new South Carolina impoundments decreases with reservoir age, beginning as early as five years after impoundment. However in northern Manitoba, Bodaly et al. (In press) found no significant declines in fish mercury levels within five to eight years after impoundment, with the possible exception of whitefish (Coregonus clupeaformis). Reservoirs age more quickly in the temperate climate of South Carolina than in subarctic northern Manitoba. The mercury methylation and bioaccumulation rates, which vary directly with the aging process, may decrease due to the following combination of factors:

- Relatively cold temperture;
- Low levels of reservoir primary productivity;
- Death and replacement of the initial fish population;
- A continually deepening layer of predominately inorganic sediment which is expected to act as a blanket to isolate the inundated soils and vegetation from the overlying water column.

It is therefore, likely that biota in the proposed impoundments will experience an initial increase in bioaccumulation of mercury during and after filling, however, the bioaccumulation should decrease as the reservoir ages.

We have found no studies of mercury accumulation in fish downstream from newly impounded reservoirs. The impact of the Project on mercury accumulation in fish downstream will be a function of mercury exported from the reservoirs and in situ affects on mercury in downstream habitats. Since mercury is transported primarily in suspension (inorganic Hg), a net reduction in the flux of mercury downstream will result from impoundment construction. The extent of transport of methylmercury from the reservoirs cannot be predicted. Mercury accumulation in fish downstream from the dams may be largely a process of in situ (riverbed) methylation and uptake. This will be influenced by Project-related changes in river productivity at all trophic levels. Instream mercury methylation (and accumulation) may change with alterations in microbial action resulting from changes in streamflow variability, suspended sediments, turbidity, temperature, productivity, and supply of organic carbon to methylating bacteria.

RISK TO THE PUBLIC

State water quality criteria for the "growth and propagation" of fish, shellfish and other aquatic life and wildlife (ACC 1984) cite federal criteria for toxic metals. The criterion for mercury of all forms (total recoverable Hg) is 0.05 ug/L (EPA 1976). A critique of this criterion states that many natural waters exceed this level of Hg (Klein et al. 1979) and suggests future criteria distinguish between various mercury species. Upon examination of the Hg levels shown in Table 7.1, it is obvious that the Hg criterion is consistently being exceeded in the Susitna River, although 0.05 ug/L is below the 0.1 ug/L limit of detectability for the USGS method (APA 1983a, b).

A complete risk assessment is not possible with the existing data base. Dose (dietary Hg) and effect (somatic and genetic) relationships would need to be estimated. Current levels of Hg in resident fishes are not known. The incremental increase in health risk due to impoundment, leaching and bioaccumulation of Hg is not yet quantifiable.

SUMMARY

Post-impoundment water quality studies have shown only one metal, mercury, to systematically bioaccumulate to ecologically dangerous concentrations as a direct result of river impoundment (Abernathy and Cumbie 1977; Bodaly et al. In press; Meister et al. 1987).

After impoundment, microbial methylation of mercury from organic matter in soils and newly inundated detritus of Watana and Devil Canyon Reservoirs is likely to result in mercury levels in reservoir fish higher than current concentrations. However, certain environmental conditions in the reservoirs will tend to minimize mercury biomethylation and subsequent bioaccumulation notably:

- Low year-round water temperature;
- Low benthic microbiological activity;
- Continual Blanketing of inundated organic matter with a layer of inorganic sediments;
- Relatively limited fish populations.

The impact of the Project on mercury in downstream fishes will be a function of two things: mercury exported from the reservoirs and *in situ* methylation and uptake of mercury in downstream habitats. Total flux of mercury downstream of the proposed reservoirs will be substantially less than under current conditions. Methylmercury leaving the reservoirs is not predictable. Mercury accumulation in fish downstream may be largely due to *in situ* methylation and uptake, but will likely be influenced by Project-induced changes in stream biological productivity.

7.3 CADMIUM

OCCURRENCE IN THE SUSITNA RIVER

As with mercury, the USGS has monitored cadmium (Cd) levels in the Susitna River in recent years. The results of their monitoring are shown in Table 7.1 and appear in the original License Application as Figure E.2.107 and E.2.108. Total recoverable Cd ranged from zero to ten ug/L; dissolved Cd was always measured to be to be less than three ug/L. These concentrations are not unusual for surface waters (Giesy and Briese 1977; Giesy and Briese 1980; McNeely et al. 1979; Moore and Ramamoorthy 1984; Steinberg 1980). Total and dissolved Cd were not significantly correlated to any other variable, including Zn, a common associate of Cd in nature.

POTENTIAL FOR LEACHING AND BIOACCUMULATION OF CADMIUM

We have found no published studies on cadmium leaching from inundated soils at new impoundments. Some leaching of Cd may be expected, but the amount should be rather low. A more quantitative estimate is not possible using the existing data base. Assuming soil Cd levels are not high, Cd leaching by humic substances will be less than many other metals, (such as Cu of Pb) because cadmium has a lower affinity for humic ligands (Giesy et al. 1978; Schnitzer and Khan 1972). Cadmium is not known to biomagnify in the food chain (McNeely et al, 1979; Selby et al. 1983).

RISK TO THE PUBLIC

State water quality criteria cite EPA (1976) standards: 1.2 ug Cd/L in hard water, 0.4 ug Cd/L in soft water. Total hardness in the Susitna River is typically between 45 and 70 mg/L as $CaCO_3$, so it is considered a moderately hard water (Todd 1970; Britton et al. 1983). Confusion about the criterion is added as EPA (1976) does not distinguish between total or dissolved cadmium. The International Join Commission (1977, as cited by

McNeely et al. 1979) has set a limit, for protect of aquatic life, at 0.2 ug/L. Comparison of these criteria with the Cd levels found in the Susitna River (Table 7.1) indicates that the levels for protection of freshwater aquatic life may be exceeded on occasion by natural variation. More accurate data and criteria are needed to completely elucidate the situation.

Cadmium does accumulate in exposed biota; accumulation is not related to trophic position. Moore and Ramamoorthy (1984) summarize Cd bioaccumulation; Cd is accumulated primarily in major organs of fish (liver, gut, skin) rather than muscle tissue so it is little threat to consumers of fish meat. Cadmium uptake is lessened by the presence of chelating agents, including humic acids (Giesy et al. 1977).

With the above discussion in mind, impoundment of the Susitna River does not present a significant risk to public health, with regard to the leaching and bioaccumulation of cadmium in the proposed reservoirs.

7.4 COPPER

Total and dissolved copper (Cu) concentrations in the Susitna River are included in Table 7.1 and in the original License Application as Figures E.2.109 and E.2.110. These data have been compiled from the annual USGS Water Resources Data Reports. Total recoverable Cu averaged 43 ug/L and ranged from less than ten ug/L to 190 ug/L. Dissolved Cu averaged 3.3 ug/L, ranging from zero to twelve ug/L. These levels of Cu are on the higher end of the range of concentrations found in unpolluted surface waters (McNeely et al. 1979; Moore and Ramamorhy 1984).

Copper is transported in the Susitna River primarily in the particulate phase; this agrees with Gibbs' (1977) study of Cu transport in the Yukon River. In warmer areas, having streams with lower levels of suspended solid, higher levels of organic carbon, and pH values less than neutral, Cu is transported primarily as the soluble form (Eisenreich et al. 1980; Geisy and Briese 1978; Tessier et al. 1980).

Total recoverable Cu concentrations in the Susitna River were significantly correlated with river discharge (r=0.4413), total suspended solids (r=0.6584), dissolved organic carbon (r=0.5974), total recoverable Fe (r=0.6634), total recoverable Mn (r=0.6025) and total recoverable Zn (r=0.7053), at least to the 0.01 level. Total recoverable Cu was correlated to total recoverable lead, total recoverable Hg and total recoverable Ni at least to the 0.05 level of significance (r=0.4998, 0.3936, and 0.4773 respectively). Dissolved Cu was found only to be correlated to dissolved Fe (r=0.4634, P<0.01). The correlation analyses strongly suggests the geochemical abundance of Cu in the watershed; the strongest correlations of total Cu were found with suspended solids, total Fe, total Mn and total Zn. Copper is frequently found in natural deposits with Zn, particularly in mining areas (McNeely et al. 1979).

POTENTIAL FOR LEACHING AND BIOACCUMULATION OF COPPER AND RISK TO THE PUBLIC

We have found no specific studies on Cu leaching from the soils of newly impounded reservoirs. No data on the content or form of Cu in the impoundment zone soils and rocks are available. However, the potential for leaching of Cu exists. Singer and Navrot (1976) showed that humic acids extract Cu (preferentially according to the relative amounts of other metals) from basalt rocks. Baker (1973) demonstrated the role of soil humic acids in solubilizing metals from various minerals; again, Cu was highly extracted, relative to other metals. Schnitzer and Khan (1972) noted copper's particular affinity for humic and fulvic ligands. This affinity is the basis for the ability of these materials to extract Cu from minerals. However, organocopper complexes are significantly less toxic than free Cu or hydroxocopper, so increased levels of dissolved Cu do not necessarily indicate a more biologically toxic condition in the aquatic habitat (Moore and Ramamoorthy 1984).

Several field studies have shown that Cu does not biomagnify in the food chain. In fish, the primary site of Cu accumulation is the liver; muscle residues are generally low, even in polluted waters (Moore and Ramamoorthy

1984). Humans possess a natural excretion mechanism for excess Cu (McNeely et al. 1979). As such, copper does not pose a significant threat to fisheries in the Susitna River.

7.5 ZINC

OCCURRENCE IN THE SUSITNA RIVER

Total recoverable and dissolved zinc concentrations in the Susitna River, as reported by USGS, are shown in Table 7.1. Total Zn varies from ten to 200 ug/L, averaging 66 ug/L. Dissolved Zn never measured over 30 ug/L and was typically between zero and ten ug/L. These levels of Zn are within typical ranges found in natural surface waters (McNeely et al. 1979; Moore and Ramamoorthy 1984). A 1967 nationwide survey reported a mean concentration of 64 ug/L (Kopp and Kroner 1967 as cited by EPA 1976).

The bivariate correlation analysis indicates that Zn behaves similar to Cu in the system; this is not unusual given the proximity of the two elements to each other in the Periodic Table of the Elements. Similar behavior of the two metals has been observed in other systems (Giesy and Briese 1978). Total Zn in the Susitna River is correlated to river discharge (r=0.6376), total suspended solids (r=0.8403), total Cu (r=0.7053), total Fe (r=0.8722), total Mn (r=0.8840), total Hg (r=r.5471) and total Ni (r=0.8123) at least to the 0.01 level of significance. Total Zn is also correlated to total Pb (r=0.4406, $P<0.05$). Dissolved Zn is negatively correlated to total Ni (r=0.6158, $P<0.05$). Contrary to studies of trace metal speciation in other systems, Zn is transported in the Susitna River primarily in the particulate phase. As is the case with copper, studies elsewhere have shown that Zn is transported primarily in the soluble phase (Benes and Steinnes 1974; Giesy and Briese 1978; Moore and Ramamoorthy, 1984; Tessier et al. 1980). The significant association between Zn, Cu and Pb suggests deposits of their carbonate and/or sulfide ores in the watershed, as these minerals frequently occur together in nature (McNeely et al. 1979).

POTENTIAL FOR LEACHING AND BIOACCUMULATION OF ZINC

We have found no studies of changes in zinc concentrations in the water column or biota of newly impounded reservoirs. It may be possible that some Zn will be leached from inundated rocks and soils, but it is impossible to quantify this with the existing data base. Studies have shown that Zn can be leached from soils and rocks by humic acids. Singer and Navrot (1976) demonstrated Zn is second only to Cu in transition metal extractability by humic acid (relative to the metal's content) from basalt rock. Baker (1973) demonstrated the ability of humic acids to extract trace quantities of Zn from various minerals and soils.

Zinc does not biomagnify as a function of trophic position. Fish normally obtain the majority of Zn from dietary sources rather than from water, with the highest residues found in specific organs: liver, kidney, spleen, gonads, pancreas. Relatively low levels of zinc are generally found in muscle tissue (Moore and Ramamoorthy 1984).

RISK TO THE PUBLIC

The original License Application states that water quality criteria for Zn have been exceeded on one or more occasions. It references the McNeely et al. (1979) criterion of 0.03 mg Zn/L for the protection of aquatic life. The State of Alaska's criterion is 1% of the 96-hour LC_{50}[4/] determined via continuous flow bioassay or 5 mg/L, whichever is less (ACC 1984). No Zn bioassay tests have been performed using the Project waters.

Regardless of the criterion, aquatic life appears to be functioning in the Susitna River with the natural levels of Zn (there is the possibility of some anthropogenic Zn from placer mining activities and atmospheric

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4/ Lethal concentration killing 50% of the organisms in 96 hours.

deposition). This element does not appear to present a hazard to the public from impoundment of the river. Zinc accumulates in fish organs, not muscle tissue, so dietary sources to man would be minimal even if Zn bioaccumulation was greater than present conditions.

7.6 MANGANESE

OCCURRENCE IN THE SUSITNA RIVER

As with other metals, total recoverable and dissolved manganese levels have been monitored in the Susitna River. These data are included in Table 7.1. Total recoverable Mn ranged from ten to 700 ug/L, averaging 270 ug/L. Dissolved Mn had a mean concentration of 15.6 ug/L and varied from zero to 180 ug/L. These values, although stated to exceed applicable water quality criteria, are typical of those found in natural surface waters (Chapnick et al. 1982; Eisenreich et al. 1980; Gibbs 1977). The total Mn concentrations are probably high, due to the high suspended sediment concentrations; total recoverable Mn in the Susitna River is significantly correlated to suspended solids ($r=0.8997$, $P<0.01$). Total recoverable Mn is also correlated to river discharge ($r=0.7664$), total recoverable Cu ($r=0.8482$) and total recoverable Zn ($r=0.8840$) at least to the 0.01 level of significance. Dissolved Mn was not found to correlate to any other variable included in the correlation analysis.

Obviously, Mn is transported primarily as part of the suspended sediment load in the Susitna River. Similarly, Gibbs (1977) found about 90% of the total Mn in the Yukon River to be transported in the particulate phase. Hydroxide coatings on particles and crystalline solids accounted for 46% and 37%, respectively, of the total Mn in the Yukon River. Gibbs found about 10% of the total Mn to be the dissolved form.

Laxen, et al. (1984) have suggested a "decoupling" of the traditional process oriented interpretation of Mn speciation; their observations do not support a link between particulate and soluble Mn phases in rivers and streams (their conclusions are not applicable to lakes). They describe two sources of manganese. One, the result of weathering processes, produces particulate Mn, a part of the suspended sediment load. The other accounts for dissolved Mn: the influx of reduced, soluble Mn (II) species leached from anoxic soil and groundwaters. Hence, hydrogeological conditions seem to govern Mn speciation in riverine systems with short residence times. Equilibrium chemistry and biological mediation govern Mn speciation in lakes and reservoirs having longer residence times. The Mn data of preproject conditions may therefore not be of great value in predicting reservoir and downstream Mn levels following river impoundment.

POTENTIAL FOR LEACHING AND BIOACCUMULATION OF MANGANESE

A number of laboratory and field studies expose the speciation dynamics of Mn in lakes and reservoirs. The chemistry of Mn is dominated by redox transitions between the relatively soluble reduced Mn (II) species and the highly insoluble oxidized Mn (IV) form. In aerated freshwaters, the equilibrium species are Mn (IV) phases (Stumm and Morgan 1981). As reservoirs stratify, anaerobiosis may develop in the hypolimnion, and Mn (II) will become the dominate form. This phenomenon is well documented (Hutchinson 1975).

The potential for leaching Mn from inundated soils and rocks is directly related to the potential for anaerobiosis in the proposed reservoirs. The likelyhood of the latter is a function of many factors, the primary two being the amount of organic material remaining in the reservoir zones upon impoundment and seasonal hydrodynamics of the reservoirs. Little if any anaerobiosis is expected in either reservoir. Therefore, little leaching (or solubilization) of Mn is predicted. Without elevated concentrations of soluble Mn, levels of Mn in biota are not expected to be above current concentrations.

RISK TO THE PUBLIC

No bioaccumulation of manganese is expected to result from impoundment of the Susitna River. As such, the incremental risk to the public is nil.

7.7 IRON

OCCURRENCE IN THE SUSITNA RIVER

Total and dissolved iron concentrations in the Susitna River, as published annually by the USGS, are tabulated (Table 7.1). Total Fe varied from 40 to 42,000 ug/L, averaging 12,816 ug/l. Dissolved Fe averaged 103 ug/L and ranged from zero to 250 ug/L. The concentrations of dissolved Fe are within natural ranges for surface waters, and, considering the suspended solids load, the total Fe levels are not unexpected.

The high total iron concentrations are probably due to the suspended sediments: total Fe in the Susitna River is significantly correlated to total suspended solids ($r=0.9248$; $P<0.01$). Total Fe concentration is also correlated to river discharge ($r=0.7713$), total Cu ($r=0.6634$), total Mn ($r=0.9306$), total Ni ($r=0.7190$), and total Zn ($r=0.8722$) at or beyond the 0.01 level of significance. Total Fe is also correlated to total Pb ($r=0.4994$, $P<0.05$). Dissolved Fe significantly correlated only to dissolved Cu ($r=0.4634$, $P<0.01$).

The primary mechanism of Fe transport in the Susitna River is suspension in the water column as particles. A similar conclusion for Fe transport in a glacial river was reached by Gibbs (1977) studying the Yukon River. Gibbs found less than 1% of total Fe to be the dissolved species. He found 48% of the Yukon's total transported Fe to be in crystalline particles and another 40% as sorbed metallic coatings (mainly ferric hydroxide) on these crystalline substrata. Eleven percent was an organic solid phase. Only the latter two Fe fractions may be considered biologically available.

Therefore, if generalizations can be permitted, perhaps about 50% of the total recoverable iron concentrations in the Susitna River (Table 7.1) are available to biota.

In studies on non-glacial systems, Gibbs (1977) showed a similar Fe speciation for the Amazon River. Tessier et al. (1980) found similar Fe speciation in 2 Quebec rivers. Eisenreich et al. (1980) found about 68% of total Fe to be crystalline particles in suspension at nonurban sites on the upper Mississippi River (19% was the dissolved specie). Numerous authors have found dissolved Fe to be controlled by the dissolved organic carbon concentration, but our correlation analysis showed no significant ($P>0.05$) relationship in the Susitna River (Beck et al. 1974; Giesy and Briese 1978).

POTENTIAL FOR LEACHING AND BIOACCUMULATION OF IRON

Four published studies relating to changes in iron concentrations in planned impoundments have been located and reviewed. Sylvester and Seabloom (1965) studied soils in the preimpoundment zone and water in the developed Howard A. Hanson Reservoir, near Tacoma, WA. In batch soil reaction studies they found anaerobiosis caused elevated Fe levels which continued until a time (about 25 days) when Fe began to coagulate with tannin and lignin compounds and precipitate. Following impoundment, a slight rise occurred in Fe levels in Reservoir water. Another batch leaching study on preimpoundment zone soils was done by Keup et al. (1970) on the Northeast Cape Fear River in eastern North Carolina. They concluded that elevated iron concentrations would result due to the high organic content of the impoundment zone soils. Keup et al. (1970) also found higher levels of Fe in anaerobic batches than in aerobic experiments. In soil leaching studies of various proposed reservoir sites in Alaska, Smith (1980) and Smith and Justice (1975) found Fe in the leachates (which were oxygen deficient or anaerobic) to increase with time in soils with substantial organic mats.

Much research has indicted organic solutes in Fe mobilization. Singer and Navrot (1976) found Fe to be the most humic acid-extractable metal in basalt rock (it was however poorly extractable, relative to the amount present). Baker (1973) showed the ability of humic acid to extract Fe from various silicate minerals (i.e. feldspar, biotite, enstatite, actinolite, and epidote). Perdue, et al. (1976) demonstrated the correlation between dissolved Fe and dissolved organic carbon in southeastern US surface waters.

Hence it appears reasonable to predict that Fe leaching will be exacerbated in the proposed Susitna reservoirs if the organic material is not cleared prior to impoundment. Organic material in the reservoir will decompose, exert an oxygen demand, and if the reservoir thermally stratifies, reduce less soluble ferric ion (Fe^{3+}) to the much more soluble ferrous iron (Fe^{2+}). This will lead to elevated iron concentrations in the reservoirs.

We have found no evidence that iron bioaccumulates with trophic position; iron bioaccumulation is not expected to occur in the Project Reservoirs.

RISK TO THE PUBLIC

The original License Application states that total (recoverable) iron in the Susitna River exceeded the water quality criterion on numerous occasions. The original License Application cites the EPA (1976) and Sittig (1981) criteria of 1 mg Fe/L for the protection of freshwater organisms. The State of Alaska water quality standards reference the federal criteria or one percent of the lowest measured 96-hour LC_{50} bioassay test, whichever is lower. These criteria however do not distinguish between total Fe and dissolved Fe. This discrepancy necessitated that total Fe must meet the criterion, an unrealistic expectation for streams carrying glacial flour. Generally, about 99% of the Fe in the Susitna River is carried in the suspended sediment load. The dissolved Fe concentrations do not exceed the 1 mg/L limit (Table 7.1), presenting little risk to the public. The total Fe concentrations will decease following impoundment since the suspended sediment load will decrease substantially (APA 1983).

7.8 ALUMINUM, LEAD, NICKEL, AND BISMUTH

ALUMINUM

Occurrence in the Susitna River

Limited monitoring of Al has been done in the Susitna River. Data provided by USGS is given in Table 7.1. R and M Consultants, Inc. (1982) provide data on dissolved aluminum concentrations. Total and dissolved alluminum data are presented in the original License Application as Figures E.2.104 and E.2.105. Total Al levels are high, but not unexpected for glacial rivers such as Susitna. The high total Al concentrations are likely associated with the large suspended sediment loads. Dissolved Al levels are very high, these levels are beyond the concentrations expected in natural waters and suggest significant acid mine drainage in the watershed or contamination during sampling (Jones et al. 1974; Stumm and Morgan 1981).

Potential for Leaching and Bioaccumulation of Aluminum

Aluminum is a practically ubiquitous element on earth, but surprisingly, its environmental behavior, toxicity and bioavailability is not completely understood. No reports have been found indicating Al leaching occurs following reservoir impoundment. Nor is Al leaching likely. Aluminum minerals are not very soluble. Admittedly, humic acids do bind Al but concentrations or organic acids in the Susitna River are insufficient to cause ecologically hazardous levels of leaching (Perdue et al. 1976; Pott et al. In press; Singer and Navrot 1976).

