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SUSITNA HYDROELECTRIC PROJECT

INSTREAM FLOW RELATIONSHIPS REPORT
TECHNICAL REPORT NO. 3

A LIMNOLOGICAL PERSPECTIVE OF POTENTIAL WATER QUALITY CHANGES

Report by
Harza-Ebasco Susitna Joint Venture

Prepared for
Alaska Power Authority

Final Report
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NOTICE

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

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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 inundation 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.

Acknowledgments

The Harza-Ebasco staff expresses its appreciation to the many people that contributed time, energy, and ideas, and who shared information without which this document would not be as complete or as accurate as it may be. Special thanks are extended to representatives of R & M Consultants, Inc., the Arctic Environmental Information and Data Center, E.W. Trihey and Associates, Alaska Department of Fish and Game (SuHydro; Habitat; F.R.E.D.; and Sport Fish Divisions), Woodward-Clyde Consultants, Inc., U.S. Geological Survey, U.S. Fish & Wildlife Service, ENTRIX, Inc., and the library staff at the University of Alaska at Anchorage and the Alaska Resources Library in Anchorage. Particular appreciation is extended to Mr. D. Pott of Harza Engineering Company for his help with the section on heavy metals, and to the word processing staff of the Harza-Ebasco Susitna Joint Venture for their dedicated work on the many drafts of this document.

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.

Water quality information has been collected, examined, and discussed in order to help produce a comprehensive understanding of seven sets of issues which may affect salmon and resident fish habitats and populations downstream of the proposed project. The seven water quality issues discussed here are:

1) suspended sediments and turbidity,
2) pH,
3) heavy metals,
4) gas supersaturation,
5) plant macronutrients,
6) dissolved oxygen and carbon concentrations, and the
7) potential reservoir and middle river trophic status.

Suspended Sediment and Turbidity

Project induced changes to the naturally cyclic regimes of suspended sediments and turbidity have been estimated. Estimated effects to the reservoir biology and trophic status are discussed. Estimated effects to the middle river biology and trophic status are also discussed, but riverine effects appear more complex and conclusions are more uncertain. Important fisheries habitat in the middle river will be affected and the indirect or secondary impacts on the salmonid fishery are questionable. Off channel mitigation measures may be necessary to balance some potentially detrimental effects.

pH and Buffering System

Hydrogen ion concentrations (pH) 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 aquatic 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. 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 selected 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 concentrations 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 dissolved gases in aquatic habitats downstream of the project. Extensive mitigation measures are presently included in the plans for design and operation of the Susitna Hydroelectric Project in order to minimize the potential for excessive dissolved gas concentrations and their 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 of the proposed reservoirs and portions of 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, phosphorus and nitrogen should exist at concentrations in excess of their demand by microbial communities during most seasons in both the reservoirs and the downstream riverine habitats directly affected by mainstem flows. Nutrient limitation of aquatic primary productivity is not expected to be an important project induced effect. Minimal rates and quantities of aquatic primary productivity are to be expected in the continuously turbid reservoirs and in some mainstem riverine environments affected by project flows.

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 of both project reservoirs is expected to be strongly light limited and to be primarily dependent on heterotrophic 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 relatively deep, middle reach riverine habitats which remain continuously turbid is expected to decrease with respect to the natural condition. More peripheral riverine habitats which are relatively shallow, clear, or intermittently turbid are expected to maintain or increase their biological productivity. Streambed substrate improvement (with respect to biological productivity) is expected in many middle reach habitats.

1.0 INTRODUCTION

1.1 OBJECTIVES

The objectives of this report are multifold. One primary objective is to briefly describe selected, natural water quality characteristics of the unregulated middle reach of the Susitna River. A second objective is to describe selected aspects of the morphology and operation of the proposed project. A third objective is to discuss some potential water quality changes which may result from construction and operation of the proposed project. A forth objective is to estimate and discuss some of the limnological characteristics of the proposed project reservoirs and some potentially important project induced effects which may occur in middle river reach (River Mile 152 through 98.5) downstream, especially as they relate to the riverine fishery.

1.2 BRIEF SUMMARY OF INFORMATION SOURCES

Information summarized or referenced in this report is derived 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 (APA). 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, personal communications with aquatic biologists and other professionals having experience with 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 to the Federal Energy Regulatory Commission (FERC) by the State of Alaska. 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 6,900 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-consumptively (except for small evaporation losses) utilize waters of the Susitna River for hydroelectric power production. All water will be returned 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) . The river and its tributaries are free flowing from their headwaters in the glaciers of the Alaska and Talkeetna mountain ranges to the river's mouth. Although the Susitna is not ranked amongst the principal 50 rivers in the United States in terms of length (Todd 1970), it is included amongst the major unregulated rivers remaining in the U.S. (Ward and Stanford 1979).

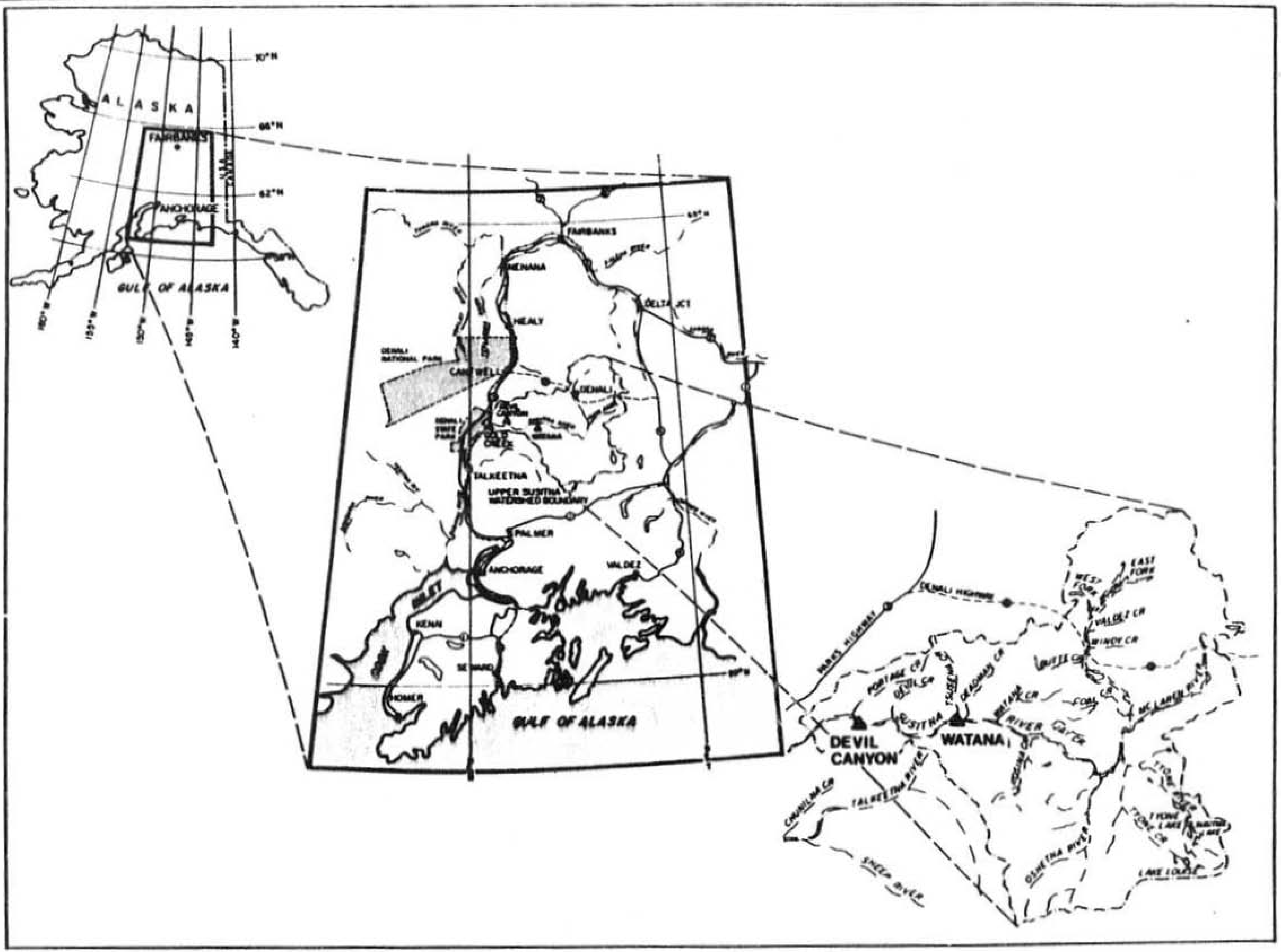


figure 2.1 LOCATION MAP

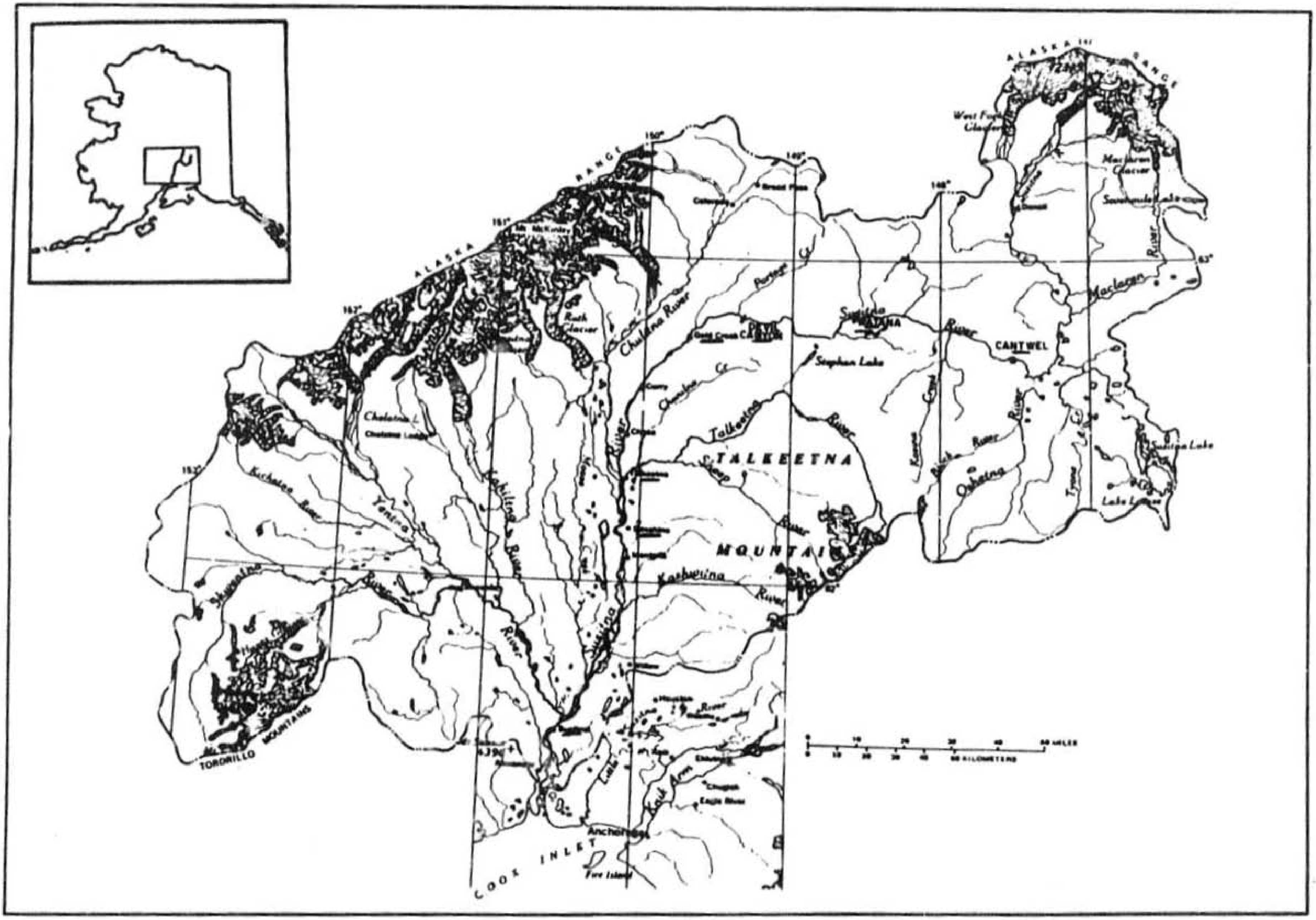
The Susitna River watershed is bounded by the Alaska Range of mountains to the north, west and southwest. To the east-southeast the river basin is bounded by the Talkeetna Mountains, while to the east - northeast the basin is bounded by the northern Talkeetna plateau and the Gulkana uplands (Figure 2.2). Elevations within the drainage basin range from 20,320 feet (6,194 meters) above mean sea level (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 (Arctic Environmental and Information Data Center (AEIDC) 1984, 1985).

Detailed riverine watershed and morphological descriptions are plentiful in several project documents (AEIDC 1985b, Harza-Ebasco (H-E) 1985b, 1985e, 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.

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 (m.y.) 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. y. ago).

FIGURE 2.2 SUSITNA RIVER WATERSHED INCLUDING MAJOR TRIBUTARIES 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. One of these diorite plutons lies under the Watana dam site. During and following these latter intrusions 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 occurred during the Jurassic (160-210 m.y.ago), the second during the late Cretaceous (65-110 m.y. ago), and the third in the middle to late Tertiary (40 m.y. ago). Intrusion 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 of 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 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 overlain by up to 450 feet of glacial and fluvial deposits. Downstream, at the proposed Devil Canyon dam site, 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 previously mentioned lithic materials, soils, and vegetation are the source of most of the milieu 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 primarily derived from weathering of watershed geological entities. Their generalized mineralogy has been analyzed by polarized light microscopy (R&M Consultants, Inc. 1984c, and 1982d) and the results are presented in Table 2.1. Petrographic analyses of these rock fragments are 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. Analysis of these particulates (Table 2.2) indicates the major mineral and elemental groups which will influence or be a part of the river's water quality.

From the foregoing description it is obvious that south central Alaska lies within a zone of geological instability. This zone is a tectonic mosaic of continental structural blocks and fragments and has been associated with igneous, volcanic and thermal activity. The relation between such active plate boundary zones and metallic ore deposits is fairly well accepted (Flint and Skinner 1977). It appears that the Susitna River watershed lies within one of the well known mercuriferous belts located along the western North American continental border (Figure 2.3), and this probably explains, at least in part, the relatively high concentrations of mercury found in riverine water and suspended sediment samples. More detailed discussions of mercury and other trace metals are presented in Chapter 7.

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

TABLE 2.1

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

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 COMPOSING COMMONLY ANALYZED
SUSPENDED SEDIMENT PARTICLES FROM THE SUSITNA AND OTHER NEARBY
GLACIAL RIVER DRAINAGES

Mineral	Elements
Pyrites ($Fe S_2$)	Fe, S
Quartz (SiO_2)	Si, O
Orthoclase feldspar ($KALSI_3O_8$)	K, Al, Si, O
Plagiocase feldspar ($Na Ai Si_3 O_8$; $Ca Al_2 Si_2O_8$; etc.)	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 ($2 Fe_2 O_3.3 H_2O$)	Fe, O
Biotite mica (complex K, Mg, Fe Al and Ti hydroxy fluro 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 ($K_x Al_4[Si_{2-x}Al_xO_{20}]OH_4$)	K, Al, Si, O, H
Kaolinite ($Al_4 [Si_4O_{10}] (OH)_8$)	Al, Si, O
Montmorillonite $(Na,K)_{x+y}(Al_{2-x}Mg_x)_2$ $[(Si_{1-4}Al_4)_8O_{20}]OH_4\text{-}nH_2O$	Na, K, Al, Mg, Si, O
Chlorite $(Mg Al)_{12} [(Si, Al)_8 O_{20}) (OH_{16})_{19}$	Mg, Al, Si, O
Calcite ($Ca CO_3$)	Ca, C, O

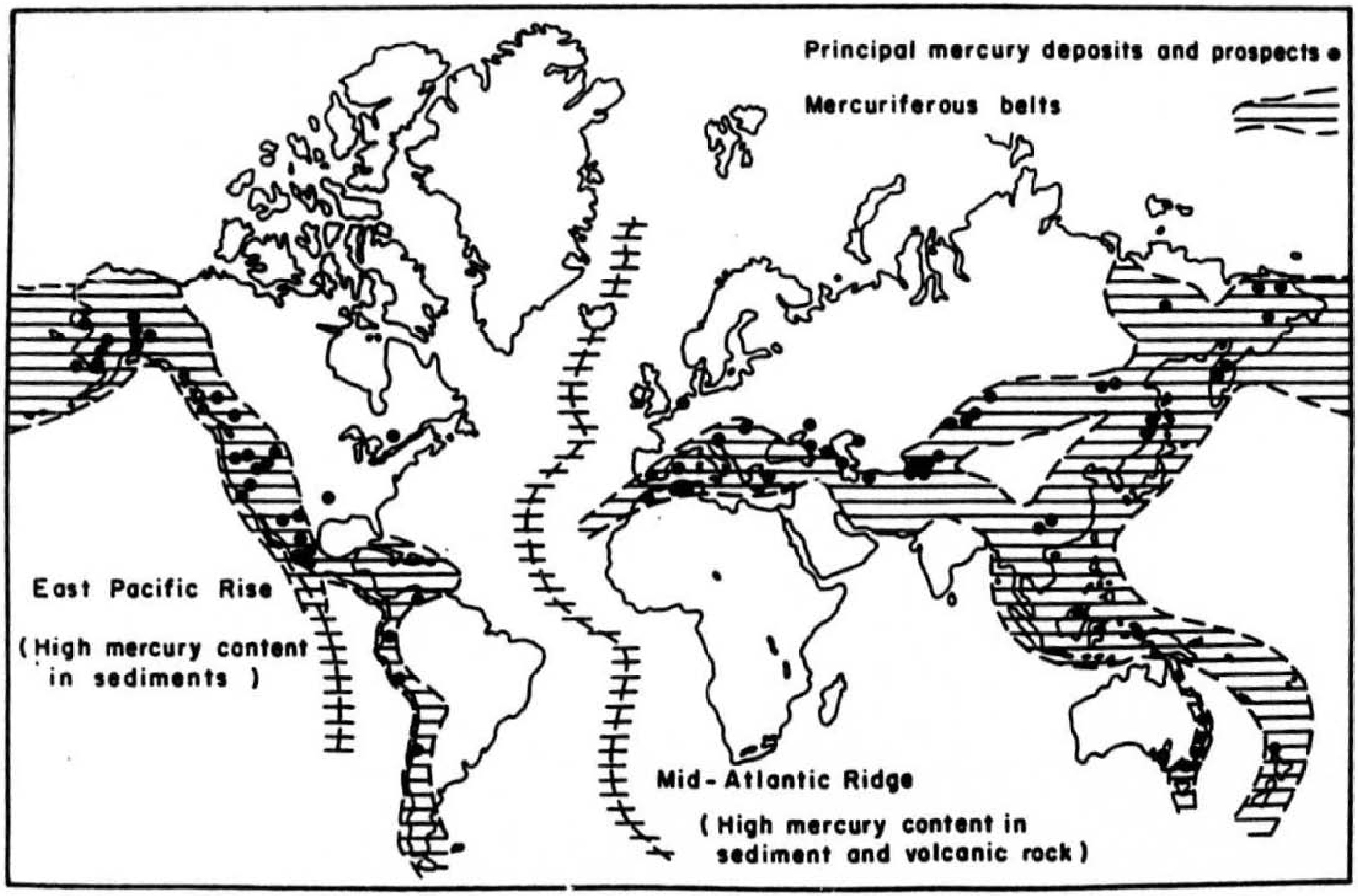


Figure 2.3 Mercuriferous Belts of the Earth (Source:Jonasson and Boyle 1972, as cited in Moore and Ramamoorthy 1984)

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).

Within the proposed Watana Reservoir inundation zone(i.e. approximately 38,000 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 within 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). The forests and shrublands 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 exist which are classified as wetlands. The wetlands on the upland plateaus include riparian zones, ponds, and lakes and 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, occasional black spruce, cotton grass tussocks, rushes, willows, labrador tea, Dwarf Arctic birch, blueberries, cranberries, bearberries, crowberries,

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) 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 paper birch) forest. However, physical disturbances such as ice jams, 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 elements necessary for aquatic life exist in at least minimal 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, substrate 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, generally characterized by intermittent activity, are known to exist in the drainage (APA 1983e).

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.

Winds at the Watana Dam site are predominantly from the north and east in the winter, and from the north and west in the summer. Maximum summer wind speeds are generally less in winter. Wind speeds are generally less than 20 miles per hour (10 meters/sec).

The mean temperatures in the reservoir area are approximately -5°F in winter and 55°F in summer. The approximate range of temperatures within the reservoir impoundment zones are between -58°F and 95°F (APA 1983a). The lower river basin, which is closer to the coastline, is better buffered against extreme temperature fluctuations by the proximity of Cook Inlet marine waters. Mean annual precipitation is about 20 inches in the lower basin, increasing to about 40 inches near Devil Canyon, and to nearly 70 inches at the northeastern watershed divide near Susitna Glacier.

South central Alaska's winters are long and cold with as little as six hours of daylight near the winter solstice. Near the summer solstice temperatures are considerably warmer and daylight extends for periods in excess of eighteen hours per day. Photosynthetically available radiation (PAR) is maximal during June and minimal in December (Figure 2.4). The daily total PAR can be as much as 60 fold higher on summer solstice when compared to winter solstice, and can approach hourly flux rates which are almost 20 fold higher in summer compared to winter (Figure 2.5).

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,

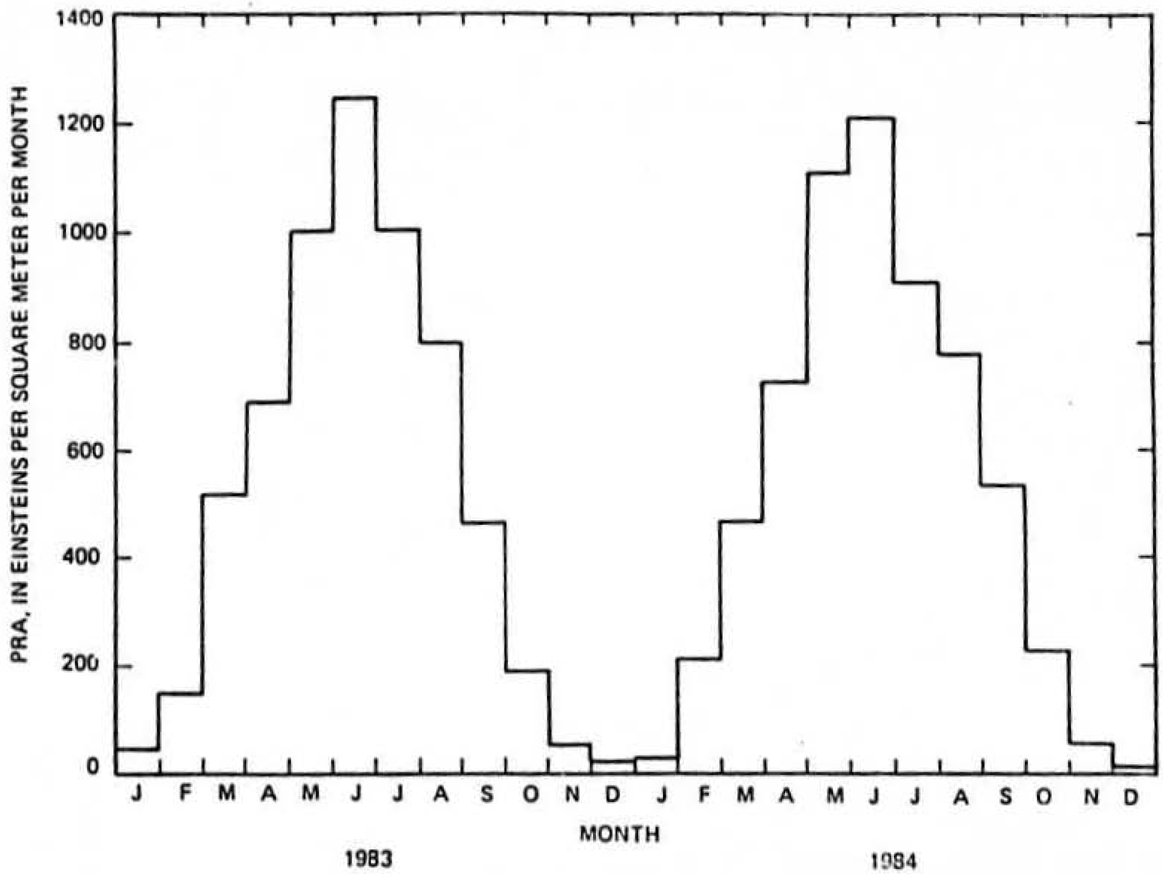


FIGURE 2.4 MONTHLY INPUT OF PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR) (AT BIG LAKE, ALASKA) IN THE SUSITNA RIVER WATERSHED. SOURCE: ROWE 1985

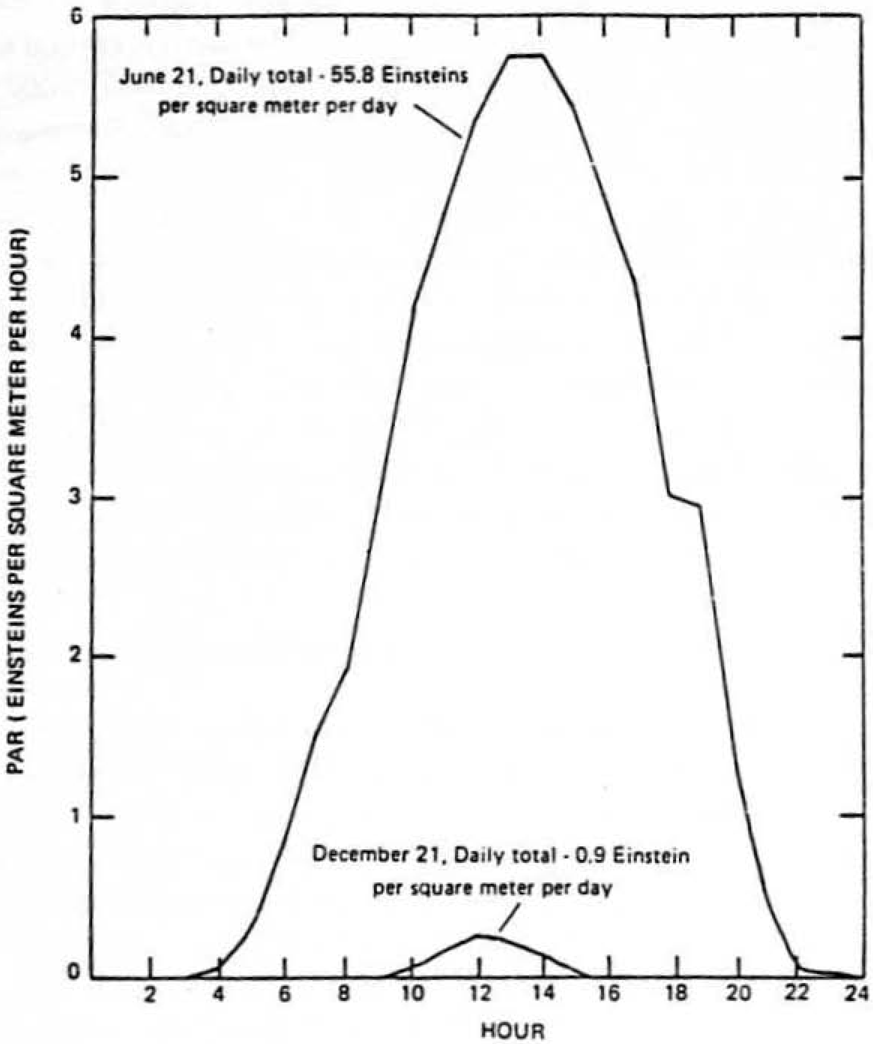


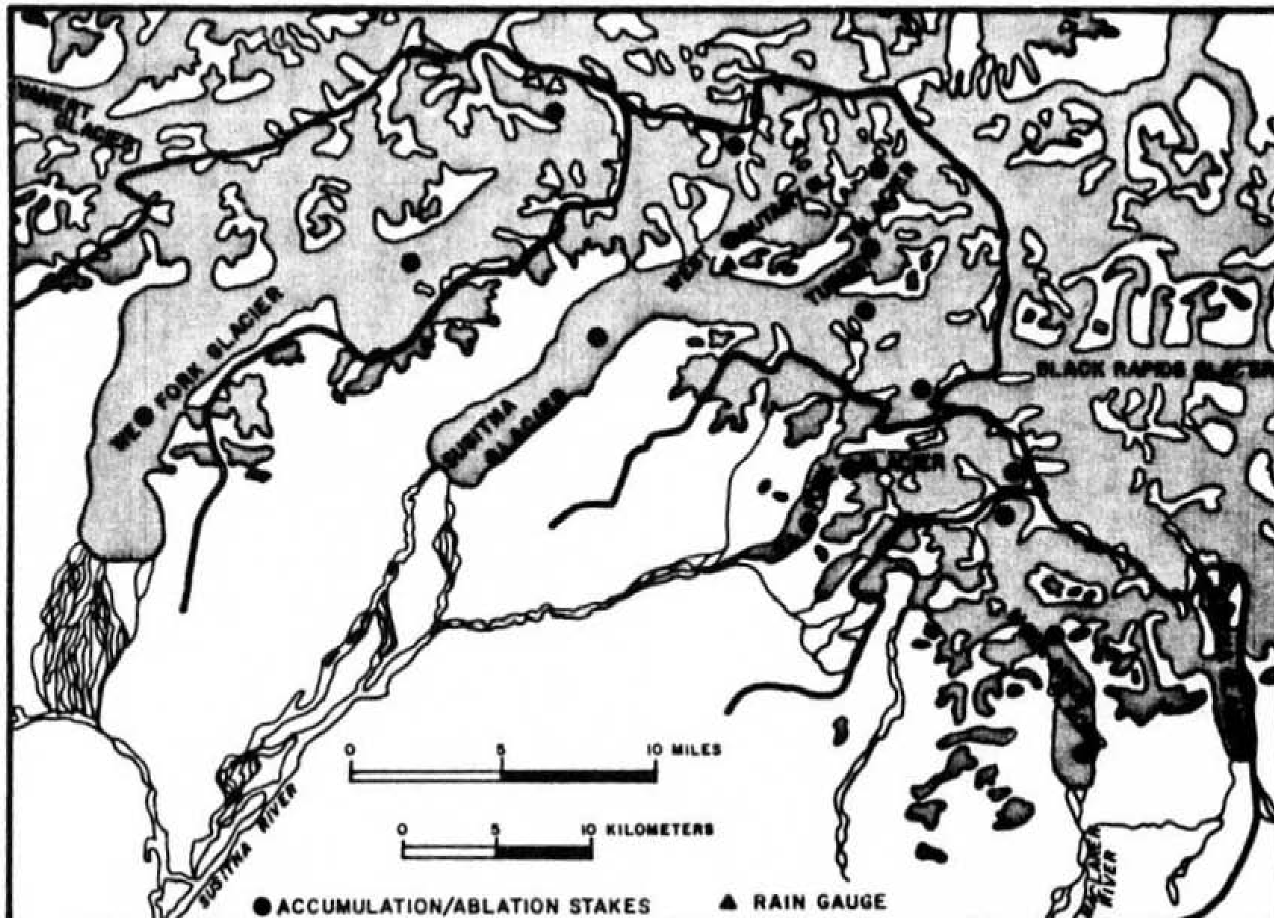
FIGURE 2.5 HOURLY INPUT OF PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR) DURING SUMMER AND WINTER SOLSTICES OF 1983 AT BIG LAKE, IN SOUTH CENTRAL ALASKA'S SUSITNA RIVER WATERSHED.