Relatively little research has been performed on bioaccumulation of Al in aquatic animals. Al can be found at trace levels in the tissues of almost every organism (Burrows 1977). Little evidence exists to indicate an Al bioaccumulation problem in the potential reservoirs.

LEAD

Occurrence in the Susitna River

Total recoverable lead concentrations are included in Table 7.1. Total recoverable Pb was typically 23 ug/L, ranging from zero to 199 ug/L. Although not unusual for mining areas, these concentrations of Pb are rather high (Giesy and Briese 1978; Moore and Ramamoorthy 1984; Tessier et al. 1980).

The high levels of Pb in the Susitna River are probably due to the high suspended sediment load. Total recoverable Pb correlated with suspended solids (r=0.4709), total recoverable Cu (r=0.4998), total recoverable Fe (r=).4994), total recoverable mercury (r=0.4406) at least to the 0.05 level of significance.

Potential for Leaching and Bioaccumulation of Lead

There is very little potential for Pb to be leached from the newly flooded soils. Lead minerals are not very soluble (McNeely et al. 1977). We have found no recorded instances of elevated Pb concentrations in newly impounded reservoirs.

Although Pb can be isolated from the tissues of many aquatic organisms, residues in organisms from unpolluted waters are not great. Pb is not a threat to fishery resources except in cases of extreme pollution (Moore and Ramamoorthy 1984). Methylation of Pb is rare in nature and consequently organolead is seldom found in fish tissues. The 96-hr LC_{50} for total Pb generally falls within the range 500 to 10,000 ug/L, well above the levels recorded in the Susitna River (Moore and Ramamoorthy 1984).

NICKEL

Occurrence in the Susitna River

Total recoverable Ni concentrations in the Susitna River are shown in Table 7.1. Averaging 27 ug/L, the concentrations range from one to 53 ug Ni/L. These levels are comparable to those found in the Yukon River by Gibbs (1977). McNeely et al. (1979) report that the median freshwater concentration of Ni in North American river is 100 ug/L, however our review of the literature suggests a typical concentration closer to 20 ug/L (Gibbs 1977; Giesy and Briese 1978, Moore and Ramamoorthy 1984; Steinberg 1980). Total recoverable Ni in the Susitna River correlated with total recoverable Mn ($r=0.8482$) and total recoverable Zn ($r=0.8123$) at least to the 0.01 level of significance. Total Ni also significantly correlated to dissolved Zn ($r=0.6158$, $P<0.05$).

Potential for Leaching and Bioaccumulation of Nickel

No evidence has been found to indicate that elevated Ni concentrations occur in new reservoirs. Humic acids can leach limited amounts of Ni from basalt rock, but these products will likely be rapidly adsorbed onto suspended particles (Singer and Navrot 1976).

Nickel does not bioaccumulate as a function of trophic position. Nickel accumulates more readily in fish organs (liver, kidney, gills) than muscle (Hutchinson et al. 1975 as cited by Moore and Ramamoorthy 1984). In the heavily polluted Illinois River, average concentrations of Ni in sediments, invertebrates, and in the muscle of omnivorous and carnivorous fish were 27, 11, 0.18, and 0.13 mg/kg respectfully (Mathis and Cummings 1973 as cited by Moore and Ramamoorthy 1984). Little risk from Ni is therefore likely to consumers of resident fishes following impoundment of the Susitna River.

BISMUTH

Very little ecological information on bismuth has been located. Manual search for such included Chemical Abstracts, Biological abstracts, Pollution Abstracts, and various texts on toxicology and environmental health.

The original License Application states that dissolved Bi exceeded the recommended criterion of 3.5 ug Bi/L. However the detection limit for the analytical method was 50 ug/L (R and M Consultants, Inc. 1982 as cited by APA 1983a, b). The original License Application contained information on 26 analyses of Bi in Susitna River water, of these 26, dissolved Bi was detected 3 times. Data on Bi occurrence in the Susitna River, and the ecological significance of such is insufficient to generate conclusive statements on potential leaching and/or bioaccumulation in the proposed reservoirs. However, we have not found any reports or publications suggesting Bi-related ecological problems in water development projects.

7.9 CONCLUSIONS AND RECOMMENDATIONS

This review of the literature has resulted in an understanding of the risk to the general public due to leaching of metals from soils in the impoundment zone of the proposed Susitna Reservoirs. Increased concentrations of toxic metals in the reservoir waters may result from:

1. Dissolution of inundated soils and rocks;

2. Increased rates of mineral dissolution due to the chelation of metals by humic substances;

3. Biologically - mediated reactions involving metals in flooded topsoil horizons.

Our literature review has found only one metal, mercury, to systematically bioaccumulate to ecologically dangerous concentrations as a direct result of impoundment (Abernathy and Cumbie 1977; Bodaly et al. In press, Cox et al. 1979; Meister et al. 1979). Other metals, even though present in relatively high concentrations in the Susitna River, are not likely to present a leaching on bioaccumulation problem following impoundment.

After impoundment, microbial methylation of mercury from newly inundated materials of Watana and Devil canyon Reservoirs is likely to result in mercury levels in reservoir fish higher than current concentrations. Environmental conditions in the reservoirs will tend to minimize mercury biomethylation and subsequent bioaccumulation.

The impact of the Project on mercury in fishes downstream of the reservoirs will be a function of two things: mercury exported from the reservoirs and in situ methylation and uptake of mercury in downstream habitats. Total flux of mercury downstream of the proposed reservoirs will be substantially less than under current conditions. Methylmercury concentrations leaving the reservoirs are not predictable. Mercury accumulation in fish downstream may be largely due to in situ methylation and uptake, but will likely be influenced by Project-induced changes in stream biological productivity at all trophic levels.

Total recoverable concentrations of all metals transported downstream will decline following river impoundment. Much of the total recoverable moieties are associated with the suspended solids; since the reservoirs will trap much of the suspended sediment load, total metal concentrations downstream of the project should decrease following impoundment.

There appears to be little potential for leaching and bioaccumulation of heavy metals in the proposed reservoirs, with the notable exception of mercury. No mitigation plans have been formulated; rather studies should first define the occurrence of heavy metals in the water and aquatic biota.

7.10 Appendix - Correlation Analysis of Metals and other Aquatic Habitat Characteristics

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PROBLMMETALS17    3001                                          1
DELETE0001
(F6.0,F4.0,F3.1,2F2.0,F3.0,F2.0,F5.0,4F3.0,1X,2F1.1,1X,F2.0,F3.0,F2.0)
 52000 915        50  20000100100370 40 2  50 00
 20000 656        50  10000     320100 3     00
  8500  22              850 40    20  0 2    30
 17500 327 28 0   31 415000 90 10250  4 40 23 60 6
 42600 680180 5 1190 519000120 47320 10 32 2912010
  1520   0 16      2 1   40 15  3 10  3     2 10
 24500 303 20 1 1 23 312000140   210  7    22 5014
 34600 812     1  56 714000120 15200  0    36 90 5
  3800   2 26 0    5 4  160 40  0 10  4 11 10 2030
 55000 735    0   52 426000190 25550  7 60 52200 6
 86300 713 47 1 0 42 323000250 21450 10 31 29 9020
 58700 659 47     30 520000220   400 10 2  33 00 9
 701001620         751229000200 41620 14 21 4013017
 47500 159    10 0 20 5 3000120   110 10 22     1010
  5300   2    10 0 10 2  240 60    30 30 01     30 0
 67900 257     2 1 4010 3300140 16100  0        20 0
 99100 705      0 50 026000 30   540  0 30    100 0
 30000 191      0     1 5400 40   130  0 34     3010
  6790          0    2  560 90    40 30 00     2010
 86000 370      0 20 110000150   230  0 00     5020
148000149000110 1 90 142000 70   870 20 20    100 4
  7020  10007 0 0  7 4  360 60  3 20 20 00     2010
  6420   2     1 1  3 1  230 60  7 20 20 00     1010
 55300      10 0 1 24 4 5600110 10120 10 10     3010
120000 773 23 2 1 45 124000 20 27500  0 21     9010
  9090   3 93 0 1  3 2  490 90 11 40 10 10     10 3
 86600 603 60 1 0 25 414000170 60 10 10 20     5010
 95200 416009 1 1 29 112000  0 12250 10 10     6010
 87700 901006 0    37 126000 40 16580  4 10     00
  9360   3    0 0  5 2  450150  2 30 30 10  4 20
144000 458 59 0   26 216000 20  4270  5 10 19 50
2070001490 37 0 0 75 338000140 16700 10 10 40140 7
  7780   4 21 0    3 0  390160  1 30 20 10  6 60
 88600 326 34 2   28 715000 90 33410  6 30 22 5020
173000 920 29 0   90 520000 50 96500  7 02 36160 6
  4000   9         2 1  320 65    30 17      1 10
 54800 526        20 5 990190 14240 11 1  17 60
103000 797     1  32 3 7900 69  5570  6 22 53110 5
FINISH
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input file "METALS"
to BMD03DX

BMD03D - CORRELATION WITH ITEM DELETION - REVISED DECEMBER 24, 1975
HEALTH SCIENCES COMPUTING FACILITY, UCLA

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PROBLEM CODE.....................METALS
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NUMBER OF CASES..................    38
NUMBER OF TRANSGENERATION CARDS..     0
NUMBER OF VARIABLES ADDED........     0
NUMBER OF VARIABLE FORMAT CARD(S)    01
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TRANSGENERATION (IF ANY) OCCURS BEFORE ITEM DELETION

VARIABLE FORMAT CARD(S)
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MEANS AND STANDARD DEVIATIONS

VARIABLE	MEAN	STANDARD DEVIATION	NUMBER OF ITEMS
01	58606.8421	51892.5819	38
02	500.9722	450.7574	36
03	3.8450	4.0358	20
04	3.4206	3.7151	14
05	1.0000	0.0000	09
06	37.0057	36.0738	35
07	3.5152	2.6235	33
08	12815.5263	11559.7593	38
09	103.0270	61.5237	36
10	24.1200	26.6432	25
11	270.0000	236.4032	38
12	17.9091	30.4399	33
13	0.2206	0.1607	20
14	0.1700	0.0949	10
15	26.6000	16.1454	20
16	65.5263	49.5219	30
17	10.8800	6.2538	25

VARIABLE NUMBER	VARIABLE NAME
1	Discharge
2	Total Suspended Solids
3	Dissolved Organic Carbon
4	Total Cadmiun
5	Dissolved Cd
6	Total Copper
7	Dissolved Cu
8	Total Iron
9	Dissolved Fe
10	Total Lead
11	Total Manganese
12	Dissolved Mn
13	Total Mercury
14	Dissolved Hg
15	Total Nickel
16	Total Zinc
17	Dissolved Zn

CORRELATION MATRIX
(SAMPLE SIZES IN PARENTHESES)

VARIABLE NO.

		01	02	03	04	05	06	07	08	09	10
01	*	1.00000	0.73130	-0.09025	-0.03320	0.00000$	0.44128	0.04265	0.77128	0.02150	0.32017

		(38)	(36)	(20)	(14)	(09)	(35)	(33)	(38)	(36)	(25)
02	*	0.73130 (36)	1.00000 (36)	-0.01270 (19)	0.04817 (14)	0.00000$ (08)	0.65845 (34)	0.30078 (31)	0.92483 (36)	0.25354 (34)	0.47091 (24)
03	*	-0.09025 (20)	-0.01270 (19)	1.00000 (20)	0.05444 (08)	0.00000$ (07)	0.59737 (20)	0.32106 (19)	-0.02258 (20)	0.23073 (19)	0.29727 (16)
04	*	-0.03320 (14)	0.04817 (14)	0.05444 (08)	1.00000 (14)	0.00000$ (07)	0.18410 (14)	-0.14087 (14)	0.12954 (14)	-0.28064 (13)	0.46743 (10)
05	*	0.00000$ (09)	0.00000$ (08)	0.00000$ (07)	0.00000$ (07)	1.00000 (09)	0.00000$ (09)	0.00000$ (09)	0.00000$ (09)	0.00000$ (08)	0.00000$ (07)
06	*	0.44128 (35)	0.65845 (34)	0.59737 (20)	0.18410 (14)	0.00000$ (09)	1.00000 (35)	0.30428 (31)	0.66341 (35)	0.11488 (33)	0.49978 (25)
07	*	0.04265 (33)	0.30078 (31)	0.32106 (19)	-0.14087 (14)	0.00000$ (09)	0.30428 (31)	1.00000 (33)	0.15007 (33)	0.46336 (32)	0.34319 (23)
08	*	0.77128 (38)	0.92483 (36)	-0.02258 (20)	0.12954 (14)	0.00000$ (09)	0.66341 (35)	0.15007 (33)	1.00000 (38)	0.18885 (36)	0.49939 (25)
09	*	0.02150 (36)	0.25354 (34)	0.23073 (19)	-0.28064 (13)	0.00000$ (08)	0.11488 (33)	0.46336 (32)	0.18885 (36)	1.00000 (36)	0.05233 (24)
10	*	0.32017 (25)	0.47091 (24)	0.29727 (16)	0.46743 (10)	0.00000$ (07)	0.49978 (25)	0.34319 (23)	0.49939 (25)	0.05233 (24)	1.00000 (25)
11	*	0.76639 (38)	0.89967 (36)	-0.12569 (20)	0.11304 (14)	0.00000$ (09)	0.60253 (35)	0.14932 (33)	0.93063 (38)	0.11033 (36)	0.34512 (25)
12	*	-0.20698 (33)	0.03250 (31)	-0.09278 (19)	0.60729 (12)	0.00000$ (07)	0.04009 (32)	-0.18662 (30)	0.01737 (33)	0.01853 (31)	0.26635 (23)
13	*	0.18239 (28)	0.16927 (27)	0.07706 (17)	-0.01641 (09)	0.00000$ (06)	0.39358 (26)	0.21490 (23)	0.34184 (28)	-0.01249 (26)	0.55377 (20)
14	*	-0.04309 (10)	-0.22467 (10)	0.59114 (05)	0.12851 (06)	0.00000$ (02)	0.43691 (09)	-0.28377 (10)	-0.23560 (10)	-0.30749 (10)	0.34272 (06)
15	*	0.50199 (20)	0.78963 (20)	0.20899 (12)	-0.22745 (06)	0.00000$ (02)	0.47731 (20)	0.44943 (10)	0.71898 (20)	0.24232 (20)	0.40101 (16)
16	*	0.63758 (38)	0.04028 (36)	0.07415 (20)	0.12444 (14)	0.00000$ (09)	0.70529 (35)	0.19044 (33)	0.87219 (38)	0.24179 (36)	0.44061 (25)
17	*	-0.18303	-0.23705	-0.09301	-0.30320	0.00000$	-0.21708	0.10434	-0.20286	0.13008	0.09267

(25) (23) (16) (12) (08) (23) (25) (25) (24) (17)

A $ INDICATES THE COEFFICIENT IS NOT COMPUTED DUE TO A ZERO DIVISOR, A ZERO IS INSERTED.

CORRELATION MATRIX
(SAMPLE SIZES IN PARENTHESES)

VARIABLE NO. (CONTINUED)

	11	12	13	14	15	16	17
01 *	0.76639 (30)	-0.20698 (33)	0.18239 (28)	-0.04309 (10)	0.50199 (20)	0.63758 (38)	-0.18303 (25)
02 *	0.89967 (36)	0.03250 (31)	0.16927 (27)	-0.22467 (10)	0.78963 (20)	0.84028 (36)	-0.23705 (25)
03 *	-0.12569 (20)	-0.09270 (19)	0.07786 (17)	0.59114 (05)	0.28899 (12)	0.07415 (20)	-0.09301 (16)
04 *	0.11304 (14)	0.60729 (12)	-0.01641 (09)	0.12851 (06)	-0.22745 (06)	0.12444 (14)	-0.30320 (12)
05 *	0.00000$ (09)	0.00000$ (07)	0.00000$ (06)	0.00000$ (02)	0.00000$ (02)	0.00000$ (09)	0.00000$ (08)
06 *	0.60253 (35)	0.04009 (32)	0.39350 (26)	0.43691 (09)	0.47731 (20)	0.70529 (35)	-0.21700 (25)
07 *	0.14932 (33)	-0.10662 (30)	0.21490 (23)	-0.20377 (10)	0.44943 (10)	0.19044 (33)	0.10434 (25)
08 *	0.93063 (38)	0.01737 (33)	0.34104 (20)	-0.23560 (10)	0.71090 (20)	0.87219 (38)	-0.20206 (25)
09 *	0.11033 (36)	0.01053 (31)	-0.01249 (26)	-0.30749 (10)	0.24232 (20)	0.24179 (36)	0.13000 (24)
10 *	0.34512 (25)	0.26635 (23)	0.55377 (20)	0.34272 (06)	0.40101 (16)	0.44061 (25)	0.09267 (17)
11 *	1.00000 (38)	-0.02005 (33)	0.32706 (28)	-0.17112 (10)	0.04022 (20)	0.08396 (38)	-0.22300 (25)
12 *	-0.02005 (33)	1.00000 (33)	0.04130 (24)	-0.41120 (08)	-0.00155 (20)	-0.00477 (33)	-0.10760 (23)
13 *	0.32706	0.04130	1.00000	0.23965	0.39794	0.54714	-0.20915

		(28)	(24)	(20)	(09)	(16)	(28)	(19)	(
14	*	-0.17112	-0.41120	0.23965	1.00000	0.47602	-0.13975	-0.49931	
		(10)	(08)	(09)	(10)	(06)	(10)	(09)	(
15	*	0.04022	-0.00155	0.39794	0.47602	1.00000	0.01230	-0.61577	
		(20)	(20)	(16)	(06)	(20)	(20)	(13)	(
16	*	0.08396	-0.00477	0.54714	-0.13975	0.01230	1.00000	-0.30717	
		(30)	(33)	(20)	(10)	(20)	(30)	(25)	(
17	*	-0.22300	-0.10760	-0.20915	-0.49931	-0.61577	-0.30717	1.00000	
		(25)	(23)	(19)	(09)	(13)	(25)	(25)	(

A $ INDICATES THE COEFFICIENT IS NOT COMPUTED DUE TO A ZERO DIVISOR. A ZERO IS INSERTED.

```
===> LI OUT
===>
===>
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===> LI
===>
===>
===>
===>
===>
===> FLUSH
===> HARD8
MAP:     1563X492*OUT      80 OF=4    P=3    C=36
```

8.0 THE POTENTIAL FOR GAS SUPERSATURATION RELATED TO THE PROJECT

The significance of potential changes in dissolved gas on salmon and resident fish habitats and populations has been identified as a fisheries issue for this project. The following information discusses the current status of our knowledge regarding these topics.

8.1 DISCUSSION

The absolute quantity of dissolved gas that water can hold is a function of water temperature and pressure. The capacity of water to hold gas in solution (dissolved) increases with increasing pressure and decreases with increasing temperature. Dissolved gas supersaturation occurs when either the temperature or pressure of water with a given amount of dissolved gas concentration changes to the extent that it exceeds saturated levels at the new conditions.

Gas supersaturation can affect the biochemistry, physiology, and behavior of aquatic organisms by causing gas bubble disease. When fish encounter water having dissolved gas concentrations in excess of saturation, the gas in the water diffuses through the gills, tending towards equilibrium within the fish at the supersaturated level. Then, when the fish leaves the zone of supersaturated water, gases in the blood and other body fluids begin to come out of solution, forming bubbles inside the fish. The bubbles can cause circulation blockages and disruption of tissues. The overall effects on an organism can vary from sublethal stress to death (Fickeison and Schneider 1976).

8.1.1 Causes of Supersaturation

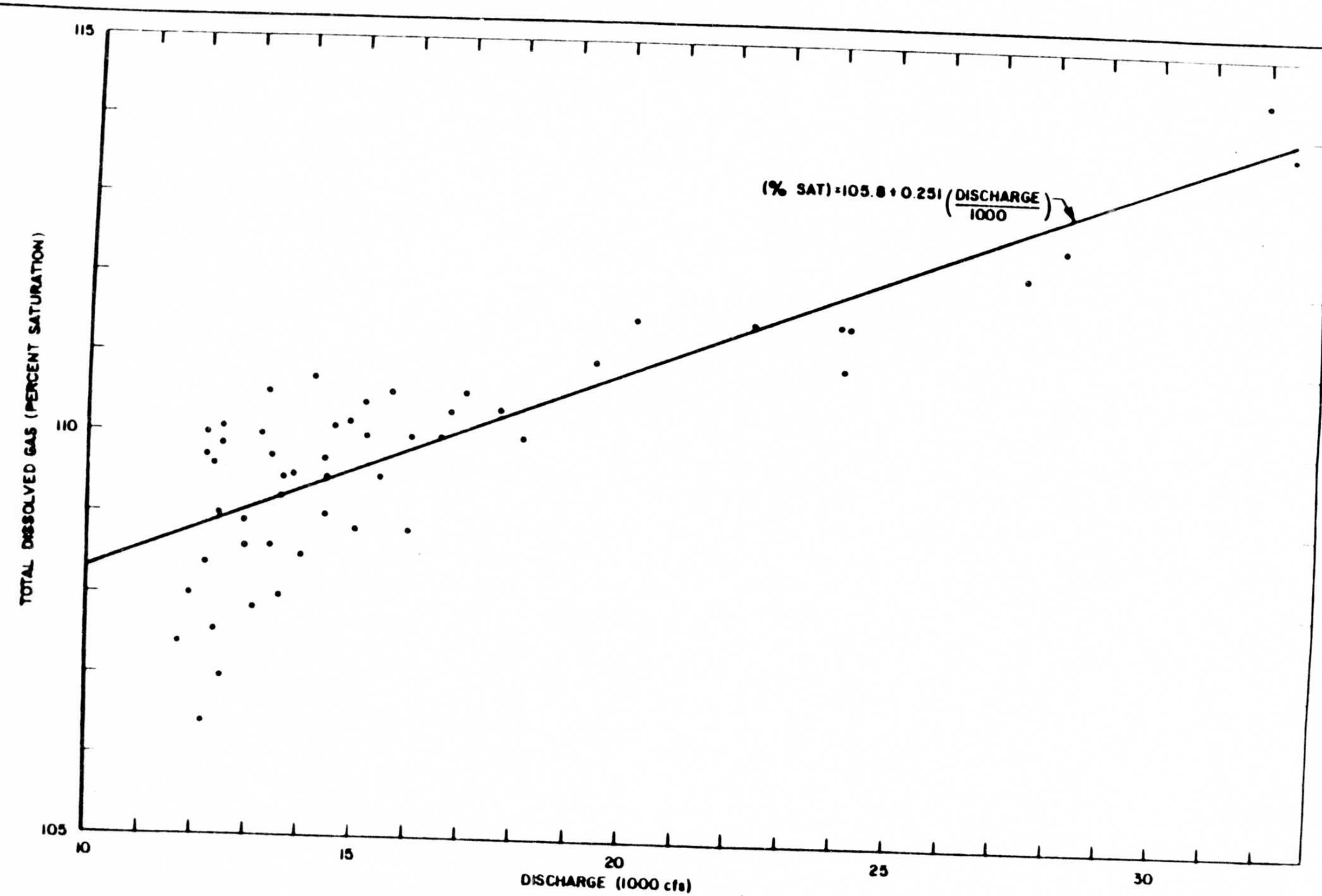
Supersaturated dissolved gas concentrations may occur at dams and hydroelectric facilities by any of the following mechanisms:

1. Spillway discharges entering the receiving stream can cause entrainment of air bubbles to depth where the change in hydrostatic pressure results in higher dissolved gas concentrations.

2. Leakage of air into powerhouse turbines, where sufficient pressures may exist to force excess gas concentrations into solution. In some hydroelectric facilities air is "bled" into turbines to prevent cavitation damage to turbine runners.

3. Withdrawal of nitrogen saturated water from depth in a body of water, such as the cold hypolimnion layers of a reservoir, and delivery to warmer temperatures and lower pressures, which may then result in a temporary condition of gas supersaturation, until aquatic gas concentrations can equilibrate with the atmosphere. This situation does not have any turbulence associated with it; turbulence would result in more rapid equilibration to ambient conditions.

Gas supersaturation has not been observed in the Susitna River upstream of Devil Canyon (e.g. upstream of river mile 150-163). Gold Creek, located below Devil Canyon, enters the Susitna mainstem at approximately 100 percent gas saturation. It is presumed that other rapidly flowing tributaries also enter the mainstem Susitna with approximately 100 percent gas saturation levels. Gas supersaturaion is apparently produced in the mainstem Susitna, under natural conditions, within Devil Canyon rapids. Gas supersaturated water appears to be caused by the entrainment of air in the rapids and pressurization of the water in plunge pools. The measured levels of gas concentration appear to be directly related to river discharge rates flowing through the canyon, within the discharge ranges observed to date (i.e. 10,000-32,500 cfs) (ADF&G 1982; APA 1983a,b, Fig. 8.1). Although gas concentrations of 115 to 116 percent have been observed at the mouth of Devil Canyon, neither fish embolisms nor evidence of gas bubble disease have been observed in the Susitna River to date (ADF&G 1982). Alaska water



TOTAL DISSOLVED GAS (PERCENT SATURATION) VS. DISCHARGE

SOURCE: APA 1983

FIGURE 8.1

quality standards specify maximum allowable total dissolved gas levels of 110 percent of saturation at any point of sample collection (18 Alaska Administrative Code 70.020).

An additional concern regarding gas supersaturation is the rate at which supersaturated gas in flowing river water returns to equilibrium through contact with the atmosphere. The rate at which gas will come out of solution is dependent on the water temperature and the exposure of the water to lower gas pressures. Gas supersaturated water has been observed to persist for long downstream distances where adequate opportunities did not exist for the dissolved gases to equilibrate with the atmosphere (Boyer 1974; Fickeison and Schneider 1976).

Measurements of total gas concentration in several reaches downstream of Devil Canyon at 16,000 cfs and 32,500 cfs have been used to study the rate of dissipation of gas supersaturation in the Susitna. Analysis of the data indicates that the dissipation rate can be modeled by an exponential decay function and that the amount of supersaturation is reduced by approximately 50 percent in the first 20 miles downstream. The dissipation rates have not been modeled further than 20 miles downstream, but any continuing supersaturated conditions would be expected to continue decreasing, possibly at faster rates of decline due to shallower channel depths, more water surface area in contact with the atmosphere, and dilution of mainstem waters by tributary influent (ADF&G 1982).

8.1.2 Biological Effects

The potential biological effects of excessive gas supersaturation below Devil Canyon rapids, should the situation occur, would depend on several factors, including:

1. The seasonal timing of supersaturation.

2. The level of supersaturation.

3. The downstream extent of supersaturated water.

4. The amount of time that the organisms are exposed to the condition.

5. The biological characteristics of the organisms in question.

Large controlled releases are most likely to occur during middle to late summer or early fall when the reservoir(s) are full, under most conditions, according to proposed operational schemes (APA 1983a,b, H-E 1984f). At this time, adult salmon will be using the Middle River mainstem channel as a migratory route to spawning habitats. The mainstem channel and peripheral habitats will also be utilized for rearing by juvenile salmon and resident fish during this period. Under with-project conditions, and without any mitigation measures, potential biological effects of excessive gas supersaturation might involve disruptions of adult salmon inmigration to spawning areas, and/or detrimental effects on rearing juvenile salmon or resident fish. The effects of gas supersaturation are often less severe and less prolonged on smaller organisms (Fickeison and Schneider 1976; Dawley et al. 1975). Consequently, impacts on small organisms might be less than for inmigrant adult salmon. In addition, high levels of gas supersaturation will most likely coincide with high volume flow events of relatively short duration. During high flow events, mobile aquatic organisms such as juvenile fish will likely seek the slower velocities and better water quality conditions in the more shallow, peripheral habitats. In any case, high flow events will be shorter in duration and will occur less frequently with the Project in place as compared to natural conditions.

8.2 MITIGATION

8.2.1 Mitigation Measures to Avoid Negative Biological Impact

Project design and operations have been proposed to minimize the potential for impacts on downstream fisheries due to excessive gas supersaturation.

For normal powerhouse discharges, and for all floods with recurrence intervals of less than 50 years, the Project is not expected to cause excessive concentrations of supersaturated gas. The operational plans would usually result in gas saturation levels which are equal to or less than naturally existing levels, primarily because the frequency and magnitude of high flows through Devil Canyon would be diminished.

8.2.2 Structural and Operational Mechanisms for Avoiding Gas Supersaturation

By using the reservoir storage capacity coupled with specialized powerhouse tailrace and outlet works designs, floods with recurrence intervals of up to 50 years can be discharged without spillway usage thus minimizing the potential for dissolved gas concentrations which will exceed naturally occurring levels.

Turbine tailrace waters from Watana Stages I and III will be discharged thorough two 34 foot diameter tunnels beneath the surface of the river at the downstream toe of the dam. This method of discharge will avoid entrainment of air, excessive turbulence and pressurization of any gas-water mixture which might result in dissolved gas supersaturation.

Fixed-cone valves have been selected to be used at Watana Dam during Stages I and III to minimize the potential for gas supersaturation in controlled spills. Watana Dam will withdraw water for controlled spills from el. 1930. The discharges will be released through any of six, 78 inch fixed cone valves located approximately 105 feet above tailwater on the downstream toe of the dam. Water released through the fixed-cone valves will form a dispersed jet which is designed to dissipate the energy of the released water. It is not possible to prevent outlet work releases from entraining air, therefore it is necessary to prevent the release waters from penetrating to a great enough depth in tailwaters to prevent excessive pressures which can cause gas supersaturation. Fixed-cone valves were selected to be used on outlet works because they can disperse the flow of water and decrease its intensity and velocity of impact with tailwaters.

Little literature and no precedent data are available regarding the performance of fixed-cone valves in reducing or preventing supersaturated discharges. As such, a theoretical assessment of their anticipated performance was conducted based upon available studies of the aeration efficiency of similar Howell-Bunger valves (fixed-cone) and the physical and geometric characteristics of diffused jets discharging freely into the atmosphere (Elder and Dougherty 1952, Allis Chalmers, Chen and Davis 1964, Falvey 1980, Johnson 1967, Johnson 1975).

The results of the assessment indicate that estimated gas concentrations that would occur as a result of a flow release are 100 to 105 percent of saturation downstream of Watana Dam. Concentrations will be within this range for up to the 50-year flood. Supersaturation will still occur in Devil Canyon, but with-project levels are expected to be less than naturally-occurring levels because of regulation of flood peaks by the project and the use of the outlet works cone valves. Operation of the spillway for floods less frequent than the 50-year flood is expected to result in increased gas concentrations. However, because the dam will reduce downstream flood peaks, gas concentrations may be less than those occurring naturally for these floods.

To support these conclusions, a field test of similar valves was undertaken at the Lake Comanche Dam on the Mokelume River in California (Ecological Analysts 1982). The results of the tests indicate that the valves prevented supersaturation and, to a limited extent, may have reduced existing nitrogen concentrations. Flows of 4,000 cfs with a dissolved nitrogen concentration of 101 percent at the intake structure were passed through four Howell-Bunger valves. Gas concentrations in the discharge were 97 percent. At 330 feet and 660 feet (100 and 200 m) downstream, concentrations were 95 and 97 percent, respectively.

The outlet works capacity for Watana Stage I is 24,000 cfs, while the powerhouse capacity is about 14,000 cfs. Maximum downstream discharge from the dam except in cases exceeding the 50 year flood event and when the reservoir surcharge capacity has been exceeded, will therefore not exceed 38,000 cfs.

Fixed cone valves have been included at Devil Canyon, and a flood storage pool provided to allow storage and release of all floods up to the 50-year event without using the spillway and thus minimizing gas supersaturation downstream.

The Devil Canyon Dam will include seven valves at two levels with a total design capacity of 42,000 cfs. Four 102-inch diameter valves, each with a capacity of 6,300 cfs, will be located approximately 170 feet above normal tailwater. Three more valves, with diameters of 90 inches and capacities of 5,600 cfs, will be located approximately 50 feet above normal tailwater elevations. The Devil Canyon powerhouse capacity for both Stage II and III is 14,000 cfs. Operation of these valves is expected to result in a maximum dissolved gas concentration of between 105 and 110 percent for the 50-year flood event, immediately downstream of Devil Canyon Dam. This assumes that gas concentrations from use of the Watana cone valves of 100 to 105 percent are not dissipated in the Devil Canyon Reservoir. This is a reduction from naturally-occurring levels which would annually exceed 115 percent.

Fixed cone valves will be provided on the Watana and Devil Canyon outlet works to disperse excess releases and minimize the potential for gas supersaturation in excess of naturally occurring levels. The capacity of the Watana outlet works will be approximately 30,000 cfs during Stage III as compared to 24,000 cfs during Stage I because of the additional hydraulic head on the valves. Likewise, the powerhouse capacity for Watana Stage III is increased to about 22,000 cfs.

During the early years of Stage III operation the outlet works will be operated approximately as frequently in Stage III as in Stage II. However, as energy demands increase, more water will be used for power and outlet works operation will decrease. The ability of the project to control floods in excess of the 50-year event will be improved.

In addition to using reservoir storage to control and reduce peak flows, and the use of fixed-cone valves to dissipate energy from controlled spills, one additional factor will help minimize dissolved gas supersaturation in downstream habitats. At Devil Canyon dam the powerhouse tailrace will route turbine tailwaters downstream through a tunnel 38 feet in diameter and approximately 6,800 feet long. The tailrace waters will be discharged under the river surface and downstream of nearly all the violent Devil Canyon rapids. This long tailrace tunnel discharge will help dilute any flows still discharged through Devil Canyon outlet works and/or spillways, and will thereby help avoid any downstream gas supersaturation conditions.

9.0 AQUATIC NUTRIENT CHANGES RELATED TO THE PROJECT

The significance of change in water quality parameters (nutrients) to salmon and resident fish habitats and populations downstream of the dams has been identified as a fisheries issue for this project. The following information discusses the current status of our knowledge regarding this topic.

9.1 Discussion

9.1.1 Basic Considerations.

The primary issue concerning nutrients and the Susitna Hydroelectric Project is the effect that project construction and operation will have on the trophic status and fish resources of the proposed reservoirs and the riverine habitats downstream from the Project (FERC 1984). An aquatic habitat's trophic status is an indication of its relative degree of richness or poverty with regard to the rate of supply of its biologically useful organic energy. Generally, the richer the trophic status of an aquatic subsystem, the greater its ability to contribute biologically useful energy to fish productivity.

The trophic status of an aquatic habitat, whether that habitat is characterized by slow (lentic) or fast (lotic) flowing water, is largely determined by the rate at which biologically useful organic material is recruited from two basic sources: primary production of new organic materials produced by aquatic photosynthesis (autochthony) and organic materials derived from terrestrial sources (allochthony). Limnologists have long recognized the importance of aquatically produced organic carbon compounds to the trophic status of lakes, ponds and reservoirs (Wetzel 1975), and they are recently becoming more aware of the importance of aquatic productivity in unshaded riverine habitats as well

(Wetzel 1975, Minshall 1978, Cummins 1979, Murphy et al. 1981, Conners and Naiman 1984).

Most freshwater lake and reservoir habitats of temperate North America have their aquatic production of new organic material limited by low supplies of biologically available phosphorus and/or nitrogen (Wetzel 1975, Hutchinson 1973, Rast and Lee 1978, Vollenweider and Kerekes 1980). The data supporting macronutrient limitation of autochthonous productivity in lotic habitats is much more limited (Huntsman 1948; Moore 1977; Peterson et al. 1985b). The aquatic productivity of new organic material in lotic habitats, on the other hand, is frequently limited by a more complex array of environmental variables which includes not only macronutrient concentrations but also temperature, high flow variability, high velocities, turbulence, low light levels, and unstable substrate for attached algae anchor points (Cushing et al. 1980, Lowe 1979, Newbold et al. 1981, Minshall 1978, Minshall et al. 1983, Murphy et al. 1981, Vannote et al. 1980).

Observation of the Susitna River mainstem and peripheral habitats during recent field seasons has so far disclosed only two brief periods when substantial standing crops of attached algae consistently occur (ie., in spring, before intensive and highly turbid freshet flows, and in fall, after high volume and highly turbid summer flows begin to diminish). In fall 1984 and 1985 luxuriant crops of attached filamentous algae were photographed along many reaches of the mainstem channel and in many side-channels and side-sloughs. The attached algae appeared to grow luxuriantly in many places where incident solar radiation could penetrate to stable streambed substrate. Quantifications of aquatic primary productivity and standing crops of attached algae are not available for any reach of the Susitna. The relative importance of autochthonous vs. allochthonous production to the flow of energy between trophic levels leading to fish resources or to the trophic status of the Susitna River is unknown. Nevertheless, regardless of the actual quantity of newly produced organic material in the river, it likely serves as a very important, high quality food source for microbial populations with varied food requirements as well as for invertebrate and vertebrate herbivores and detritus feeders (Cummins, 1979). These detrivores and herbivores, in turn, may become food for vertebrate predators such as juvenile salmonids and resident fishes which, in turn, may become food for birds and mammals (Hynes 1970).

9.1.2 Aquatic Primary Productivity. Under natural conditions, the factors which appear to be the most important in limiting aquatic primary productivity in the Susitna River are:

- Highly variable water stages which cause desiccation or freezing of dewatered attached algae,
- Relatively cold thermal regimes with low mean and maximal temperatures,
- Unstable streambed substrate,
- Scour by suspended sediment particles,
- Scour by frazil ice, anchor ice, or other ice processes,
- Sedimentation of streambed substrate and smothering of small organisms by small particulates,
- Light limitation, during most seasons, by ice and snow cover or high turbidity levels.

Substantial growth of attached algae occurs in spring and fall when flows in the mainstem and peripheral river habitats are relatively stable and the negative effects of suspended sediments are reduced. The occurrence of rapidly growing standing crops of attached algae observed during these periods is indirect evidence that at least minimal supplies of biologically available phosphorus and nitrogen were present in the river water during at least the spring and fall.

Shortages of the major macronutrients such as phosphorus and nitrogen which are sufficient to dramatically limit aquatic primary productivity are not expected to occur in the unregulated Susitna River during any season, nor during any year.

Concentrations of total phosphorus and total nitrogen which are general representative indicators of different trophic categories in relatively clear, freshwater lakes of north temperate latitudes have been fairly well established (Table 9.1). However, for turbid lakes and turbid reservoirs (Jones and Bachman 1978, Kerekes 1982, Walker 1982), or for rivers and streams of any size, comparable relationships between representative macronutrient concentrations and different trophic categories have not been well established (Cushing et al. 1980, Moore 1977). In fact, the science of stream limnology, in contrast to lake and reservoir limnology, has not been able to establish any generalized categories or terminology describing the relative trophic status of streams and rivers in terms of oligotrophy (impoverished or low rates of biological energy supply), mesotrophy (medium rates of biological energy supply) and eutrophy (high levels of biological energy supply) (Cushing, et al. 1980).

Chemical assays for phosphorus and nitrogen levels in the Susitna River have shown highly variable macronutrient concentrations occurring in the river during summer, winter and breakup (APA 1983a,b). During most sampling periods and at most sampling stations, concentrations of the various phosphorus and nitrogen compounds have been found to vary from less than detectable levels to much greater total concentrations than would be necessary to support moderate biomass (10-20 ug/l Total P and <500 ug/l Total N) or even excessive biomass (>20 ug/l Total P and >500 ug/l Total N) of phytoplankton (See Figures 9.1 and 9.2) if the nutrients were in a clear temperature latitude lake.

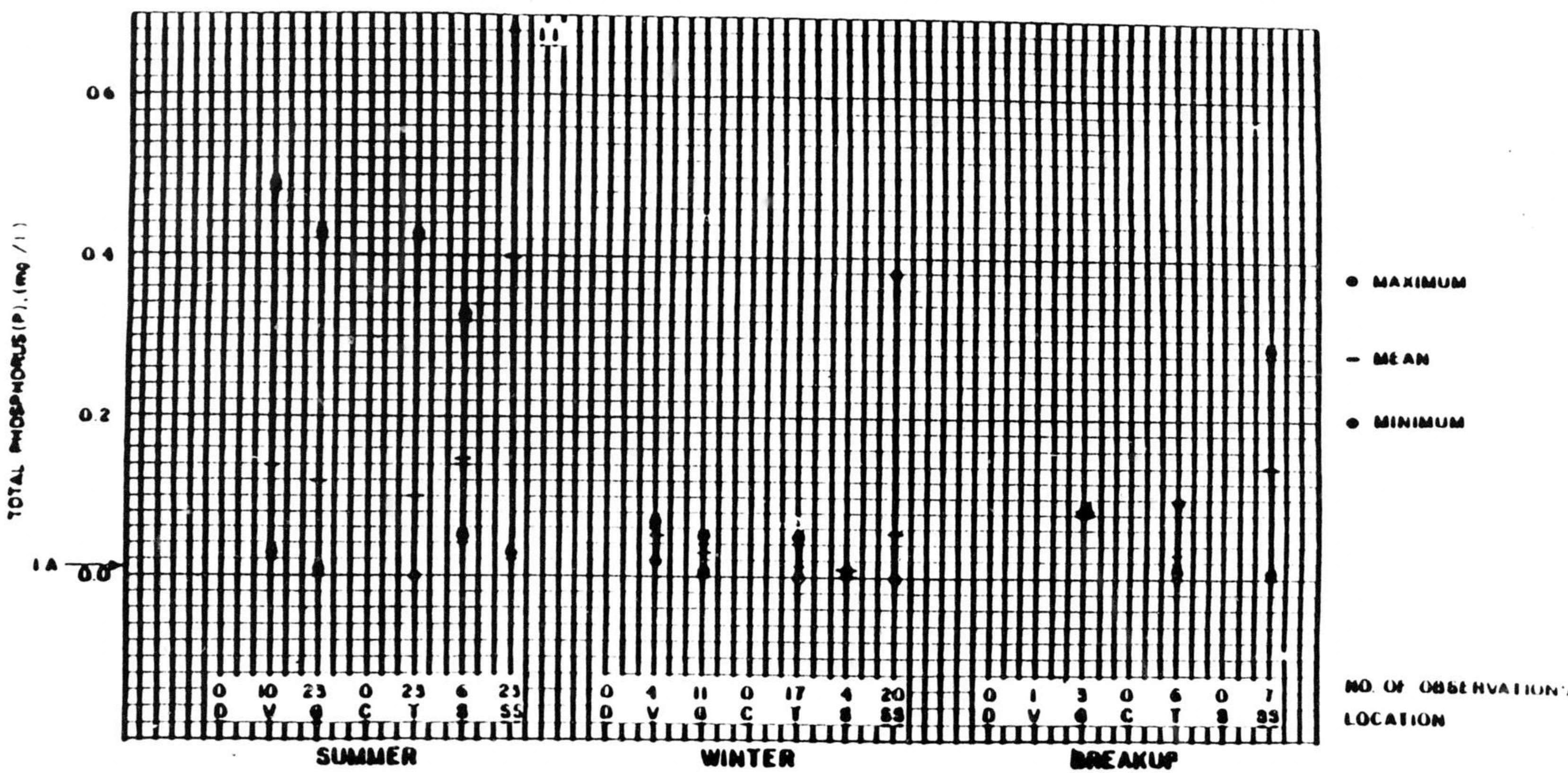
Although concentrations of total nitrogen and phosphorus which are generally representative of any given trophic status of subarctic rivers have not been established, it is reasonable to assume that concentrations generally accepted as indicators of lake trophic status, and possibly even lower

Table 9.1

SUSITNA HYDROELECTRIC PROJECT
GENERAL RANGES OF TOTAL PHOSPHORUS AND TOTAL NITROGEN WHICH ARE RELATIVELY CHARACTERISTIC OF DIFFERENT TROPHIC CATEGORIES IN RELATIVELY CLEAR LAKES AND RESERVOIRS

Trophic Type	Total P(ug/l)	Total N (ug/l)
Ultra-oligotrophic	< 5	< 1-250
Oligotrophic	5-10	
Oligo-mesotrophic	< 10	250-600
Mesotrophic	10-30	
Meso-eutrophic	10-30	500-1,100
Eutrophic	10-30	
Hypereutrophic	30- > 5,000	500-15,000

Source: Adopted from Wetzel (1975)



D-DENALI V-VEE CANYON G-GOLD CREEK C-CHULITNA T-TALKEETNA S-SUNSHINE SS-SUSITNA STATION

NOTES:

1A CRITERION: LESS THAN 0.01 mg/l FOR ELEMENTAL PHOSPHORUS (EPA 1976).