SOURCE: ROWE 1985

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 undergoes 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 (Figures 2.2 and 2.6). 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 gaging station approaches maximal flows during the warmest days of the year (which usually occur in July and August). Minimal winter flows of approximately 100 to 200 cfs occur during January and February (Figure 2.7). Mean annual discharge at Denali is approximately 2,800 cfs. Between the Denali stream gauge and Vee Canyon the Susitna receives the glacial tributary MacLaren River (RM 260), the non-glacial, but humic acid stained Tyone River (RM 247), and the glacial Oshetna River (RM 233). The Susitna at Vee Canyon (RM 223) conveys a mean annual flow of approximately 6,404 cfs of water (Figure 2.7) and approximately 5.7 million tons of suspended



GLACIER NAMES AND LOCATIONS, DRAINAGE DIVIDES, STAKE LOCATIONS AND RAIN GAUGE SITE.

figure 2.6

Source: Clarke et al. 1985

sediment predominately during the period May-September (Harza-Ebasco, 1984a). From Vee Canyon, the Susitna flows westerly in a deep, narrow valley towards the Watana dam site while losing elevation from approximately 2,000 feet MSL to 1,450 MSL. At the Watana Dam site (RM 184.4) the Susitna drains an area of approximately 5,180 sq. mi. and has a mean annual discharge of approximately 8,000 cfs. From the Watana Dam site through the upstream portion of Devil Canyon the Susitna River drops in elevation from 1,450 feet MSL to approximately 900 MSL at the Devil Canyon Dam site (RM 152.2). The Susitna River's mean annual discharge at the Devil Canyon Dam site is approximately 9,200 cfs (APA 1985), and it drains a total area of approximately 5,810 square miles. The river drops precipitously through 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 gaging 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 approximately 9,700 cfs (Figure 2.7).

The "middle" Susitna reach 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 to 12 feet per linear mile (Figure 2.8) or approximately 500 feet in 54 miles.

The majority (approximately 90%) of the upper and middle Susitna River flow usually occurs during the May-October periods of each year (Figures 2.7 and 2.9). Peak flows at the Gold Creek monitoring station have varied from 25,000 - 35,000 cfs in fairly dry years (Figure 2.9, 1970 hydrograph) to approximately 90,000 cfs during flood peaks due to freshet discharge composed of snowmelt and rainfall (Figure 2.9, 1964 hydrograph). Glacial melt, which usually reaches its peak in July and August, can contribute to high river discharges when combined with relatively large precipitation

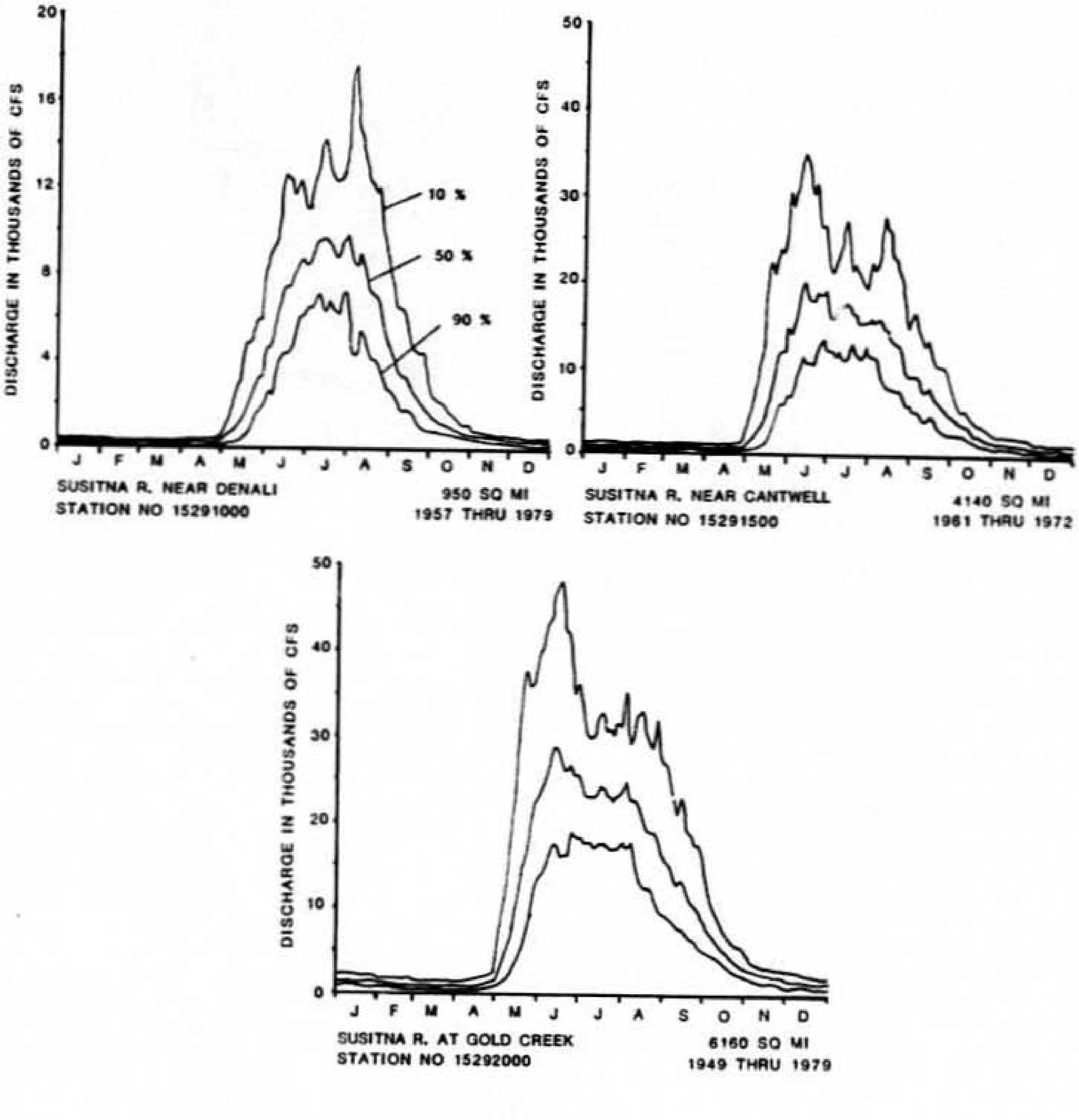


Figure 2.7 DAILY SUSITNA RIVER DISCHARGES
WHICH WOULD BE EXCEEDED 10, 50 & 90 % OF THE TIME.
(NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION 1982)

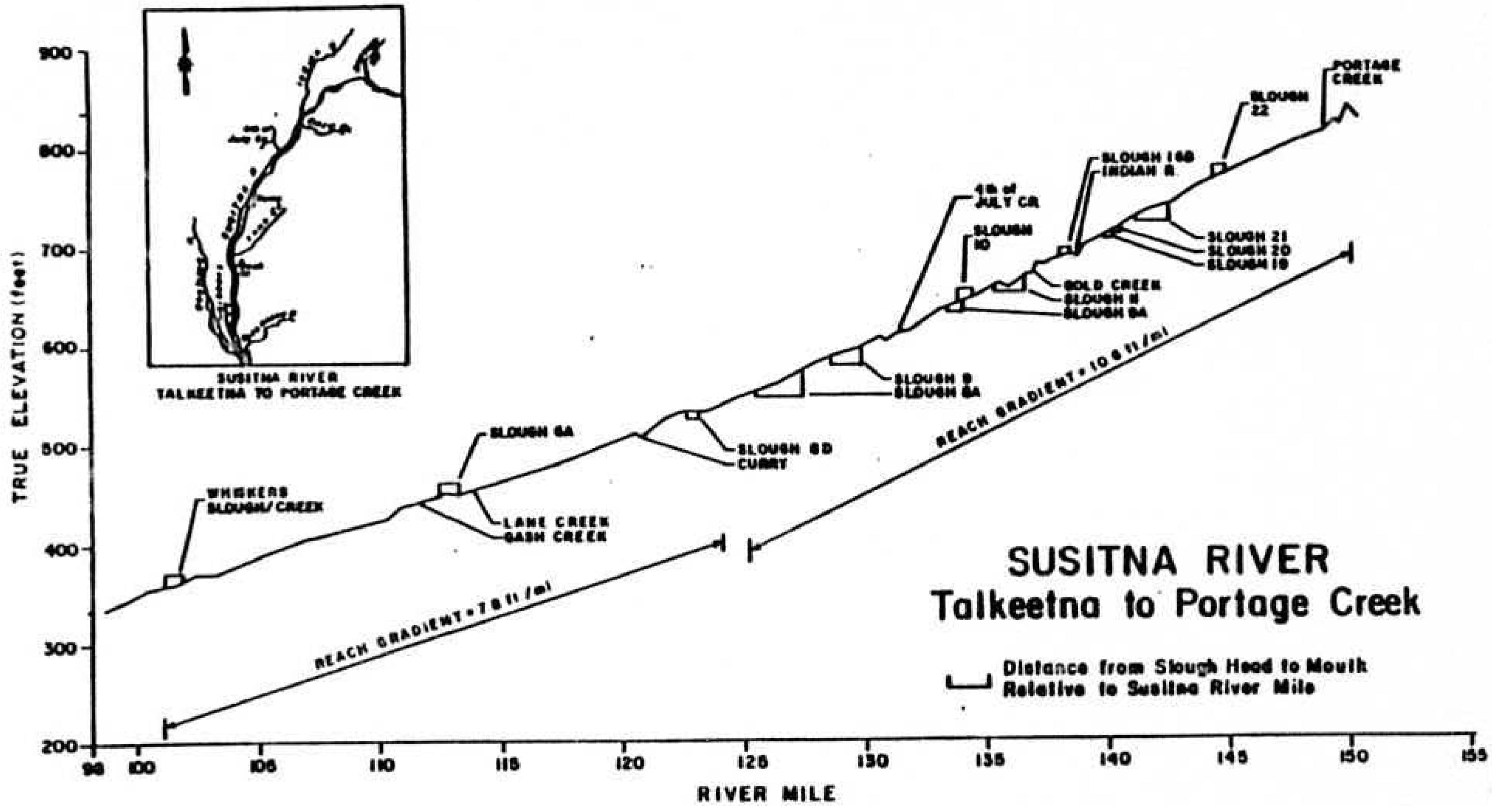


Figure 2. 8 Gradient of the Susitna River from Talkeetna to Portage Creek.

Source: ADF&G 1982

events in middle or late summer (Figure 2.9, 1967 hydrograph). Glaciers located on the south slopes of the Alaska Range occupy approximately 290 square miles or about 5.9 percent of the Susitna River drainage basin (Figure 2.1 and 2.5). During drought years, such as 1969, it has been estimated that glacier runoff may contribute approximately 30 percent of the Susitna's discharge at the Watana dam site. During 1981-1983 glacier runoff accounted for approximately 18 percent of flow at the Watana dam site (Clarke et al. 1985).

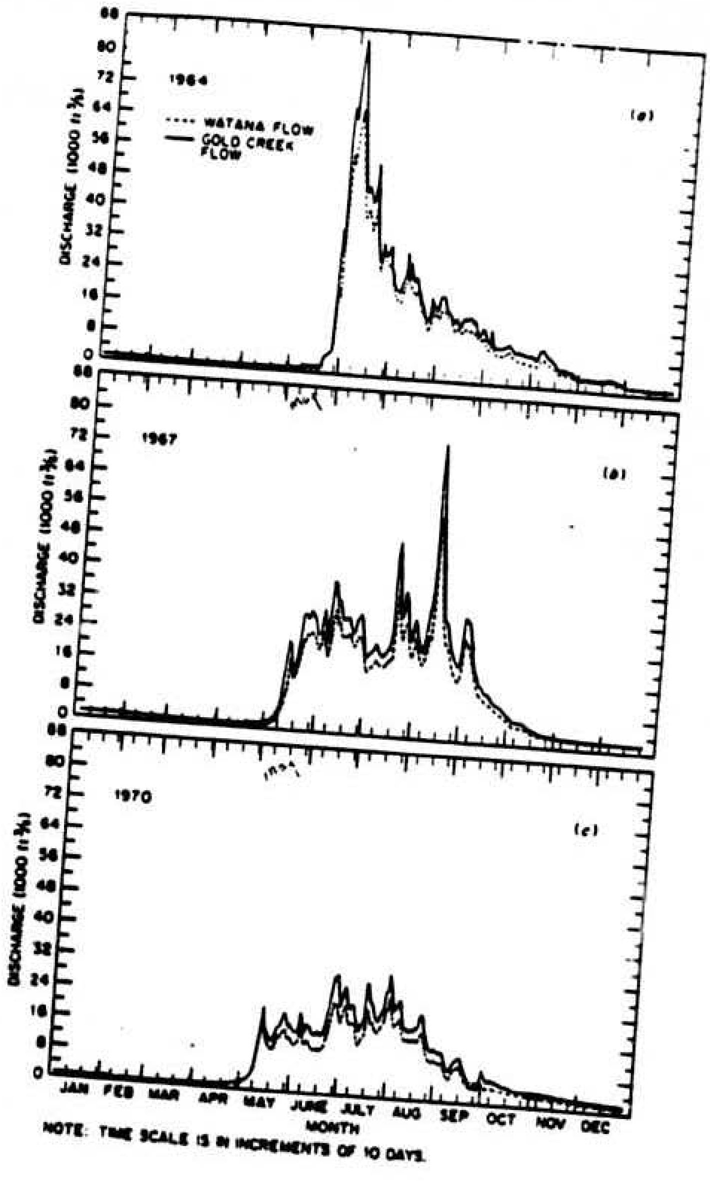


Figure 2.9 Representatiave annual hydrographs at the Watana dam site and the Gold Creek gaging station for two wet years with spring (1964) and fall (1967) floods and for one dry year (1970). Source: FERC 1984

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 phase of the project. The reservoir 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 4.3 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 2.4 million acre-feet of active storage, which corresponds to roughly 40 percent of the mean annual flow at the damsite. While functioning alone, it will operate as a base load power plant with daily variations ranging from zero to ± 10 percent of weekly flows.

The Watana Stage I powerhouse will have four generators served by four multi-level intakes spaced between el. 1,800 and el. 1,980. In general, the uppermost intake level available for use would be operated in order to obtain maximum head for power production and to release water of the most optimum quality. Turbine tailrace waters will be discharged through a 34 foot diameter, concrete lined tunnel, discharging beneath the surface of the river 1,000 feet downstream of the dam toe.

Water for controlled spills will be withdrawn from the reservoir through an intake located at el. 1,930 and discharged through outlet works controlled by six, 78-inch fixed-cone valves. These fixed-cone valves compose the terminal point of the outlet works. Water discharged from these valves will

Table 3.1

SUSITNA HYDROELECTRIC PROJECT
MORPHOLOGICAL AND HYDROLOGICAL FEATURES - WATANA RESERVOIR

	Watana Stage III	Watana Stage I
Elevation (maximum surcharge level)	2,199 MSL (671 m)	2,017 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	3.7×10^6 m) acre-ft. (4.6×10^9 m^3)	2.4×10^6 acre-ft 19,900 acres
Maximum Surface Area	38,000 acres (60mi^2)	
Maximum Length	approx. 48 miles (77 km)	39 mi.
Maximum Width	approx. 8 miles (12.8 km)	3 mi.
Maximum Depth	735 ft. (223 m)	650 mi.
Mean Depth	250 ft. (76 m)	______
Gross Storage (total volume)	9.5×10^6 acre-ft. (11.7×10^9 m^3)	4.3×10^6 acre-ft
Shoreline Length	183 miles (295 km)	______
Mean Hydraulic Residence Time	1.65 years	______
Drainage Basin	5,180 mi^2 (13,416 km)	5,180 m^2
Mean River Inflow	8,050 CFS ($226\ m^3s^{-1}$)	8,050 CFS
Peak Flood Inflows		
PMF	326,000 CFS ($9,226\ m^3s^{-1}$)	SAME
10,000 yr.	174,000 CFS ($4,924\ m^3s^{-1}$)	SAME
50 yr.	89,500 CFS ($2,533\ m^3s^{-1}$)	SAME
25 yr.	79,800 CFS ($2,258\ m^3s^{-1}$)	SAME
Tailwater Elevation	1,455 ft. MSL (443.5 m)	1,455 MSL
Area of Inundation - Stage I1/		19,900 acres
water and barren ground		4,146 acres
vegetation		15,297 acres
Area of Inundation - Stage III1/	16,692 acres additional	
water and barren	586 acres additional	
ground vegetation	16,106 acres additional	
Total Area of Inundation-Stage III1/	36,135 acres	

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

form a diffuse spray. The cone valves are located approximately 105 feet above the downstream tailwater elevation at 1,455 ft. MSL. Fixed-cone valves have been designed to dissipate the energy of the falling waters by creating spray over a relatively large surface area. Spray discharges are desirable in order to avoid plunging water and the potential for producing gas supersaturation. Spillway usage is expected to occur only when river inflows exceed the one in 50-year flood (APA 1985).

The outlet works capacity at Watana Stage I is 24,000 cfs, while the powerhouse capacity is about 12,000 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 use.

3.1.2 Devil Canyon Stage II

Devil Canyon Stage II is the second stage of the project. 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, with 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 compared to the larger Watana reservoir. Its main function will be to develop high head for efficient power generation per unit of water discharge. It will be used extensively to generate base load power and will serve to reregulate peak water discharges released from Watana Stages I and III (Table 3.2).

During construction of the 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

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 $x10^6 m^3$)
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)	$1.1x10^6$ acre-ft.($1.4x10^9 m^3$)
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	9,160 CFS (259 $m^3 s^{-1}$)
Peak Flood Inflows	
PMF	358,000 CFS (w/Watana)
10,000 yr.	184,000 CFS (w/Watana)
50 yr.	46,000 CFS (w/Watana)
25 yr.	44,600 CFS (w/Watana)
Tailwater Elevation	850 ft. MSL
Area of Inundation-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.

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. (446 m) MSL with an actual height of 646 ft. above its foundation. A three foot parapet will be added to raise the crest to el. 1,466. 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 24-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 3,790 CFS (i.e. 15,160 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 outlet works and/or spillways and will thereby help minimize 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, as 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 the deeper valves will be discharged approximately 50 feet above downstream tailwaters. The water surface elevation downstream of Devil Canyon Dam will be approximately 900 feet MSL. From there, discharged waters will enter the remaining two mile stretch of Devil Canyon rapids before mixing with turbine 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 final 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 of 3.7×10^6 acre-feet (APA 1983c,d) (Table 3.1). In the final planned configuration, Watana Stage III would be utilized as a peaking power plant with the more downstream Devil Canyon Reservoir serving to reregulate its downstream discharges.

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 intakes for withdrawals between el. 2,000 and el. 2,170 will be added for the four generators originally installed during Watana Stage I, and the lower intakes utilized originally in Stage I will be closed. Thus Watana Stage III will have a total of six generators.

Watana Stage III powerhouse hydraulic capacities total approximately 23,000 cfs with an additional outlet works total capacity of approximately 24,000 cfs.

3.2 GENERALIZED RESERVOIR OPERATIONS AND DOWNSTREAM FLOWS

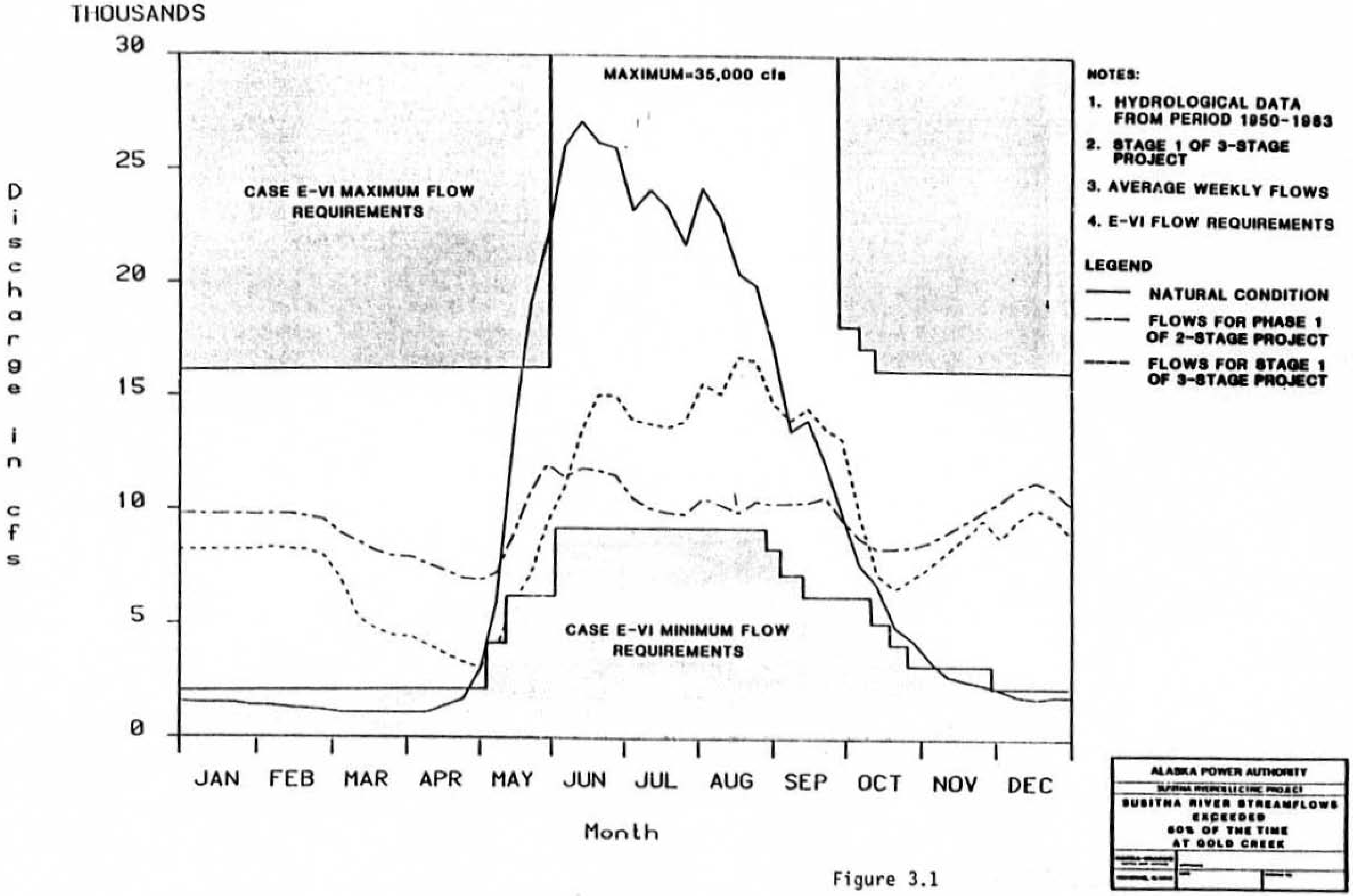
Reservoir operation simulations have been conducted in order to minimize the cost of providing power to the Alaska Railbelt, while simultaneously conforming to environmental guidelines specified for protection of certain habitat features downstream. Key constraints on the reservoir operation simulations are the project system power demands and the minimum and maximum instream weekly flow requirements at Gold Creek. The release for power is governed by a system operating guide designed to optimize energy generation. Any flow required to meet downstream environmental flow requirements in excess of scheduled power releases is first routed through the powerhouse if the total system power demand is great enough or 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, if necessary, through the appropriate spillway(s).

Case E-VI is the Applicant's selected preferred flow case for minimizing the cost of power generation while protecting the environmental habitat. Detailed discussion of E-VI and other flow regime considerations are contained in another project document (APA 1985). Basically, Case E-VI flow requirements maintain summer minimum discharges at Gold Creek of 9,000 cfs (8,000 cfs in a 1:10 low flow year), while allowing summer maximum discharges of no more than 35,000 cfs when the water level in the reservoir exceeds the normal maximum pool level and inflow exceeds 35,000 cfs. Average weekly flows exceed 35,000 cfs in about 15 percent and 20 percent of the simulated years in Stage I and II, respectively, and about 12 percent and 3 percent of the years in early and late Stage III respectively. Peak flood flows will exceed 35,000 cfs about every other year in Stage I, II and early Stage III, and about every 10 years in late Stage III. 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 weekly average streamflows simulated to be exceeded 50 percent of the time for the staged hydroelectric project in Stage I, Stage II, early Stage III, and late 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

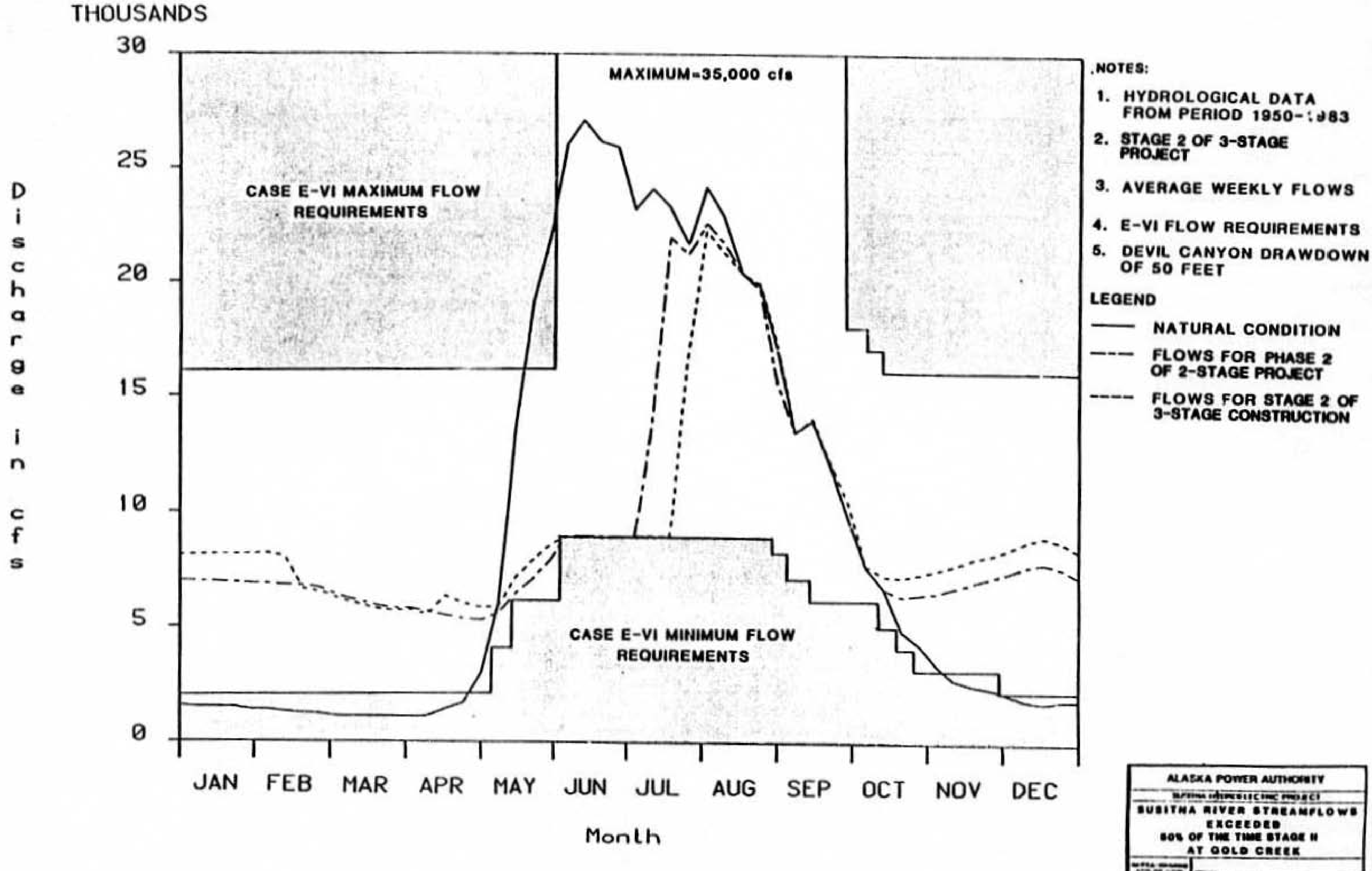
A minimum instream flow requirement is prescribed at Gold Creek to ensure that the project will release flows for environmental purposes. The historical intervening flow between Watana and Gold Creek is assumed to be available to supplement the project releases to meet the minimum flow requirement. If 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 12,000 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.