1B ESTABLISHED TO PROTECT FRESHWATER AQUATIC ORGANISMS

2 AT VEE CANYON, 4 SUMMER OBSERVATIONS, 2 WINTER OBSERVATIONS, AND THE 1 BREAKUP OBSERVATION WERE LESS THAN 0.05 mg/l

3 AT GOLD CREEK, 6 SUMMER OBSERVATIONS, 3 WINTER OBSERVATIONS, AND 1 BREAKUP OBSERVATION WERE LESS THAN 0.05 mg/l

4 AT SUNSHINE, 2 WINTER OBSERVATIONS WERE LESS THAN 0.01 mg/l

5 AT SUSITNA STATION, 2 WINTER OBSERVATIONS WERE LESS THAN 0.01 mg/l.

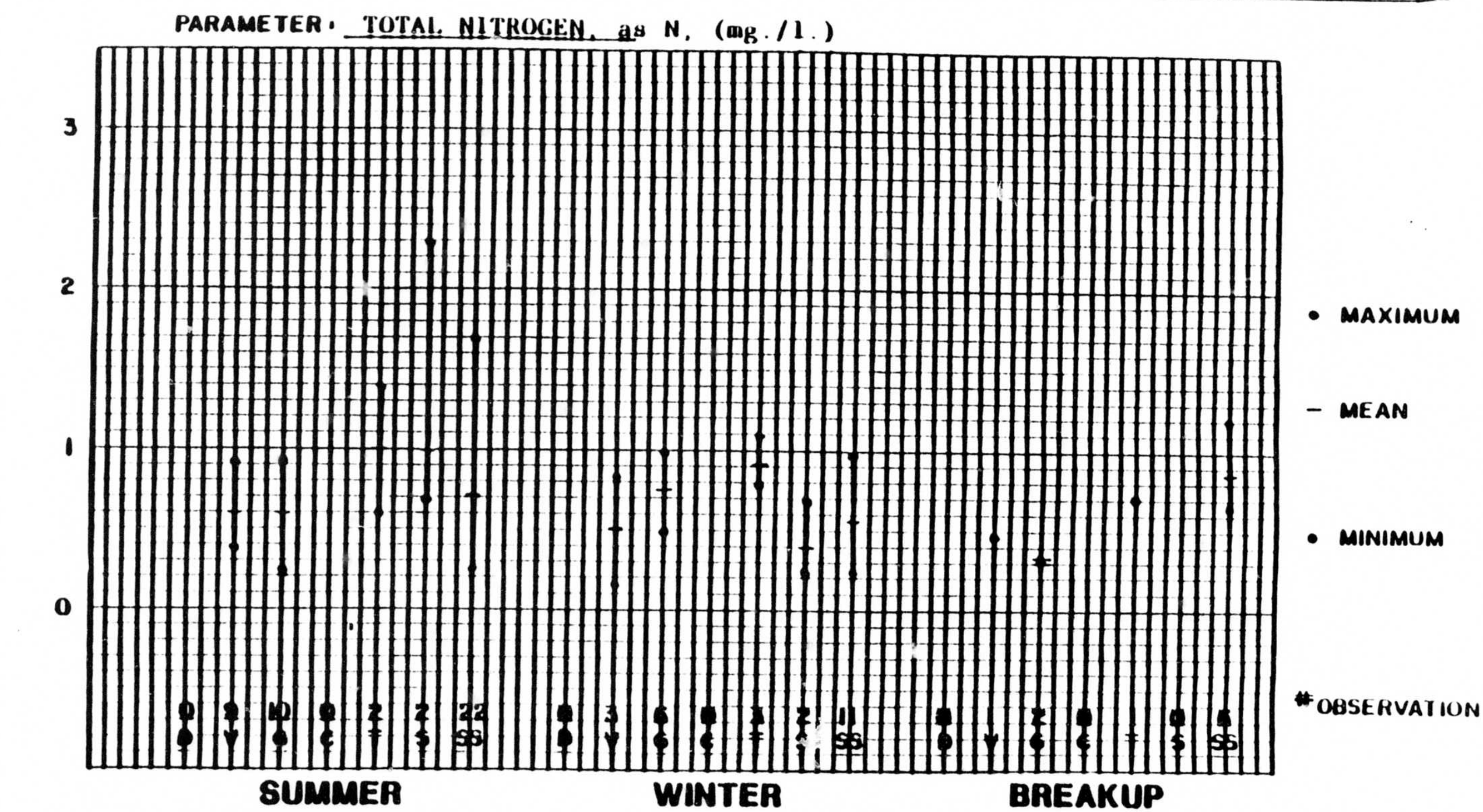
FIGURE E.9.1

SUSITNA HYDROELECTRIC PROJECT

DATA SUMMARY - TOTAL PHOSPHORUS

SOURCE: USGS AND R&M

Source: APA 1983



D- DENALI V- VEE CANYON G- GOLD CREEK C- CHULITNA T- TALKEETNA S - SUNSHINE SS- SUSITNA STATION

No criterion established

FIGURE 9.2

SUSITNA HYDROELECTRIC PROJECT

DATA SUMMARY - TOTAL NITROGEN

Source: Peterson et al. 19..

concentrations, would be applicable to north temperate or subarctic rivers. Under such an assumption, concentrations of macronutrients in the Susitna River would not appear to be limiting to aquatic primary productivity under present environmental conditions during summer, winter or breakup time periods (See Figures 9.1 and 9.2).

9.1.3 Anticipated With-Project Conditions - Reservoirs

Construction and operation of the proposed project will produce a reservoir habitat in which phosphorus and nitrogen are both added to and removed from the impounded river water. Additions of phosphorus and nitrogen to the proposed reservoirs are expected to occur primarily due to:

- o Mainstem river, tributary and groundwater influents;
- o Surface runoff from eroding reservoir sidewalls and reservoir drawdown zones;
- o Liberation of nutrients due to microbial decay of inundated organic material;
- o Leaching of nutrients from newly inundated soils by chemical and biochemical processes;
- o Treated secondary sewage effluents from construction-related facilities;
- o Particulate fallout from atmospheric sources;
- o Direct precipitation in the form of rain and snow;

Substantial losses of macronutrients which enter the project reservoirs will be expected to occur. The majority of phosphorus atoms entering the project reservoirs are expected to precipitate out with the sediment particles on which they arrive and to remain permanently stored on the reservoir bottom. Microbial denitrification activity and precipitation of nitrogen compounds attached to particulates will be expected to remove some of the nitrogen added to the reservoirs. However, nitrogen fixation by aquatic microbes may add small quantities of biologically available nitrogen compounds to the reservoirs. Overall, the reservoirs are expected to act as nutrient sinks, and phosphorus and nitrogen exports to downstream areas should be reduced (Hannan 1979, Wetzel 1975, Stuart 1983).

9.1.4 Expected Reservoir Trophic Status

The present state of knowledge of subarctic reservoir limnology indicates that both project reservoirs will be classifiable as having extremely unproductive trophic states. The major factors limiting the aquatic primary productivity of both project reservoirs are not expected to be nitrogen or phosphorus supplies, but rather low light conditions (due to turbidity and to ice and snow cover), cold temperatures, lack of any substantial littoral zone, and large drawdown zones due to project operations.

During most of the project's lifetime, organic material recruited from terrestrial sources is not expected to add substantial amounts of readily usable organic matter to the reservoirs' detritus food base (Wetzel 1975; Hobbie 1980) and it may even help depress the potential primary production (Jackson and Hecky 1980). The relatively short bulk residence time estimated for the reservoir waters and the relatively refractile nature of most of the influent organic material indicates that little chemically or biochemically mediated change in the food quality of the terrestrially produced organic material will occur before it is discharged from the reservoirs. Thus the project reservoirs will not be expected to contribute large amounts of high quality organic food materials to downstream riverine habitats, and will be likely to serve as traps and permanent storage sights for much of their allochthonously derived macronutrients and organic carbon (Wetzel 1975, Hannan 1979, Stuart 1983).

The project reservoirs, like most reservoirs around the world, will be expected to go through a mild "trophic upsurge" period after filling, characterized by slight increases in biologically available phosphorus, nitrogen, organic detritus and suspended sediments (Grimard and Jones 1982, Therien, et al. 1982, Ostrofsky and Duthie 1980, Jackson and Hecky 1980; Crawford and Rosenberg 1984). Both reservoirs are expected to experience slight oxygen declines in their deeper zones, especially during winter stratification. Both reservoirs are expected to have relatively low rates of biologically mediated nutrient flow during their entire lifetimes, and are expected to support only minimal bacteria, fungi, phytoplankton, zooplankton, benthic invertebrate and fish populations.

9.2 Anticipated With-Project Conditions: Riverine Habitats Downstream

With-project conditions in the mainstem and peripheral habitats directly affected by mainstem flows from May to September are expected to be slightly more favorable to primary productivity than preproject conditions. Several characteristics thought to severely limit primary productivity (substrate scour, substrate instability, streambed sedimentation by fine particles, high turbidity, high flow variability) are expected to have less negative influence on aquatic primary productivity by periphyton under with-project summer conditions.

Regulation of river flows to provide lower than natural water stages during summer may also prevent highly turbid mainstem waters from affecting the aquatic periphyton productivity of many clear, running water habitats peripheral to the mainstem. Any enhancement of primary production in peripheral riverine habitats during summer may serve to enhance the trophic status and biological productivity at all trophic levels of the Middle river reach.

9.2.1 Downstream Nutrients Flow

The total amount of phosphorus transported to downstream riverine habitats will undoubtedly be reduced, but the relative concentration of phosphorus per unit weight of suspended sediment will probably be increased by project operations. This phenomenon is expected to occur because the smaller average size of suspended particulates discharged from the Project should have a much larger ratio of surface area to weight compared to preproject suspended sediments, and because phosphorus is frequently complexed to the surfaces of suspended particles (Schreiber and Rausch 1979).

Various forms of phosphorus were analyzed in the two Susitna River samples collected for analyses in the settling column experiments conducted in the summer of 1984. The results (Table 9.2) indicated that the first sample collected, which had a TSS concentration of 181 mg/l, had a total phosphorus (TP-by acid persulfate digestion) content of approximately 190 ug/l. Approximately 85 percent of that TP was inorganic particulate phosphorus (IPP). The second sample collected contained 410 mg/l TSS and 532 ug/l TP. Approximately 65 percent of the TP in the second sample was IPP. In both samples the organic particulate phosphorus (OPP) was approximately 12-13 percent of the TP, while the orthophosphate (FRP) content was 8-15 percent of the TP.

Mean annual values of particulates in the chronically turbid effluents discharged from the project will be at least 50 mg/l TSS. If one assumes that these particulates will contain al least the same amount of TP per unit of mass as the "natural" TSS (i.e. 0.1 percent by weight), then the annual average TP of the project discharges will contain at least 50 ug/l TP associated with the TSS particles.

Large discrepancies exist in the literature regarding the amount of the "particulate phosphorus" which might be "biologically available" (i.e. BAP). Conservative estimates of BAP on aquatic sediments range from 5-10 percent

Table 9.2

SUSITNA HYDROELECTRIC PROJECT
PHOSPHORUS IN SUSITNA RIVER SAMPLES

All values are reported as ugL^{-1} (ppb) as P.

	7/31/84	8/06/84
TP	190.4	532.4
TFP	16.9	82.1
FRP	15.9	77.1
IPP	161.5	343.5
OPP	24.9	62.9

TP = total phosphorus
TFP = total filterable phosphorus
FRP = filterable reactive phosphorus (orthophosphate)
IPP = inorganic particulate phosphorus
OPP = organic particulate phosphorus

TP = TFP + IPP + OPP

Data Analyses: ADF&G FRED Limnology Laboratory, Soldotna, Ak.

by weight, more liberal estimates may be much larger. The techniques used to estimate BAP are not standardized or agreed upon (Lee, Jones and Rast 1980; Wildung and Schmidt 1973; Grobler and Davies 1979; Rast and Lee 1978; Stanford, et al. 1984). However, little doubt exists that phosphorus atoms associated with inorganic and organic materials are exchangeable, and to a limited extent biological available, to micro-organisms positioned nearby (Golterman 1975; Lean 1973; 1973a; Lean and Rigler 1974; Paerl and Lean 1976; Ammerman and Azam 1985).

In areas where substrates become "dusted" by glacial flour, epilithic communities which are dominated by mucilage secreting/mat forming microbes will cause nutrient rich suspended particulates to accumulate in aufwuchs type communities (Smith 1950; Prescott 1962; 1970; Hobbie 1980). Cyanophyta with the capacity to fix their own nitrogen source and secrete copius mucilage may have an obvious competitive advantage compared to other periphyton in such habitats.

In habitats with suitable illumination, temperature, velocity, turbulence and substrate, etc., aufwuchs communities incorporating inorganic particulates will have a concentrated and usable source of metabollically essential phosphorus and other trace elements due to suspended sediments.

Although the concentration of nitrogen may decrease during passage through the project reservoirs, additional sources of nitrogen are expected to be added to riverine habitats downstream of the project by tributary and groundwater influents, by aeolian inputs of nitrogen in rainfall and precipitating particulates, by organic detritus derived from the terrestrial environment and by instream nitrogen fixation (Fontaine and Bartell 1983; Triska, et al. 1984; Peterson, et al. 1985b). Riparian vegetation, especially alder (Alnus sp.), is an excellent and well recognized source of fixed nitrogen for nearby aquatic environments (Wetzel 1975, Livingston 1963), and alder is a common component of the riparian vegetation along the Susitna River. Excess nitrogen appeared to be available for biota in the phosphorus-limited Kuparuk River, and increased nitrate removal from the river water was associated with experimental additions of readily biologically available phosphorus (Peterson, et al. 1985b).

9.2.2 Trophic Status and Fisheries Effects Summary

The trophic status of both project reservoirs is expected to be classified as ultra-oligotrophic (i.e. a low rate of biological productivity at all trophic levels) for the lifetime of the project. Project-induced changes in nitrogen and phosphorus concentrations in the reservoirs are not expected to be sufficient to alter their relative importance in the hierarchy of factors which will act to limit aquatic primary productivity (i.e. light, temperature, hydraulic residence time, etc.).

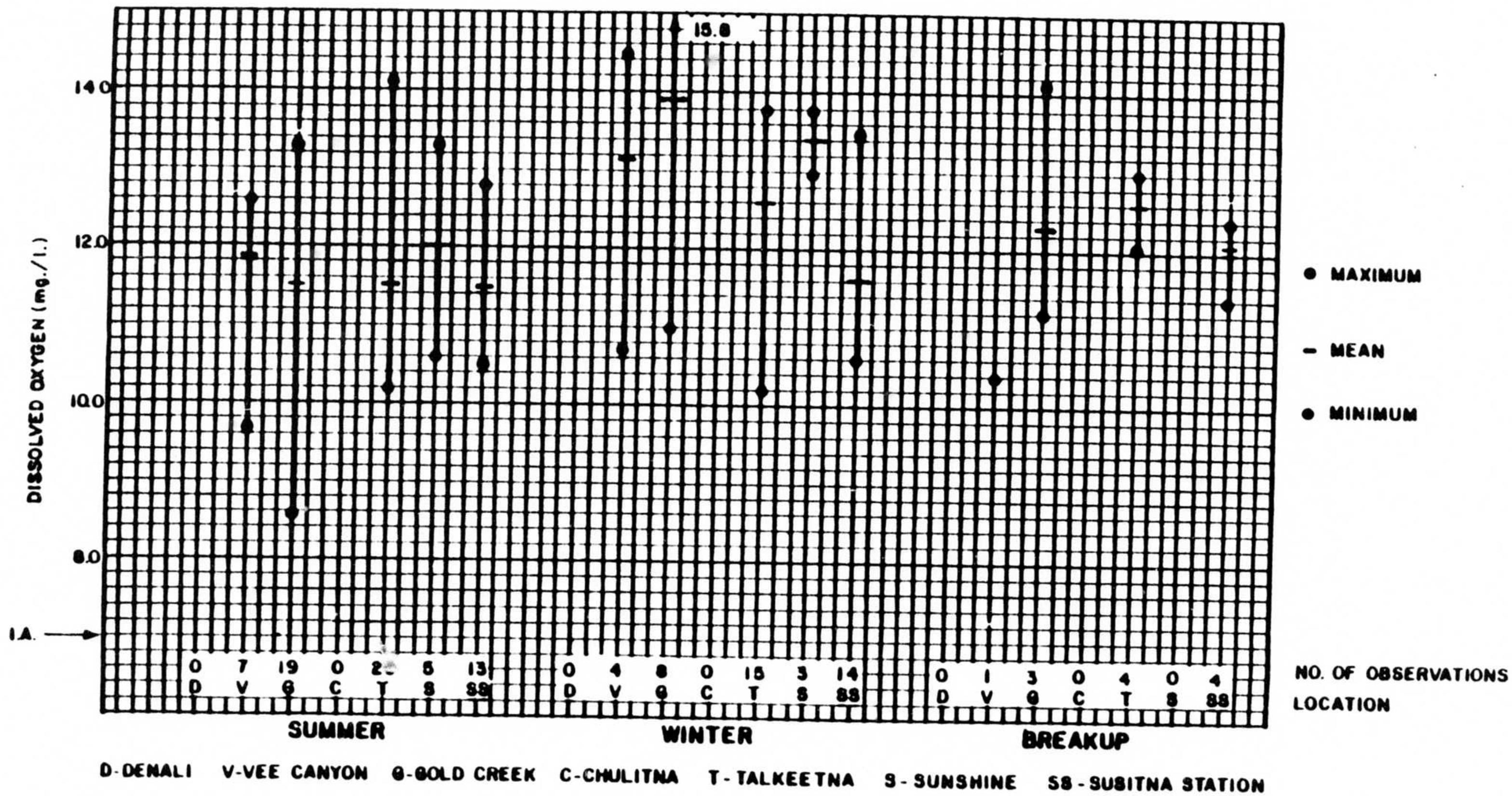
The trophic status of glacial streams and rivers is usually relatively impoverished (Milner 1983, Steffan 1971, Van Stappen 1984, Ward, et al. 1982), as are streams receiving particulate placer mine wastes (Lloyd 1985, Van Nieuwenhuyse 1983).

The trophic status of the Middle River mainstem is presumed to be relatively impoverished at present, especially relative to non-glacial rivers at the same latitude. Project-induced changes in macronutrients are not expected to change the Middle River trophic status. Periodic high turbidity and suspended sediment levels presently act to limit Middle river aquatic productivity at all trophic levels. Chronic, moderate to high turbidity and suspended sediment levels, expected under with-project conditions, are expected to continue to minimize aquatic productivity at all trophic levels and in many habitats of the river carrying constantly turbid mainstem flows. Although mainstem aquatic productivity is still expected to be strongly limited by the projected with-project suspended sediment regime, conditions for attached algal productivity on the margins of the turbid mainstem may be improved under with-project conditions in areas where sunlight can penetrate to stable streambed substrate. A somewhat analogous situation has been observed in the chronically turbid Kasilof River of the Kenai peninsula. Peripheral riverine habitats that may be inundated less often by mainstem flows under with-project conditions are expected to maintain or increase their aquatic productivity relative to natural conditions.

10.0 DISSOLVED OXYGEN, ORGANIC CARBON AND PROJECT EFFECTS

Concentrations of dissolved oxygen in the natural riverine habitats have been found to be moderately high or very high during all seasons. Winter values have been found to vary from 11.6 to 13.9 mg/l. Winter dissolved oxygen concentrations have averaged being approximately 98 percent saturated at Gold Creek, and 80 percent saturated further downstream at Susitna Station. Summer dissolved oxygen concentrations at Gold Creek have frequently ranged from 11.5 mg/l to 12.0 mg/l which equates to summer saturation levels of approximately 97-105 percent. Dissolved oxygen concentration and percent saturation data collected at several stations during different seasons have been presented as they were in the original license application (Figures 10.1 and 10.2). Additional dissolved oxygen data were obtained from several Susitna River mainstem and tributary habitats during field surveys in 1983 (Figures 10.3 and 10.4). All existing data have consistently indicated relatively high dissolved oxygen concentrations during all seasons in all Susitna River surface waters.

Total organic carbon (TOC) concentrations have been analyzed in several Susitna River samples and have varied between 1.0 and 41.0 mg/l (R&M Consultants, Inc. 1982a, 1982b). Most measured TOC values have been less than 5 mg/l at various Susitna River stations during both winter and summer seasons (U.S.G.S. 1980, 1981, 1982, 1983). Susitna River TOC concentrations are similar to TOC values from other large rivers in Alaska which drain watersheds containing similar vegetation (R&M Consultants, Inc. and Peterson and Assoc. 1982; US.S.G.S. 1980, 1981, 1982, 1983). The majority of the TOC is composed of dissolved organic carbon (DOC), with the remainder being found in the particulate from (POC). These findings are completely within the realm of the values to be expected for both lentic and lotic fresh waters (Wetzel 1975; Ward and Stanford 1979; Hobbie 1980; Naiman 1982, 1983a).



NOTES

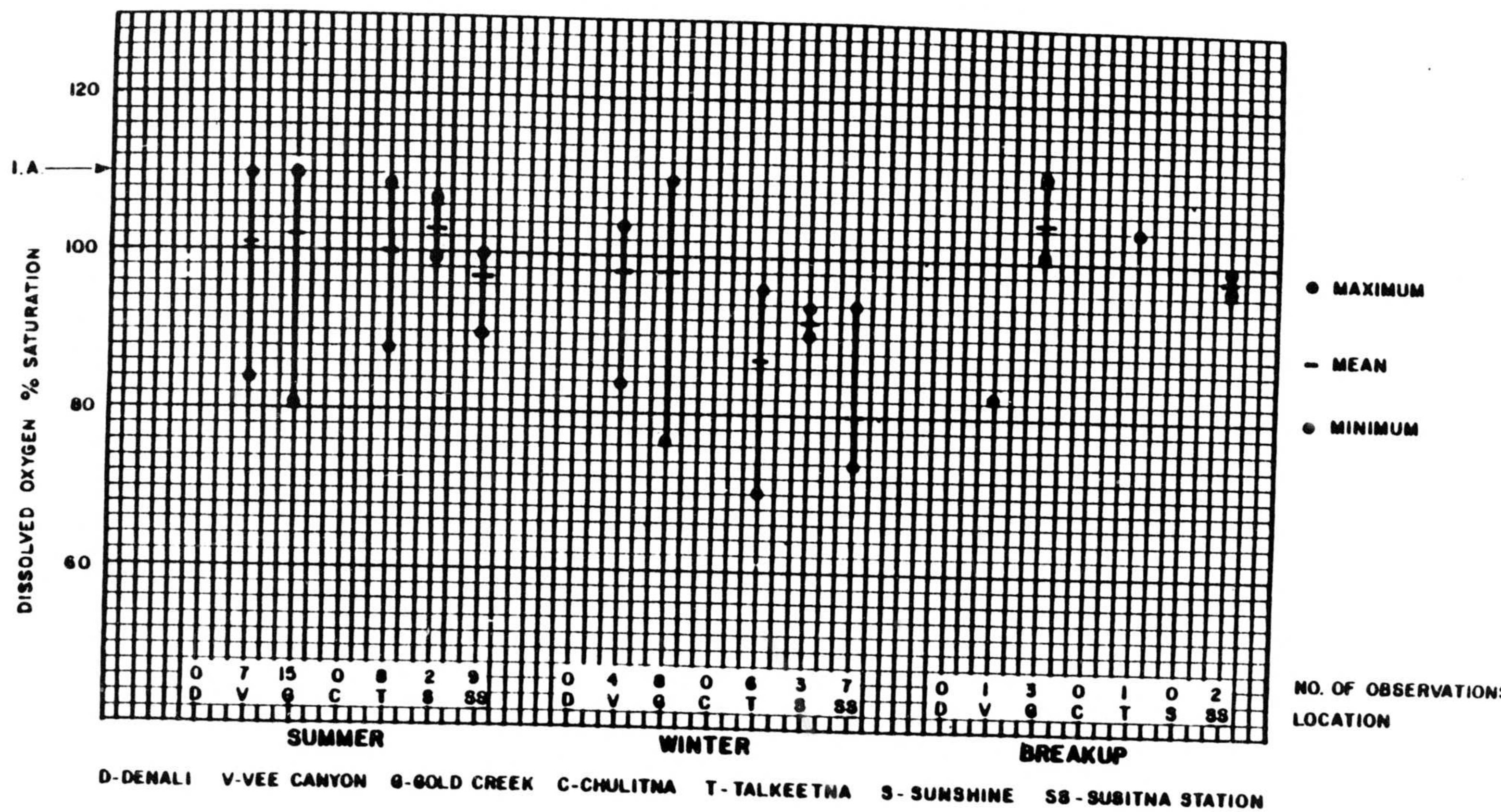
1. A. CRITERIA: GREATER THAN 7mg./l. BUT IN NO CASE SHALL DISSOLVED OXYGEN EXCEED 17 mg./l (ADEC 1979).

1. B. ESTABLISHED FOR THE PROTECTION OF ANADROMOUS AND RESIDENT FISH.

DATA SUMMARY - DISSOLVED OXYGEN

SOURCE: USGS AND R & M

FIGURE 10.1



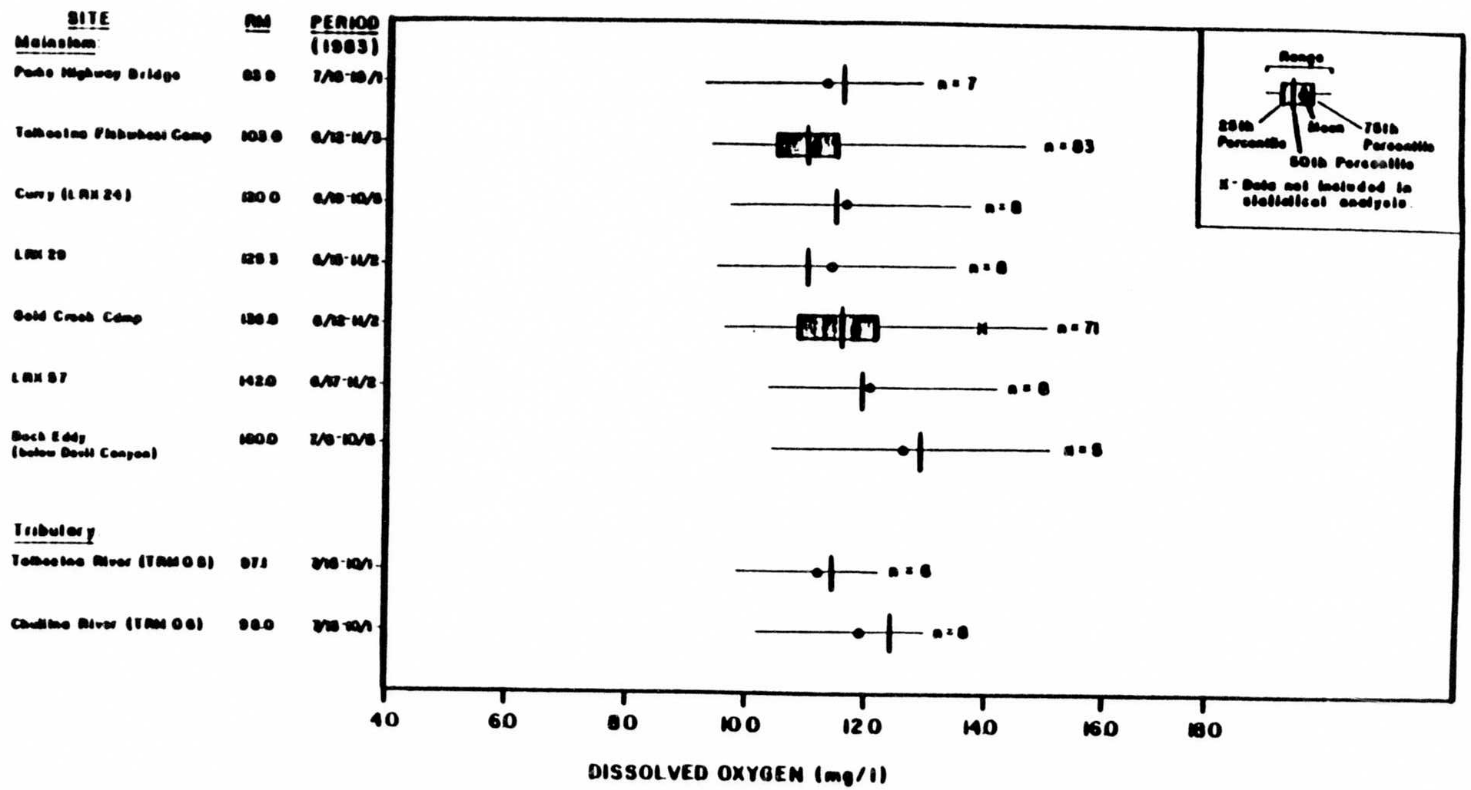
NOTES:

1. A. CRITERION: THE CONCENTRATION OF TOTAL DISSOLVED GAS SHALL NOT EXCEED 110 % SATURATION AT ANY POINT (ADEC, 1979).
1. B. ESTABLISHED FOR THE PROTECTION OF ANADROMOUS AND RESIDENT FISH.

DATA SUMMARY – DISSOLVED OXYGEN % SATURATION

SOURCE: USGS AND R&M

FIGURE 10.2

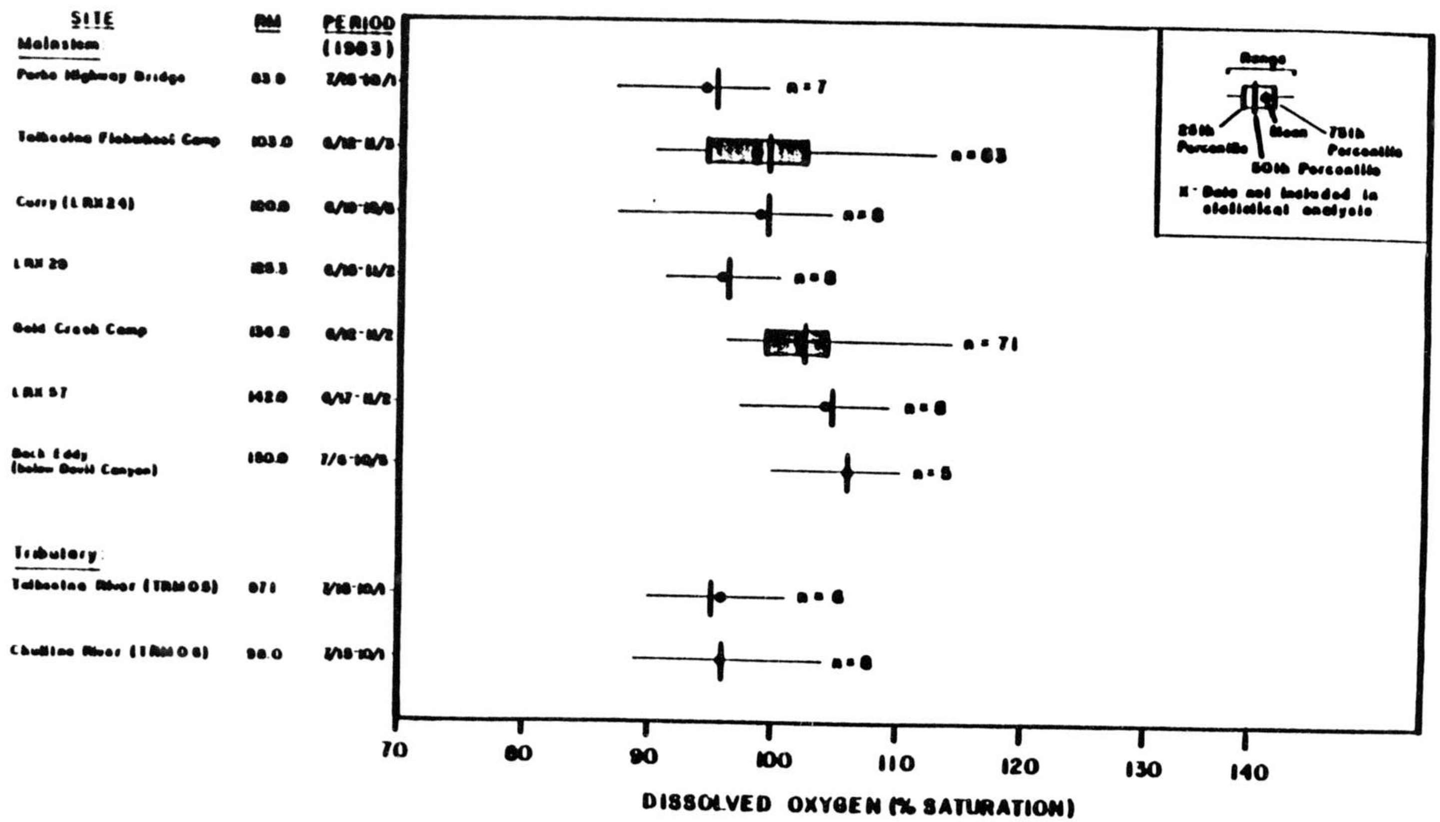


Dissolved oxygen data summary showing range, 25th, 50th (median), and 75th percentile for mainstem and tributary water quality study sites

DISSOLVED OXYGEN DATA SUMMARY

SOURCE: ADF & G 1984c

FIGURE 10.3



Dissolved oxygen percent saturation data summary showing range, 25th, 50th (median), and 75th percentile for mainstem and tributary water quality study sites.

DISSOLVED OXYGEN DATA SUMMARY

SOURCE ADF&G 1984c

FIGURE 10.4

Chemical oxygen demand (COD) values for Susitna River samples are relatively low. Summer COD values ranged rm 8 to 39 mg/l at Vee Canyon, and ranged from 1 to 24 mg/l at Gold Creek. Winter COD values were typically lower than summer values, ranging from 6 to 13 mg/l at Vee Canyon and from 2 to 16 mg/l at Gold Creek (U.S.G.S. 1980, 1981, 1982, 1983). No biochemical oxygen demand (BOD) data have been analyzed for the Susitna River, but BOD values would also be expected to be relatively low.

As previously discussed, much of the organic carbon recruited from allochthonous sources into lotic habitats is suspected as having relatively poor food quality (Cummins 1979) and as being relatively refractory to microbial degredation (Hutchinson 1975; Hobbie 1980). It is assumed that most of the TOC in the Susitna River mainstem is largely composed of humic materials derived from tundra runoff. This humic material is probably primarily composed of complex molecules with high molecular weights, and which can be generally categorized as humic acids, fulvic acids and insoluble humins. Humic materials behave as weakly acidic polyelectrolytes, have a strong propensity for complexing with metallic cations (Hg, Pb, Cu, Xn, Cd, Ni, Cr, Co, V and especially Fe, etc.), and for interacting strongly with the mineral surfaces of suspended sediments by absorption processes (Jackson, et.al. 1978; Hobbie 1980).

Studies by Naiman (1982, 1983a, 1983b) and Conners and Naiman (1984) have indicated the decreasing importance of allochthonously derived organic carbon with increasing stream size in community oxygen metablolism of boreal forest watersheds in eastern Canada. Naiman's work also emphasizes the increasing importance of autochthonous lotic periphyton production with increasing stream size in these same open canopied boreal streams. Recent work in an Alaskan arctic stream (Peterson, et al. 1985b) indicated that the biological productivity of this naturally heterotrophic stream depended in large part on the metabolism of allochthonously derived organic matter originating in its tundra watershed. Peterson, et al. (1985b) demonstrated that the biological productivity of this open canopied stream could be significantly enhanced by stimulating the autochthonous productivity of the epilithic community by experimental phosphorus addition.

10.1 WITH-PROJECT CONDITIONS AND EFFECTS

Limnological conditions in both project reservoirs are expected to minimize the formation of oxygen deficient water layers at most depths. No significant BOD loading is expected for either reservoir from the construction camp or village, due to the wastewater treatment facilities currently proposed (APA 1983a). Selective removal of large timber from certain areas of the inundation zone will eliminate a small amount of associated oxygen demand. Flooded organic matter on the reservoir bottom and sidewalls will still remain and may create some localized oxygen depletion. However, the process of decomposition will be relatively slow at the prevailing cold temperatures, and any waters experiencing oxygen depletion are expected to be substantially diluted by the large volume of reservoir water which is expected to have a relatively high dissolved oxygen content. A large volume of literature related to Alaskan, Canadian, Swedish and Norwegian lakes and reservoirs was examined with no mention found of problems due to oxygen deficits in epilimnion release waters of large reservoirs (Grimas 1961; Grimas and Nilsson 1965; Gill 1971; Gill and Cooke 1974; Geen 1975; Campbell, et al. 1975; Ward and Stanford 1979; Baxter and Glaude 1980; Acres Consulting Services Limited 1981; Koenings and Kyle 1982; Koenings 1983, 1984; Hecky, et al. 1984).

The stratification that is anticipated in the reservoirs is expected to minimize oxygen replenishment to the hypolimnion, especially during the ice covered periods. However, spring turnover, together with the large freshet inflow of highly oxygenated (probably O_2 saturated) water will cause substantial reoxygenation of of any hypolimnion oxygen deficicient waters which may occur. It is anticipated that the upper 200 feet (60m) of the impoundments will maintain high enough oxygen concentrations (>8.0) to avoid any biological problems for native fish.

Quantitative estimates of any oxygen deficiencies which may occur cannot be presently determined. This would require more extensive knowledge than is presently available regarding the quantity and quality of organic detritus to be inundated,f biological and chemical oxygen demand rates, and more detailed knowledge of reservoir hydrodynamics, including density currents (Grimas 1961; Grimas and Nilsson 1965; Wunderlich 1967 and 1971; Allanson 1973; Slotta 1973; Straskraba 1973; Williams 1973; Wunderlich and Elder 1973; Soltero, et al 1974; Hutchinson 1975; Cornett and Rigler 1979; Duthie 1979, Hannan 1979; Therien, et al. 1982).

Downstream from the reservoirs biologically important oxygen deficits are not expected. Most discharge waters will be drawn from well oxygenated surficial layers in both reservoirs. Any oxygen deficient water released from either dam will be rapidly reoxygenated due to turbulence and and equilibration with the atmosphere during discharge from the outlet works and during downstream flow.

Detrimental biological effects are not expected in either the project reservoirs or riverine habitats immediately downstream due to project induced changes in dissolved oxygen concentrations.

Lakes and reservoirs with surface discharges are well known traps for allochthonously and autochthonously derived materials, including organic carbon (Wetzel 1975; Stuart 1983; Whalen and Cornwell 1985; Soballe and Bachman 1984. It can be concluded, therefore, that in the long term of the project lifetime the project will decrease the amount of allochthonously supplied organic carbon to the downstream riverine habitats. The project reservoirs, during their early filling and operation phases, will likely cause a short term increase in downstream organic carbon transport (Crawford and Rosenberg 1984). This effect should decrease, however, as the reservoirs age.

Although the allochthonous organic carbon input to the reservoirs will likely be relatively refractory to microbial degradation (Hutchinson 1975, Hobbie 1980), and the overall quantity exiting from the reservoirs will be reduced when compared to the inflow, heterotropic microbial processing of the organics within the reservoir may somewhat improve the food quality of that organic material which is exported from the reservoirs (Crawford and Rosenberg 1984). It is presently impossible to quantitatively estimate the long term impact of reduced inputs of allochthonously derived organic carbon (TOC, DOC or POC) to the biological productivity of the Susitna River middle reach mainstem habitats. Qualitatively, it may be safe to assume a decrease in biological productivity in downstream mainstem riverine habitats due to: 1) substantial reservoir trapping of allochthonously derived organic carbon; 2) virtually no production in nor export from the reservoirs of autochthonously derived organic carbon, and 3) minimal mainstem riverine autochthonous primary production due to high, chronic turbidity.

11.0 BRIEF SUMMARY OF PROJECTED WATER QUALITY CHARACTERISTICS IN RELATION TO TROPHIC STATUS AND COMPOSITION OF THE AQUATIC COMMUNITY

11.1 RESERVIOR BIOTIC COMMUNITIES AND TROPHIC STATUS

Impoundment of the Susitna River will produce a wide variety of physical, chemical and biological changes in the newly created lentic environments which will affect their potential trophic status and biological communities.

Within the project reserviors morphological as well as other limnological characteristics indicate that biological activity in the water column will be the most important site of metabolic activity with regard to the long term reservoir biological productivity and trophic status (Hutchinson 1967 and 1975; Wetzel 1975). The newly flooded surfaces of the reservoir floors and sidewalls will be of lesser importance as sites of biological activity when compared to metabolism in the water column. The importance of biological activity in and on flooded reservoir substrates is expected to decline with reservoir aging because of gradually decreasing releases of organic matter and nutrients into the overlying water column (Grimas 1961; Nilsson 1964; Rodhe 1964; Grimas and Nilsson 1965; Lindstrom 1973; Ostrofsky and Duthie 1975; Ostrofsky and Duthie 1978; Ostrofsky and Duthie 1980; Hecky et al. 1984; Hannan 1979; Duthie 1979; Baxter and Glaude 1980; Peterson and Associates and R & M Consultants 1982; Grimard and Jones 1982).

The project reservoirs are expected to be relatively unproductive compared to the known trophic status of many bodies of fresh water (Table 11.1). Among the key limnological characteristics which are anticipated to minimize the productive potential of the project reservoirs are:

Table 11.1

SUSITNA HYDROELECTRIC PROJECT
TROPHIC STATUS AND RATES OF ANNUAL PRIMARY PRODUCTIVITY OBSERVED IN VARIOUS LAKES, LAKE-RESERVOIRS AND RESERVOIRS IN TEMPERATURE, SUBARCTIC AND ARCTIC REGIONS OF THE NORTHERN HEMISPHERE

Water Body	Trophic Classification	Annual Primary Productivity 2/ gCm^{-2} yr^{-1} Approximate Estimates	Latitude
Tundra Ponds (Barrow, Alaska)	Ultra-Oligotrophic	<1	71
Waldo (Oregon)	Ultra-Oligotrophic	<1	44
Experimental Lakes Area (Canada)	Ultra-Oligotrophic 1/	<2	50
Char (N.W.T. Canada)	Ultra-Oligotrophic 1/	4	74
Meretta (NW.T. - Canada)	Ultra-Oligotrophic	11	
Great Bear (N.W.T. Canada)	Ultra-Oligotrophic 1/	5-20	66
Great Slave (N.W.T. Canada)	Ultra-Oligotrophic 1/	5-20	62
Winnipeg (Manitoba, Canada)	Ultra-Oligotrophic 1/	5-20	53
Smallwood Res. (Labrador Plateau, Canada)	Ultra-Oligotrophic 1/	5-20	53
Watana - Devil Canyon Reservoir (Alaska)	Ultra-Oligotrophic 1/	1-20	63
Gabbro Lake (Labrador Plateau, Canada)	Ultra-Oligotrophic 1/	5-20	54
Lobstick Lake (Labrador Plateau, Canada)	Ultra-Oligotrophic 1/	5-20	54
Tustumena Lake (Alaska)	Ultra-Oligotrophic	5-20	60
LaGrande Lake-Reservoirs Quebec, Canada)	Ultra-Oligotrophic	<30	53
Southern Indian LK Reservoirs (Manitoba, Canada)	Oligotrophic	<60	57
Koocanusa Reservoir (Montana-British Columbia)	Ultra-Oligotrophic	29	49
Kamloops (British Columbia, Canada)	Ultra-Oligotrophic	32	50
Castle (California)	Ultra-Oligotrophic	36	40
Lawrence (Michigan)	Oligotrophic	41	42
Lunzar Untersee (Austria)	Oligotrophic	45	48
Superior (USA-Canada)	Oligotrophic	50	48
Tahoe (Nevada-California)	Oligotrophic	70	39
Cresent Lake (Alaska)	Oligotrophic 1/	<90	61
George (New York)	Oligo-Mesotrophic	72	43
Huron (USA-Canada)	Oligotrohpic	100	43
Flathead (Montana)	Oligo-Mesotrophic	123	48
Michigan (USA)	Mesotrophic	130-150	45

1/ Estimated
2/ Primarily composed of phytoplankton studies

Source: (MODIFIED AFTER STUART, 1983)

Table 11.1 (Cont'd)

Water Body	Trophic Classification	Annual Primary Productivity gCm^{-2} yr^{-1} Approximate Estimates	Latitude
Clear (Calfornia)	Mesotrophic	160	42
Crooked (Indiana)	Mesotrophic	171	40
Ontario (USA-Canada)	Mesotrophic	180	44
Erie (USA-Canada) (East Basin)	Mesotrophic	180	42
Belwood Reservoir (Ontario)	Mesotrophic	<200	43
Cayuga (New York)	Mesotrophic	200	43
North Lake Reservoir (Texas)	Mesotrophic	200	33
Sammamish (Washington)	Mesotrophic	238	48
Esrom (Denmark-1959)	Mesotrophic	260	55
Lac Leman (Switzerland-1975)	Eutrophic	300	46
Minnetonka (Minnesota)	Eutrophic	300	46
Erie (USA-Canada) (West Basin)	Eutrophic	310	42
Waco Reservoir (Texas)	Eutrophic	310	31
Washington (Washington-1971)	Mesotrophic	354	48
Frederiksborg Slotssø(Denmark)	Eutrophic	376	56
Wintergreen (Michigan)	Eutrophic	369	43
Sollerød So (Denmark)	Eutrophic	522	56
Sylvan (Indiana)	Eutrophic	570	40
Lanao (Philippines)	Eutrophic	620	15
Victoria (Africa)	Eutrophic	640	0
Washington (Washington 1963-64 Pre Diversion of Sewage)	Eutrophic	766	48
Mendota (Wisconsin 1965-1966)	Eutrophic	1100	43

- Relatively high turbidity values and consequently shallow euphotic zones;
- Relatively low mean annual temperatures;
- Relatively great maximum and mean depths;
- Relatively short hydraulic residence times;
- Relatively large total volume per unit of surface area;
- Large total volume for dilution of inundation zone leachates;
- "Sediment blanket" effect for retarding and minimizing leachates;
- Near surface withdrawal of water and entrained plankters;
- Possibilities of a relatively unstable vertical density structure and the consequent potential for a relatively deep mixed surface layer compared to the euphotic zone depth.