THOUSANDS
Discharge in cfs
30
25
20
15
10
5
0
MAXIMUM=35,000 cfs
CASE E-VI MAXIMUM FLOW REQUIREMENTS
CASE E-VI MINIMUM FLOW REQUIREMENTS
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
NOTES:
1. HYDROLOGICAL DATA FROM PERIOD 1950-1983
2. STAGE 1 OF 3-STAGE PROJECT
3. AVERAGE WEEKLY FLOWS
4. E-VI FLOW REQUIREMENTS
LEGEND
NATURAL CONDITION
FLOWS FOR PHASE 1 OF 2-STAGE PROJECT
FLOWS FOR STAGE 1 OF 3-STAGE PROJECT
ALASKA POWER AUTHORITY
SUSITNA RIVER STREAMFLOWS EXCEEDED 60% OF THE TIME AT GOLD CREEK

Figure 3.1


THOUSANDS
30
25
20
15
10
5
0
Discharge in cfs
CASE E-VI MAXIMUM FLOW REQUIREMENTS
MAXIMUM=35,000 cfs
CASE E-VI MINIMUM FLOW REQUIREMENTS
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
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OCT
NOV
DEC
Month
NOTES:
1. HYDROLOGICAL DATA FROM PERIOD 1950-1983
2. STAGE 2 OF 3-STAGE PROJECT
3. AVERAGE WEEKLY FLOWS
4. E-VI FLOW REQUIREMENTS
5. DEVIL CANYON DRAWDOWN OF 50 FEET
LEGEND
NATURAL CONDITION
FLOWS FOR PHASE 2 OF 2-STAGE PROJECT
FLOWS FOR STAGE 2 OF 3-STAGE CONSTRUCTION
ALASKA POWER AUTHORITY
SUSITNA RIVER STREAMFLOWS
EXCEEDED
OF THE TIME STAGE II
AT GOLD CREEK

Figure 3.2

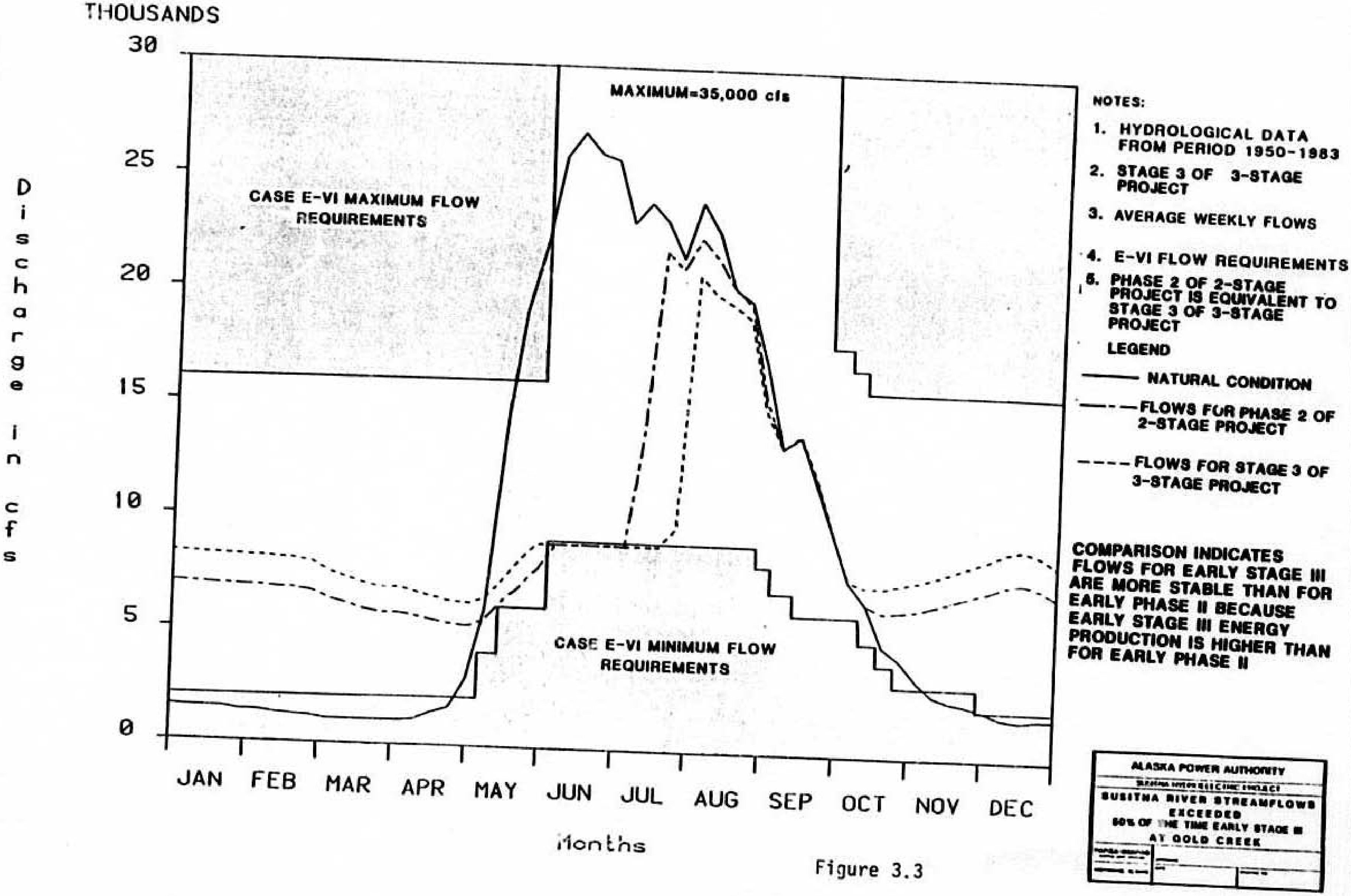
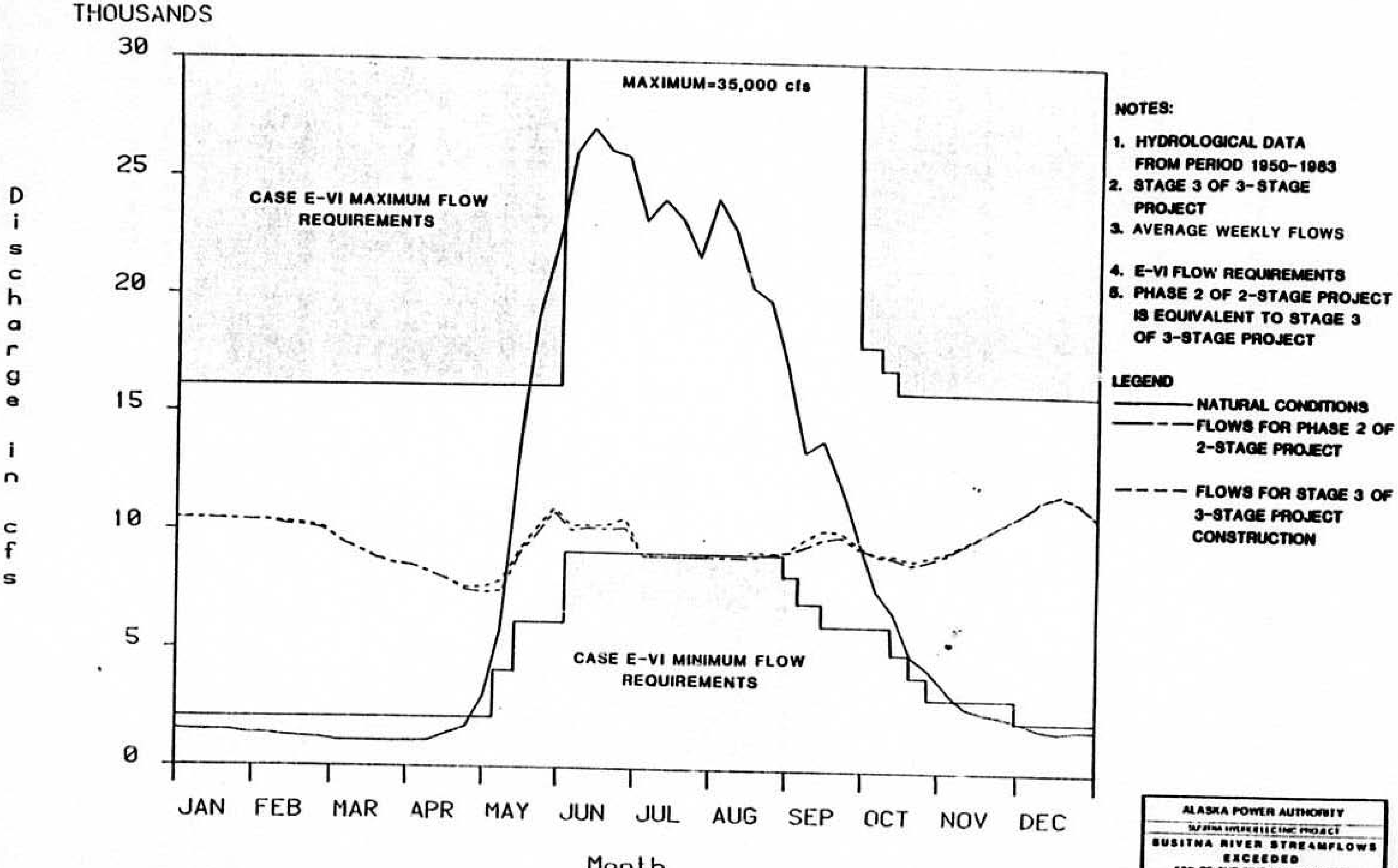

THOUSANDS
30
25
20
15
10
5
0
Discharge in cfs
MAXIMUM=35,000 cfs
CASE E-VI MAXIMUM FLOW REQUIREMENTS
CASE E-VI MINIMUM FLOW REQUIREMENTS
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Months
NOTES:
1. HYDROLOGICAL DATA FROM PERIOD 1950-1983
2. STAGE 3 OF 3-STAGE PROJECT
3. AVERAGE WEEKLY FLOWS
4. E-VI FLOW REQUIREMENTS
5. PHASE 2 OF 2-STAGE PROJECT IS EQUIVALENT TO STAGE 3 OF 3-STAGE PROJECT
LEGEND
NATURAL CONDITION
FLOWS FOR PHASE 2 OF 2-STAGE PROJECT
FLOWS FOR STAGE 3 OF 3-STAGE PROJECT
COMPARISON INDICATES FLOWS FOR EARLY STAGE III ARE MORE STABLE THAN FOR EARLY PHASE II BECAUSE EARLY STAGE III ENERGY PRODUCTION IS HIGHER THAN FOR EARLY PHASE II
ALASKA POWER AUTHORITY
SUSITNA RIVER STREAMFLOWS
EXCEEDED
AT GOLD CREEK

Figure 3.3



ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

SUSITNA RIVER STREAMFLOWS EXCEEDED 50% OF THE TIME LATE STAGE III AT GOLD CREEK

Figure 3.4

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. It is to be refilled if it is not full, provided the total inflow is greater than the release required to meet the environmental flow requirement.

An operating guide will be 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 be 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.

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The powerhouse hydraulic capacities are about 12,000 cfs at Watana Stage I and about 15,000 cfs at Devil Canyon. The capacity is about 23,000 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. While the capacity of the Watana outlet works in Stage III is 30,000 cfs, it is not planned to operate them at flows greater than 24,000 cfs, since this may cause inflows to Devil Canyon to exceed the Devil Canyon outlet works capacity and result in premature opening of the Devil Canyon spillway. 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. 2,017 ft. for the Watana Stage I Dam and el. 2,199 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 (May through October) and the "winter" or ice-covered season (November through April). The spring and fall transition periods between characteristic summer and winter water quality periods 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.

During the ice-covered season the Susitna is characterized by relatively low and stable flows, as is the case for many subarctic rivers (National Oceanic and Atmospheric Administration 1982). It is characterized by a relatively high dissolved solids content and low concentrations of suspended particulates. Both of these characteristics are due to the dominant influences of ground 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 ground water table in the valley's subsurface aquifer. The acidic nature of atmospheric precipitation, some of which percolates through the watershed soils and sub-surface 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 the concentrations of other dissolved gases. For example carbon dioxide contents of Susitna River ground water 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 (e.g. Ch. 7).

Freshet runoff, atmospheric precipitation, glacial melt, and most other tributary flows dilute river surface flow concentrations of many dissolved chemical entities during the open water season. Sheet erosion of basin soils and erosion and resuspension of bed load and stream bank particulates by high discharges results 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-APRIL FOR THE PERIOD 1980-1982

Parameter	May-October		November - April	
	Range	Mean	Range	Mean
Mean Flow (cfs)	4,000-50,000	18,000	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 a,b; R and M Consultants, Inc. 1982.

425833
860527

4.2 EXPECTED WATER QUALITY CHANGES -GENERALIZED

Construction and operation of the proposed project will alter most water quality characteristics in the impoundment zone and in downstream riverine habitats which are directly affected 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 occurring 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 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 an effect in habitats where high turbidity levels continuously prevail. However, mitigation measures are being proposed to help maintain natural levels of fish productivity.

Several important water quality characteristics have been examined in order to estimate their approximate values and/or concentrations which 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.

TABLE 4.2

SUSITNA HYDROELECTRIC PROJECT
ESTIMATED APPROXIMATE WATER QUALITY CHARACTERISTICS OF
THE 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)	Chlorophycea 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	Approximately 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 μ filters)	0-200 mg/l
Total Suspended Sediments (centrifuged)	5-400 mg/l
Turbidity	15-400 NTU
Total Nitrogen	<1000 ug/l
Total Bioavailable P	<20-30 ug/l

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 environmencal effects are found in the following chapters of this text (e.g. Chapters 5 through 11).

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, Nottingham and Drage, Inc. and I.P. Hutchinson 1982; FERC 1984; Harza-Ebasco 1984a, 1985d; R & M Consultants, Inc. et al. 1985). 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; APA 1985; Harza-Ebasco 1985d; 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 efforts utilizing a computerized simulation model called DYRESM[1/] and especially created sub-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 (APA 1985; Harza-Ebasco 1985d). 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 estimate available of the 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 yields 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 the riverine aquatic habitats.

Some 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 regimes are expected to minimize biological productivity in both reservoirs and in some downstream riverine habitats. Changes to be expected at the microbial, detritivore, primary producer and macroinvertebrate trophic levels under with project conditions, are not quantifiable. Basic knowledge of

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1/ DYRESM: Dynamic reservoir simulation model (Patterson, Imberger, Hebbert and Loh 1977) the water quality characteristics expected in downstream discharges together with various other Susitna River characteristics, indicates that:

- continuously turbid and relatively deep riverine habitats may have reduced biological productivity when compared to the natural conditions because of reduced autochthonous production and reduced allochthonous organic detritus inputs from upstream;

- clear and intermittently turbid habitats which will be relatively shallow may experience the same or increased biological productivity when compared to the natural conditions because of fertilization by deposited glacial flour particulates juxtaposed with epilithon; improvements of the condition of some streambed substrates; and reduced scour by coarse particulates in the suspended sediment load.

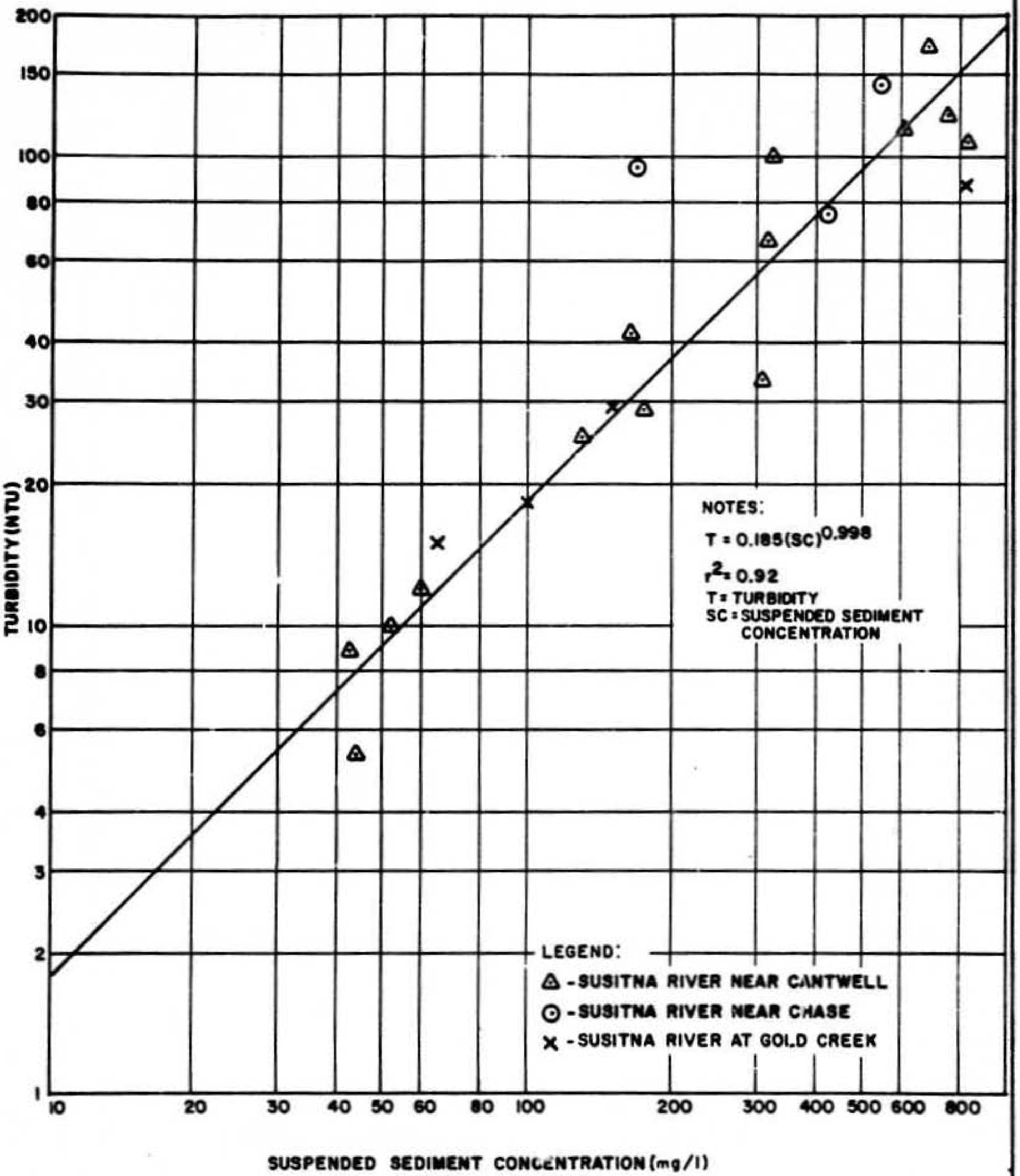
Extensive literature reviews have indicated that the estimated with-project susp nded sediment and turbidity regimes will have minimal acute effects on adult and juvenile resident fish and salmon. Direct effects on fish may result in sublethal stress, but not mortality. Evidence is lacking regarding the effects on fish of long-term exposure to the expected with-project levels of suspended sediments and turbidity under the expected environmental conditions. Evidence from studies in other turbid stream habitats implies that fish may survive the direct effects of continuous suspended loads and moderate turbidity if forced to overwinter in mainstem habitats. The indirect effects of sublethal stress on fish and other organisms due to the altered sediment regime are expected to be quantitatively unpredictable and very complex.

Approximate levels of suspended sediment and turbidity generally associated with various levels of aquatic habitat protection are presented in a following section.

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, American Public Health Association 1980). The particulates suspended in a sample which contribute the greatest turbidity per unit weight are generally larger than 1.0 micron mean beta diameter but less than 10 microns mean beta diameter (Gibbs 1974, Hecky and McCullough 1984, Peterson et al. 1985a, Edmundson and Koenings 1985). The light scattering and absorbing properties of inorganic particulates suspended in water are influenced not only by their size, shape 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.

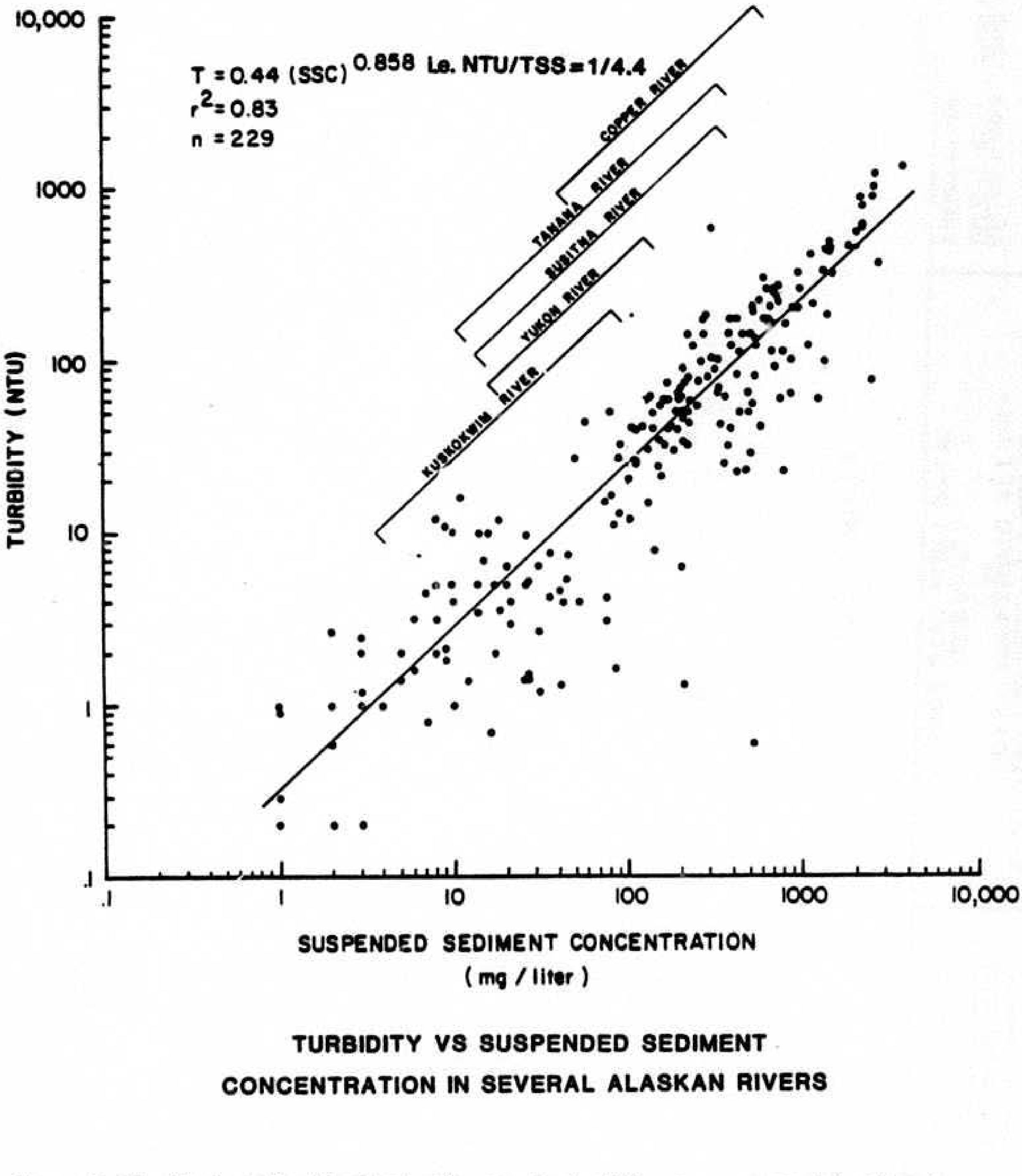
The relationships between suspended sediment concentration (TSS in mg/l) and turbidity (nephelometric turbidity units or NTU's) have been investigated in both large and small lotic environments in Alaska (R & M Consultants, Inc. 1982c, e, 1984b, 1985; Peratrovich, Nottingham and Drage, Inc. and I.P. Hutchinson 1982; Lloyd 1985; Peterson et al. 1985a). Most data from large glacial rivers 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 generally 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 be 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



TURBIDITY VS.
SUSPENDED SEDIMENT CONCENTRATION
SUSITNA RIVER

Figure 5.1

SOURCE: PERATROVICH, NOTTINGHAM AND DRAGE 1982



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

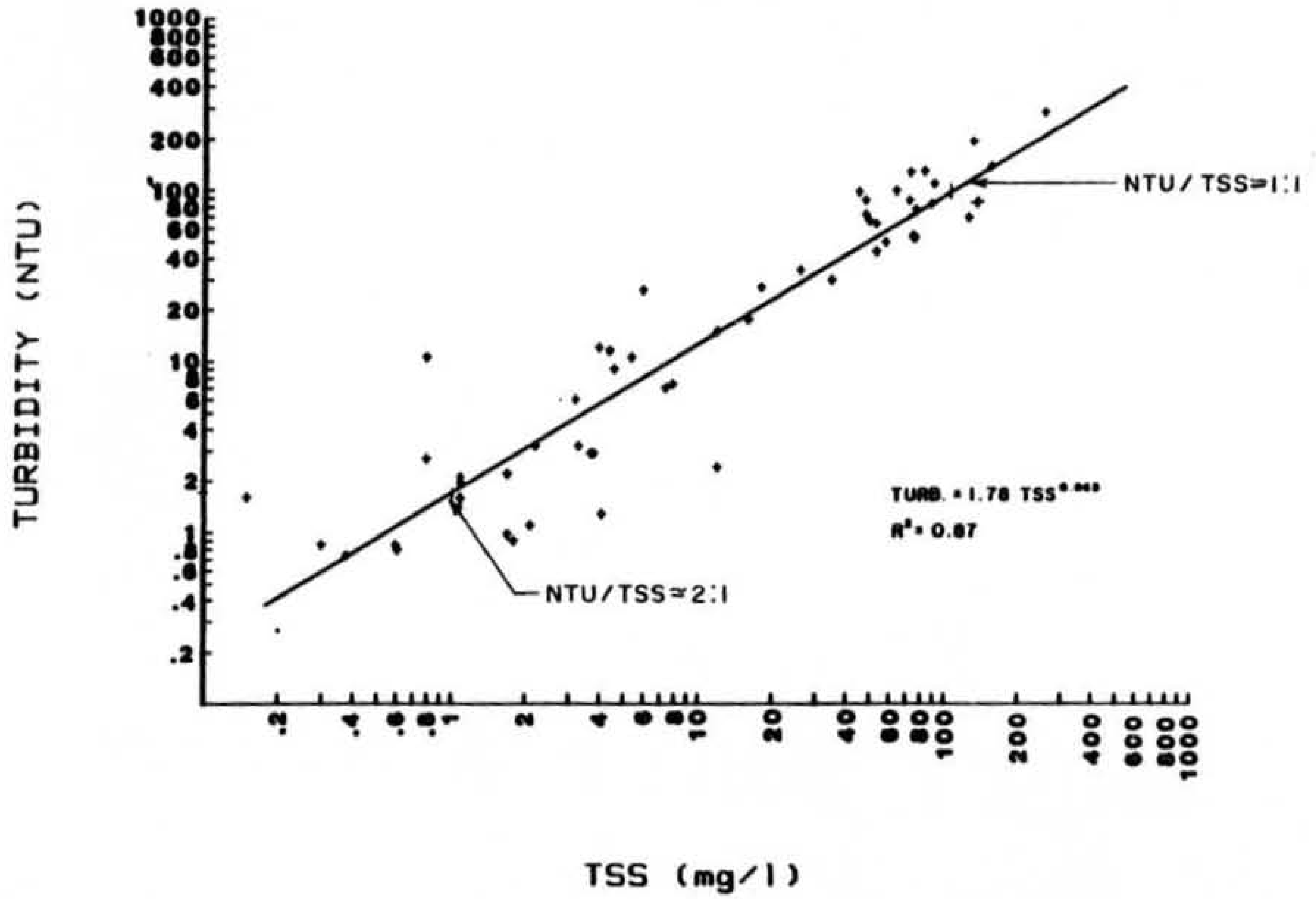


FIGURE 5.3

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

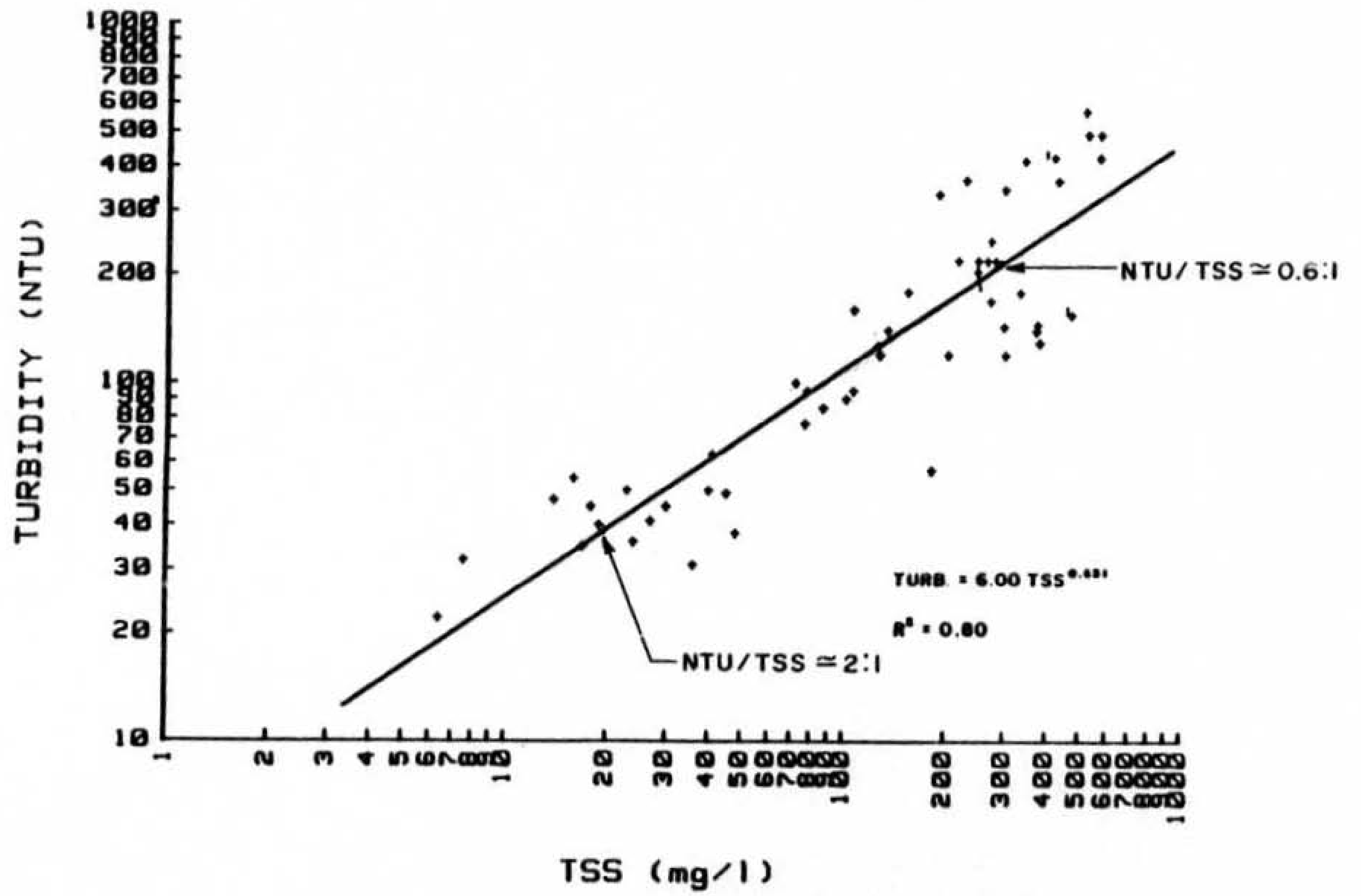


FIGURE 5.4

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

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).

Lloyd (1985), using data from another study on wastewater discharge from fifteen 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. From the information presented in Lloyd's plot (Figure 5.6) it may be concluded 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 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, because smaller particulates generally produce more turbidity per unit weight than larger particulates.

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 from 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 although different "ratio lines" would intersect the Y - axis at different values. Also if turbidity were entirely caused by TSS then regression analyses would predict that turbidity would be entirely caused by suspended solids. The three formerly depicted figures do not support either of these relationships. All three figures do, however, suggest that the

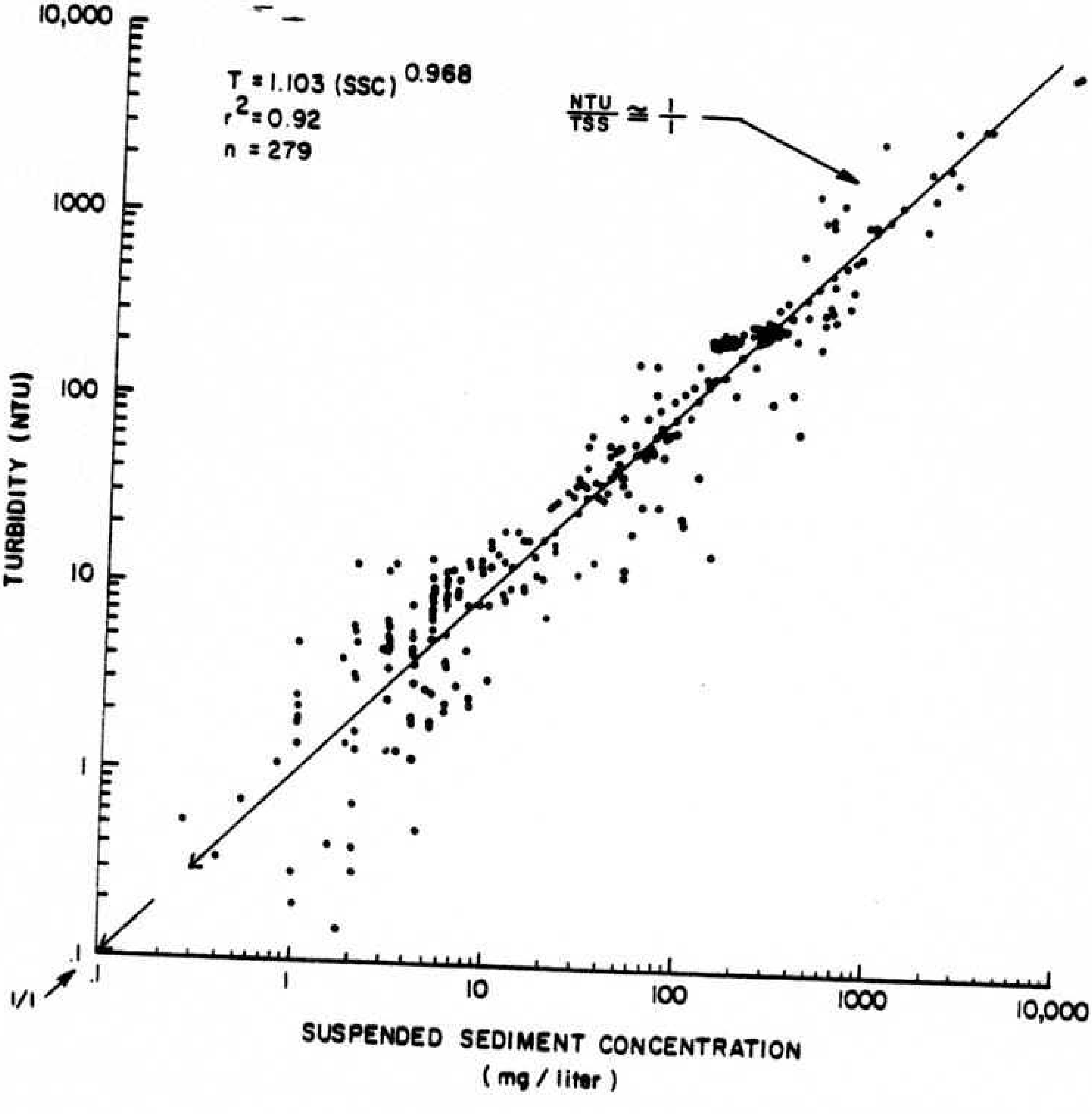


Figure 5.5 Empirical relationship of turbidity versus suspended sediment concentration for placer-mined and neighboring unmined streams in interior Alaska, sampled during summer, 1983-1984 (derived in this report from data provided by Post, 1984; Toland, 1984). (Adapted From Lloyd 1985)

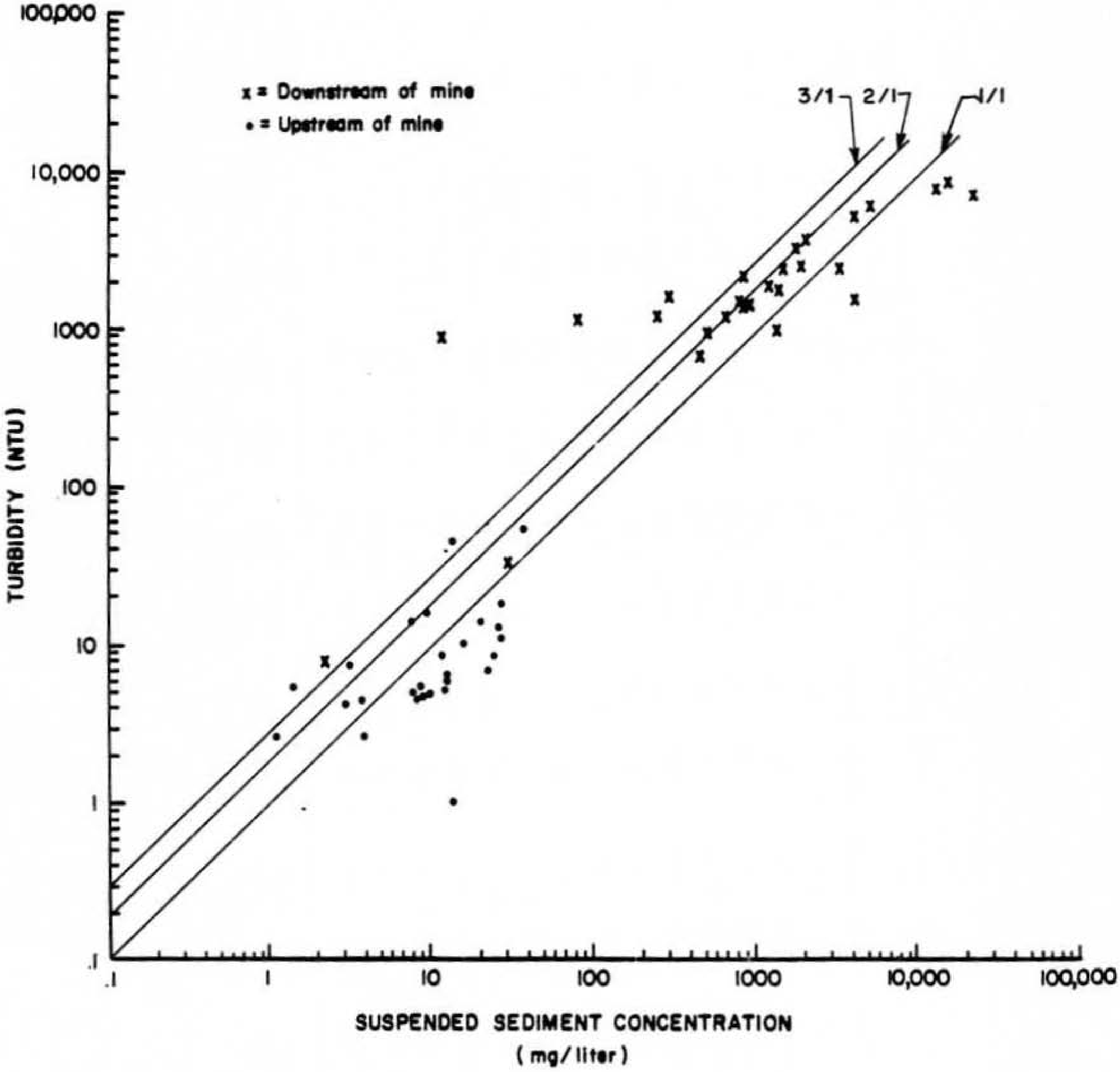


Figure 5.6 Plot of turbidity and suspended sediment concentration for certain placer-mined streams in Alaska (plotted in this report from data presented in R&M Consultants, 1982a). (Adapted From Lloyd 1985)

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

MINE SITE	0 HOUR TSS mg/l	0 HOUR Turb NTU	6 HOUR TSS mg/l	6 HOUR Turb NTU	12 HOUR TSS mg/l	12 HOUR Turb NTU	24 HOUR TSS mg/l	24 HOUR Turb NTU	48 HOUR TSS mg/l	48 HOUR Turb NTU	72 HOUR TSS mg/l	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	60.8	130	35.2	45	1.28
Porcu-pine	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				
Middle	146	124	100	172	
Bottom	108			174	165
				148	
3 Hours					
Top	120				
Middle	115	119	96	134	
Bottom	122			154	141
				136	
6 Hours					
Top	63				
Middle	105	93	75	144	
Bottom	111			125	138
				144	
12 Hours					
Top	49				
Middle	85	78	63	100	
Bottom	100			118	115
				126	
24 Hours					
Top	34				
Middle	64	57	46	90	
Bottom	74			108	101
				104	
48 Hours					
Top	32				
Middle	59	52	42	90	
Bottom	66			110	104
				112	
72 Hours					
Top	34				
Middle	48	50	41	76	
Bottom	69			112	103
				120	
96 Hours					
Top	38				
Middle	49	48	39	90	
Bottom	56			94	96
				104	

NTU/TSS
2.37
1.92
1.86
$\bar{x}$=2.05

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

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

Table 5.3
Settling Column Run #2
Total Suspended Solids and Turbidity

	TSS (mg/l)	Avg TSS	Avg* Percent Remaining	Turbidity (NTU)	Avg Turbidity	NTU/TSS
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						2.62
Top	78			204		1.96
Middle	106	101	30	208	210	1.85
Bottom	119			220		$\overline{X}=2.14$

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

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

R&M CONSULTANTS, INC.

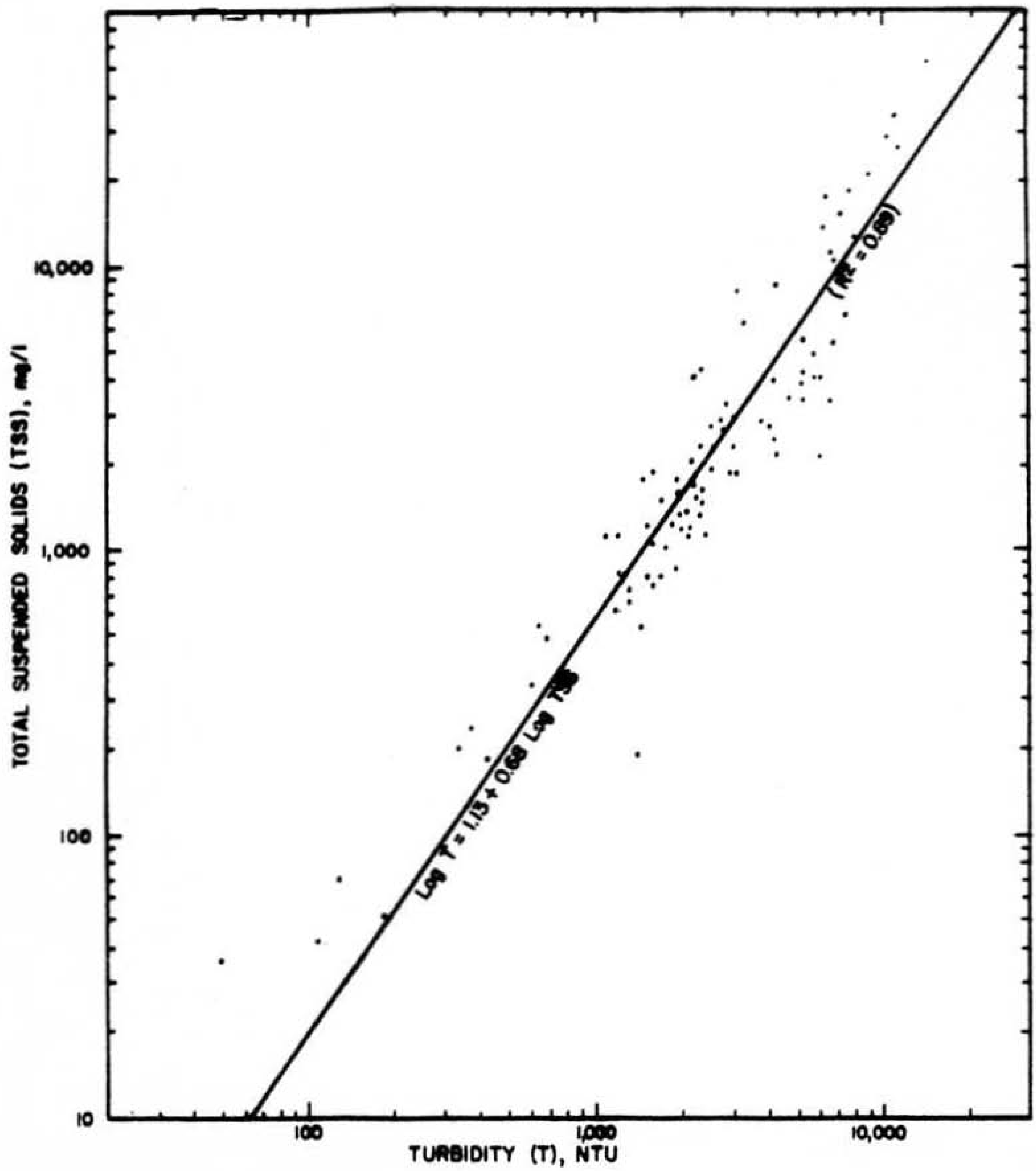


Figure 5.7

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

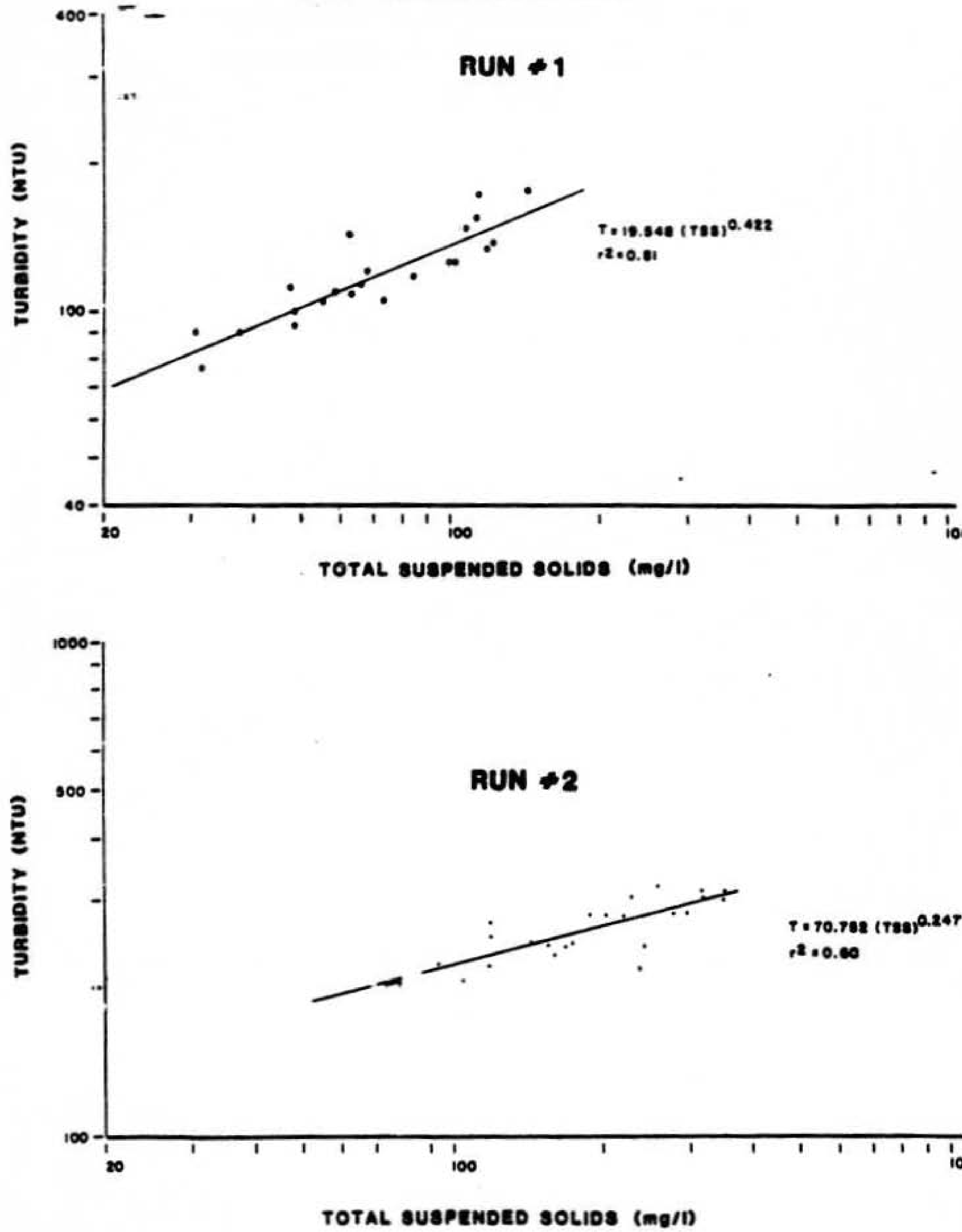


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FIGURE 5.8

HARZA-EBASCO
SUSITNA JOINT VENTURE

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

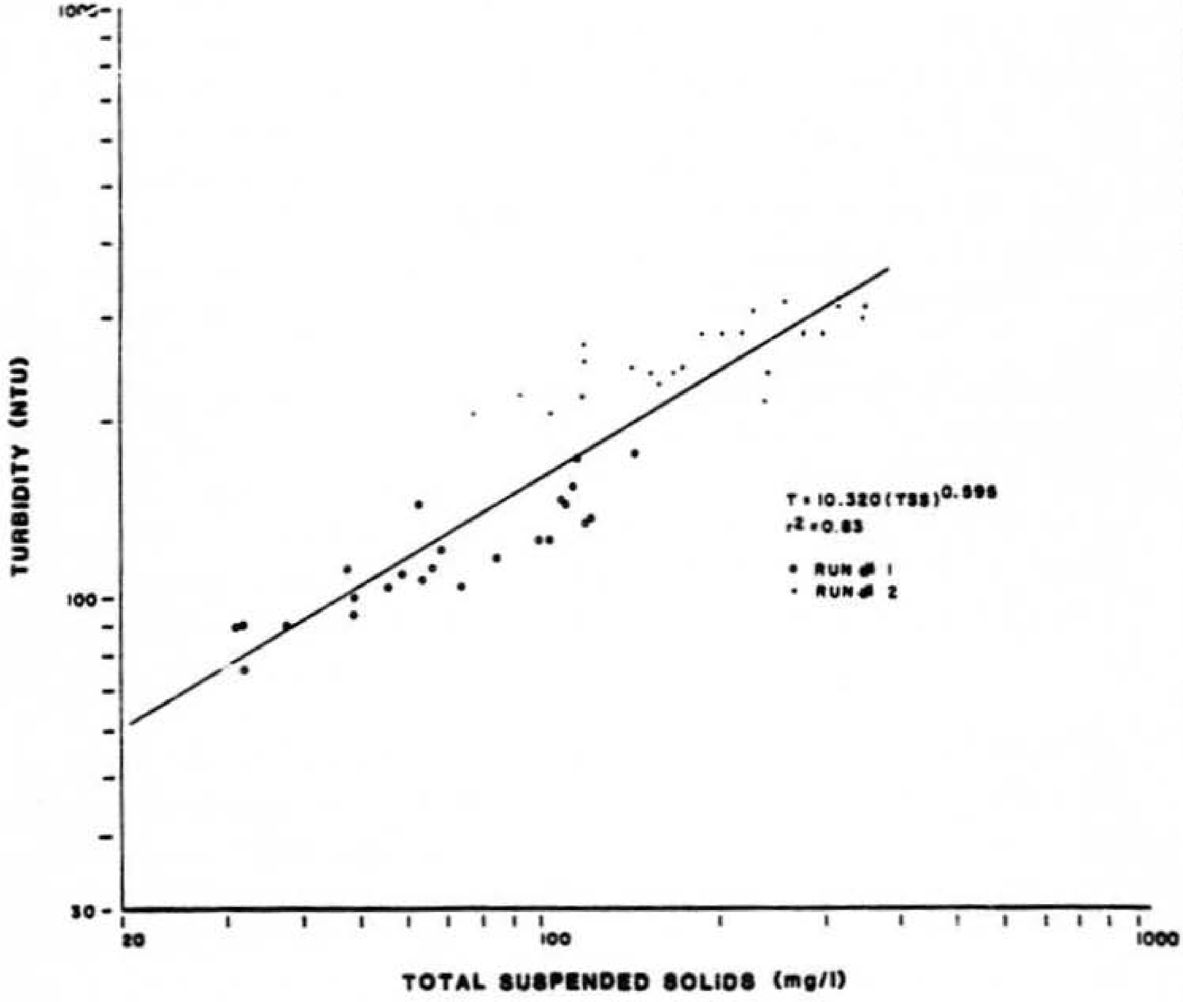

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FIGURE 5.9

HARZA-EBASCO
SUSITNA JOINT VENTURE

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 faster settling 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 together with photomicrographic evidence indicated that relatively smaller particles (with greater surface area and consequently greater light scattering capabilities per unit weight) remained in suspension in greater concentration after 96 hours of settling (R & M Consultants, Inc 1984b).

It would be reasonable to assume that the ratio NTU/TSS would have increased with increasing time elapsed in the settling columns. At some point, however, had the experiments continued, the ratio NTU/TSS would have decreased its rate of change from that shown in Figures 5.7, 5.8, and 5.9. The final NTU/TSS ratio would not be predictable and would ultimately depend on miniscule changes (in turbulence, biology, and chemistry, etc.) which would occur within the settling columns.

Large lakes and reservoirs are much more turbulent than "quiescent" settling columns. Prolonged rates of settling in large and relatively turbulent reservoirs and lakes experiencing hydrologic, climatic, geochemical and biological changes would be expected to produce relatively large and variable ratios of NTU/TSS with little predictability of the absolute ratio value or of times of change in the ratio value. It may be hypothesized that ratios of NTU/TSS in a large reservoir like Watana and in its discharges may be $\geq$2:1 and highly variable in time. Empirical data have been gathered to test this hypothesis.

Empirical data from six glacial lakes have been assembled for analysis of the relationships between turbidity and suspended sediments in lentic

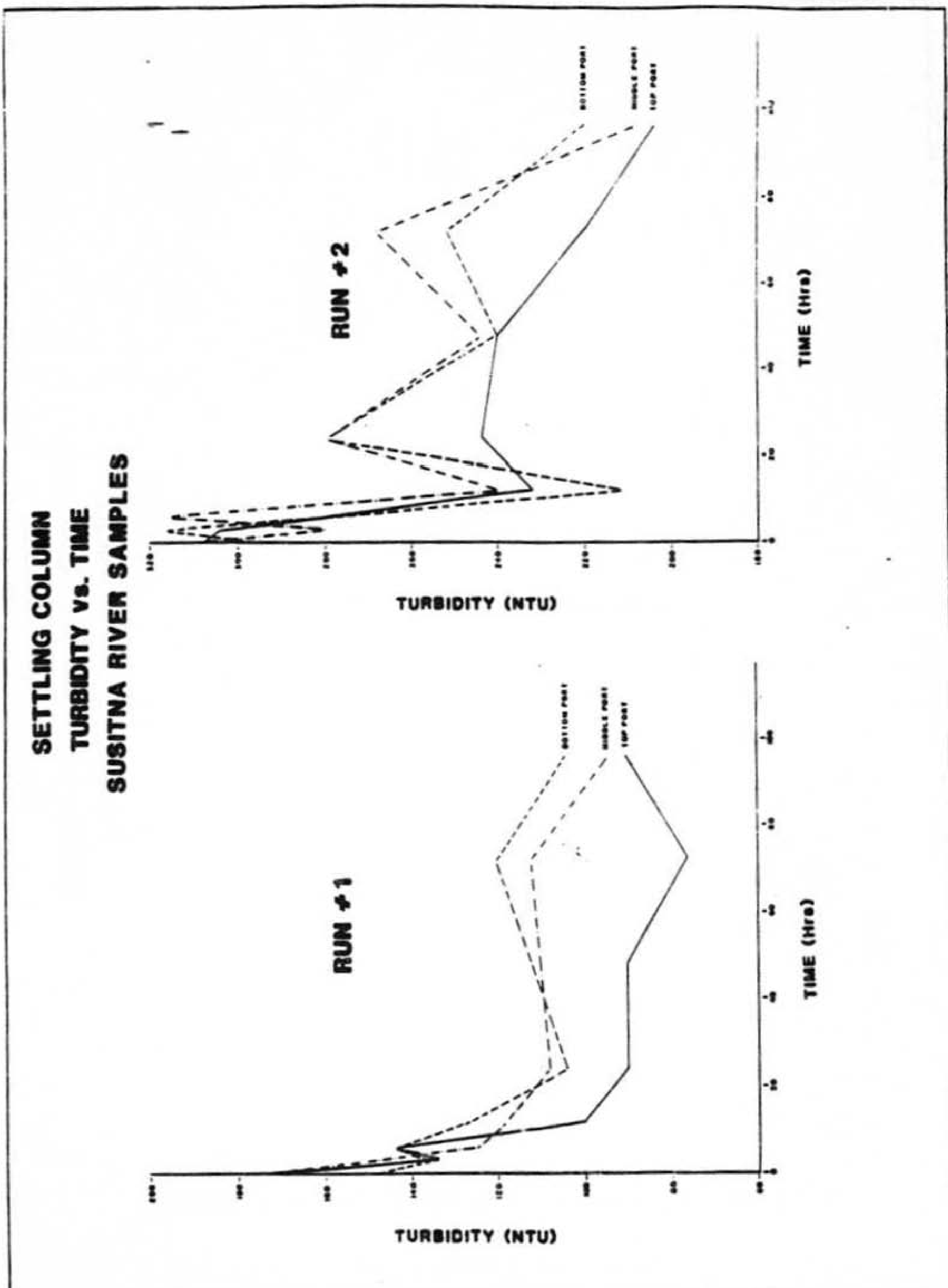

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FIGURE 5.10

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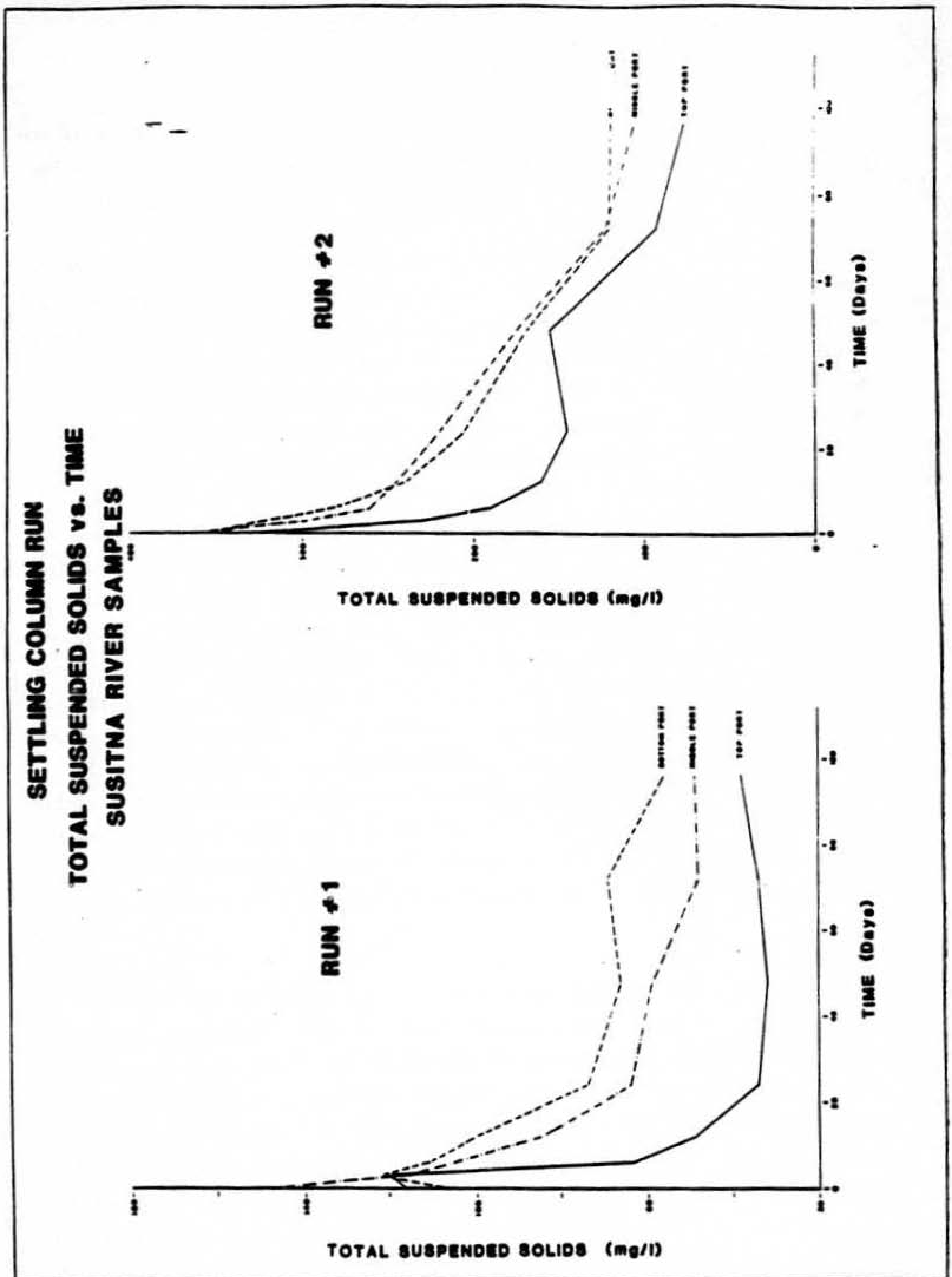

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FIGURE 5.11

HARZA-EBASCO
SUSITNA JOINT VENTURE

habitats of south central Alaska (Table 5.4). The assembled data also include information collected from the tailrace of the hydroelectric powerhouse at Eklutna Lake.

Analysis of the NTU and TSS data in different data sets is complicated by the fact that different technologies are frequently utilized by different investigators to collect similar data. For example, different investigators calibrate their nephelometers in different ways, and different nephelometers are frequently utilized by each investigator. Different nephelometers, even calibrated ones, frequently yield turbidity values as much as 10 to 20 percent (or more) different from each other for the same or similar samples. Filtration techniques involving different types of filters and/or different pore sizes of the same filter type can produce dramatically different estimates of suspended sediment concentrations. For example, in work done on tailrace waters from the Eklutna Lake hydroelectric facility (J.M. Montgomery, Consulting Engineers, Inc. et al. 1984), a decrease in filter pore size from 0.7um to 0.1 - 0.2um caused a doubling of the estimated concentration of suspended particulates. Basically different gravimetric methods for analysis of suspended sediment concentrations also yield different results for the same samples. For example, in work done at a subartic Canadian lake (Hecky and McCullough 1984), gravimetric analysis of suspended particulates concentrated by centrifugation (involving all particles >0.06um nominal diameter) yielded concentrations 1.8 times greater than for particulates concentrated by Whatman GFC filters (nominal pore size 1.0um).

In Table 5.4 the turbidity data for Tustumena, Tazlina, Klutina and Tonsina Lakes were evaluated with a single nephelometer, however, the suspended sediment concentrations were evaluated by yet another technique different from those previously described. The technique for estimating the suspended sediment concentration in the latter four lakes involved evaluating the difference between total solids and total dissolved solids. The differences and similarities between the results from the latter technique and methods involving centrifuges and filters are not well known.

At this point it should suffice to state that: 1) there is no logical reason

TABLE 5.4

SUSITNA HYDROELECTRIC PROJECT
EMPIRICALLY DERIVED RATIOS OF TURBIDITY/SUSPENDED SEDIMENT IN SOUTH CENTRAL ALASKAN LENTIC ENVIRONMENTS INFLUENCED BY GLACIAL FLOUR

Water Body	Observation Period	Data Source	Surface Area (acres)	Maximum Depth (feet)	Mean Depth (feet)	Hydraulic Residence (years)	Number of Data Pairs	Mean/Median NTU:TSS
1. Eklutna Lake	1982	1/	3,420	200	121	1.77	26	27.03:1/4.52:1
2. Eklutna Lake	1984	3/	3,420	200	121	1.77	203	4.38:1/ 3:1
3. Eklutna Lake Tailrace	1983	2/	3,420	200	121	1.77	27	3.03:1/2.15:1
4. Eklutna Lake Tailrace	1984	3/	3,420	200	121	1.77	51	3.62:1/2.94:1
5. Bradley Lake	1979-1980	4/	1,568	268	190	0.85	38	3.49:1/ 1.5:1
6. Tustumena Lake	1985	5/	72,769	1,000	408	41	12	4.77:1/1.41:1
7. Tazlina Lake	1984	5/	38,528	N.A.	223	3.79	5	1.54:1/1.39:1
8. Klutina Lake	1984	5/	16,588	N.A.	147	3.10	5	0.78:1/ 0.5:1
9. Tonsina Lake	1984	5/	3,395	N.A.	174	1.98	7	0.98:1/1.01:1
						Table Mean		5.5:1/2.0:1

1/ R & M Consultants, Inc. 1982
2/ J.M. Montgomery, Consulting Engineers, Inc. et. al. 1984
3/ R & M Consultants, Inc. 1984
4/ Ott Water Engineers, Inc. et. al. 1981
5/ Koenings, J., ADF&G F.R.E.D. Division, Personal Communication

to expect to find a consistantly close relationship between turbidity and suspended sediment concentration in natural waters; 2) only a <u>very generalized</u> relationship between turbidity and suspended sediments which distinguishes between lentic and lotic NTU/TSS ratios may be expected to be described for natural waters in south central Alaska; and 3) a large part of the problem with the establishment of a relationship between turbidity and suspended sediments is complicated by the lack of standardized technologies for assessment of the two values.

The data in Table 5.4 indicate that the mean NTU/TSS ratios are generally higher than the median NTU/TSS ratios for glacial lakes. Analysis of the raw data used to compile Table 5.4 indicates that the mean NTU/TSS ratio values are susceptible to being biased toward high values by technical sampling problems which are beyond the scope of this discussion (e.g. see the mean NTU/TSS value of the Eklutna Lake data for 1982 of 27.03:1). The grand mean of all the mean NTU/TSS values in Table 5.4 is 5.5:1, while the grand mean of all the median NTU/TSS values in the table is 2.0:1.

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 mean and median values of 3.62:1 and 2.94:1, respectively. Ratios of NTU/TSS in Eklutna Lake actually varied from <0.6:1 to >50:1, with mean and median values of 4.38:1 and 3:1, respectively.

The foregoing 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.

Analysis of all the preceding data 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 2.0:1 or greater.