Reservoir trophic status is typically determined in part by the relative amounts of critical nutrients (carbon, silicon, nitrogen and phosphorus, etc.) as well as by the morphology, and hydraulic, thermal, optical, and climatological regimes, and the geographic location, etc. The most recent estimates of Stage I, II, and III reservoir suspended sediment concentrations and turbidity indicate that the euphotic zone of both reservoirs will be substantially restricted during most, if not all, seasons. The productivity of the project reservoirs is expected to be primarily light limited. An analagous situation of a continuously turbid, subarctic reservoir exhibiting light limited primary production has been observed (Hecky and Guildford 1984; Planas and Hecky 1984; Hecky 1984; Hecky et al. 1984). Both project reservoirs are expected to be classified as ultra-oligotrophic for their operational lifetime. Due to the expected light limitation, the standard types of emperically derived models for predicting reservoir trophic response from nutrient loading and nutrient concentration relationships (Vollenweider 1975; Dillon 1975; Jones and Backman 1976; and Larcen and Mercier 1976) are not expected to be applicable for predicting the trophic status of the project reservoirs (Kerekes 1982; Walker 1982; Rast and Lee 1978; Mueller 1982; and Soballe and Bachman 1984).

Artificial phosphorus loading of the Watana reservoir from domestic sources was investigated by Peterson and Nichols (1982). They concluded that the maximum allowable artificial loading is equivalent to the waste from 115,800 permanent residents, if oligotrophic conditions are to be maintained and if the reservoir was expected to be clear. However, their estimate is conservative since the effects of low light penetration have been neglected.

Reduction of riverine born suspended sediments by settling within the reservoir will result in a sediment blanket effect. Organic materials on the reservoir floor and side walls will eventually become coated and/or buried by settled (mostly inorganic) particulates. The sediment blanket effect will have a retardant effect on leaching and biological cycling of macro and micro nutrient ions, primary and secondary productivity and organic detritus oxidation (Wetzel 1975, Campbell et al. 1975, Crawford and Rosenberg 1984, Wiens and Rosenberg 1984, Hecky and McCollough 1984).

Development of a small but viable phytoplankton population composed of primarily Bacillariophyceae, Chrysophaecae, Dinofyceae and Chlorophyceae with a microplankton community of photosynthetic bacteria and mostly unicellular Cyanophyceae is expected to be formed within the project reservoir(s). The plankton community is expected to remain at low or very low densities and to be primarily located within the wind mixed surface strata. Heterotrophic bacteria, fungi and actinomycetes are expected to dominate the hypolimnion biological communities (Grimas and Nilsson 1965; Geen 1974, Wetzel 1975, Duthie 1979, Baxter and Claude 1980, Hecky and

Guildford 1984, Hecky et al. 1984, Koenings and Kyle 1982).

Development of a limited but viable zooplankton community primarily composed of Protozoa, Rotifera, Copepoda and very low densities of Cladocera and Insecta is expected in the project reservoirs. Cladocera typically exist at low or very low densities in natural lakes heavily influenced by glacial flour in subarctic lentic environments (Wetzel 1985, Grimas and Nilsson 1965, Pinel-Alloul et al. 1982, Patalis and Salki 1984, Koenings and Kyle 1982).

A macrobenthic community with relatively low densities of Insecta, Oligochaeta, and Mollusca is expected to form immediately after impoundment. Macrobenthos densities will probably decrease after the first 5-10 years of reservoir aging (Wetzel 1975, Grimas 1965, Hutchinson 1967, Grimas and Nilsson 1965, Wiens and Rosenberg 1984, Crawford and Rosenberg 1984, Bilyj 1984, Rosenberg et al. 1984, Hecky et al. 1984).

The density of resident fish communities in the project reservoirs is expected to be low throughout the project life time.

11.2 MIDDLE RIVER BIOLOGY AND PROJECTED TROPHIC STATUS

With regard to general metabolic activity, the river habitats are expected to present a contrasting situation to that in the reservoirs. The most important site of biological activity affecting the productivity and trophic status of the riverine habitats will be the streambed substrate and streambed interstitial spaces (Hynes 1970; Cummins 1974; Moore 1977; Kawecka et al. 1978; Barton and Lock 1979; Ward and Stanford 1979; Cushing et al. 1980; Ward et al. 1982; Vannote et al. 1980; Newbold et al. 1981; Murphy et al. 1981; Minshall et al. 1983; Conners and Naiman 1984; Søballe and Bachmann 1984; Lloyd 1985; Peterson et al. 1985b). Biological activity in the riverine water column is expected to be of minimal importance to the overall stream biological productivity and trophic status.

Although quantitative estimates of the trophic status of the Susitna River middle reach do not exist, cursory qualitative observations by several researchers have estimated the productivity to be relatively low at all trophic levels. This observation is in agreement with observations made on several lotic habitats having glacial stream characteristics which indicate that they appear relatively unproductive compared to other lotic habitats (Hynes 1970, Steffan 1971, Ward and Stanford 1979, Ward et al. 1982, Milner 1983, Van Stappen 1984, Lloyd 1985).

The complex array of environmental variables which presently appear to minimize the middle reach biological productivity at the microbial, macroinvertebrate, and perhaps the fishery trophic levels include:

- o Relatively low mean annual temperatures;

- o Relatively high flow variability during the annual hydrologic cycle; and associated with the high flows the associated high turbulence, velocities and related drag which contribute to streambed substrate instability;

- o Relatively high suspended sediment and bedload concentrations for four to five months of each year which contributes to at least the following effects:

  - Relatively high sedimentation of streambed substrates resulting in detrimentally high concentrations of fine particulates in the streambed material and the associated embedded quality of much of the streambed substrate;

  - Relatively large particle size of the suspended sediment which contributes to high rates of sedimentation, scour of microbial epilithic communities on large streambed substrate, and unstable streambed substrates which are less than optimal for microbial or macroinvertebrate colonization;

- Relatively high turbidity values resulting in very limited euphotic zones during the more potentially productive portion of each annual cycle when the maximal solar irradiance occurs.

Anticipated effects of the project include modifications to all of the previously listed environmental variables. However, of the previously listed variables which the project will affect, an altered suspended sediment regime is likely to cause two of the more profound effects which will impact the potential productivity of the microbial, macroinvertebrate, and perhaps the fisheries communities in the middle river reach. These two effects, as briefly discussed below, may have ecological interactions which are fundamentally antagonistic and offsetting to each other with regard to their effects on aquatic community ecology of the middle river reach.

Decreased biological productivity, as yet unquantified, is expected to occur in mainstem channels with constantly turbid riverine flows. The chronic turbidity may substantially limit the penetration of incident light and the productivity and standing crops of the microbial epilithic community in most mainstem influenced habitats during most seasons. At least two concepts should be considered in relation to the potentially detrimental effects of a chronically high turbidity regime:

o Although the high natural productivity and standing crop of microbial epilithon occurring in naturally clear spring and fall transition periods will likely be attenuated, the predicted With-project turbidity regime may reach low enough turbidity values during the early spring (March-May) to allow for adequate light penetration to some shallow and stable substrate and stimulate a brief and limited growth pulse of epilithon. The most dominant algal genera are expected to include Spirogyra, Zygnema, Ulothrix, Hydrurus, Microspora, Lyngbya, Phormidium, Anabaena, Nostoc, Nitzschia, Gomphonema, Cocconeis, Meridion, Cymbella and

Achnanthes. Such a spring periphyton growth pulse may potentially be beneficial to a portion of the existing macroinvertebrate community (i.e. most likely generalist-omnivores in the group Chironomidae).

o Although highly turbid conditions will substantially restrict light penetration, the small size and large collective surface area of the suspended particulates which cause the turbidity may also serve as a basic source of phosphorus and micronutrients to any juxtapositioned microbial epilithic community. Thus, in habitats peripheral to the mainstem where wetted areas are shallow enough to allow adequate light penetration to reach stable streambed substrate and where other environmental factors are suitable, the attached epilithon community may thrive at rates in excess of those presently occurring (especially mucous secreting, mat forming algae like cyanophyta). A somewhat analagous situation has been observed in some shallow water microhabitats of the chronically turbid, but very fertile waters of the Kasilof River, draining chronically turbid Tustumena Lake on the Alaskan Kenai Peninsula. Reduced scour of microbial epilithic communities by relatively large particulates (silt, sand and gravel) is expected to enhance the probability of greater standing crops of microbial epilithic communities on stable, wetted substrates in shallow peripheral habitats existing in the middle reach. This has also been hypothesized and observed on the Kasilof River.

A second major effect of the anticipated altered suspended sediment regime is the permanent storage of most particulates coarser than 10-20 microns diameter (silt, sand, gravel, etc.) behind the dams while simultaneously flushing and removing the same sized particulates from some surficial and shallow interstitial layers of the middle river streambed. Relatively large flushing flows to help facilitate this removal of fines (simulated maxima may reach 38,000 cfs) are anticipated to be available from combined powerhouse and/or cone valve discharges within portions of several summers during the second stage of project operations. Streambed substrate disturbance during these high flow events and the attendant flushing of fine streambed particulates from the system, without their replacement from upstream sources, is expected to substantially enhance the heterogeneity and volume of streambed substrate niches. Such changes should enhance the potential for greater biomass production of benthic macroinvertebrates and the smaller, immature life stages of fishes which may utilize these niches.

The current state of impact assessment regarding these latter two changes resulting from the anticipated altered suspended sediment regime leads to two tentative conclusions:

First: the chronically high turbidity will detrimentally impact the productivity of biological communities in most relatively deep riverine habitats, while possibly enhancing the productivities of biological communities in relatively shallow, peripheral habitats where incident light can penetrate to wetted streambed substrate;

Second: removal of surficial fines by scour and degradation without replacement from upstream may create substantial additional habitat on and within the coarser streambed substrate in most riverine habitats.

Conclusive estimates of the overall, combined impact on the middle reach trophic status from both of these expected changes are not presently possible to make with high confidence. It presently appears that the expected benficial impacts resulting from more extensive and heterogenous coarse substrate habitat may be negated, at least in part, by food limitation due to chronically high turbidity and reduction of allochthonous organic carbon inputs from upstream.

11.3 SUMMARY THOUGHTS REGARDING POTENTIAL PROJECT INDUCED WATER QUALITY CHANGES

Changes of the natural regime of suspended sediments may potentially be one of the more biologically offensive water quality consequences of this project. For these and other reasons, mitigation plans are being proposed to improve and protect important aquatic habitats peripheral to mainstem river channels.

Although much aquatic literature emphasizes the more negative aspects of suspended sediments and turbidity, it may also be useful to briefly examine other knowledge regarding this subject. In this vein of thought, it should be remembered that small, suspendable, inorganic particulates are historically among the oldest and most natural entities found in water and are also primary sources of essential elements needed by all forms of life, including aquatic biota. The elemental and mineralogic properties of small inorganic particulates often enable them to be efficient focal points for the concentration of dissolved and particulate inorganic materials. Often these "scavenging" effects help to bind, and make less bioloically available, otherwise potentially toxic ions, like heavy metal cations.

Tiny inorganic particulates are also known to aid in adsorbing and concentrating dissolved organic detritus, thus enhancing and facilitating one of the more important biological processes of all - the microbial catabolism and recycling of formerly living biota. Without aquatic and terrestrial recycling of organic detritus, future life could not exist.

The theoretical assumption that an infinite continuum of NTU/TSS relationships exists within aquatic environments is a concept which may need to be empirically tested with regard to this project. It may be empirically testable and documentable that a useful generalization may exist for a separate and fairly distinct lentic and lotic relationship between turbidity and suspended sediments. If a sufficiently distinct lentic relationship can be documented as a reality, then better projections for Watana discharge turbidities may be estimateable. Better estimates of the potential effects of the project will obviously be a valuable tool for decision making regarding any potentially necessary mitigation.

It is worth mentioning that much evidence exists that aquatic organisms in lotic environments are often endowed with specialized attributes which promote relatively efficient functioning in their particular environmental niche. Aquatic insects are often noted in biological literature for their extensive morphological and behavioral specializations which apparently aid their successful colonization of many diverse aquatic habitats (Hynes 1970; Merritt and Cummins 1978). Dipterans in general, and Chironomidae in particular, are an extremely diverse insect group with specialized characteristics allowing them to occupy a varied range of both terrestrial and aquatic habitats. Chironomidae are able to successfully colonize an extraordinarily diverse array of both lentic and lotic aquatic habitats, among them are included relatively harsh environments including very cold and turbid glacial melt water streams (Merritt and Cummins 1978; Kawecka et al. 1978; Hobbie 1980; Milner 1983). If Susitna mainstem habitats become a more harsh lotic environment due to Project operations, the Chironomidae may be among the more likely invertebrates to successfully colonize even the more demanding lotic environments. In addition, chironomid larvae and adults are preferred food items for some species of juvenile Oncorhynchus.

Another note is worth considering with regard to project induced water quality considerations for the Susitna River. Salmon as a group, including both Salmo and Oncorhynchus species, have probably evolved for at least 500,000 to 1,000,000 years through at least four major and several minor Ice Ages in Europe, Asia and North America. During their speciations and dispersions in streams and oceans between 35° and 75° north latitudes they have undoubtedly encountered and endured extremely varied riverine suspended sediment regimes including situations of chronic turbidity and high suspended sediment loading. All existing species of salmon appear to have evolved certain behavioral and presumably physiological adaptations for selecting and surviving in lotic environments which are subject to variable suspended sediment regimes. Present Susitna River salmon stocks, as have their historical relatives, will adjust to project-induced water quality changes.

One final note should be considered regarding potential project induced limnological changes. To the extent of our present knowledge, the potential for a mercury bioaccumulation hazard due to construction and operation of the project exists. This does not mean that a mercury bioaccumultion problem presently exists nor does it mean that it will exist. The environment is replete with potential hazards for all forms of biota. Awareness of potential environmental hazards, to the lives of humans and other biota, is a wise entity to cultivate. By being aware of environmental actions and using our capacity for forethought, many environmental hazards may be negated, rendered negligable and/or avoided.

REFERENCES

Alaska Administrative Code (A.A.C) 1984. Title 18, Environmental Conservation, Chapter 70, Water Quality Standards. Last Amended 30 March 1984.

Abernathy A.R., and P.M. Cumbie 1977. Mercury accumulation by largemouth bass (Micropterus salmoides) in recently impounded reservoirs. Bull. Environ. contam. Taxicol. 17(55): 595-602.

Acres Consulting Services Limited 1981. Reservoir clearing and preparation - environmental protection strategies, Niagara Falls, Ontario, 112 pp., plus biolography and 3 appendices.

Alabaster, J.S. and R. Lloyd 1980. Water Quality Criteria for Freshwater Fish, Butterworths, London, 283 pp.

Alaska Department of Fish and Game 1982. Susitna Hydro Aquatic Studies Report Phase II. Basic Data Report Vol. 4. Aquatic Habitat and Instream Flow Studies. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1983a. Susitna Hydro Aquatic Studies. Phase II, Basic Data Report. Vol. 5, Upper Susitna River Impoundment Studies, 1982. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1983b. Susitna Hydro Aquatic Studies. Phase II, Basic Data Report. Vol. 4. Aquatic Habitat and Instream Flow Studies, 1982. Parts I and II. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1984a. Susitna Hydro Aquatic Studies Report Series Adult Anadromous Fish Investigations: May - October 1983. Report No. 1. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1984b. Susitna Hydro Aquatic Studies. Report No. 2. Resident and Juvenile Anadromous Fish Investigations, May-October 1983. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1984c. Susitna Hydro Aquatic Studies. Report No. 3. Aquatic Habitat and Instream Investigations. Ch. 4. Water Quality Investigations: May-October 1983. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1985a. Draft. Susitna Hydro Aquatic Studies. Report No. 7, Part 2. The Relative Abundance, Distribution, and Instream Flow Relationships of Juvenile Salmon in the Lower Susitna River. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1985b. Susitna Hydro Aquatic Studies Report No. 8. Availability of Invertebrate Food Sources for Rearing Juvenile Chinook Salmon in Turbid Susitna River Habitats. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1985c. Susitna Hydro Aquatic Studies. Resident and Juvenile Anadromous Fish Investigations, May - October 1984. Report No. 7, Part 1. The migration and Growth of Juvenile Salmon in the Susitna River. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1985d. Susitna Hydro Aquatic Studies. Winter Aquatic Investigations, September 1983 - May 1984. Vol. An Evaluation of the Incubation Life-Phase of Chum Salmon in the Middle Susitna River, Alaska. Prepared for Alaska Power Authority, Anchorage, Alaska.

Alaska Power Authority 1983a. Final application for license for major project. Susitna Hydroelectric Project. Before the Federal Energy Regulatory Commission, accepted by FERC 27 July, 1983. Vol. 5A, Exh. E, Chapters 1 and 2. Alaska Power Authority. Susitna Hydroelectric Project.

_____, 1983b. Final application for license for major project. Susitna Hydroelectric Project. Before the Federal Energy Regulatory Commission, accepted by FERC 27 July 1983. Vol. 5B, Exh. E, Chapter 2 - Figures. Alaska Power Authority. Susitna Hydroelectric Project.

_____, 1983c. Final application for license for major project. Susitna Hydroelectric Project. Before the Federal Energy Regulatory Commission. Exh. F, Vol. 3, Supporting Design Report. Alaska Power Authority. Susitna Hydroelectric Project. 1 Vol.

_____, 1983d. Final application for license for major project. Susitna Hydroelectric Project. Before the Federal Energy Regulatory Commission. Exh. F, Vol. 3-Plates, Supporting Design Report. Alaska Power Authority. Susitna Hydroelctric Project. 1 Vol.

_____, 1983e. Final application for license for major project. Susitna Hydroelectric Project. Before the Federal Energy Regulatory Commission Accepted by FERC 27 July 1983. Exh. e, Vol. 7, Ch. 6 Geological and soil Resources. Alska Power Authority. Susitna Hydroelectric Project.

_____, 1983f. Final application for license for major project. Susitna Hydroelectric Project. Before the Federal Energy Regulatory Commission, accepted by FERC 27 July 1983. Vol. 6A, Exh. E. Ch. 3. Fish, Wildlife, and Botanical Resources, Text. Alaska Power Authority. Susitna Hydroelectric Project.

_____, 1983g. Final Application for license for major project. Susitna Hydroelectric Project. Before the Federal Energy Regulatory Commission, accepted by FERC 27 July 1983. Vol. 6B Figures, Exh. E., Ch. 3. Fish, Wildlife and Botanical Resources. Alaska Power Authority. Susitna Hydroelectric Project.

Allan, R.J. 1978. Natural controls of dissolved solids in Boundary Reservoir, Saskatchewan. Canadian Wat. Res. J. 3(3):78-96.

Allanson, B.R. 1973. Summary: Physical limnology of man-made lakes. in: Man-Made Lakes: Their Problems and Environmental Effects. W.C. Ackerman, G.F. White, and E.B. Worthington, edis. Am. Geophys. Union, Washington, D.C. 1134 pp.

Allis-Chalmers. No Date. Howell-Bunger and Ring-Jet Valves.

American Public Health Association (APHA) 1980. Standard Methods for the Examination of Water and Waste Water. Fifteenth edition. Am. Pub. Health Assoc. Press, Washington, D.C. 1134 pp.

Ammerman, J.W. and F. Azam 1985. Bacterial 5'-nucleotidase in aquatic ecosystems: a novel mechanism of phosphrous regeneration. Science, Vol. 227: 1338-1340.

Anderson, J.E., S.R. Ekman, B. Lunden, H.C. Olsen, T. Ziegler and G. Ostrem 1970. English summary: Sediment transport studies at selected glacial streams in Norway. Report No. 1/72, Vasdragsdirecttorstet, Hydrologisk Avdeling, Oslo, Norway. 00: 110-131.

Arctic Environmental Information and Data Center 1984. Susitna Hydroelectric Project Aquatic Impact Assessment: Effects of Project-Related Changes in Temperature, Turbidity and Stream Discharge on Upper Susitna Salmon Resources During June through September. Prepared for Alaska Power Authority, Anchorage, Alaska.

______, 1985. Geomorphic Change in the Middle Susitna River Since 1949. Prepared under contract to Harza-Ebasco Susitna Joint Venture for Alaska Power Authority, Anchorage, Alaska.

Austin, R.W. 1973. Problems in measuring turbidity as a water quality parameter. Paper presented at USEPA seminar on Methodology for Monitoring the Marine Environment at Seattle, WA. Oct. 16-18, 1973. Reprinted with author's permission by Martek Instruments, Inc.

Baker, W.E. 1973. The role of humic acids from Tasmanian podzolic soils in mineral degradation and metal mobilization. Geochim. Cosmochim. Acta 37: 269-281.

Barnett, A.P. 1974. Hydrological Studies of Slims River, Yukon, June-August 1970. Icefield Ranges Research Project: Scientific Results. Vol. 4. Amer. Geographical Society - 1974. pp. 143-150.

Barton, D.R. 1980. Benthic macroinvertebrate communities of the Athabasca River near Ft. Mackay, Alberta. Hydrobiologia 74; 151-160.

Barton, D.R. and M.A. Lock 1979. Numerical abundance and biomass of bacteria, algae, and macrobenthos of a large northern river, the Athabasca. Int. Revue Ges. Hydrobiol. 64; 3: 345-359.

Bryan, M.L. 1974a. Sublacustrine Morphology and Deposition, Kluane Lake, Yukon Territory. Icefield Ranges Research Project: Scientific Results. Vol. 4. Amer. Geographical Socieity - 1974. pp. 171-187.