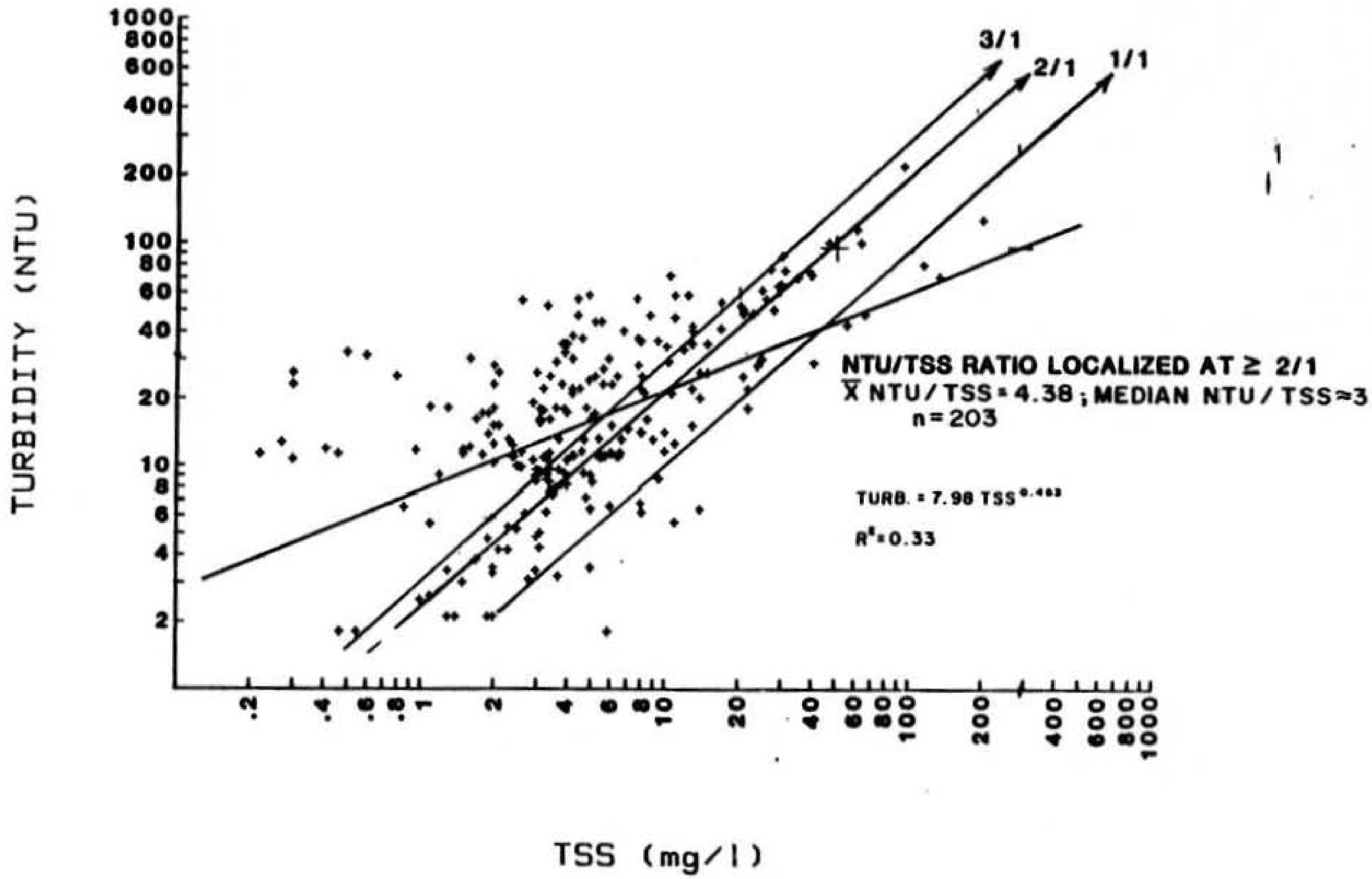


FIGURE 5.12

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

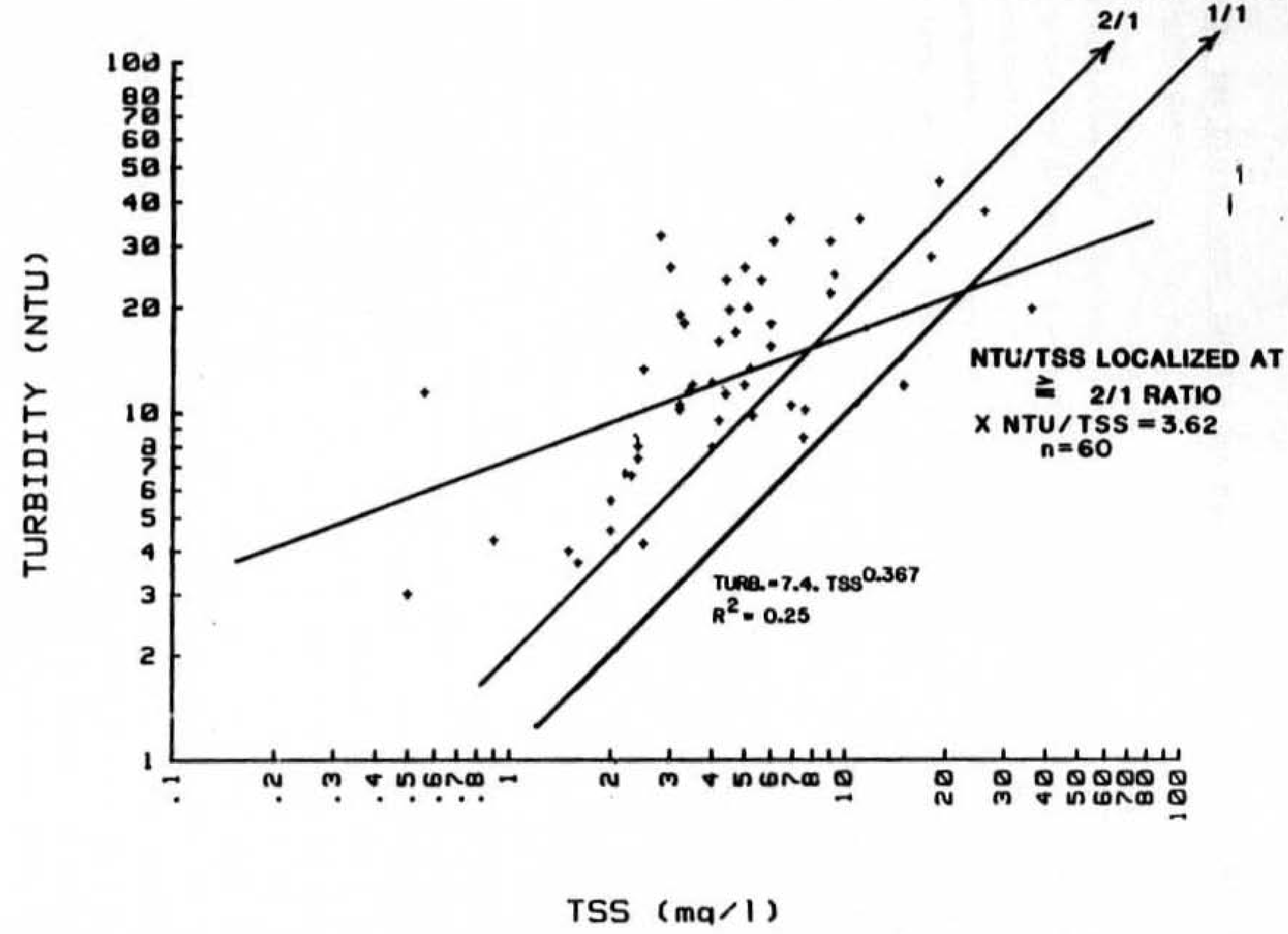


FIGURE 5.13

PREPARED BY:
R&M CONSULTANTS, INC.

1984 TAILRACE DATA: TURBIDITY vs. TOTAL SUSPENDED SOLIDS

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

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 by modifying and extending the DYRESM model. 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 a reasonable limit. This allows for a greater number of 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 principal 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 dissolved solids 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, dissolved solids, 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 it may also 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 the 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 the manner in which 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 DYRESM 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 winters of 1982-1983 and 1983-1984 indicate that the ice cover formation on Eklutna Lake begins 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 to 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 (Harza-Ebasco 1984a). The 100-year deposit is approximately 4.3 percent of the Stage III gross storage volume or 9.6 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 to 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 to 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 the average particle size of sediments leaving glacial lakes is 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). This occurs because the larger particles settle out in the reservoir. 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 composition 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 Eklutna Lake (R & M Consultants, Inc. 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 were modeled as follows:

- meteorological forces,

- o turbulent mixing,
- o suspended sediment induced vertical mixing, and
- o 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 predetermined time intervals, the vertical distance a sediment particle sinks at a prescribed velocity is compared to the minimum simulated layer thickness. The subdaily time step is then 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, from 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 Eklutna Lake were based on the total suspended sediments measured twice weekly 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 1.53×10^{-6} meter per second was used for the 0 to 3 micron sediments and 2.00×10^{-5} meter per second for the 3 to 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 to 3 micron sediments and 3 to 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 may be 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. They may also be due to local erosion or slumping of nearby sediment slopes. It is not possible to account for these temporary local fluctuations in the model since the weather station is located on the opposite end of the lake and cannot register such local variation in winds.

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

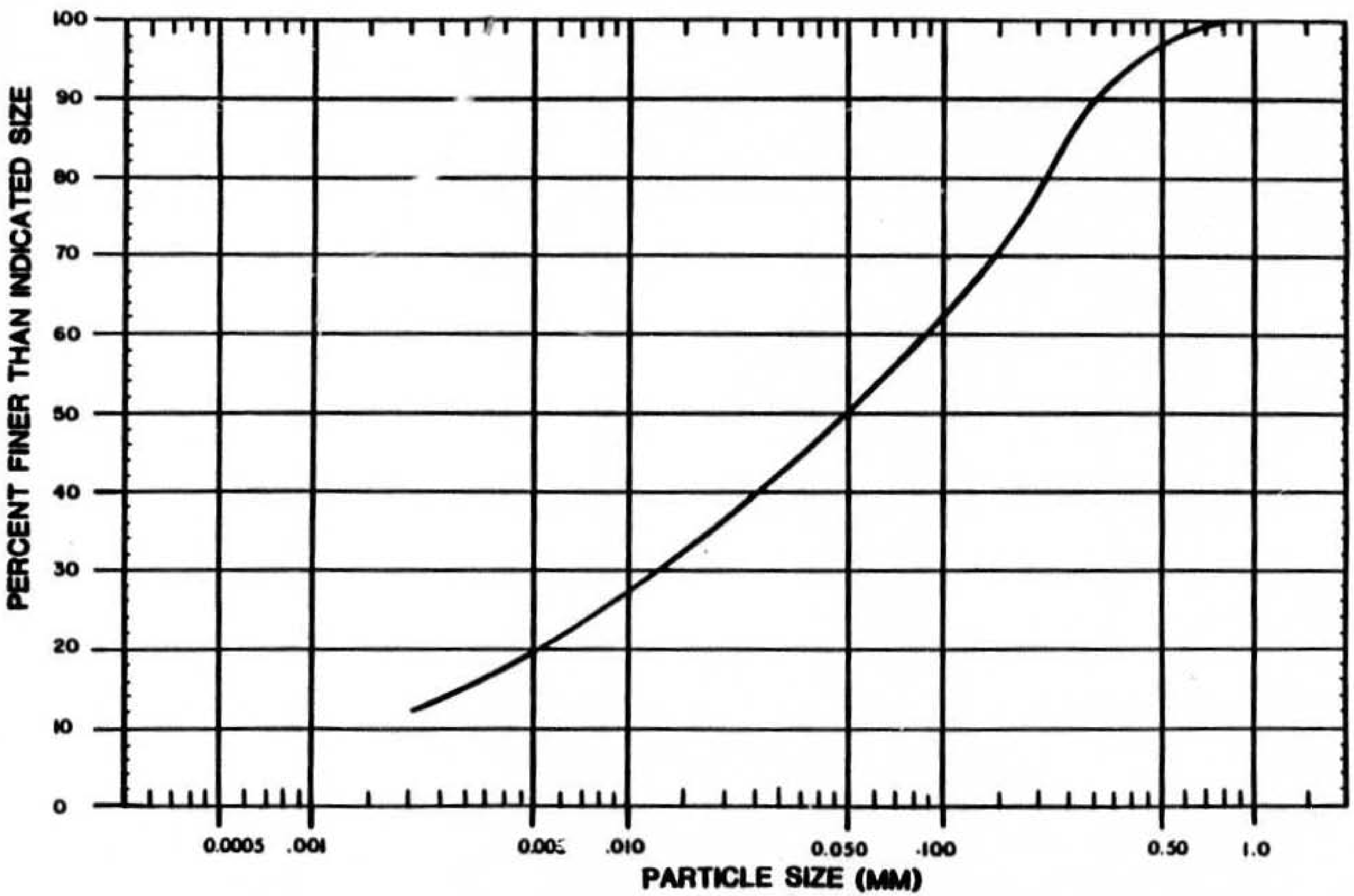
5.3.5 Susitna Reservoir Modeling

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 the Cantwell and Gold Creek USGS sampling stations. 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 to 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 to 3 and 3 to 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.

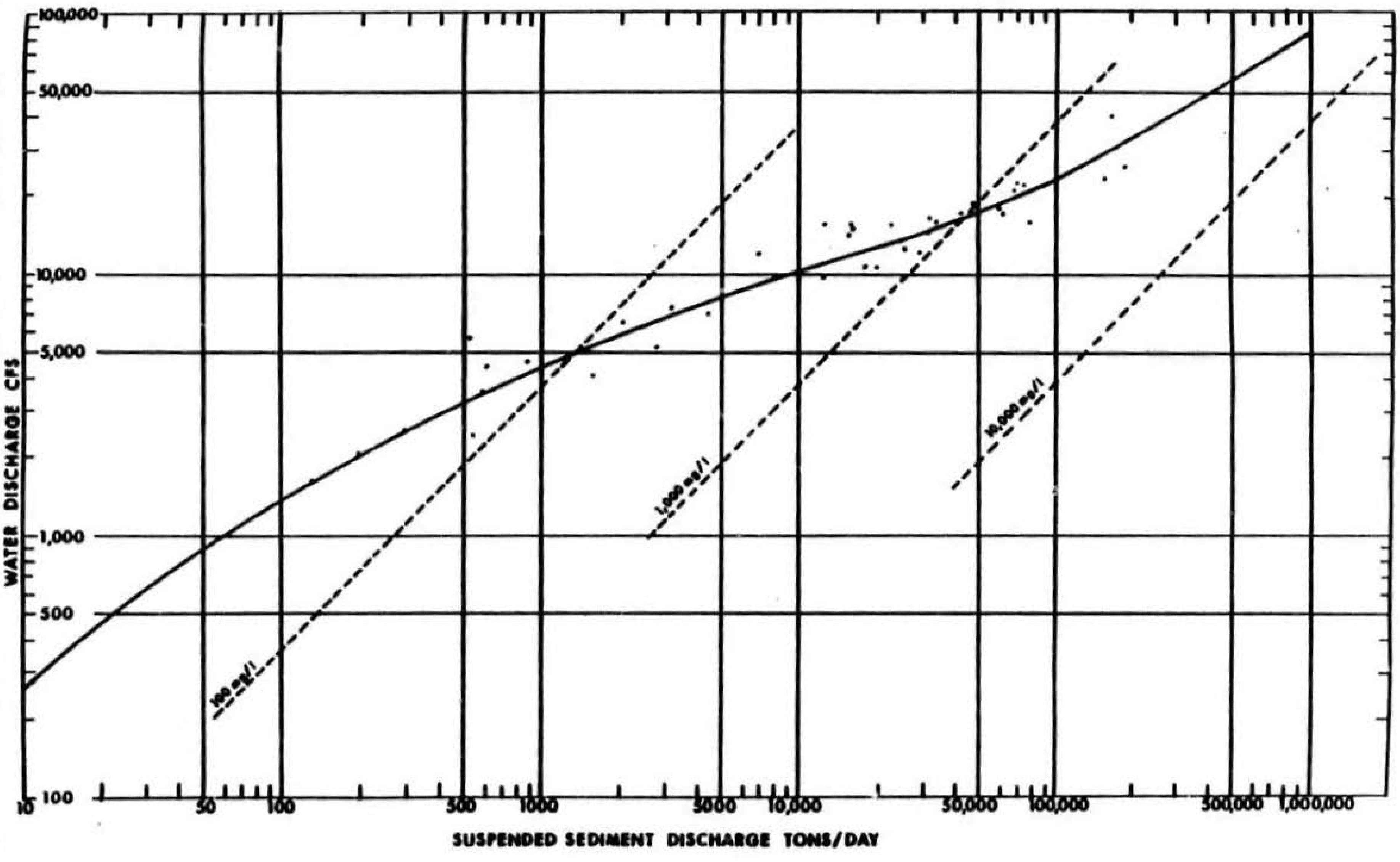
The total amount of sediment influent to the reservoir was estimated by transposing the suspended sediment transport data at the USGS gaging station on the Susitna River at Gold Creek. Figure 5.16 shows the estimated relationship between the discharge and sediment load at the gaging station. Based on this relationship and daily flows at Gold Creeks, the daily transport rates were derived. These rates were transposed to Watana using the procedures given in a previous report (Harza-Ebasco 1984a). The resulting amount of sediment influent to the reservoir for 1970, 1981 and 1982, representing years of near minimum, maximum and average sediment inflows are approximately 4,200,000, 8,500,000 and 5,600,000 tons, respectively.

The amount of sediment influent of each particle size range was determined from the suspended sediment particle size distribution curve of samples taken near Cantwell as shown in Figure 5.15. Fifteen percent of the total



SUSPENDED SEDIMENT SIZE DISTRIBUTION
SUSITNA RIVER NEAR CANTWELL

Figure 5-14



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

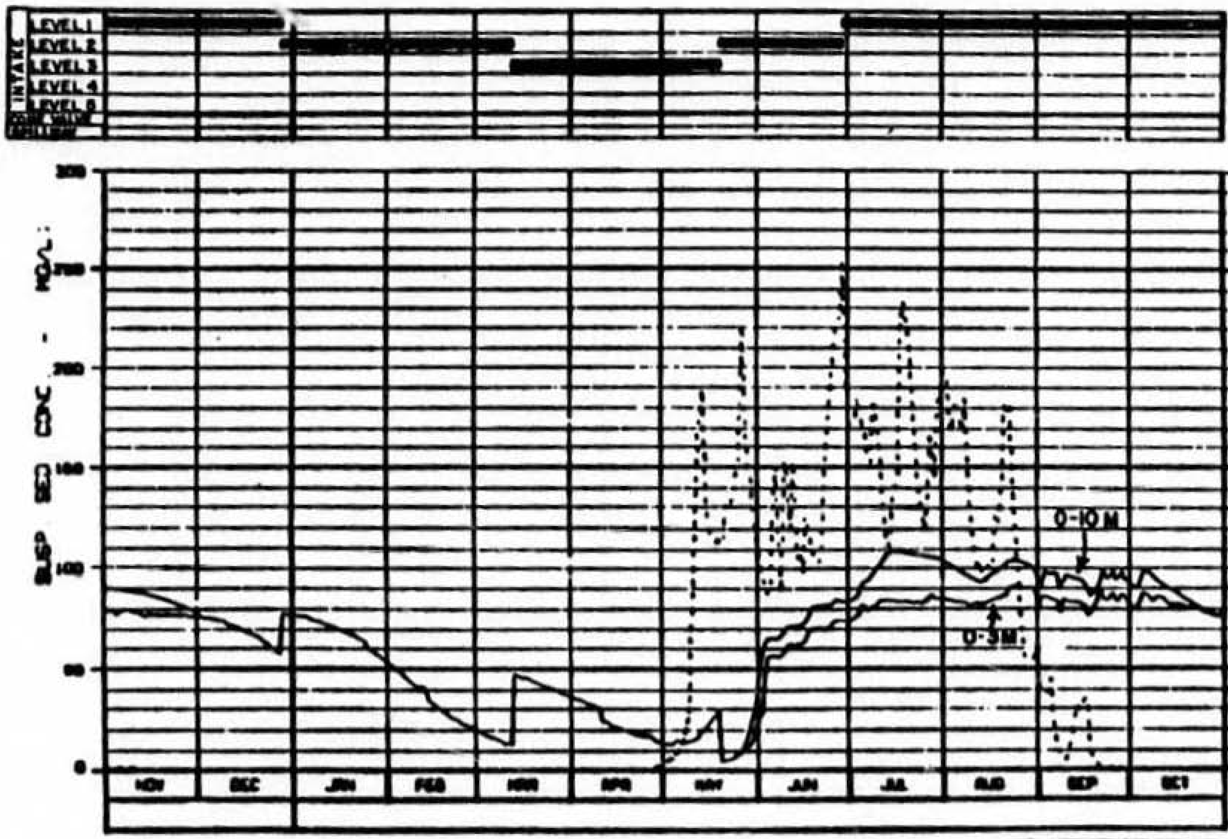
Figure 5-15

sediment influent was assigned to the 3 to 10 micron range and 12 percent to the 0 to 3 micron range.

The suspended sediment concentrations in the reservoir and the outflows were simulated for the 1970, 1981, 1982 and 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 to 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, although the sediment inflow will be negligible, a large portion of the 0 to 3 micron particle size sediments influent during the summer will remain in suspension for a relatively long period of time due to their slow settling velocities. These particles will continue to affect the suspended sediment level of the reservoir outflow. As shown in Figure 5.19, the outflow suspended sediment concentration would approach somewhat 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 to 3000 mg/l to about 60 to 150 mg/l and, in the winter, the suspended sediment level will be increased from about 1 to 80 mg/l to about 20 to 100 mg/l.



LEGEND:

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

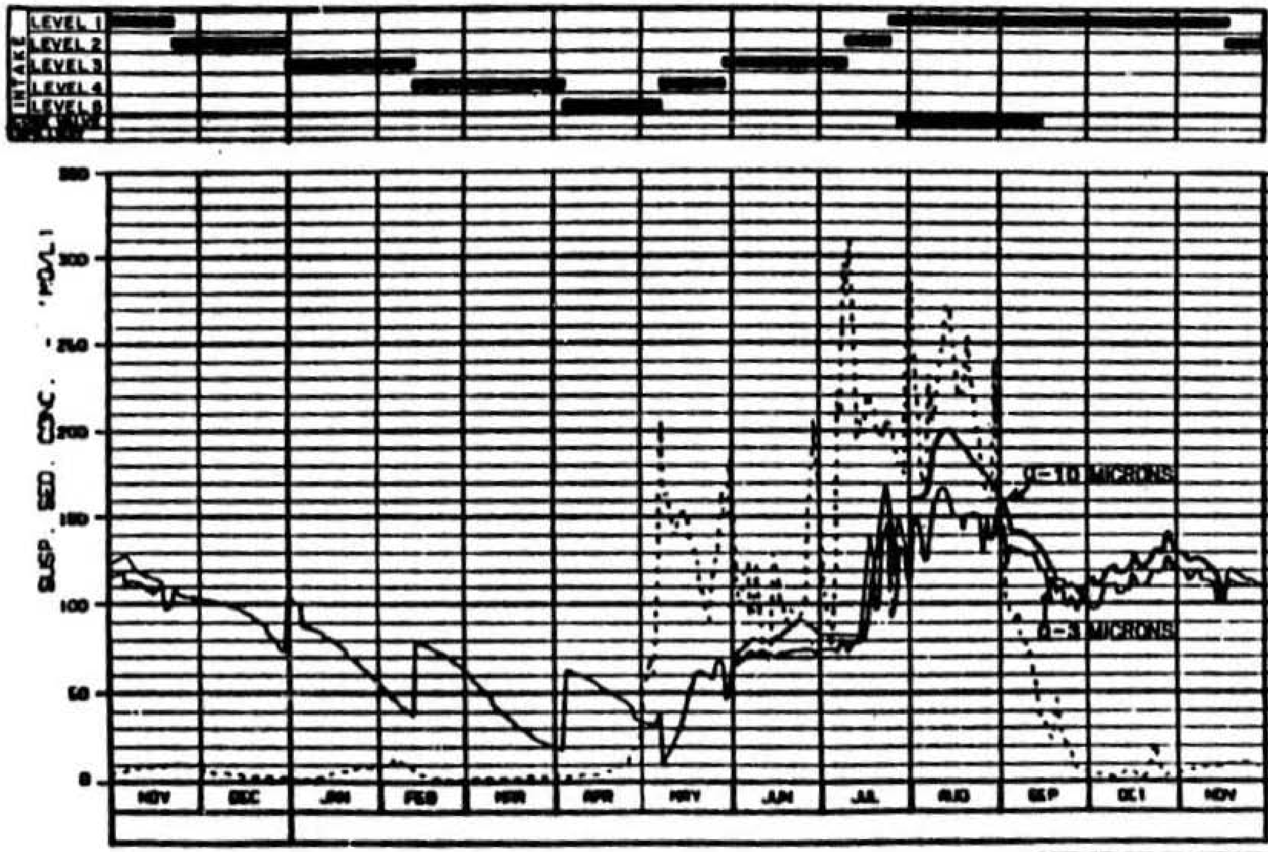
······· INFLOW SUSP. SED. CONCENTRATION (MG/L) (0-3 MICRONS ONLY)

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 LOW INFLOW YEAR
HARZA-EBASCO JOINT VENTURE

Figure 5-16



LEGEND:

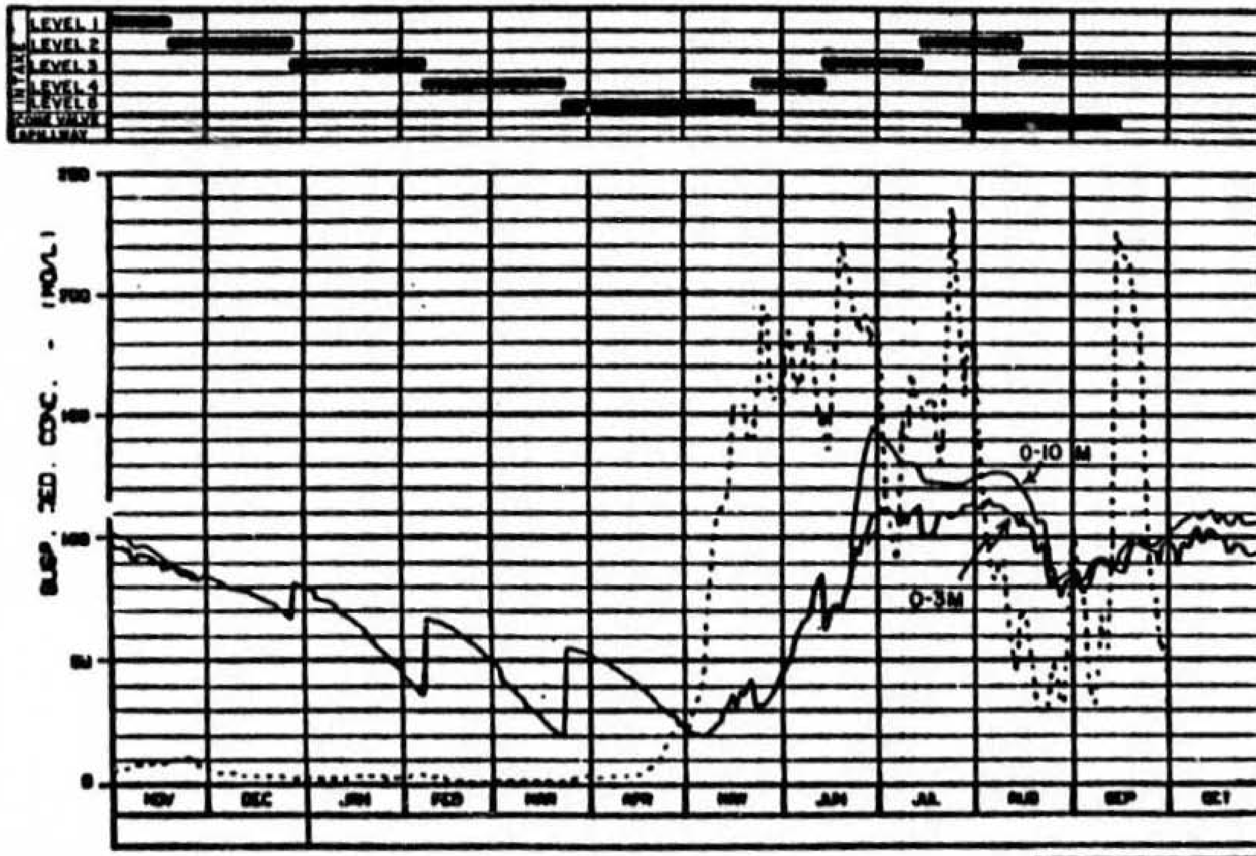
——— PREDICTED OUTFLOW SUSP. SED. CONCENTRATION (MG/L)

- - - - - 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 5-17



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

ALASKA POWER AUTHORITY

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

HARZA-EBASCO JOINT VENTURE

Figure 5-18

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 energy demands near the middle of the Stage II period (Figures 5.20 and 5.21). Using late Stage III energy demands, average year sediment inflows and Case E-VI flows, estimates of sediment discharges from Devil Canyon and Watana Reservoirs have been modeled (Figure 5.22 and 5.23).

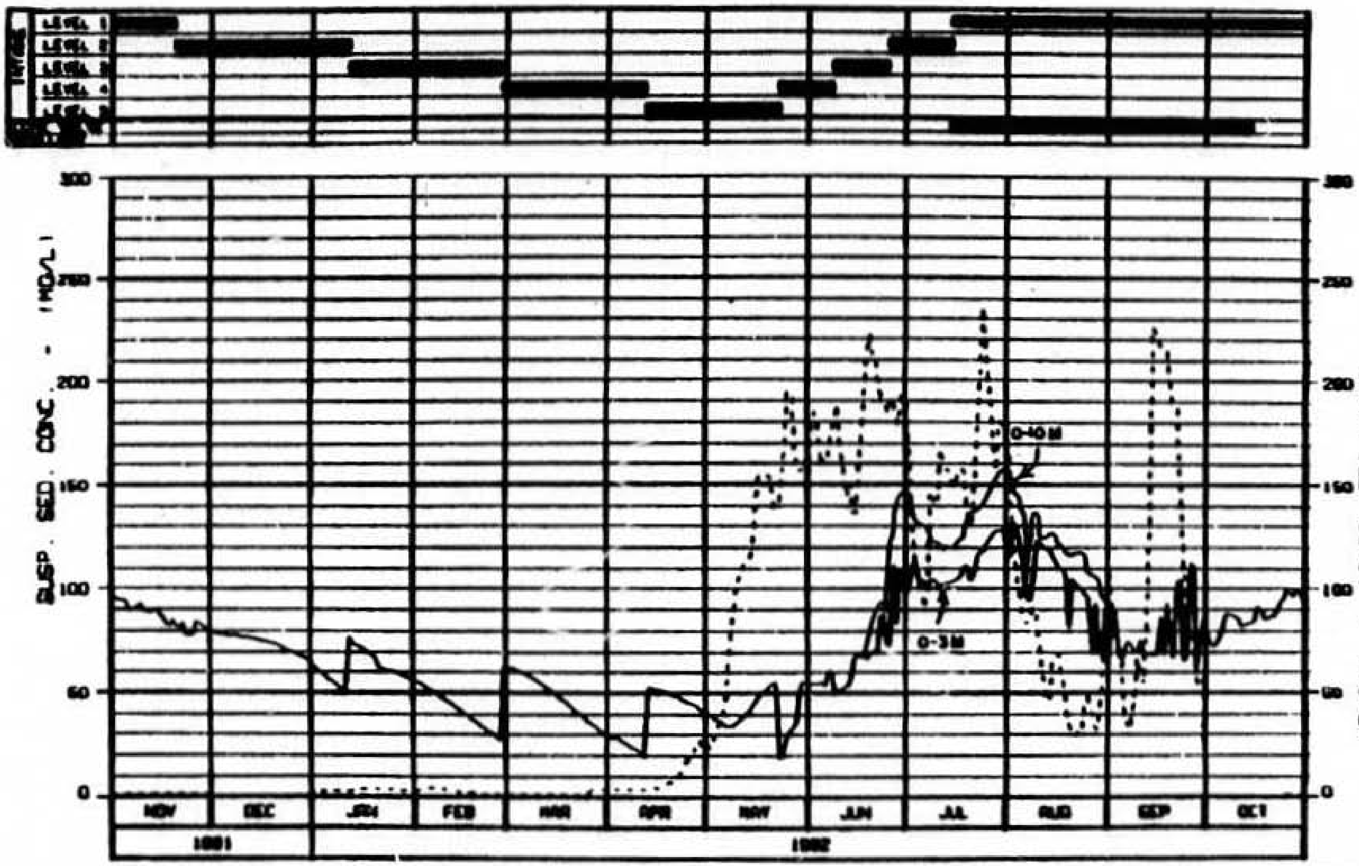
Graphically displayed and tabularized results indicate that the average monthly sediment concentration estimated to exist in the project discharges will be decreased during each successive project stage (Figure 5.24, and Tables 5.4, 5.5, 5.6). The results also indicate the expected decrease in sediment concentrations during summer, and expected increase in sediment concentrations in winter.