_____, 1974b. Sedimentation in Kluane Lake. Icefield Ranges Research Project: Scientific Results. Vol. 4. Amer. Geographical Society - 1974. pp. 171-187.

_____, 1974c. Water Masses in Southern Kluane Lake. Icefield Ranges Research Project: Scientific Results. Vol. 4. Amer. Geographical Society - 1974. pp. 163-169.

Baxter, R.M. and P. Glaude 1980. Environmental effects of dams and impoundments in Canada: experience and prospects. Can Bull. Fish. aquat. Sci. 205: 34 pp.

Beck, K.C., J.H. Reuter, and E.M. Perdue 1974. Organic and inorganic geochemistry of some coastal plain rivers of the southeastern United States. Geochim. Cosmochim. Acta 38: 3410364.

Becker, C.D. 1973. Food and growth parameters of juvenile chinook salmon (Oncortghyncus tshawytscha) in central Columbia River. Fishery Bulletin: Vol. 71, No. 2: 387-400.

Bell, M.C. 1980. Fisheries handbook of Engineering Requirements and Biological Criteria. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Benes, P. and E. Steinnes 1974. In Situ dialysis for the determination of the state of trace elements in natural waters. Water Research 8:947-953.

Beschta, R.L. and W.L. Jackson 1979. The intrusion of fine sediments in a stable gravel bed. J. Fish. Res. Bd. Can. 36: 204-210.

Bilyj, B. 1984. Descriptions of two new species of Tanypodinae (Diptera: Chironomidae) from Southern Indian Lake, Canada. Can. J. Fish. Aquat. Sci. 41 (4): 659-681.

Bisogni, J.J. Jr., A.W. Lawrence 1975. Kinetics of mercury methylation in aerobic and anaerobic aquatic environments. J. Water Poll. Cont. Fed. 74(1): 135-152.

Bisson, P.A. and R.E. Bilby 1982. Avoidance of suspended sediments by juvenile coho salmon. North Am. J. of Fish Management 4: 371-374.

Bjornn, T.C., M.A. Brusven, M.P. Molnau, J.H. Milligan, R.A. Kampt, E. Chacho, and C. Schaye 1977. Transport of granitic sediment in streams and its effects on insects and fish. bulletin No. 17, College of Forestry, Wildlife and Range Sciences, Univ. Of Idaho, 43 pp.

Bodaly, R.A., R.E. Hecky, and R.J.P. Fudge (In Press) Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. Can. J. Fish. Aquat. Sci.

_____, T.W.D. Johnson, R.J.P. Fudge and J.W. Clayton 1984, Collapse of lake whitefish (Coregonus clupeaformis) fishery in Southern Indian lake, Manitoba, following lake impoundment and river diversion. Can. J. Fish. Aquat. Sci. 41: 692-700.

_____, D.M. Rosenberg, M.N. Goboury, R.E. Hecky, R.W. Newbury and K. Patalis 1983. Ecological effects of hydroelectric development in northern Manitoba, Canada: the Churchhill-Nelson River Diversion. in: "Effects of Pollutants at the Ecosystem Level, "SCOPE, 22, John Wiley and Sons, Toronto. pp. 273-310.

Boyer, P.B. 1974. Gas supersaturation problems in the Columbia River. in: Man-Made Lakes: their Problems and Environmental Effects. W.C. Akerman, F.G. White and E.B. Worthington, ed.s. Am. Geophys. Union, Washington, D.C. pp. 701-705.

Britton, L.J. K.E. Goddard and J.C. Briggs 1983. Quality of Rivers of the United States, 1976 Water Year, Based on the National Stream Quality Accounting Network (NASQAN). U.S. Geological Survey Open-File Report 80-594. 423 pp.

Brune, G.M. 1953. Trap efficiencies of reservoirs. Trans. Amer. Geophys. Union. Misc. Publication 970. U.S. Department of Agriculture.

Brusven, M.A. and K.V. Prather 1974. Influence of stream sediments on distribution of macrobenthos. J. Entomol. Soc. Brit. Columbia; pp. 25-32.

Burger, C.V., D.B. Wangard, R.L. Wilmot and A.N. Palmisano 1982. Salmon investigations in the Kenai river, Alaska, 1979-1981. U.S.F&W; 181 pp.

Burrows, W.D. 1977. Aquatic aluminum: chemistry, toxicology, and environmental prevalence. Critical Reviews in Environmental Control 7; 167-209.

Campbell, P.G., B. Bobee, A. Caille, M.J. Demalsy, P. Demalsy, J.L. Sasserville and S.A. Visser 1975. Pre-impoundment site preparation: a study of the effects of topsoil stripping on reservoir water quality. Verh. Internat. Verein. Limnol. 19:1768-1777.

Carling, P.A. 1984. Deposition of fine and coarse sand in an open-work gravel bed. Can. J. Fish. Aquat. Sci. 41:236-270.

Chapin, F.S. III and K. VanCleve 1978. Nitrogen and phosphorus distribution in an Alaskan tussock tundra ecosystem: natural patterns and implications for development. In: Environmental Chemistry on Cycling Processes. D.C. Adrians and I.L. Brisbain, ed.s. Washington: Energy Research and Development Agency.

Chapnick, S.D., W.S. Moore, and K.H. Nealson 1982. Microbially mediated manganese oxidation in a freshwater lake. Limnol. Oceanogr. 27(6): 1004-1014.

Chen, T.F. and J.R. Davis. 1964. Disintegration of a turbulent water jet. Journal of the Hydraulics Division, American Society of Civil Engineers. HY1.

Christman, R.F. and E.T. Gjessing, ed.s. 1983. Aquatic and terrestrial humic materials. Ann Arbor Science Publishers, Ann Arbor, MI. 538 pp.

Conners, M.E. and R.J. Naiman 1984. Particulate allochthanous inputs: relationships with stream size in an undisturbed watershed. Can. J. Fish Aquat. Sci. 41: 1473-1484.

Cooper, A.C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. Int. Pa. Sal. Fish. Comm. Bull. 18. 71 pp.

Cordone, A.J. and D.E. Kelley 1961. The influence of inorganic sediment on the aquatic life of streams. Calif. Fish and Game 47: 189-228.

Cox, J.A., Carnahan, J. DiNunzio, J., McCoy, J., and Meister, J., 1979. Source of mercury in fish in new impoundments. Bull. Environ. Contam. Toxicol. 23:779-783.

Cranston, R.E. and Buckley, D.E. 1972. Mercury pathways in a river and estuary. Environ. Sci. Technol. 6:274-278.

Crawford, P.J. and D.M. Rosenberg 1984. Breakdown of conifer needle debris in a new northern reservoir, Southern Indian Lake, Manitoba. Can J. Fish. Aquat. Sci. 41:649-658.

Csejtey, B., W.H. Nelson, D.L. Jones, N.J. Siberling, R.M. Dean, M.S. Morris, M.A. Lamphere, J.G. Smith, and M.L. Silberman. 1978. Reconnaissance Geologic Map and Geochronology, Talkeetna Mountains Quadrangle, Northern Part of Anchorage Quadrangle, and Southwest Corner of Healy Quadrangle, Alaska. USGS. Open File Report 78-558-H, 60 pp.

Cornett, R.J. and F.H. Rigler 1979. Hypolimnetic oxygen deficits: their prediction and interpretation. Science, Vol. 205. pp. 580-581.

Cummins, K.W., 1974. Structure on function of stream exosystems. Bioscience 24: 631-641.

_____, 1979. The natural stream ecosystem. In: Ward, J.V. nd J.A. Stanford, eds, "The Ecology of Regulated Streams", New York, pp. 7-24.

Cushing, C.E., C.D. McIntire, J.R. Sedell, K.W. Cummins, G.W. Minshall, R.C. Peterson and R.L. Vannote. 1980. Comparative study of physical-chemical variables of streams using multivariate analysis. Arch. Hydrobiol., 89(3):343-352.

Dauble, D.D., R.H. Gray and T.L. Page. 1980. Importance of insects and zooplankton in the diet of 0-age chinook salmon (Oncorhynchus tshawytscha) in the central Columbia River. Northwest Science, Vol. 54, No. 4, pp 253-258.

Davis, J.A. 1984. Complexation of trace metals by absorbed natural organic matter. Geochim. Cosmochim. Acta 48:679-691.

Dawley, E., B. Monk, M. Schiewe, F. Ossiander, and W. Ebel. 1976. Salmonid bioassay of supersaturated dissolved air in water. EPA-600/3-76-056. 49 pp.

Denisova, A.I. 1977. Factors governing the biological productivity, regime, and content of biogenic and organic substances in the sequence of Dniepr reservoirs. Water Resources 5(6):885-895.

Dillion, P.J. 1975. The phosphorus budget of Cameron Lake, Ontario: The importance of flushing rate to the degree of eutrophy in lakes. Limnol. Oceanogr. 19:28-39.

Dott, R.H. and R.L. Batten. 1981. Evolution of the Earth. McGraw-Hill, Inc., New York, 573 pp. plus appendices and index.

Duffer, W.R., and C.C. Harlin. 1971. Changes in water quality resulting from impoundment. National Water Quality Control Research Program, R.S. Kerr Water Research Center, USEPA, Ada, Oklahoma, 110 pp.

Duthie, H.C. 1979. Limnology of subarctic Canadian lakes and some effects of impoundment. Arctic and Alpine Research, 11(2):145-158.

Ecological Analysts Inc. 1982. Lake Comanche Dissolved Nitrogen Study, Concord California. Prepared for Milo Bell.

Efford, I.E. 1975. Assessment of the impact of hydro-dams. J. Fish. Res. Board Can. 32: 196-209.

Einstein, H.A. 1968. Deposition of suspended particles in a gravel bed. J. Hydraulics Division, Proceedings of the American Society of Civil Engineers, V. 94, p. 1197-1205.

_____, 1972. Sedimentation (Suspended Solids). in: River Ecology and Man, ed's R.T. Oglesby, C.A. Carlson, and J.A. McCann., ed.s., Acad. Press, New York,

Eisenreich, S.J., M.R. Hoffman, D, Rastetter, D., E. Yost, and W.J. Maier, 1980. Metal transport phases in the upper Mississippi River. Adv. Chem. Ser. 189:135-176.

Elder, R.A. and G.B. Dougherty. 1952. Characteristics of Fixed Dispersion Cone Valves. Transactions of the American Society of Civil Engineers. Paper No. 2567.

EPA (Environmental Protection Agency). 1976. Quality Criteria for Water. United States Environmental Protection Agency, Washington, D.C.

_____, Ambient Water Quality for Mercury. EPA 440-5-80-058, United States Environmental Protection Agency, Washington, DC 136 p.

Fahnesstock, R.K. 1974. Morphology of Slims River. Icefield Ranges Research Project: Scientific Results. Vol. 4. Amer. Geographical Society - 1974. pp. 161-172.

Falvey, H.T. 1980. Air-Water Flow in Hydraulic Structures. U.S. Department of the Interior, Bureau of Reclamation. Engineering Monograph No. 41.

Fan, S. 1976. The role of sediment problems in hydroelectric development. Federal Interagency Sedimentation Conference.

Federal Energy Regulatory Commission. 1984. Draft Environmental Impact Statement for Susitna Hydroelectic Project. FERC No. 7114 - Alaska, FERC/DEIS-0038. Washington, D.C.

Fickeison, D.H. and M.J. Schneider. 1976. Gas Bubble Disease: Proceedings of Workshop held Richland, Washington, 1974. NTIS Office of Public Affairs, Energy Research and Development Administration, 122 pp.

Fimreite, N., W.N. Holsworth, J.A. Keith, P.A. Pearce, and I.M. Gruchy, 1971. Mercury in fish and fish-eating birds near sites of industrial contamination in Canada. Can. Field. Nat. 85:211-220.

Flint, R.F. and B.J. Skinner 1977. Physical Geology, second edition, John Wiley and Sons, New York.

Fontaine, W.T. and S.M. Bartell 1983. [Editors] Dynamics of Lotic Ecosystems. Ann Arbor Science Publishers, Ann Arbor, Michigan, U.S.A.

Fudge, R.J.P. and R.A. Bodaly 1984. Post impoundment winter sedimentation and survival of lake white fish (Coregonus clupeaformis) eggs in Southern Indian Lake, Manitoba. Can. J. Fish. Aquat. Sci. 41: 701-705.

Geen, G.H. 1975. Ecological consequences of the proposed Moran Dam on the Fraser River. J. Fish. Res. Bd. Can. 32(1): 126-135.

Gibbons, D.R. and E.O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. U.S.D.A. Forest Service General Technical Report PNW-10, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 145 pp.

Gibbs, R.J. 1974 Principles of studying suspended solids in water. In: Suspended solids in Water, edited by R.J. Gibbs. An Office of Naval Research Symposium, Dept. of the Navy, pp.1-15.

_____, Transport phases of transition metals in the Amazon and Yukon rivers. Geol. Soc. Amer. Bull 88:829-843.

Giesy, J.P. and Briese, L.A. 1977. Metals associated with organic carbon extracted from Okefenokee Swamp water. Chem. Geol. 20:109-120.

_____, and Briese, L.A. 1978. Trace metal transport by particulates and organic carbon in two South Carolina streams. Verh. Internat. Verein. Limnol. 20:1401-1417.

_____, and Briese, L.A. 1980. Metal binding capacity of northern European surface waters for Cd, Cu, and Pb. Organic Geochem. 2:57-67.

_____, Briese, L.A. and Leversee, G.J. 1978. Metal binding capacity of selected Maine surface waters. Environ. Geol. 2(5):257-268.

_____, Leversee, G.J., and Williams, D.R. 1977. Effects of naturally occurring aquatic organic fractions on cadmium toxicity to Simocephalus serrulatus (Daphnidae) and Gambusia affinis (Poeciliidae). Water Res. 12:1013-1020.

Gill, D. 1971. Damming the Mackenzie: A theoretical assessment of the long-term influence of the river impoundment on the ecology of the Mackenzie river delta. Proc. Peach-Athabasca Delta Symp. Jan. 14-15, 1971, Univ. of Alberta, Edmonton, pp. 204-234.

____, and A.D. Cooke, 1974. Controversies over hydroelectric developments in sub-arctic Canada. Polar Record 17(107): 109-127.

Godin, J.G. 1980. Temporal aspects of juvenile pink salmon (Onorhynchus gorbuscha) emergence from a simulated gravel redd. Canadian Journal of Zoology. 58(5):735-744.

Golterman, H.L. 1975. Physiological Limnology: An Approach to the Physiology of Lake Ecosystems. Elsevier Scientific Publ. Co., Amsterdam. 489 pp.

Grimard, Y. and H.G. Jones 1982. Trophic upsurge in new reservoirs: a model for total phosphorus concentrations. Can J. Fish. Aquat. Sci 39:1473-1483.

Grimas, U. 1961. The bottom fauna of natural and impounded lakes in northern Sweden (Amkarvattnet and Blasjon). Rep. No. 42:183-237, Institute of Freshwater Research, Drottingholm, Sweden.

_____, 1965. Inlet impoundments. An attempt to preserve littoral animals in regulated subarctic lakes. Rep. No 46: 22-30. Institute for Freshwater Research, Drottningholm, Sweden.

_____, and N.A. Nilsson, 1965. On the food chain in some north Swedish river reservoirs. Rep. No. 46: 31-48. Institute of Freshwater Research, Drottningholm, Sweden.

Grobler, D.C. and E. Davies 1979. The availability of sediment phosphate to algae. Water. S.A. 5(3): 114-122.

Groot, C. 1982. Modification on a theme - a perspective on migratory behavior of Pacific salmon. Pages 1-21 in E.L. Brannon and E.O. Salo, eds. Proceedings of the Salmon and Trout Migratory Behavior Symposium, 1st, University of Washington, Seattle, June 3-5.

Gunnison, D., R.L. Chen, and J.M. Brannon. 1983. Relationships of materials of flooded soils and sediments to the water quality of reservoirs - I. Oxygen consumption rates. Water Res. 17(11): 1609-1617.

Haag, R.W. 1974. Nutrient limitations to plant production in two tundra communities. Can. J. Bot. 52:103-116.

Hannan, H.H. 1979. Chemical modifications in reservoir-regulated streams. In: Ward, J.V. and J.A. Stanford, eds, "The Ecology of Regulated Streams," New York, pp.75-94.

Hannan, P.J. and Thompson, N.P., 1977. Uptake and release of Hg-203 by selected soil and sediment samples. J. Water Poll. Control. Fed. 49:842-847.

Harvey, H.H. 1976. Aquatic environmental quality: problems and proposals. J. Fish. Res. Board Can. 33: 2634-2670.

Harza-Ebasco Susitna Joint Venture. 1984a. Susitna Hydroelectic Project. Reservoir and River Sedimentation Report. Prepared for Alaska Power Authority, Anchorage, AK.

_____, 1984b. Instream Ice Calibration of Computer Model. Final report. Alaska Power Authority. Susitna Hyroelectric Project. Alaska Power Authority Document 1122.

_____, 1984c. Lower Susitna River Sedimentation Study: Project Effects on Suspended Sediment Concentration. Prepared for Alaska Power Authority. 47 pp. plus appendices and exhibits.

_____, 1984e. Susitna Hydroelectric Project Slough Geohydrology Studies. Alaska Power Authority.

_____, 1984g. Eklutna Lake temperature and ice study with six month simulation for Watana Reservoir. Prepared for Alaska Power Authority, Anchorage, Alaska.

_____, 1984f. Evaluation of alternative flow requirements. Prepared for Alaska Power Authority, Anchorage, Alaska. 55 pp.

Hecky, R.E., and H.A. Ayles, 1974. Summary of fisheries - limnology investigations on Southern Indian Lake. Report for the Lake Winnipeg, Churchill and Nelson Rivers Study Board, Fisheries and Marine Service, Environment Canada, Winnipeg, Manitoba. 26 pp.

_____, 1984. Thermal and optical characteristics of Southern Indian Lake before, during and after impoundment and Churchill River diversion. Can. J. Fish. Aquat. Sci. 41:579-590.

_____, and S.J. Gildford. 1984. Primary productivity of Southern Indian Lake before, during and after impoundment. Can. J. Fish. Aquat. Sci. 41:591-604.

_____, and G.K. McCullough. 1984. Effects of impoundment and diversion the sediment budget and nearshore sedimentation of Southern Indian Lake Can. J. Fish Aquat. Sci. 41:567-578.

_____, R.W. Newbury, R.A. Bodaly, K. Patalas and D.M. Rosenburg. 1985 Environmental impact prediction and assessment: the Southern Indian Lake experience. Can. J. Fish. Aquat. Sci. 41:720-732.

Hobbie, J.E. 1980. Editor: Limnology of Tundra Ponds. US/IBP Synthesis Series 13, Dowded, Hutchinson and Ross, Inc., Strousberg, Pennsylvania. 514 pp.

Huang, W.H. and Keller, W.D. 1970. Dissolution of rock-forming silicate minerals in organic acids: simulated first-stage weathering of fresh minerals surfaces. The Amer. Minerol. 55:2076-2095.

Huntsman, A.G. 1948. Fertility and fertilization of streams. J. Fish. Res. Bd. Can. 7(5), pp. 248-253.

Hutchinson, G.E. 1975. A Treatise on Limnology. Vol. 1: Geography, Physics and Chemistry. John Wiley, New York. 1015 pp.

_____, 1967. A Treatise on Limnology. Vol. II. Introduction to Lake Biology and the Linmoplankton. J. Wiley and Sons, New York, 1115 pp.

_____, 1973. Eutrophication. Amer. Sci. 61(3):269-279.

Hutchinson, T.C., A. Fedorenko, J. Fitchko, A. Kufa, J. Van Loon, and J. Lichwa, 1975. Movement and compartmentation of nickel and copper in an aquatic ecosystem. In: Hemphill, D.D. [Editor], Trace Substances in Environmental Health - IX. A Symposium. Univ. Missouri Press, Columbia, MO. pp. 89-105.

Hynes, H.B.N. 1970. The Ecology of Running Waters. Univ. of Toronto Press. Totonto. 555 pp.

_____, 1973. The effects of sediment on the biota in running water. pp. 652-663, In: Fluvial Processes and Sedimentation. Proc. Hydrology Symp., Edmonton, Alberta, May 8-9, 1973. Prepared for the Subcommittee on Hydrology by the Inland Waters Directorate Canada, 759 pp.

Imberger, J., J. Patterson, B. Hebbert, and I. Loh. 1978. Dynamics of reservoirs of medium size. Jour. Hydraulic Dev., Proc. American Society of Civil Engineers. 104 (No. H45): 725-743.

_____, and J.C. Patterson 1980. A dynamic reservoir simulation model - DYRESM: 5. Proc. Symposium on Predictive Ability of surface Water Flow and Transport Models. Berkely, Calif.

International Joint Commission. 1977. New and Revised Specific Water Quality Objectives. Vol. II. Great Lakes Water Quality Board Report.

Iwamoto, R.N., E.O. Salo., M.A. Madej and R.L. McComas 1978. Sediment and water quality: A review of the literature including a suggested approach for water quality criteria with summary of workshop and conclusions and recommendations. EPA 910/9-78-048; 252 pp.

Jackson, K.S., Jonasson, I.R. and Skippen, G.B. 1978. The nature of metals - sediment - water interaction in freshwater bodies, with emphasis on the role of organic matter. Earth-Sci. Rev. 14:97-146.

Jackson, T.A. and R.E. Hecky. 1980. Depression of primary productivity by humic matter in lake and reservoir waters of the boreal forest zone. Can. Fish. Aquat. Sci.37:2300-2317.

Jernelov, A. and Lann, H. 1973. Studies in Sweden on feasibility of some Sci. Methods for restoration of mercury-contaminated bodies of water. Environ. Sci. Technol. 7(8):712-718.

Johasson, I.R., and Boyle, R.W. 1972. Geochemistry of mercury and origins natural contamination of the environment. Can. Mining & Mettalurg. Bull January, 1972. pp. 1-8.

Johnson, G. 1967. The Effect of Entrained Air on the Scouring Capacity of Water Jets. Proceedings of the 12th Congress of the International Association for Hydraulic Research, Fort Collins, Co. Vol. 3.

Johnson, P.L. 1975. Prediction of Dissolved Gas at Hydraulic Structures. U.S. Department of the Interior, Bureau of Reclamation. Report No. Gr-8-75.

Jones, B.F., Kennedy, V.C., and Zellweger, G.W. 1974. Comparison of observation and calculated concentrations of dissolved Al and Fe in stream water. Water Resources Research 10 (4):791-793.