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 become 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



LEGEND:

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

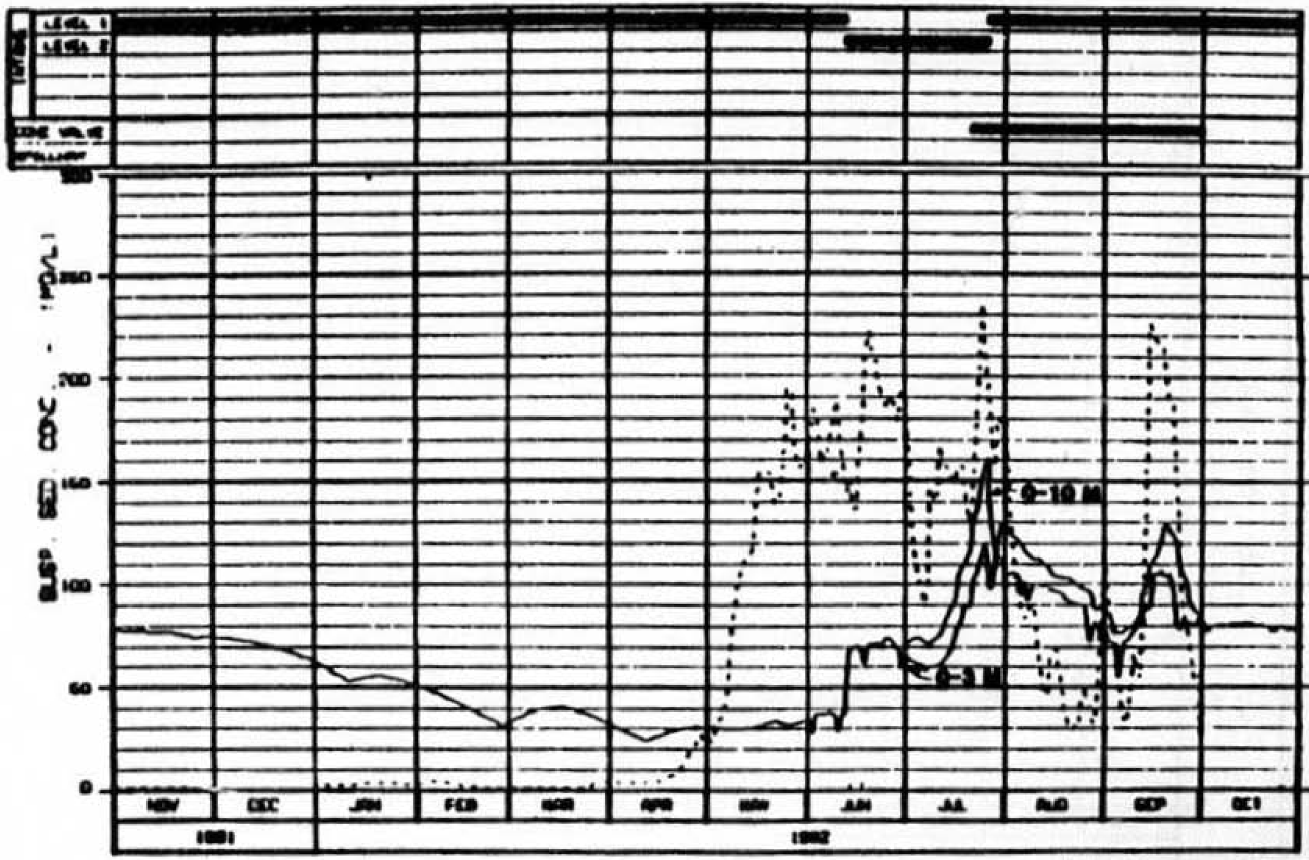
······· INFLOW SUSP. SED. CONCENTRATION (MG/L) (0-3 MICRONS ONLY)

NOTES:

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

ALASKA POWER AUTHORITY	
SUSITNA PROJECT	
WATANA RESERVOIR	
OUTFLOW SUSPENDED SOLIDS	
STAGE II AVERAGE YEAR	
HARZA-EBASCO JOINT VENTURE	

Figure 5-19



LEGEND:

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

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

NOTES:

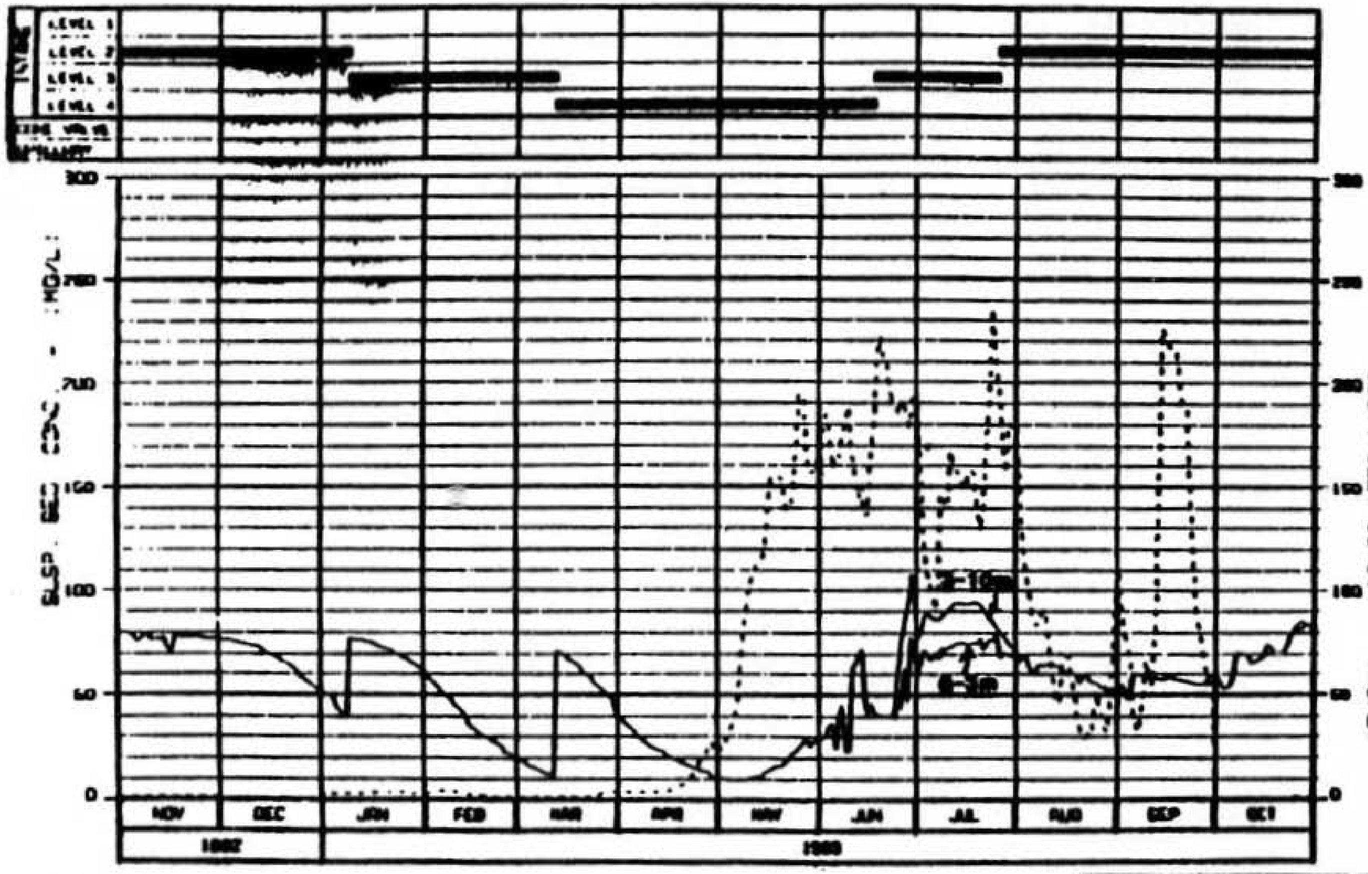
1. SSC INFLOW VALUES REPRESENT THE 0-3 MICRON RANGE AND ARE 15% OF TSS.

ALASKA POWER AUTHORITY

DEVIL CANYON OUTFLOW (0-10) SUSPENDED SOLIDS STAGE II AVERAGE YEAR

HARZA-EBASCO JOINT VENTURE

Figure 5-20



LEGEND:

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

NOTES:

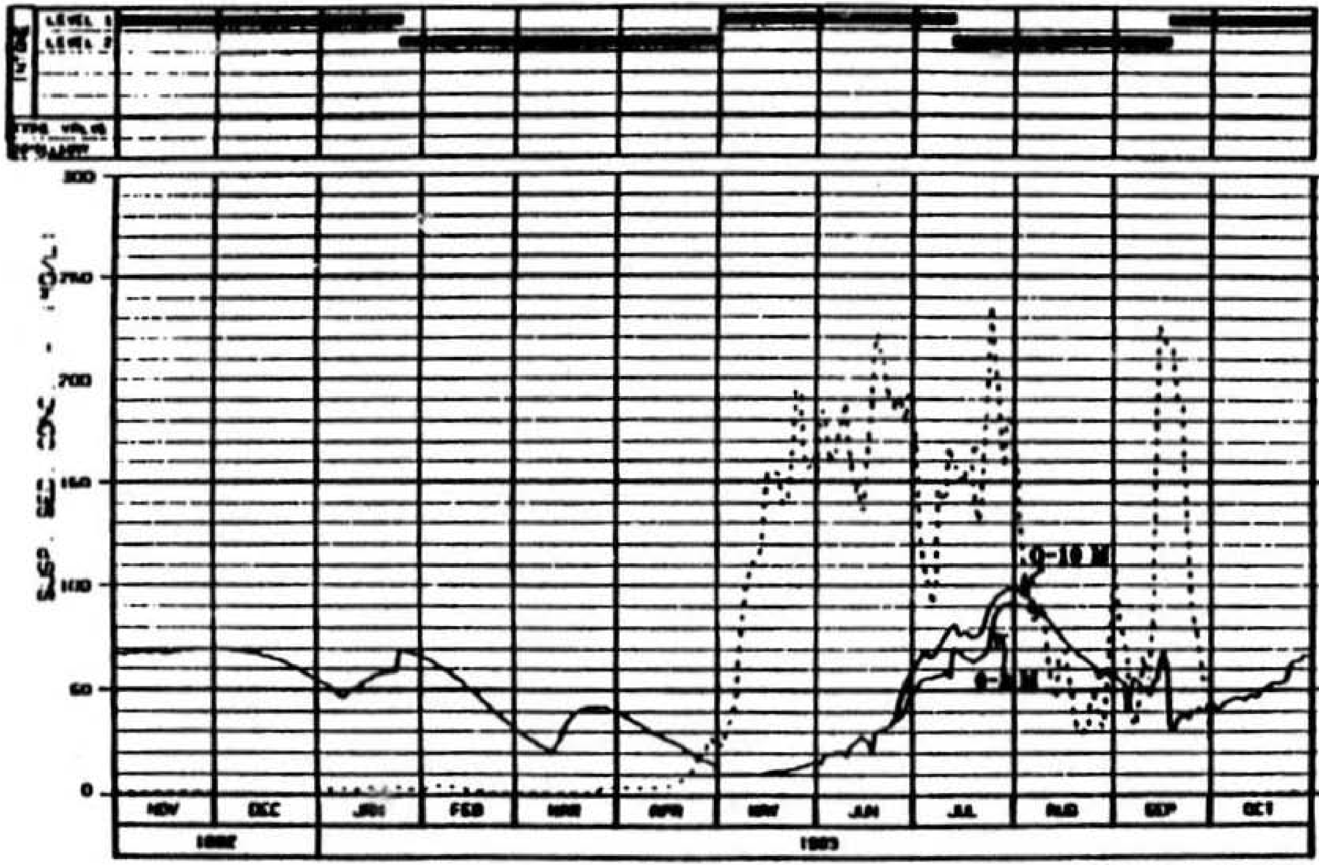
1. SSC INFLOW VALUES REPRESENT THE 0-3 MICRON RANGE AND ARE 15% OF TSS

ALASKA POWER AUTHORITY

STAGE III WATANA OUTFLOW SUSPENDED SOLIDS (0-10 MICRONS) AVERAGE YEAR

HARZA-EBASCO JOINT VENTURE

Figure 5-21



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 16% OF THE TOTAL SUSPENDED SEDIMENT INFLOW

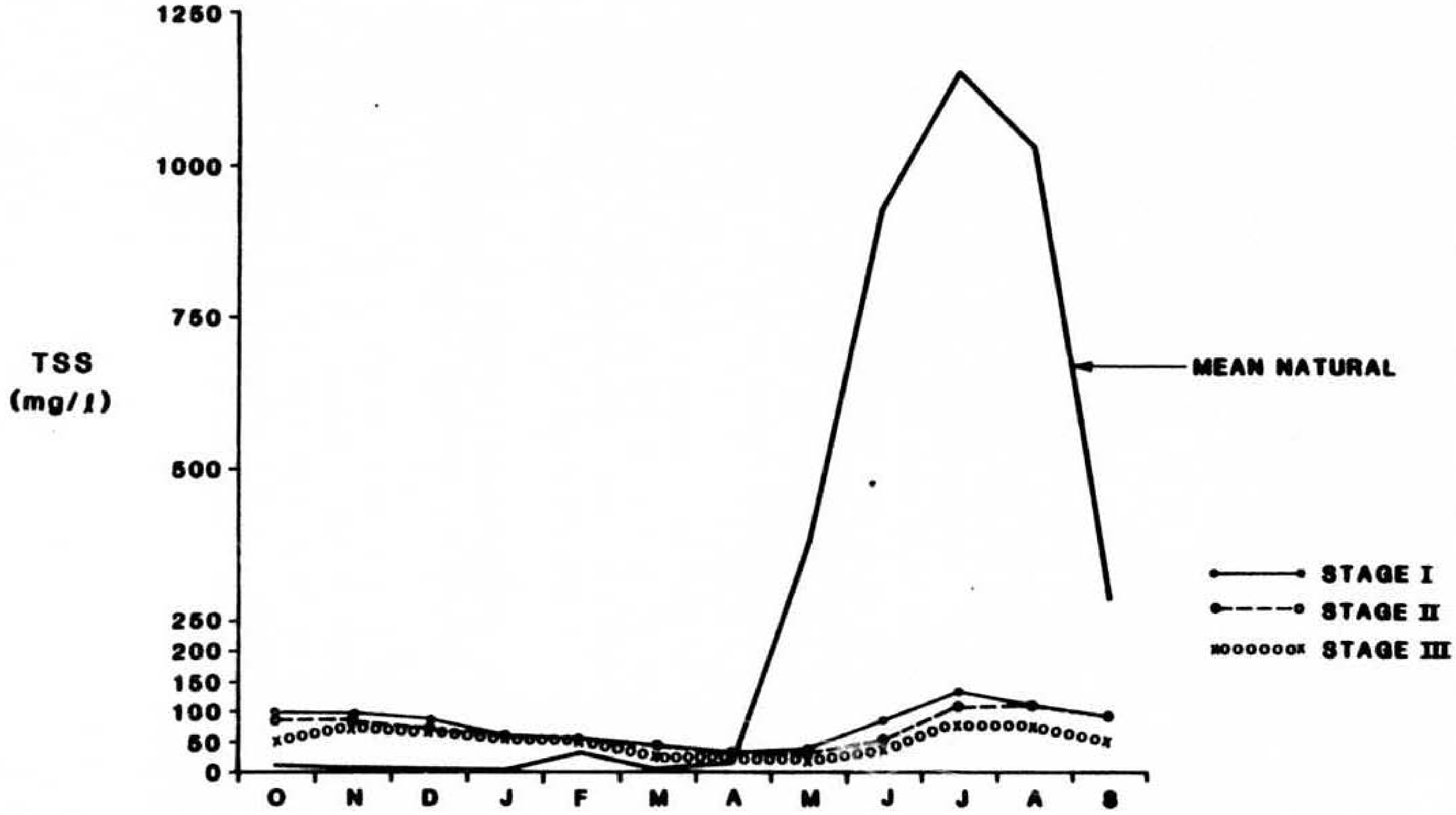
ALASKA POWER AUTHORITY

SUSITNA PROJECT

STAGE III DEVIL CANYON OUTFLOW SUSPENDED SOLIDS (0-10 MICRONS) AVERAGE YEAR

HARZA-EBASCO JOINT VENTURE

Figure 5-22



ESTIMATED MEAN MONTHLY SUSPENDED SEDIMENT CONCENTRATIONS FOR PROJECT DISCHARGES

Figure 5-23

through the reservoir and contribute to suspended sediment in the river. The shoreline deposits are primarily glacial till comprised of silty-sands (SM) but including some sandy clays (SC). Geotechnical investigations near the dam site indicate that, of the material smaller than three inches in size, less than 15 percent is smaller than five microns. The reservoir suspended sediment modeling indicates that material of 3 to 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, thus its most important water qualtiy impact will be to increase turbidity at the reservoir's surface.

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 characteristic important to all forms of aquatic life. For this reason 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, qualitative estimates of project effects have been 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 to 10 NTU). During the open water season (May to 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.

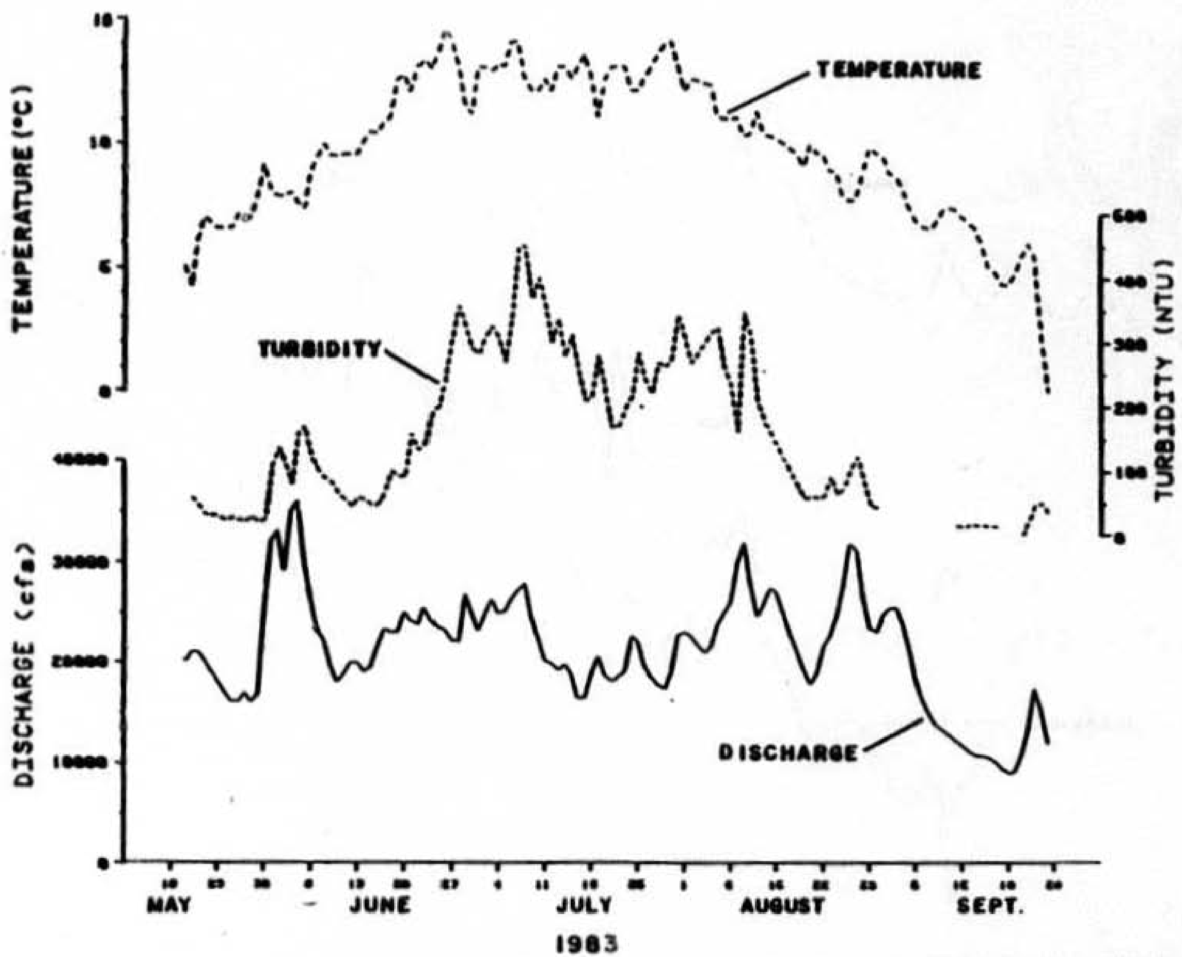
5.4.2 Eklutna Lake Turbidity Regimes

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:

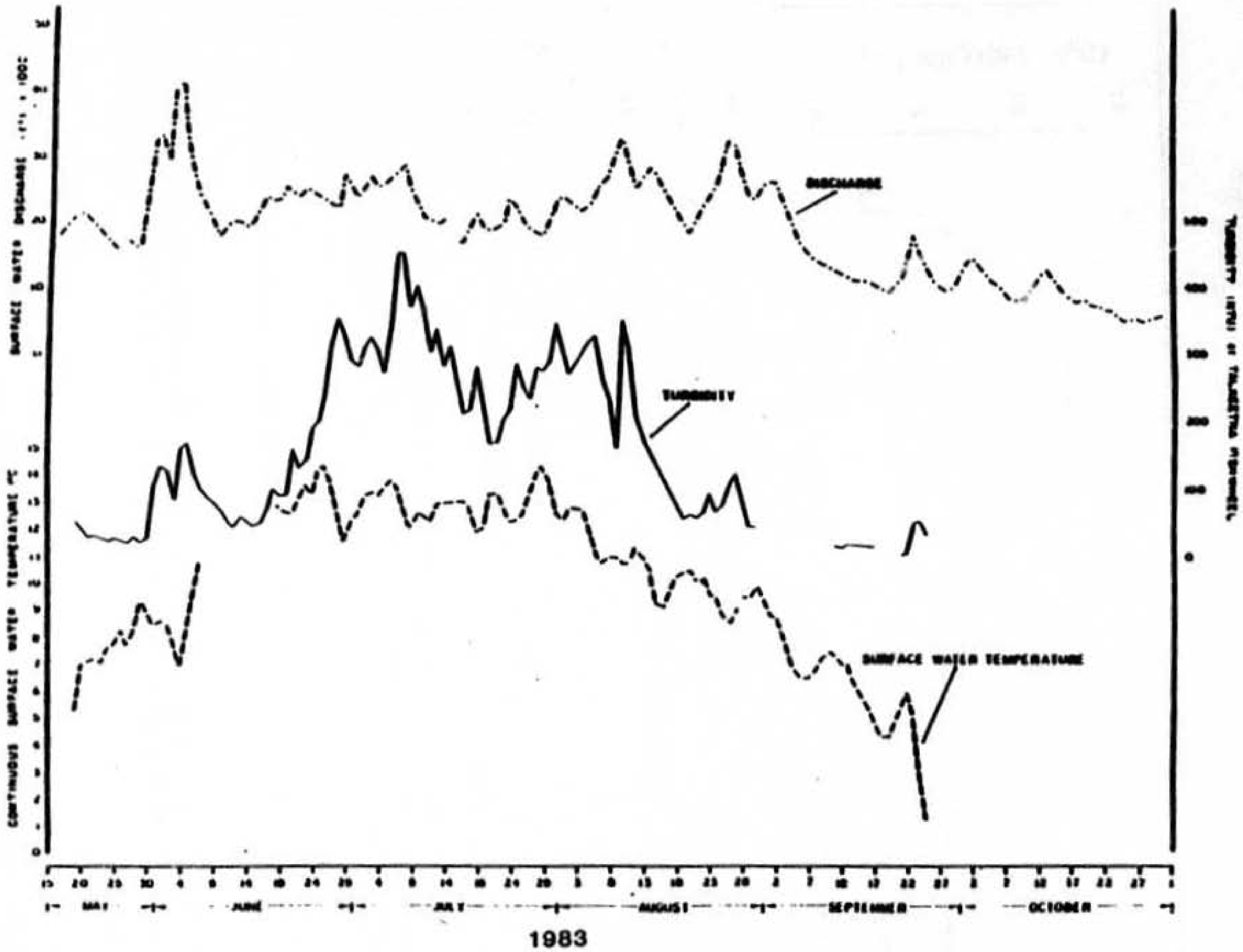
- o The drainage area for Eklutna is less than 3 percent that of Watana;



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

Figure 5-24

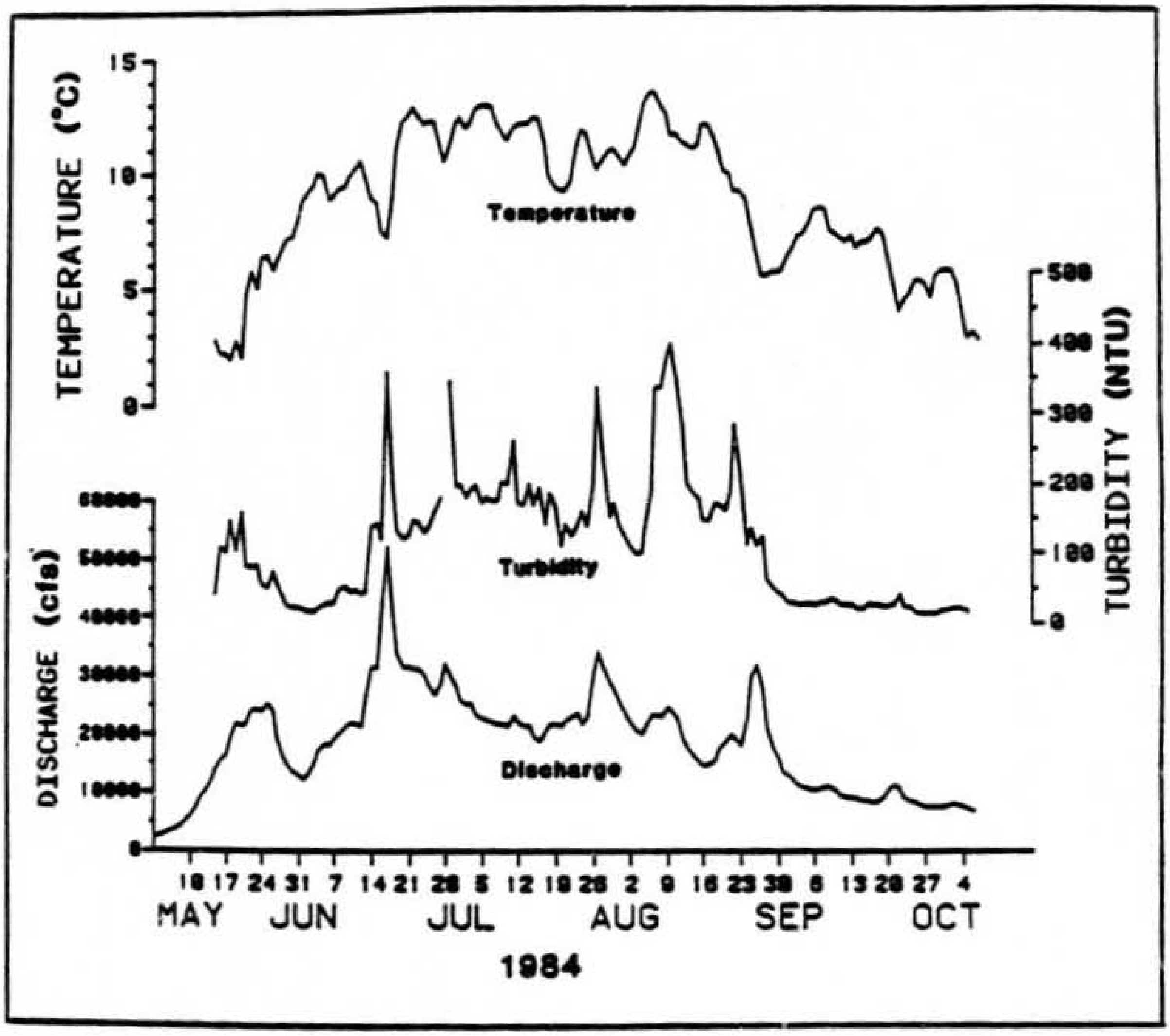
SOURCE: ADF & G 1984c



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

Figure 5-25

SOURCE: ADF&G 1984c



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 5-26

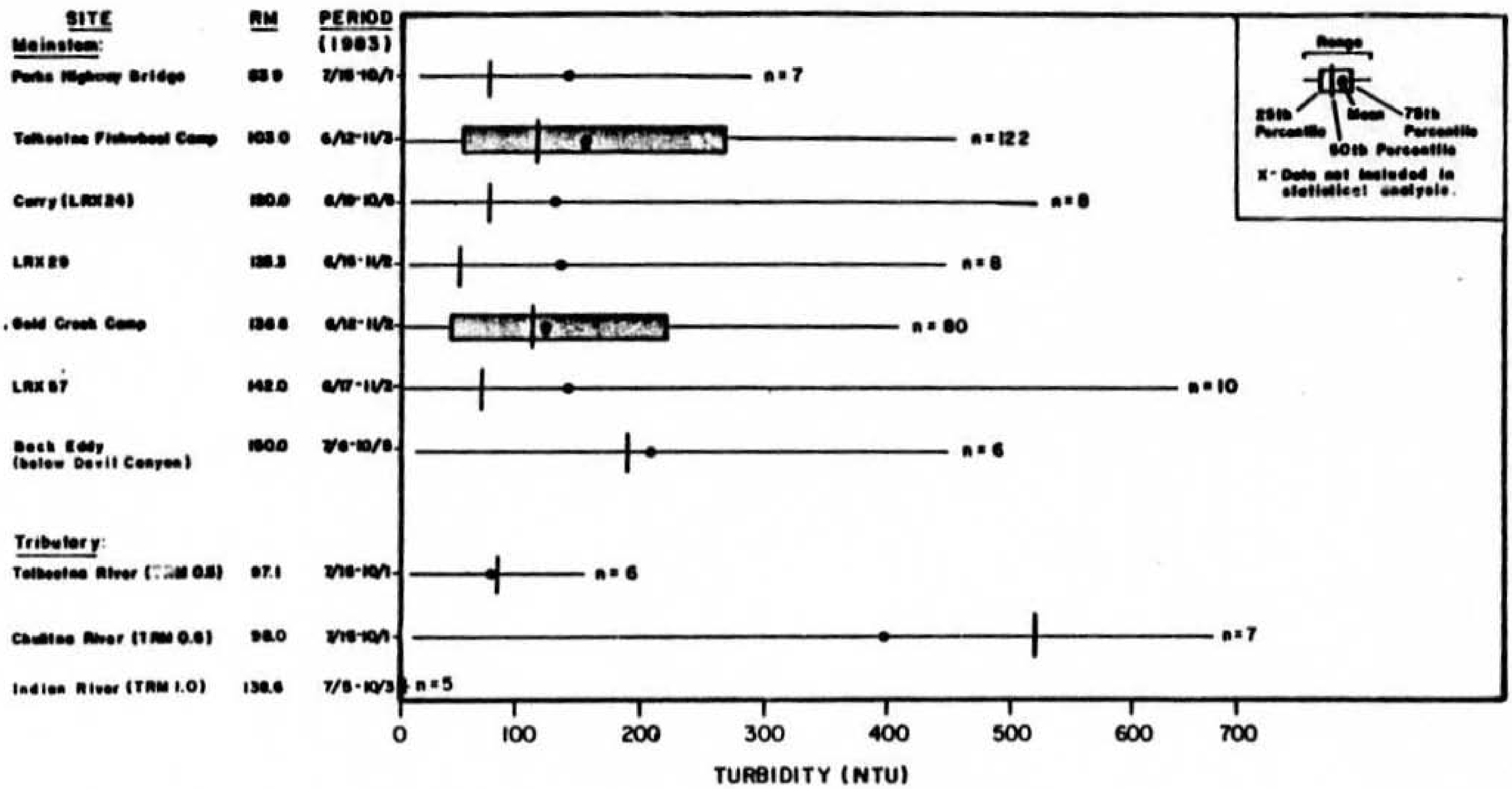


Figure 5.27 Turbidity data summary showing range, 25th, 50th (median), and 75th percentile for mainstem and tributary study sites.