Jones, J.R. and R.W. Bachman 1976. Prediction of phosphorus and chlorophyll levels in lakes. J. Wat. Poll. Control Fed. 48 (9): 2176-2186.

_____, and R.W. Bachman. 1978. Phosphorus removal by sedimentation some Iowa reservoirs. Ver. Internat. Verein Limnol., 20, pp. 1576-1580.

Kawecka, B., A. Kownacki and M. Kownacka 1978. Food relations between algae and bottom fauna communities in glacial streams. Verh. Internat. Verein. Limnol. 20: 1527-1530.

Kerekes, J.J. 1982. The application of phosphorus load-trophic response relationships to reservoirs. Can. Wat. Res. J., Vol. 7, No. 1, pp. 349-354.

Kjeldson, O. and G. Ostrem 1975. English Summary: Sediment transport in Norwegian glacier streams. Report No. 3-77. Norges vassdrags - og elektrisitetsvesen, Hydrologisk avdeling, pp. 44-47.

Keup, L.E., McKee, G.D., Raabe, E.W., and Warner, R.W. 1970. Water quality effects of leaching from submerged soils. J. Amer. Water Wrks. Assoc. 62 (6):391-396.

Klein, D.H., Calabrese, A., D'Itri, F.M., McKim, J.M., Phillips, G.R., Reish, D.J., and Willford, W.A. 1979. Mercury. In Thurston, R.V., Russo, R.C., Fetterolf, C.M., Edsal, T.A., and Barber, Y.M. [Ed]. A Review of the E.P.A. Red Book: Quality Criteria for Water. American Fisheries Society, Bethesda, MD.

Koenings, J. 1983. ADF&G FRED Division. Personnal communication.

Koenings, J.P. 1984 and 1985. Unpublished data and personal communications, F.R.E.D. Division, ADF&G, Soldotna, Alaska.

_____, and G.B. Kyle 1982. Limnology and fisheries investigation Cresent Lake (1979-1982). Alaska Dept. of Fish and Game, Division of Fisheries Rehabilitation, Enhancement and Development (FRED). Soldotna, Alaska, 110 pp.

Kopp, J.F. and R.C. Kroner, 1967. Trace Metals in Waters of the United States. U.S. Dept. Interior, Federal Water Pollution Control Administration Cincinnati, Ohio.

Kownacka, M. and A. Kownacki 1972. Vertical distribution of zoocenoses in the streams of the Tatra, Caucasus and Balkans Mts. Verh. Internati. Verein. Limnol. 18: 742-750.

Kubanis, S.B. 1982. Revegetation techniques in arctic and subarctic environments. Office of the Federal Inspector, Alaska Natural Gas Transportation System, 40 pp.

Kucera, E. 1983. Mink and otter as indicators of mercury in Manitoba waters. Can. J. Zool. 61: 2250-2256.

Larcen, D.P. and H.T. Mercier 1976. Phosphorus retention capacity of lakes. J. Fish. Res. Bd. Can. 33: 1742-1750.

Laughlin, W.M. 1973. Fertilizers. P. 24-36. In: University of Alaska (d) Revegetation Workshp. Notes. Fairbanks: Univ. of Alaska cooperative Extensions Service. 239 pp.

Lagler, K.F., J.E. Bardach, and R.R. Miller 1962. Ichthyology. John Wiley & Sons,. New York, 545 pp.

Laxen, D.P.H., W. Davidson, and C. Woof, 1984. Manganese chemistry in rivers and streams. Geochim. Cosmochim. Acta. 48:2107-2111.

Lean, D.R.S. 1973. Phosphorus dynamics in lake water. Science 1979: 678-680.

_____1973a. Movements of phosphorus between its biologically important forms in lake water. J. Fish. Res. Db. Can. 30: 1525-1536.

_____ and F.H. Rigler. 1974. A test of the hypothesis that abiotic phosphate complexing influences phosphorus kinetics in epilimnetic lake water. Limnol. Oceanogr. 19(5): 784-788.

Lee, G. F., R.A. Jones and W. Rast. 1980. Availability of phosphorus to phytoplankton and its implications for phosphorus management strategies. IN: Loehr, R.C., C.S. Martin and W. Rast (Ed.). Phosphorus Management Strategies for Lakes. Ann Arbor Science Publ., Inc. 490 pp.

Lehumkuhl, D.M. 1979. Environmental disturbance and life histories: principles and examples. J. Fish. Res. board Can. 37:329-334.

Leopold, L.B., M.G. Wolman and J.P. Miller 1964. Fluvial Process In Geomorphology. Feeman, San Francisco, Calif. 552 p.

Lindstrom, T. 1973. Life in a lake reservoir: fewer options, decreased production. AMBIO, pp. 145-153.

Livingston, D.A. 1963. Alaska, Yukon, Northwest Territories and Greenland. In: Frey, D.G., ed. "Limnology in North America", Univ. of Wisc. Press, Madison, pp. 559-574.

Lloyd, D.S. 1985. Turbidity In Freshwater Habitats of Alaska: A Review of Pulblished and Unpublished Literature Relative to the use of Turbidity as a Water Quality Standard. Report No. 85-1, Alaska Department of Fish and Game, Habitat Division, Juneau, Alaska, 101 pp.

Lockwood, R.A. and K.Y. Chen, 1973. Absorption of Hg (II) by Hydrous Manganese Oxides. Environ. Sci. Technol. 7(11):1028-1034.

Lowe, R.L. 1979. Phytobenthic ecology and regulated streams. In: Ward, J.V. and J.A. Stanford, eds, "The Ecology of Regulated Streams.", New York, pp.25-34.

Mathis, B.J. and Cummings, T.F. 1973. Selected metals in sediments, water, and biota in the Illinois River. J. Water Poll. Contr. Fed. 45:1573-1583.

McClelland, W.T. and M.A. Brusven 1980. Effects of sedimentation on the behavior and distribution of riffle insects in a laboratory stream. Aquatic Insects Vol. 2(No. 3); pp. 161-169.

McKendrick, J.D. 1978. Revegetation of disturbed sand dunes near Northway, Alaska. First Year Progress Report to Northwest Alaskan Pipeline Company. Palmer, Alaska. 69 pp.

McNeely, R.N., Neimanis, V.P. and Dwyer, L. 1979. Water Quality Sourcebook, a Guide to Water Quality Parameters. Environment Canada. Ottawa, Canada. 89 pp.

Meister, J.F., J. DiNunzio and J.A. Cox 1979. Source and level of mercury in a new impoundment. J. Amer. Water Wrks. Assoc. 1979: 574-576.

Merritt, R.W. and K.W. Cummins 1978. An Introduction to the Aquatic Insects of North America. Kendall/Hunt Publishing Co., Dubque, Iowa. 441 pp.

Milner, A.M. 1983. The ecology of post-glacial streams in Glacier Bay National Park, South-Eastern Alaska, Ph. D. Dissertation, Univ. of London, London, England, 239 pp.

Milhous, R.T. 1982. Effect of sediment transport and flow regulation of the ecology of gravel-bed rivers. in: Gravel-Bed Rivers: Fluvial Processes, Engineering and Management". Hey, R.D., F.C. Bathurst, and C.R. Thorne, Edis. John Wiley & Sons, New York, pp. 819-842.

Morrow, J.E. 1980. The Freshwater Fishes of Alaska. Anchorage 248 pp.

Minshall, G.W. 1978. Autotrophy in stream ecosystems. Bioscience 28; No. 12: pp. 767-771.

_____, R.C. Peterson, K.W. Cummins, T.L. Bott, J.R. Sedell, C.E. Cushing and R.L. Vannote. 1983. Interbiome comparison of stream ecosystem dynamics. Ecol. mono. 53(1):1-25.

Moore, J.W. 1977. Ecology of algae in a subarctic stream. Can J. Bot.55: 1838-1847.

Mosley, M.P. 1982. Analysis of the effect of changing discharge on channel morphology and instream uses in a braided river, Ohau River, New Zealand. Water Resources Research. Vol. 18, No. 4, pp. 800-812.

Moore, J.W., and Ramamoorthy, S. 1984. Heavy Metals in Natural Waters: Applied Monitoring and Impact assessment. Springer-Verlag, New York.

Morisawa, M. 1968. Streams: Their Dynamics and Morphology. McGraw-Hill, New York.

Muller, D.K. 1982. Mass balance model estimation of phosphorus concentrations in reservoirs. Water Resource Bull. 18(3): 377-382.

Muller, K. 1974. Stream drift as a chronobiological phenomenon in running water ecosystems. Ann. Rev. Ecol. Systematics. Vol. 5; pp. 309-323.

Murphy, M.L., C.P. Hawkins and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Trans. Am Fish. Soc. 110:469-478.

Naiman, R.J. 1982. Characteristics of sediment and organic cargon export from pristine boreal forest watersheds. Can. J. Fish. Aquat. Sci. 39: 1699-1718.

_____, 1983a. The influence of stream size on the food quality of section, Can. J. Zool. 61: 1995-2010.

_____, 1983b. The annual pattern and spatial distribution of aquatic oxygen metabolism in boreal forest boreal forest watersheds. Ecological Monographs 53 (1): pp. 73-94.

National Academy of Sciences 1973. Water Quality Criteria - 1972, Environmental Studies Board, National Academy of Engineering, Wash. D.C., 594 pp.

National Oceanic and Atmospheric Administration 1982. Daily flow statistics of Alaskan streams. D.L. Chapman Alaskan River Forecast Center, National Water Service, NOAA Tech. Memorandum NWS AR-35, Anchorage, AK.

Netboy, A. 1974. The Salmon: Their Fight for Servival. Houghton Mifflin Co, Boston, 595 pp.

_____, 1980. Salmon: World's Most Harassed Fish. Winchester Press, Tulsa Oklahoma, 301 pp.

Newbold, J.D., J.W. Elwood, R.V. O'Neil and W. Van Winkle. 1981. Measuring nutrient spiralling in streams. Can. J. Fish and Aquat. Sci. 38:860-863

Newbury, R.W. and G.K. McCullough 1984. Shoreline erosion and restabilization in the Southern Indian Lake reservoir. Can. J. Fish Aquat. Sci. 41:558-566.

Nilsson, B. 1976. The influence of man's activities in rivers on sediment transport. Nordic Hydrology, 7, pp. 145-160.

Nilsson, Nils-Arvid. 1964. Effects of impoundment on the feeding habits of brown trout and char in Lake Ransaren (Swedish Lappland). Verh. Internat. Verein. Limnol., XV: 444-452.

Noggle, C.C. 1978. Behavioral, Physiological, and lethal effects of suspended sediment on juvenile salmonids. Master of Science Thesis, Univ. of Wash;, 87 pp.

O'Conner, D.J. and S.W. Wielson 1981. Environmental survey of methylmercury levels in wild mink (Mustela vison) and otter (Lutra canadensis) from north eastern United States and experimental pathology of methylmercurialism in the otter. in: Worldwide Furbearer Conference, J.A. Chapman and D. Pursley, Edia. Vol. III. Worldwide Furbearer Conference Inc., pp. 1728-1745.

Ostrem G. 1975 Sediment transport in glacial meltwater streams. In: Glaciofluvial on Glaciolacstrine Sedimentation. A.V. Jopling and B.C. McDonald, [ed.s.] Special Publication No. 23, Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma. pp. 55-63.

_____, T. Ziegler, S.R. Ekman, H.C. Olsen, J.E. Anderson, B. Lunden 1970. English Summary: Sediment transport studies at selected glacier streams in Norway. Report No. 12. Stockholm University.

_____, T. Ziegler, S.R. Ekman 1969. English Summary. Sediment transport studies at selected glacier streams in Norway. Report 9, Stockholm University, Stockholm, Sweden, pp. 55-63.

Ostrofsky, M.L., and H.C. Duthie. 1975. Primary productivity, phytoplankton and limiting nutrient factors in Labrador Lakes. Int. Rev. Ges. Hydrobiol. 60(3):245-158.

_____, and H.C. Duthie. 1978. V. Manmade Lakes: An approach to modelling productivity in reservoirs. Verh. Internat. Verein. Limnol. 20: 1562-1567.

_____, and H.C. Duthie. 1980. Trophic upsurge and the relationships between phytoplankton biomass and productivity in Smallwood Reservoir, Canada. Can J. Bot. 58:1174-1180.

Ott Water Engineers, Inc. 1981. Bradley Lake Water Quality Report prepared for U.S. Army Corp. of Engineers, Alaska District, Anchorage, AK. September 1981.

Paerl, H.W. and D.R.S. Lean. 1976. Visual observation of phosphorus movement between algae, bacteria, and abiotic particles in lake waters. J. Fish. Res. Bd. Can. 33: 2805-2813.

Patalas, K. and A. Salki. 1984. Effects of impoundment and diversion on the crustacean plankton of Southern Indian Lake. Can. J. Fish. Aquat. Sci. 41:631-637.

Patterson, J., J. Imberger, B. Hebbert, and I. Loh 1977. A simulation model for reservoirs of medium size. Report No. EFM-3.

Peratrovich, Nottingham and Drage, Inc. and I.P. Hutchinson 1982. Susitna reservoirs sedimentation and water clarity study. Prepared for Acres American, Inc Anchorage, Ak. 35 pp.

Perdue, E.M., K.C. Beck, and J.H. Reuter 1976. Organic complexels of iron and aluminum in natural waters. Nature 260: 418-420.

Peterson, and Associates, and R&M Consultants, Inc. 1982. Water quality effects resulting from impoundment of the Susitna River. Prepared for Acres American, Inc. and the Alaka Power Authority. 43 pp.

_____, 1985a. Draft. Alaska Particulates Criteria Review. Prepared for ADEC, Juneau, AK., 130 pp. plus appendices A-D.

_____, 1982. Water Quality Interpretation 1981, Prepared for Acres American Incorporated under contract to the Alaska Power Authority. Anchorage, Alaska.

Peterson, B.J., J.E. Hobbie, A.E. Hershey, M.A. Lock, T.E. Ford, J.R. Vestal, V.L. McKinley M.A.J. Huller, M.C. Miller, R.M. Ventullo, G.S. Volk 1985b. Transformation of a tundra river from heterotrophy to autotrophy by addition of phosphorus Science, Vol. 229, pp, 1383-1386.

Pinell-Alloul, B., E. Magmin, G. Codin-Blumer and P. Ross. 1982. Zooplankton population dynamics during and after impoundment in a small reservoir (James Bay, Quebec). Can. Wat. Res. J. 7(1): 168-188.

Phillips, G.R., Lenhart, T.E., and Gregory, R.W. 1980. Relation between trophic position and mercury accumulation among fishes from the Tounge River Reservoir, Montana. Environ. Res. 22:73-80.

Planas, D. and R.E. Hecky 1984. Comparison of phosphorus turnovertimes in northern Manitoba reservoirs with lakes of the Experimental Lakes Area. Can. J. Fish. Aquat. Sci. 41: 605-612.

Pott, D.B., Alberts, J.J. and Elzerman, A.W. 1985. The influence of pH on the binding capacity and conditional stability constants of aluminum and naturally occurring organic matter. Chemical Geology 48. (In Press)

Potter, L., Kidd, D. and Strandiford, D. 1975. Mercury levels in Lake Powell. bioamplification of mercury in a man-made desert reservoir. Environ. Sci. Technol. 9(1):41-46.

Prescott, G.W. 1962. Algae of the Great Lakes. Wm. C. Brown Co., Dubuque. 977 pp.

_____, 1970. The Freshwater Algae. Wm. C. Brown Co., Dubuque. 348 pp.

R&M Consultants, Inc. 1981a. Susitna Hydroeclectric Project, Water Quality Annual Report 1981. Alaska Power Authority, Anchorage, Ak. Prepared for Acres American, Inc.

_____, 1982b. Water Quality Annual Report, 1982. Alaska Power Authority, Anchorage, Ak. Prepared for Acres American, Inc.

_____, 1982c. Reservoir sedimentation. Prepared for Acres American, Inc., Anchorage, Ak. 41 pp.

_____, 1982d. Glacial lake studies. Prepared for Acres American, Inc. Anchorage, Alaska 198 pp.

_____, 1982e. Placer mining wastewater settling pond demonstration project. Prepared for the State of Alaska, Department of Environmental conservation. 60 pp. with additional appendices.

_____, 1982f. Susitna Hydroelectric Project. River Morphology Report. Prepared for Acres American, Inc. 1 Vol.

_____, 1984a. Susitna Hydroelectric Project. Susitna River Ice Study Prepared under contract to Harza-Ebasco Susitna Joint Venture for the Alaska Power Authority, Anchorage, AK 1 Vol.

_____, 1984b. Draft - Suspended sediment and turbidity settling column study. 74 pp.

_____, Woodward-Clyde Consultants Inc., and Harza-Ebasco Susitna Joint Venture. 1985. Susitna Hydroelectric Project. Instream Flow Relation Ships Report Series. Physical Processes of the Middle Susitna River. Technical Report No. 2. Prepared under contract to Harza-Ebasco Susitna Joint Venture for Alaska Power Authority, Anchorage, Alaska.

Stumm, W., and Morgan, J.J., 1981. Aquatic Chemistry, 2nd Edition. John Wiley and Sons, New York, 780 pp.

Sylvester, R.O. and Seabloom, R.W. 1965. Influence of site characteristics on quality of impounded water. J. Amer. Water Wrks. Assoc. 61(12):1528-1546.

Tessier, A., Campbell, P.G.C. and Bisson, M. 1980. Trace metal speciation in the Yamaska and St. Francois Rivers (Quebec). Can. J. Earth Sci. 17:90-105. upstream and downstream of a mainstream impoundment. J. Fish. Res. Board Can. 28:45-46.

Therien, N., G. Spiller and B. Coupal. 1982. Simulation de la decomposition la matiere vegetale et des sols inondes dams les reservoirs de la region la Baie de James Canadian Water Resources Journal, Vol. 7, No. 1, pp. 375-396.

Todd, D.K. 1970. The Water Encyclopedia. Water Information Center, New York,

Triska, F.J., F.R. Sedell, K. Cromack Jr., S.V. Gregory, and F.M. McCorison. 1984 Mitrogen budget for a small coniferous forest stream. Ecological Monographs 54(1): pp. 119-140.

U.S.G.S. 1980 Water Resources Data, Alaska. Data Report AK-80-1.

_____, 1981. Water Resources Data, Alaska

_____, 1982. Water Resources Data, Alaska

_____, 1983. Water Resources Data, Alaska. Data Report AK-83-1.

U.S. Geological Survey. 1983. Sediment Discharge for the Susitna River Basin Alaska, 1981-1982. Prepared for the Alaska Power Authority, Anchorage, AK

Van Nieuwenhuyse, E.E. 1983. the effects of placer mining on the primary productivity of interior Alaska streams. M.S. thesis, Univ. of Alaska, Fairbanks, Alaska, 120 pp.

_____, and E.W. Trihey and Associates. 1984. Technical Memorandum. Preliminary analysis of the relationships between turbidity and light penetration in the Susitna River, Alaska. Prepared for Harza-Ebasco Susitna Joint Venture for Alaska Power Authority, Anchorage, Alaska.

Van Stappen, J.F. 1984. A comparison of benthic invertebrate communities three habitats of the Hoh River Valley, Olympic national Park, Washington M.A. Thesis, Univ. of Wisconsin, Stevens Point, Wisconsin. 63 pp.

Vollenweider, R.A. and J. Kerekes. 1980. The loading concept as basis f. controlling eutrophication. Philosophy and preliminary results of the I Programm on eutrophication. Prog. Wat. Tech., Vol. 12, Norway, LAWPR/Pergamon Press Ltd. 518 pp.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell and C.E. Cushing. 1980. The river continuum concept. Can. J. Fish and Aqat. Sci. 37:130-137.

Walker, W.W. 1982. An empirical analysis of phophorus, nitrogen and turbidity effects on reservoir chlorophyll-A levels. Canadian Water Resources Journal, Vol. y, No. 1, 1982.

Wangaard, D.B., and C.V. Burger. 1983. Effects of various water temperatures regimes on the egg and alevin incubation of Susitna River chum and sockeye salmon. Final Report. National Fishery Research Center, U.S. Fish and Wildlife Service, Anchorage, Alaska 43 pp.

Ward, G.M., K.W. Cummins, S.V. Gregory, R.W. Speaker, T.L. Dudley, A.K. Ward. 1982. Habitat and Food resources of invertebrate communities in South Fork Hoh river, Olympic National Park. p. 9-14, In Ecological research in national parks of the Pacific Northwest: Compiled from proceedings of the second conference on scientific research in the national parks (Nov. 1979, San Francisco, Calif. Oregon State Univ. for Res. Lab. Pub.

Wetzel, R.G. 1975. Limnology. W.B. Saunders, Co., Philadelphia, 743 pp.

Whalen, S.C. and J.C. Cornwell 1985. Nitrogen, phosphorus, and organic carbon cycling in an arctic lake. Can. J. Fish. Aquat. Sci. 42 8 797-808.

Wiens A.P. and D.M. Rosenberg 1984. Effect of impoundment and river diversion on profundal macrobenthos of Southern Indian Lake, Manitoba. Can. J. Fish. Aquat. Sci. 41: 638-648.

Wildung, R.E. and R.L. Schmidt 1973. Phosphorus release from lake sediments. EPA-R3-73-024. 185 pp.

Wilber, C.G. 1983. Turbidity In the Aquatic Environment. Charles C. Thomas, Springfield, Illinois, U.S.A. 133 pp.

Williams, W.D. 1973. Man-made lakes and changing limnological environment in Australia. in: Man-Made Lakes: Their Problems and Environmental Effects. W.C. Ackerman, G.F. White and E.B. Worthington, ed;s. Am. Geophs. Union, Washington, D.C.

Wright, D.R. and R.D. Hamilton, 1982. Release of methylmercury from sediments: effects of mercury concentration, low temperature and nutrient addition. Can. J. Fish. Aquat. Sci. 39:1459-1466.

Welch, P.S. 1952. Limnology. McGraw-Hill book Co., New York. 538 pp.

Wunderlich, W.O. 1967. The mechanics of stratified flow in reservoirs. in: "Reservoir Fishery Resources Symposium", Am. Fish. Soc., Washington, D.C.

_____, 1971. The dynamics of density-stratified reservoirs. in: "Reservoir Fisheries and Limnology", G.E. Hall, ed. Spec. Publ. No. 8, Am. Fish. Society, Washington, D.C.

_____, and R.A. Elder 1973. Mechanics of flow through man-made lakes. In: Man-Made Lakes: Their Problems and Environmental Effects, W.C. Ackerman, G.F. White and E.B. Worthington, ed.s Am. Geophs. Union, Washington, D.C.