- 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;

- Eklutna 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.);

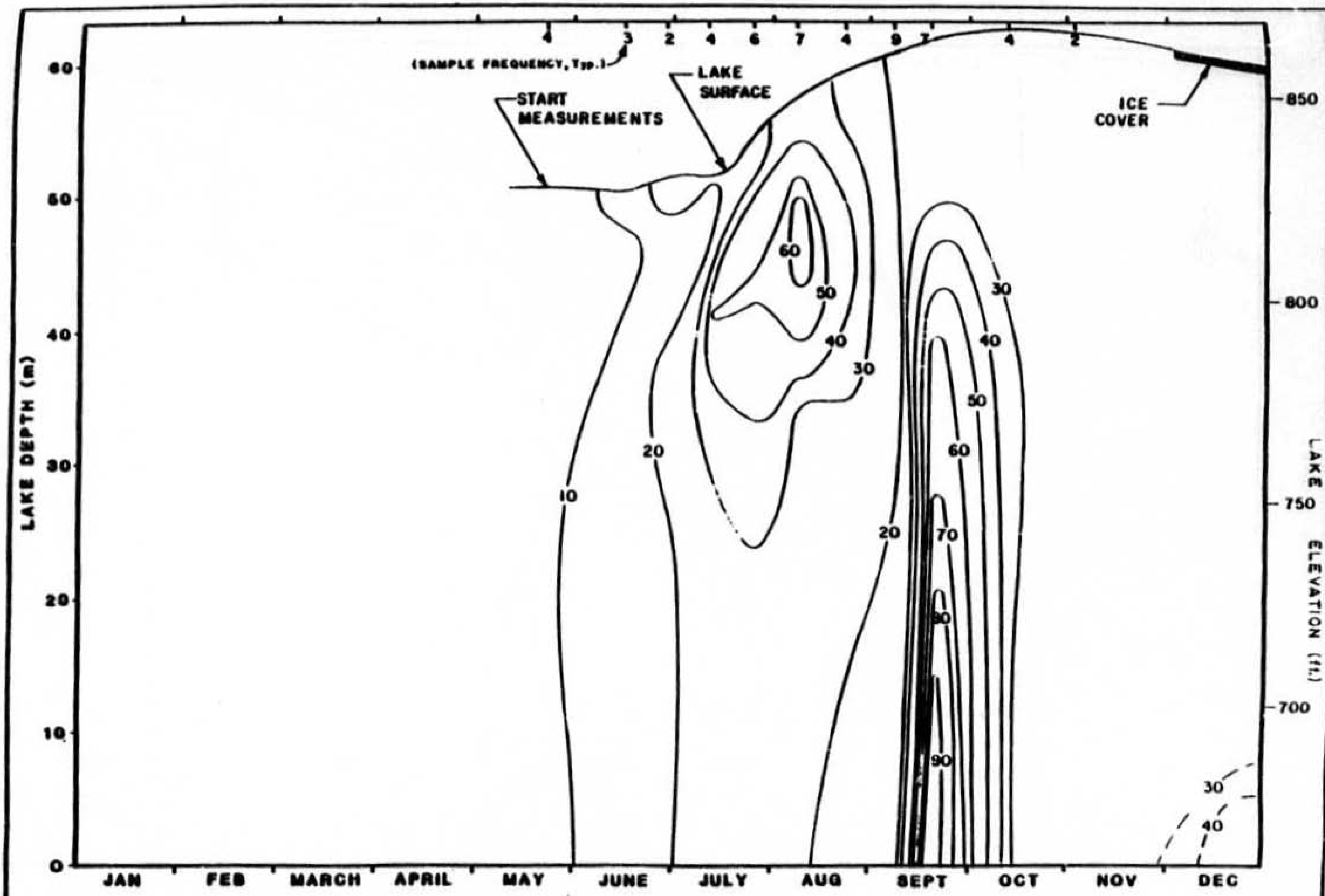
- Annual water inflow to Eklutna Lake (234,300 acre feet) is less than 5 percent that for Watana Reservoir (5,750,263 acre feet). The maximum storage capacity for Eklutna Lake (415,000 acre ft.) is also less than 5 percent than for Watana (9.5 million acre ft.);

- 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 50,000 tons) is less than 1 percent of the estimated annual sediment inflow to Watana Reservoir (approximately 6.5 million tons).

Because of the differences 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 Consultants, Inc. 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 to 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 wind mixing 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 to 35 NTU.

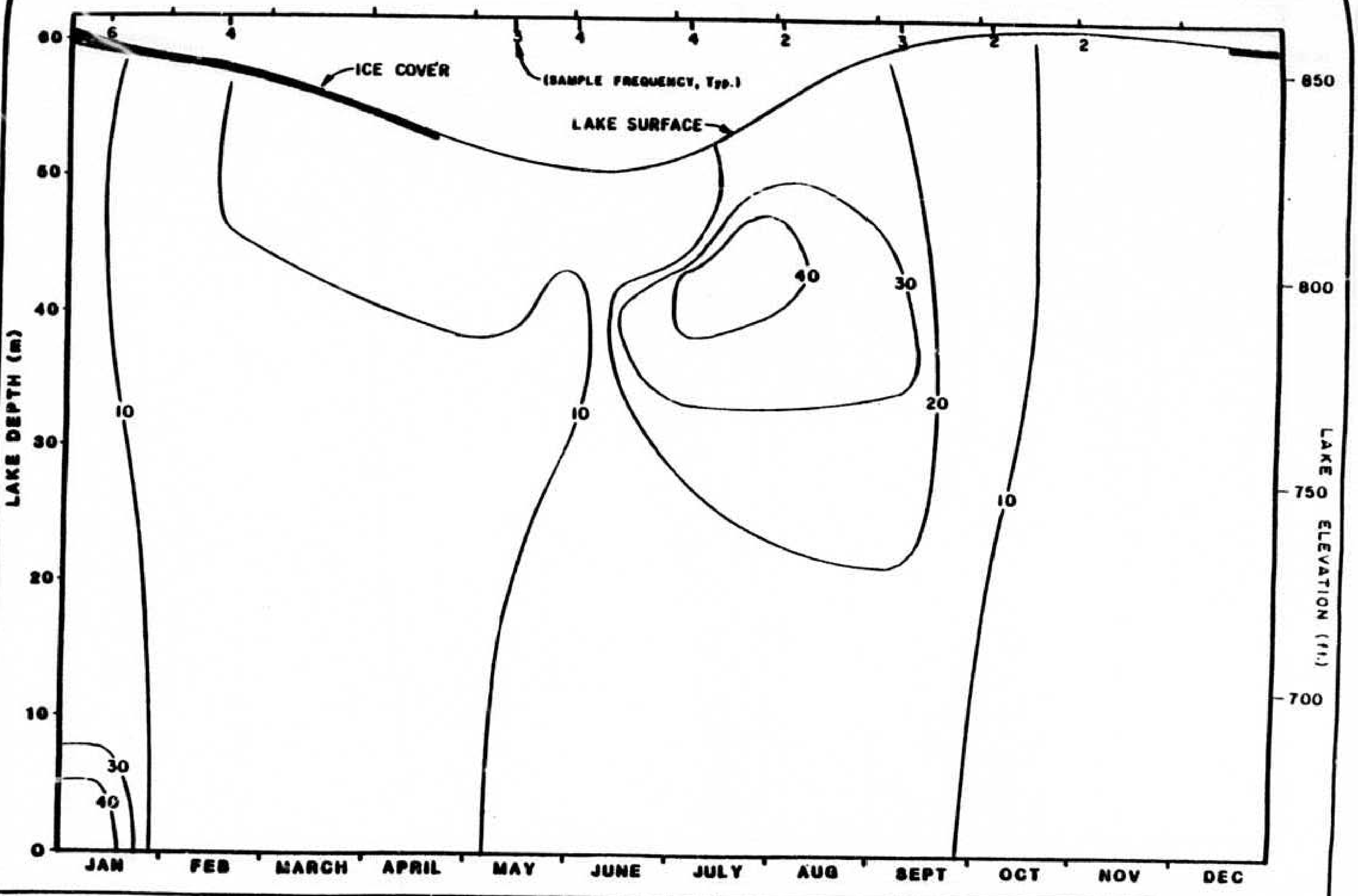


PREPARED BY:
R&M CONSULTANTS, INC.

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

Figure 5-28

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

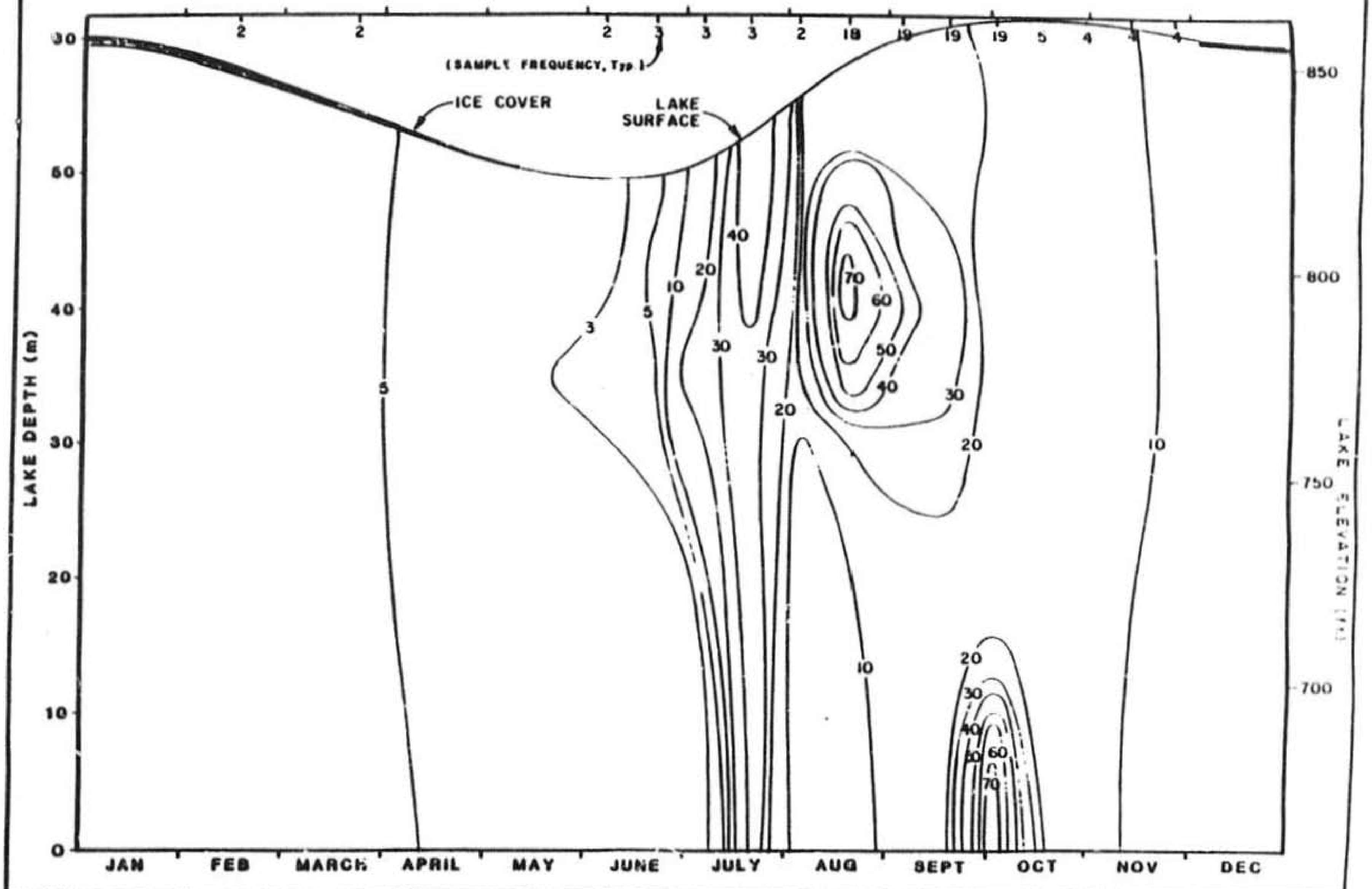


PREPARED BY:
R&M CONSULTANTS, INC.

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

Figure 5-29

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE



PREPARED BY:
R&M CONSULTANTS, INC.

ISO-TURBIDITY vs. TIME
EKLUTNA LAKE at STATION 9
1984
Figure 5-30

PREPARED FOR:
HARZA-EBASCO
SUSITNA JOINT VENTURE

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 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 several times greater. As discussed earlier, turbidity can be approximated (in south central Alaskan lentic habitats) 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 approximately 200 NTU in November, decrease to 10 to 20 NTU by January, remain at that level throughout winter, increase between May and July to 200 to 300 NTU and remain at that level until November. Average monthly sediment concentrations and estimated turbidities in with-project discharges have been calculated (Tables 5.5, 5.6, 5.7, and Figure 5.32).

5.4.4 Watana to Talkeetna

The suspended sediment concentrations and hence the turbidity in the reach between Watana and the Susitna-Chulitna confluence will be controlled by the concentration in the reservoir release and by any contribution from the reach. The contribution from the reach is not expected to be significant since the tributaries generally contain clear water and there will eventually be less glacial flour present in the streambed or on the banks which might be entrained in the flow. During summer flood periods the contribution from the intervening areas may increase concentrations in the mainstem river due to resuspension of previously deposited material.

The suspended sediment concentration may average 100 mg/l between June and December. Average May suspended sediment concentrations may be 30 to 40 mg/l. Thus, turbidities will probably average about 200 NTU from June through December and decrease to minimum values of 60 to 80 NTU by early May.

5.5 RELATIONSHIP BETWEEN TURBIDITY AND LIGHT TRANSMISSION

The intensity of photosynthetically active radiation (PAR) at depth Z (I_z) can be expressed as an exponential decay function of the surface light intensity (I_o), the depth (Z), and the negative extinction coefficient (n), such that:

$$I_z = I_o e^{-nz}$$

TABLE 5.5

SUSITNA HYDROELECTRIC PROJECT
NATURAL AND ESTIMATED MEAN MONTHLY SUSPENDED
SEDIMENT CONCENTRATIONS AND APPROXIMATE 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/1)	(mg/1)	NTU2/
January	<1-8	65	130
February	N.A.	55	110
March	1-6	45	90
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.	85	170

1/ Data derived from Table E.2.4.28; from Exhibit E, Chapter 2 data (APA, 1985.

2/ Turbidity estimated by using factor of (2x) times TSS concentrations

TABLE 5.6

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

		STAGE II OPERATION	
Month	Observed Suspended Sediment Concentrations1/	Estimated Mean Suspended Sediment Concentrations1/	Estimated Minimal Turbidity
	(mg/l)	(mg/l)	NTU2/
January	<1-8	60	120
February	N.A.	45	90
March	1-6	40	80
April	N.A.	30	60
May	65-1,110	30	60
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.	75	150

N.A. = Not Available.

1/ Data derived from Table E.2.4.49 in Exhibit E, Chapter 2 (APA 1985).

2/ Turbidity estimated by using factor of (2x) times TSS concentrations

TABLE 5.7

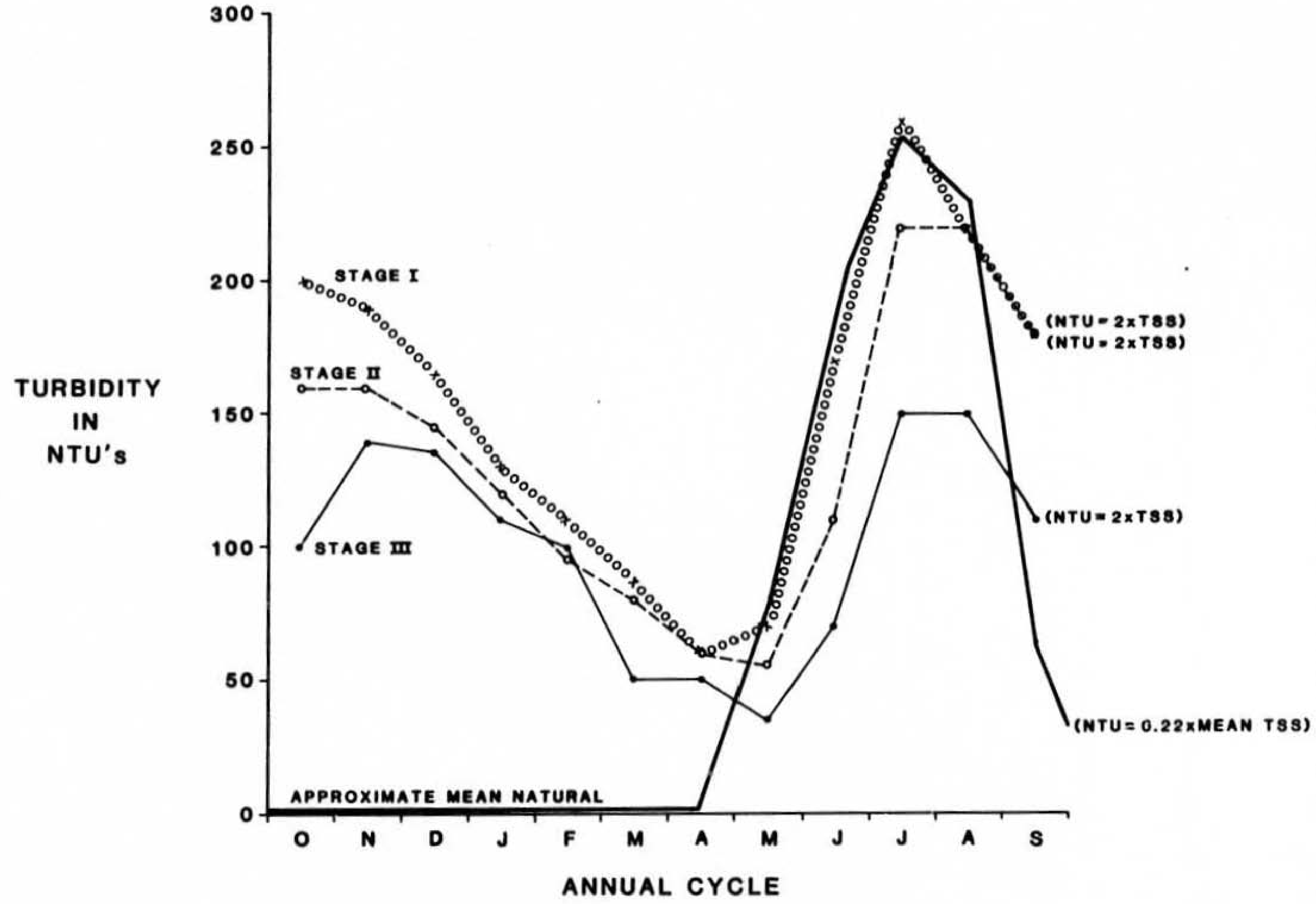
SUSITNA HYDROELECTRIC PROJECT
NATURAL AND ESTIMATED MEAN MONTHLY SUSPENDED
SEDIMENT CONCENTRATIONS AND APPROXIMATE TURBIDITY
VALUES EXPECTED TO EXIT DEVIL CANYON RESERVOIR
DURING STAGE III OPERATIONS

		STAGE III OPERATION	
Month	Observed Suspended Sediment Concentrations1/	Estimated Mean Suspended Sediment Concentrations1/	Estimated Minimal Turbidity
	(mg/1)	(mg/1)	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	15	30
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.	70	140

N.A. = Not Available.

1/ Data derived from Table E.2.4.73 in Exhibit E, Chapter 2 (APA, 1985).

2/ Turbidity estimated by using factor of (2x) times TSS concentrations



APPROXIMATE MEAN MONTHLY TURBIDITY VALUES
FOR SUSITNA RIVER MIDDLE REACH

Figure 5-31

This relationship has been widely explored and verified in limnology and oceanography (Wetzel 1975, Hutchinson 1967 and 1975).

To investigate the approximate relationship between vertical light transmission and turbidity which might exist under with-project conditions, Van Nieuwenhuyse and E. Woody Trihey and Associates (1984) have made an empirically derived approximation of a relationship between attenuation of 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:

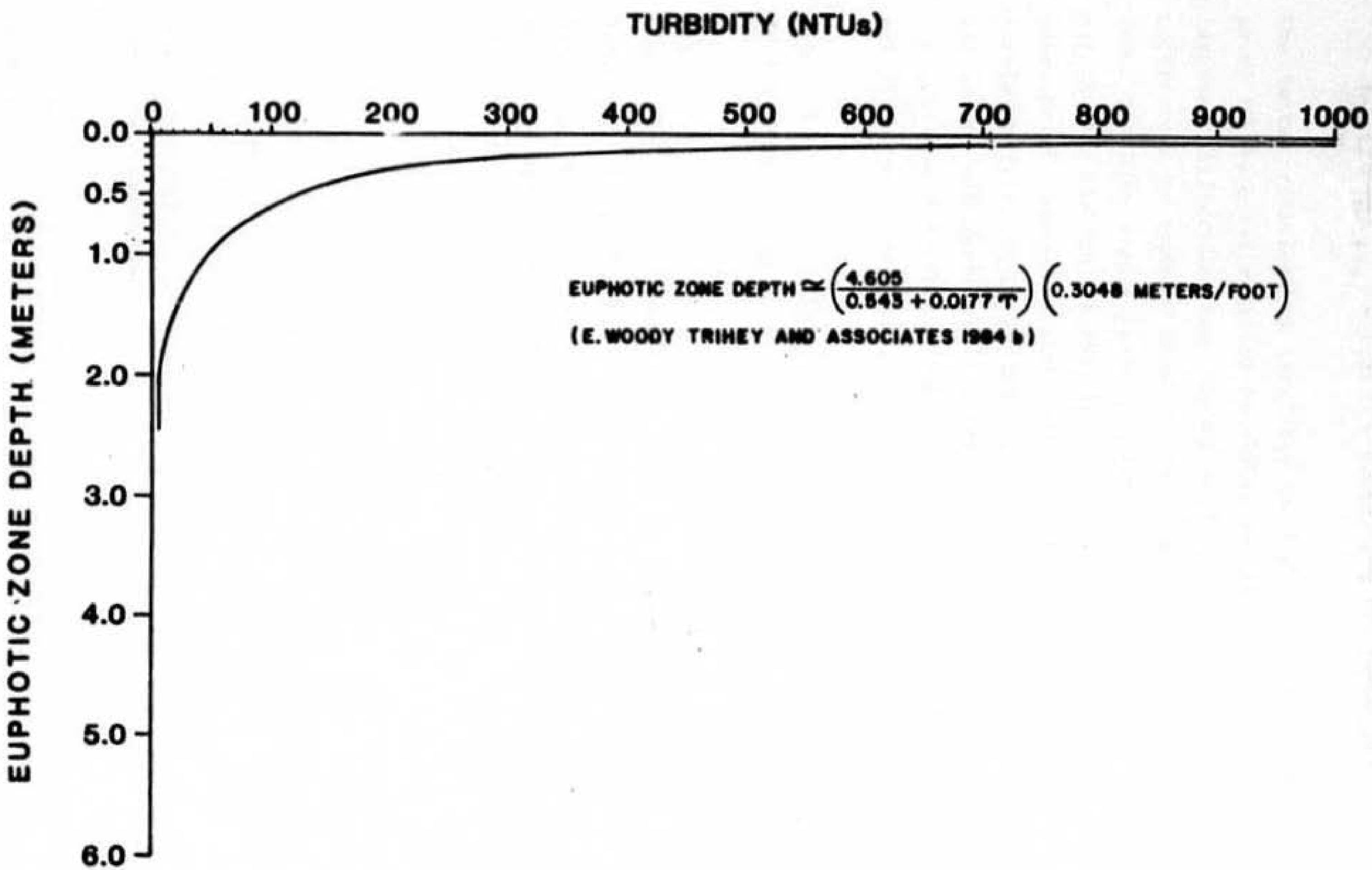
$$Z\ \text{ft.} = \frac{4.605}{(0.543 + 0.0177\ T)} \qquad \text{(EQ.5.1)}$$

Similar efforts by other workers interested in the relationship of photosynthesis and turbidity have produced additional and comparable relationships between photosynthetic compensation depths and turbidity produced predominately by particulates in several south central Alaskan lakes.

Lloyd, Koenings and LaPerriere (1985) produced the following relationship between euphotic zone depth (EZD) and turbidity (T):

$$\log EZD_{(\text{meters})} = 1.147 - 0.603 \log T \ (r^2{=}0.85) \qquad \text{(EQ.5.2)}$$

Edmundson and Koenings (1985) have derived an analagous relationship to the preceding one, such that:



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

Figure 5-32

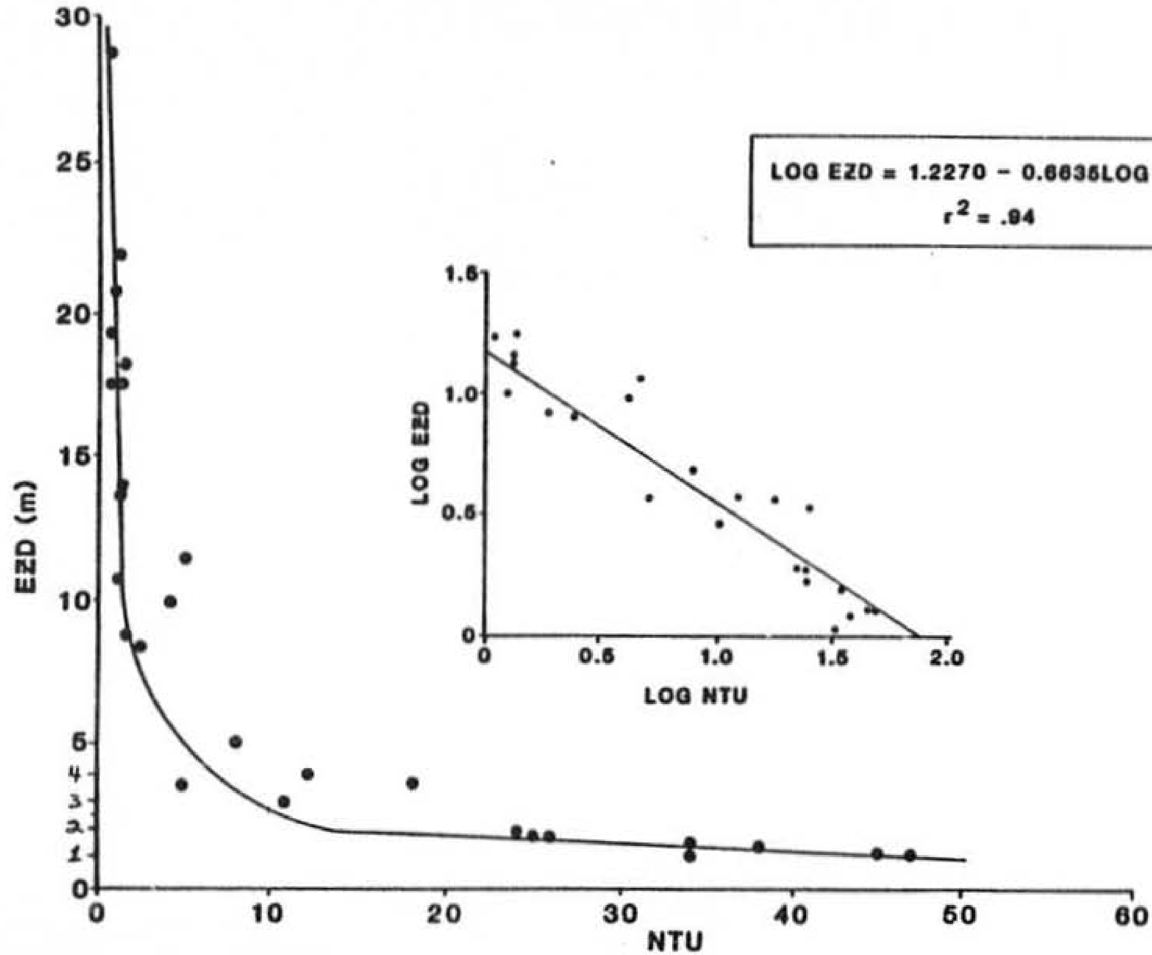
$$\log EZD_{(meters)} = 1.2270 - 0.6635 \log NTU \; (r^2=0.94) \qquad (EQ.\ 5.3)$$

The latter relationship (depicted in Figure 5.34) has a major inflection point in the curve relating turbidity and light penetration into lakes. The important inflection zone occurs at turbidity levels of 5 to 10 NTU which corresponds to euphotic zone depths of 4 to 6 meters. While th 5 to 10 NTU level has high significance in lakes with potentially deep euphotic zones, relatively shallow rivers such as the Susitna are not likely to lose substantial euphotic zone area until substantially higher levels of turbidity (i.e. 30 to 70 NTU) occur. The approximate euphotic zone depths (in meters and feet) per turbidity unit have been calculated using each of the previously referenced equations, and using the mean predicted value of all three equations (Table 5.8).

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; Merritt 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. In general, salmon tend to avoid high suspended sediment concentrations, high turbidity and areas with high rates of sedimentation.

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



THE RELATIONSHIP OF EUPHOTIC ZONE DEPTH (EZD) TO TURBIDITY (NTU).

(SOURCE: EDMUNDSEN AND KOENINGS 1985a)

Figure 5-33

TABLE 5.8

SUSITNA HYDROELECTRIC PROJECT
APPROXIMATE EUPHOTIC ZONES DEPTHS PER TURBIDITY UNIT CALCULATED
USING THREE DIFFERENT RELATIONSHIPS DEVELOPED FOR GLACIAL FLOUR AFFECTED
SYSTEMS IN SOUTH CENTRAL ALASKA

NTU	EQ. (5.1) Van Nieuwenhuse and Trihey 1984		EQ. (5.2) Lloyd et al. 1985		EQ. (5.3) Edmundson and Koenings 1985		MEAN ESTIMATED EZD (ft.)
30	1.31m	4.3 ft	1.80m	5.9 ft	1.77m	5.8 ft	5.3
40	1.13	3.7	1.52	4.9	1.46	5.8	4.5
50	0.97	3.2	1.33	4.4	1.26	4.1	3.9
60	0.88	2.9	1.19	3.9	1.11	3.7	3.5
70	0.79	2.6	1.08	3.5	1.00	3.3	3.1
80	0.73	2.4	0.99	3.2	0.92	3.0	2.9
90	0.67	2.2	0.93	3.1	0.85	2.2	2.7
100	0.71	2.0	0.27	2.9	0.79	2.6	2.5
110	0.55	1.2	0.82	2.7	0.76	2.4	2.3
120	0.52	1.7	0.78	2.6	0.70	2.3	2.2
130	0.49	1.6	0.75	2.5	0.67	2.2	2.1
140	0.46	1.5	0.71	2.3	0.64	2.1	2.0
150	0.43	1.4	0.68	2.2	0.61	2.0	1.9
160	0.43	1.4	0.66	2.2	0.58	1.9	1.8
170	0.39	1.3	0.63	2.1	0.56	1.8	1.7
180	0.37	1.2	0.61	2.0	0.54	1.8	1.7
190	0.37	1.2	0.59	1.9	0.52	1.7	1.6
200	0.34	1.1	0.57	1.9	0.50	1.6	1.5
220	0.30	1.0	0.54	1.8	0.47	1.5	1.4
260	0.27	0.9	0.49	1.6	0.42	1.4	1.3
300	0.24	0.8	0.45	1.5	0.38	1.3	1.2

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 effects 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). Effects of continuous inorganic suspended sediments at concentrations between 0 and 100 milligrams/liter on rearing juvenile and adult salmonids are usually noted as either negligible or as slightly reducing their health and survivability. Continuous exposure to fine sediments of freshly fertilized eggs, incubating eggs and developing alevins is frequently noted as stressful if not lethal.

Studies have not been found which have investigated and reported the effects of continuous exposure to suspended sediments which have lasted more than 9 to 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 which examine the effects of continuous exposure of rearing salmonids to the expected with-project winter conditions in mainstem affected channels (i.e. 0 to 3°C, <less than 150 milligrams per liter of predominately small suspended sediments; and less than 300 NTU). Evidence which has been examined, however, suggests that the direct effects of overwintering in continuous suspended sediment levels such as those expected in the mainstem habitats will be stressful but maybe survivable. It should 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. This presently occurs under existing conditions where salmonids utilize pieripheral habitat such as slough and tributaries during the winter.

Any project-induced detrimental impacts which may occur in chronically turbid channels would likely result from sedimentation effects on streambed substrate habitat, on early stages of fish life cycles (egg and alevin incubation), and on optically related fish behavior. These effects may largely result from intrusion of fine particulates into interstitial 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).

The natural sediment transport regime in the middle river sweeps approximately 4,000 acre-feet of sediment particles through this reach during the average annual cycle. The particle sizes range from the smallest colloidal particles (<0.001 um) to those in the clay, silt, sand, gravel, cobble and rubble range. If the roughly 4,000 acre-feet of one year's sediment load were to be evenly deposited in the middle river reach, instead of being swept through, then the sediments would form a layer approximately 1 to 2 feet deep which would fill the entire middle river network of streambed channels within the vegetated borders on each bank (i.e. 300 to 700 feet wide). Obviously this amount of sediment particles does not build-up such a layer of deposits each year, and is instead mostly transported through the reach. However, it is equally obvious from the preceeding knowledge that when high water discharges scour out and flush away fine sediment during any spate, there will be more than enough sediment arriving from other upstream reaches to replace any sediment deposits flushed downstream.

The impoundments will trap virtually all of the naturally transported sediment within the reservoirs, and will allow only the finest silt and clay size or smaller particles to proceed downstream. The project, as operations are presently simulated, will still release discharges in excess of 40,000 cfs during the summer seasons in all three stages. Streambed substrate disturbances and the attendant flushing of fine sediment particulates from the middle reach, without their replacement from upstream reaches, is expected to result in a substantially larger and more stabile or armoured streambed substrate in most habitats affected by with project flows (Williams 1985).

Numerous investigators have found, in laboratory experiments, that clean, coarse substrate streambeds exposed to continual flows of water with a concentration of fine particulates will experience intrusion of fine materials into the matrix of coarse streambed materials. With time, the intrusion of the fine materials stops as the interstitial spaces become filled. These investigations have also shown that the upper layer of streambed material, to a depth of approximately one or two diameters of the bed material size, is kept mostly free of very fine silts and clays by the velocity of the water.

Observations of the Kasilof River and other large glacial rivers with upstream lakes on them have revealed similar phenomena to that observed in experiments to be occurring in the field. Many areas along the Kasilof River, below Tustumena Lake, appear to have large cobble, rubble or boulder sized streambed armour layers, with a light "dusting" of glacial silts and clays on the surfaces of armouring rocks, and only limited embeddedness in fine silts and clays within or below the surficial armouring layer of rocks.

In the Susitna middle river, an armour layer of bed material essentially free of particulate sizes less than 30 to 40 mm is expected to develop within the mainstem channels. The average size of the bed material is expected to be about 40 to 70 mm. The depth of this layer will be about 80 to 140 mm. (Harza-Ebasco 1985b). In the side channels exposed to frequent flows a similar process will occur, but the average armouring size will be somewhat smaller than in the mainstem. The size of materials excluded from the bed and the depth of the armour layer will also be less.

In the sloughs which will not be frequently inundated by high flows there will be little change in bed material composition. However, the infrequent inundation by high flows and the relative lack of fine sediment in reservoir outflows should be sufficient to remove many surficial deposits of silts and sands.

In most channels there maybe some additional intrusion of fine materials into the streambed at depths below the armour layer. This will occur because the armouring of the bed and the reduction in flood flows will minimize the disruption of surface streambed materials which is necessary for the subsequent removal of fine materials below the armour layer. This will result in an increase in concentration of fine material at depth in the streambed. The intrusion of fine particulates will stop or be greatly reduced with time as the interstitial spaces become filled to capacity. The concentration of fine materials at a depth of about two feet below the armour layer surface may not exceed the concentration under natural conditions since the streambed at this depth is not disturbed frequently under natural conditions and may already be nearly saturated with fine materials. It is not known how the generalized streambed permeability may be affected by the aforementioned intrusion of fine particulates. It is anticipated that the previously described processes will result in a more stable armoured layer than that which presently exists in many middle river habitats, and that this will have generally beneficial effects for most types of stream organisms including epilithic microbes, benthic invertebrates and fishes.

Basic information about the suspended sediment concentration and turbidity levels in two other glacially affected rivers in south central Alaska have been assembled (Table 5.9). With-project conditions in mainstem affected channels of the Susitna River middle reach are expected to be less biologically productive than in either the Kenai or Kasilof Rivers because of continuously high concentrations of suspended sediment and high levels of turbidity.

TABLE 5.9

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

5.6.1 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). Continuous exposure to concentrations of 25 to 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). Continuous exposure to TSS concentrations of 80 to 400 mg/l is reported to be considered "not good", "poor", providing only "low levels of protection" and being "possibly lethal" to aquatic organisms (Gibbons and Salo 1983; Alabaster and Lloyd 1980; Bell 1980; and Wilber 1983). Continuous 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).

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 indicate 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 continuous high turbidity with its attendant reduction of vertical light penetration, may help stimulate fairly continuous drift during summer in certain habitats in the

Susitna River middle reach. Artificial darkness (opaque tarps, etc.) 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 juvenile chinook are opportunistic feeders specializing in drifting, aquatic 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 continuous exposure to high turbidity is likely to be minimization of riverine biomass production at all trophic levels. 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 certain sufficiently shallow and constantly wetted habitats (Milner 1983). At low turbidity (0 to 25 NTU), disregarding other environmental limiting factors, it may be surmised that autochthonous primary productivity and perhaps productivity at higher trophic levels would be enhanced by the fertilizing effects of nutrients associated with the suspended inorganic particulates. In sufficiently shallow habitats (<1 meter) even higher turbidity levels (i.e. 0 to 75 NTU) may be tolerated by subvertebrate trophic levels.

The upper tolerable limit of continuous 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 continuous, etc.) in different ways. Very coarse estimates of the maximum tolerable turbidity for maintaining a viable salmonid fishery in subarctic Alaska may be within the 100 to 200 NTU range for streams with mean depths of 0.5 meter or greater. The Kasilof River, which is one of the more turbid rivers on a continuous basis in south central Alaska known to maintain a self-sustaining salmonid fishery, probably rarely exceeds 15 to 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 bogs in the project reservoir sites 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 buffering system (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 common on the tundra and they frequently have a pH in the acidic range. 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

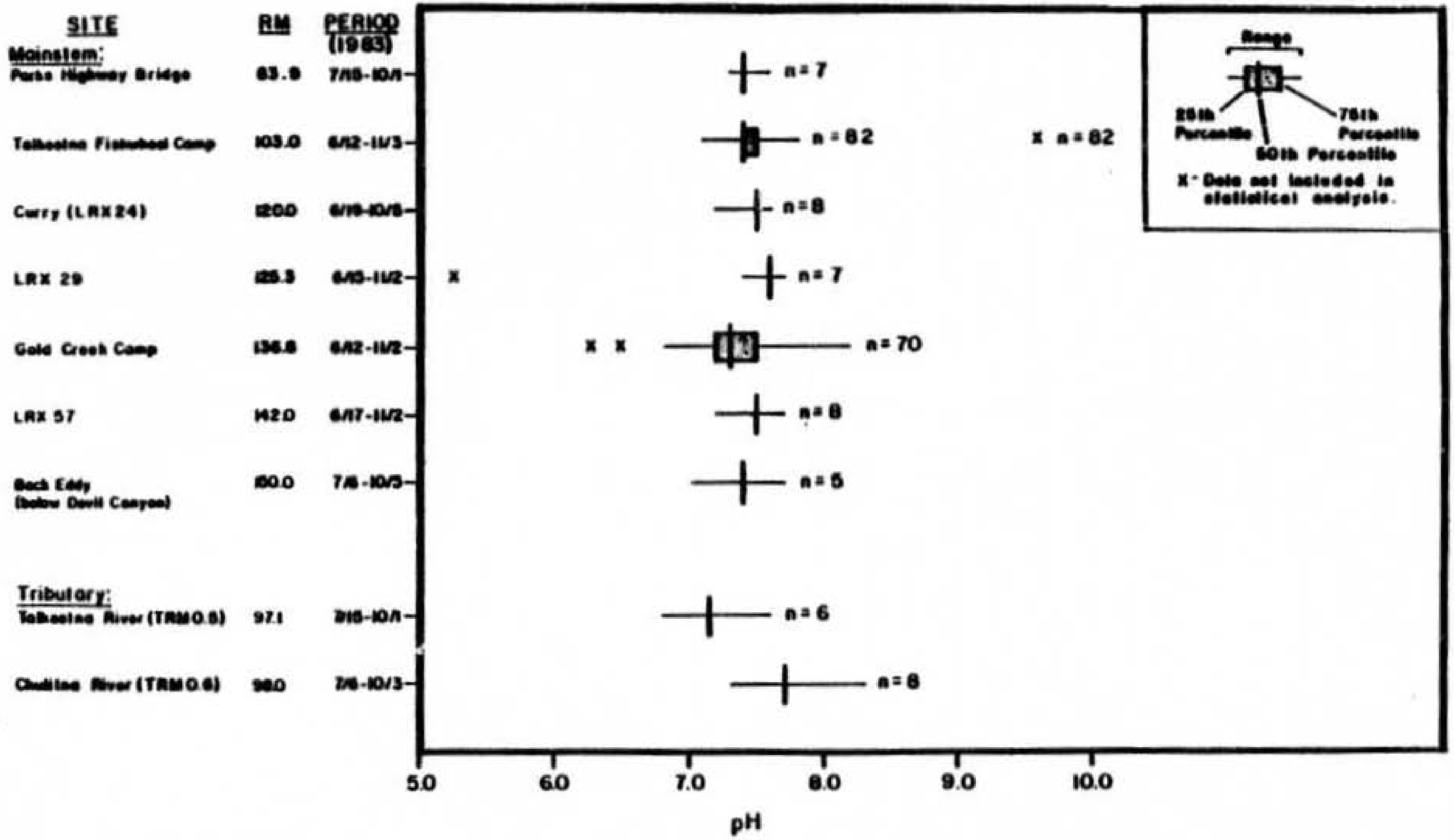


Figure 6.1 pH data summary showing range, 25th, 50th (median), and 75th percentile for mainstem and tributary water quality study sites (Source: ADF & G 1984c)

intragravel waters of 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 U.S. Fish and Wildlife Service 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 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 epilimnion releases from large reservoirs in subartic or arctic environments. No pH problems due to bog inundation are expected to be associated with this project.

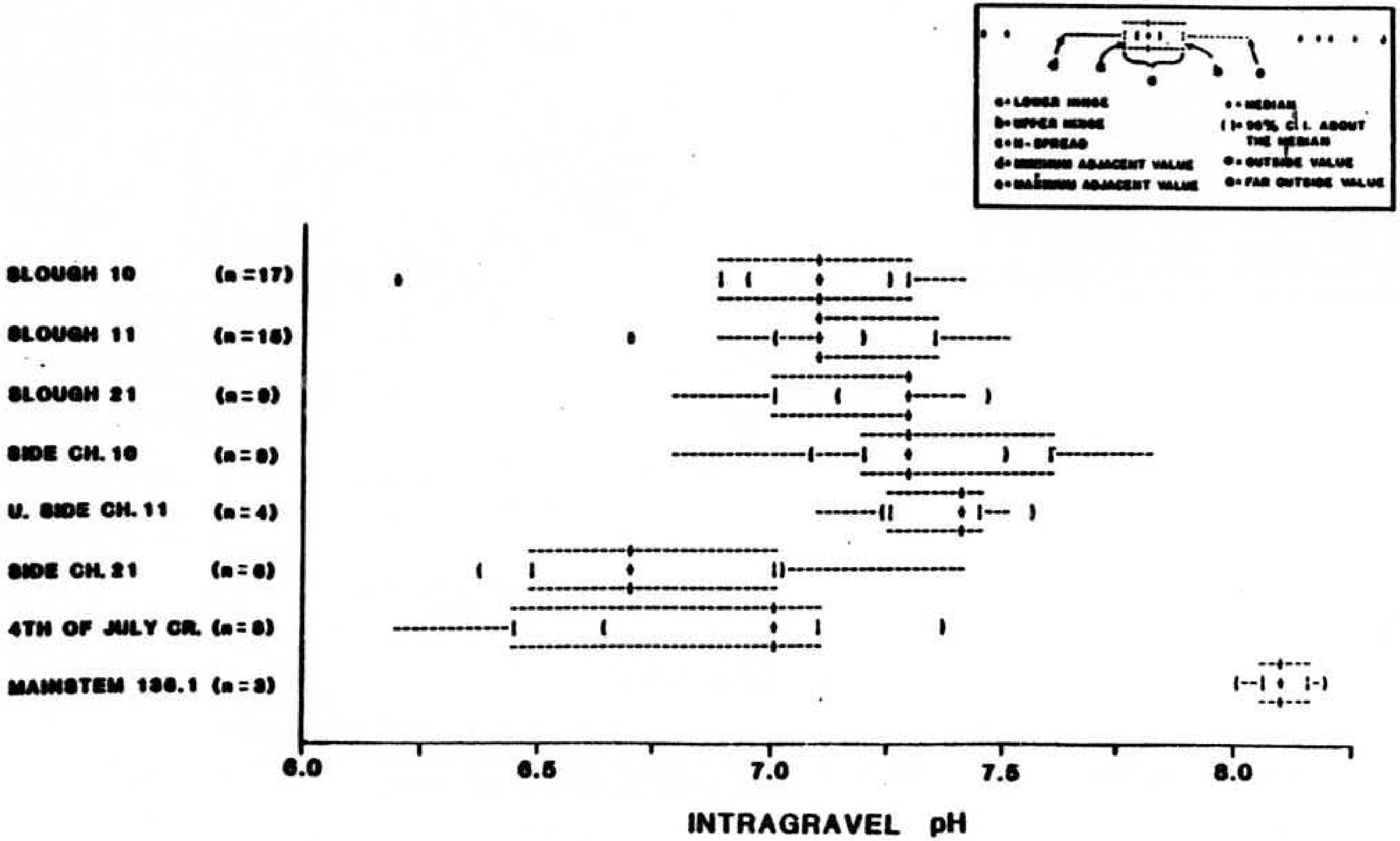


Figure 6.2 Summary, by study site, of the intragravel pH data periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (Source: ADF & G 1985 d)

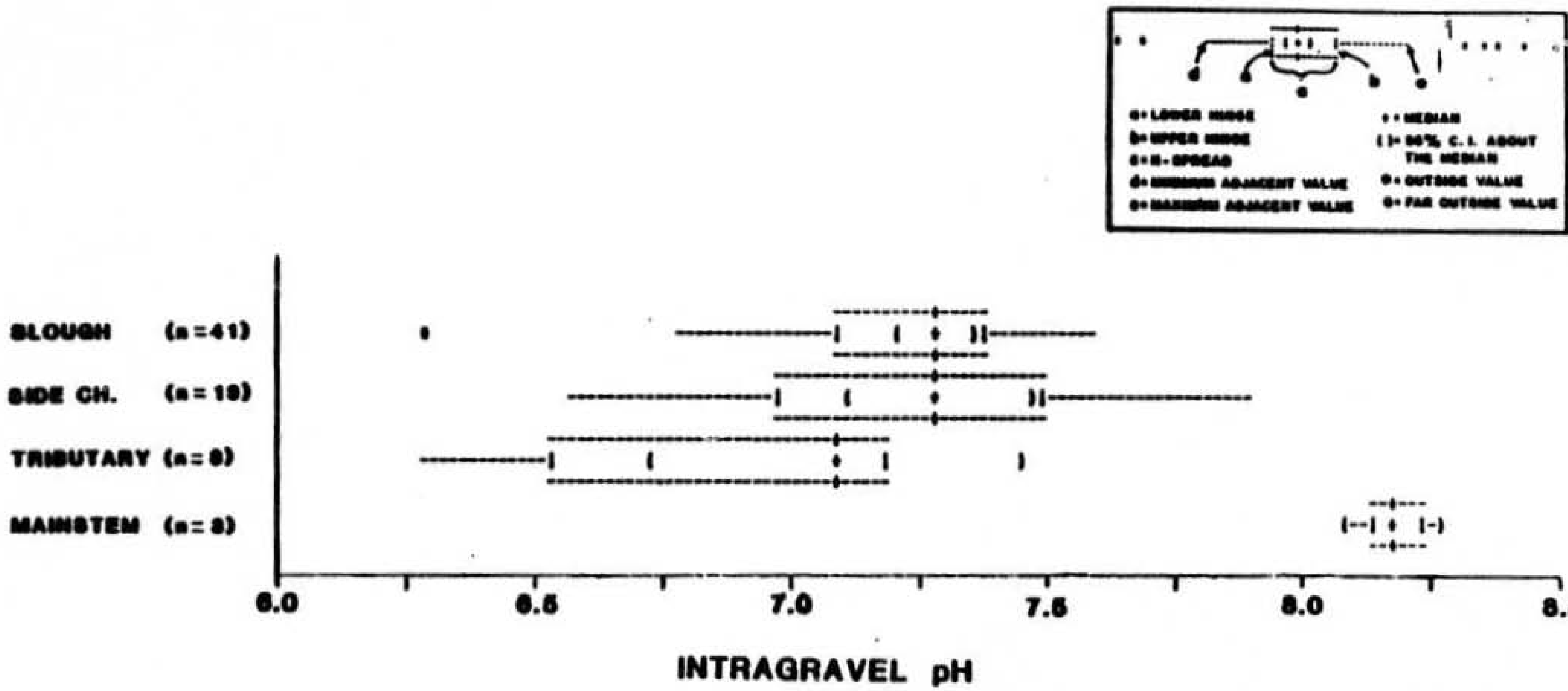


Figure 6.3 Summary, by habitat type, of the intragravel pH data periodically measured within standpipes during the 1983-84 winter period in the middle Susitna River, Alaska (Source: ADF & G 1985 d)

7.0 GENERALIZED INFORMATION REGARDING PROJECT EFFECTS ON HEAVY METALS

7.1 INTRODUCTION

Leaching of potentially toxic heavy metals 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 acceptable 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 mobilization.

A literature search was conducted by both manual and electronic means[1/], but few cases studies were found. Most water quality studies of newly impounded reservoirs have not been related to metal dynamics. The studies we found focused upon mercury bioaccumulation, because 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 (APA 1983a, b) reviews the concentrations of metals in Susitna River water and evaluates them using published criteriaand guidelines (Alaska Administrative Code (ACC) 1984; EPA 1976; McNeely et al. 1979; Sittig 1981). Many natural metal concentrations exceeded 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 watershed supports no significant industry, agriculture, or urbanization. It was concluded, consequently, that the exceedance of water quality criteria by certain metal concentrations is representative of 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 (Bi) 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 chemical content is 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 limnological characteristics 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 to 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.

et 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 processes of metal cations at solid-solution interfaces will influence prevailing metal speciation in the reservoirs (Stumm and Morgan 1981). As the reservoirs fill, metal ions available for sorp·ˈon processes will interact with suspended solids until sorption capacitie: or the sorbate limits are reached. If the sorbate (metal ion) concentration is limiting, then free metal concentrations will generally be low after sorption equilibrium is reached. If the sorbant (suspended solids) concentration is a limiting factor, then the equilibrium free metal concentrations will be higher. The former case, sorbate limiting, will likely be dominant for some metals in the proposed Susitna Reservoirs due to the high suspended solids load in the river (APA 1983a, b).

7.2 MERCURY (Hg)

7.2.1 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 mercury averaged 0.2 ug/l and ranged from zero to 0.8 ug/l. Dissolved mercury averaged 0.06 ug/l and ranged from zero to less than 0.5 ug/l. The levels of dissolved mercury shown in Table 7.1 are on the high end of the range of mercury concentrations typically found in unpolluted North American surface waters (Moore and Ramamoorthy 1984). The mercury concentrations probably 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 of other systems generally find less than ten percent of the total mercury as dissolved mercury. 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). Relatively high concentrations of dissolved mercury in the Susitna River may reflect relatively high levels of mercury complexed with dissolved humic substances.

A bivariate correlation analysis was performed to elucidate phenomena controlling mercury (and other metals) speciation in the Susitna River (see Appendix 7.13). Total recoverable mercury was significantly correlated with total recoverable zinc (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 mercury was not significantly correlated with any other variable included in the analysis. Neither total nor dissolved mercury were significantly linked with river discharge, total suspended solids, or dissolved organic carbon.

7.2.2 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 bioaccumulated 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 mercury 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 that 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 in situ enclosures in a mercury contaminated system in Ontario resulted in decreased rates of mercury bioaccumulation (Rudd and Turner 1983a). Laboratory tests by Jernelov and Lann (1973) showed that mercury 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 biomethylation 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

TABLE 7.1
SUSITNA HYDROELECTRIC PROJECT
AVAILABLE USGS DATA - METAL ANALYSES1/

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 (15292000)																		
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	26,500	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	36	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
210781	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	40	<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	25,000	90	<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	1	560	90	<100	40	30	0	0	-	20	10
230577	86,800	375	-	-	<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	30	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	6	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	790	160	1	30	20	0.1	0	6	60	<3
120681	88,600	326	3.4	-	2	<1	28	7	15,000	90	33	430	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
160782	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

425833/7/18L

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 mercury 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 researchers (Skerfving et al. 1970) have demonstrated the transference of methylmercury to humans eating contaminated fish; these same researchers showed a statistically significant ($r=0.6$; $P<0.05$) correlation between mercury concentrations in humans and the frequency of chromosome breaks in red blood cells.

7.2.3 Implications for the Susitna Hydroelectric Project

Data on mercury occurrence in the Susitna watershed is insufficient to make conclusive statements on mercury speciation and present levels in the watershed biota. However, the previous review of relevant literature supports the following conclusions regarding the potential bioaccumulation of mercury in fishes in the proposed 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 which are higher than current concentrations.

However, environmental conditions at the sediment-water interface in Watana and Devil Canyon Reservoirs will tend to minimize biomethylation and subsequent bioaccumulation of mercury. 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 may be relatively low in the oligotrophic Susitna reservoirs. Additionally, the high inputs of inorganic suspended sediments (glacial flour) may scavenge mercury from the water column by sorption and sedimentation processes. 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 from the overlying water column.

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

Bioaccumulation of mercury may occur rapidly, and mercury concentrations in fish tissues may begin to increase immediately after 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 south-temperate climate of South Carolina than in subarctic northern Manitoba. Mercury methylation and bioaccumulation rates, which appear to be directly related to the reservoir aging process, may decrease due to the following combination of factors:

- o Relatively cold temperture;
- o Low levels of reservoir primary productivity;
- o Death and replacement of the initial fish population;
- o 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 reservoirs age, and the organic fuel of microbial detrital processors decreases in quality, quantity and availability.

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 effects on mercury in downstream habitats. Since mercury is transported primarily in suspension (inorganic mercury), a net reduction in the transport 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 function 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, primary and secondary productivity, and supply of organic carbon to methylating bacteria. Middle Susitna River productivity under with-project conditions is expected to remain similar to or lower than under natural conditions. Low productivity should help minimize downstream mercury bioaccumulation.

7.2.4 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 mercury) is 0.05 ug/l (EPA 1976). A critique of this criterion states that many natural waters exceed this level of mercury (Klein et al. 1979) and suggests future criteria distinguish between various mercury species. Upon examination of the mercury levels shown in Table 7.1, it is obvious that the mercury criterion is consistently being exceeded in the Susitna River, (APA 1983a, b).

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

7.2.5 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. 1979).

After impoundment, microbial methylation of mercury from organic matter in soils and newly inundated detritus of Watana and Devil Canyon Reservoirs may 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 potential bioaccumulation problems notably:

- o Low year-round water temperature;
- o Low benthic microbiological activity;

- o Continual blanketing of inundated organic matter with a layer of mostly inorganic sediments;
- o Relatively limited fish populations.
- o Limited harvest of reservoir fish by human or other predators.

The potential 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 transport of mercury downstream of the proposed reservoirs will be substantially less than under current conditions. Methylmercury leaving the reservoirs is not predictable. Therefore, if any accumulation occurs in fish downstream, it would be largely due to in situ methylation and uptake.

7.3 CADMIUM (Cd)

7.3.1 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 cadmium ranged from not detectable to 10 ug/l; dissolved cadmium was always measured to be to be less than 3 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 cadmium were not significantly correlated to any other variable, including zinc, a common associate of cadmium in nature (see Appendix A).

7.3.2 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 cadmium may be expected, but the amount should be rather low. Assuming soil cadmium levels are not high, cadmium leaching by humic substances will be less than many other metals, (such as copper or lead) 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).

7.3.3 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 moderately hard water (Todd 1970; Britton et al. 1983). Confusion about the criterion is added as the U.S. Environmental Protection Agency (EPA 1976) does not distinguish between total or dissolved cadmium. The International Joint Commission (1977, as cited by McNeely et al. 1979) has set a limit, for protection of aquatic life, at 0.2 ug/l. Comparison of these criteria with the cadmium 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; but accumulation is not related to trophic position. Moore and Ramamoorthy (1984) summarize cadmium bioaccumulation; cadmium is accumulated primarily in major organs of fish (liver, gut, skin) rather than muscle tissue, so it poses little threat to human 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 (Cu)

7.4.1 Occurrence in the Susitna River

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 copper averaged 43 ug/l and ranged from less than 10 ug/l to 190 ug/l. Dissolved copper averaged 3.3 ug/l, ranging from not detectable to 12 ug/l. These levels of copper 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 copper transport in the Yukon River. In warmer areas, having streams with lower levels of suspended solids, higher levels of organic carbon, and pH values less than neutral, copper is transported primarily as the soluble form (Eisenreich et al. 1980; Geisy and Briese 1978; Tessier et al. 1980).

Total recoverable copper 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 iron (r=0.6634), total recoverable manganese (r=0.6025) and total recoverable zinc (r=0.7053), at least to the 0.01 level (see Appendix A). Total recoverable copper was correlated to total recoverable lead, total recoverable mercury and total recoverable nickel at least to the 0.05 level of significance (r=0.4998, 0.3936, and 0.4773 respectively). Dissolved copper was found only to be correlated to dissolved iron (r=0.4634, P<0.01). The correlation analyses strongly suggests the geochemical abundance of copper in the watershed; the strongest correlations of total copper were found with suspended solids, total iron, total manganese and total zinc. Copper is frequently found in natural deposits with zinc, particularly in mining areas (McNeely et al. 1979).

7.4.2 Potential for leaching and bioaccumulation of copper and risk to the public

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

Several field studies have shown that copper does not biomagnify in the food chain. In fish, the primary site of copper 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 copper (McNeely et al. 1979). As such, copper does not pose a significant threat to fisheries in the Susitna River.

7.5 ZINC (Zn)

7.5.1 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 zinc varies from 10 to 200 ug/l, averaging 66 ug/l. Dissolved zinc never measured over 30 ug/l and was typically between 0 and 10 ug/l. These levels of zinc 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) in fresh waters of the United States.

The bivariate correlation analysis (Appendix A) indicates that zinc behaves similar to copper 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 zinc in the Susitna River is correlated to river discharge (r=0.6376), total suspended solids (r=0.8403), total copper (r=0.7053), total iron (r=0.8722), total manganese (r=0.8840), total mercury (r=r.5471) and total nickel (r=0.8123) at least to the 0.01 level of significance. Total zinc is also correlated to total lead (r=0.4406, P<0.05). Dissolved zinc is negatively correlated to total nickel (r=0.6158, P<0.05). Contrary to studies of trace metal speciation in other systems, zinc is transported in the Susitna River primarily in the particulate phase. As is the case with copper, studies elsewhere have shown that zinc 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 zinc, copper and lead suggests deposits of their carbonate and/or sulfide ores in the watershed, as these minerals frequently occur together in nature (McNeely et al. 1979).

7.5.2 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 that some zinc will be leached from inundated rocks and soils, but it is impossible to quantify this with the existing data base. Studies have shown that zinc can be leached from soils and rocks by humic acids. Singer and Navrot (1976) demonstrated zinc is second only to copper 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 zinc from various minerals and soils.

Zinc does not biomagnify as a function of trophic position. Fish normally obtain the majority of their zinc 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). The presence of organic and inorganic chelators in solution may significantly reduce sorption of zinc by fish from non-food sources like water.

7.5.3 Risk to the public

The original License Application states that water quality criteria for zinc have been exceeded naturally on one or more occasions in the Susitna River. 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 percent of the 96-hour LC_{50}[4/] determined via continuous flow bioassay or 5 mg/l, whichever is less (ACC 1984). No zinc 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 zinc (there is the possibility of some anthropogenic zinc from placer mining activities and atmospheric deposition). This element does not appear to present a hazard to the public from impoundment of the river. Zinc accumulates to its highest concentrations in fish organs, not muscle tissue, so dietary sources to man would be minimal even if reservoir construction should cause increased zinc concentrations to occur in fish.

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

7.6 MANGANESE (Mn)

7.6.1 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 manganese ranged from 10 to 700 ug/l, averaging 270 ug/l. Dissolved manganese had a mean concentration of 15.6 ug/l and varied from non-detectable to 180 ug/l. These values, although stated to exceed applicable water quality criteria (APA 1983 a,b), are typical of those found in natural surface waters (Chapnick et al. 1982; Eisenreich et al. 1980; Gibbs 1977). The total manganese concentrations are probably high, due to the high suspended sediment concentrations since total recoverable manganese in the Susitna River is significantly correlated to suspended solids ($r=0.8997$, $P<0.01$) (Appendix A). Total recoverable manganese is also correlated to river discharge ($r=0.7664$), total recoverable copper ($r=0.8482$) and total recoverable zinc ($r=0.8840$) at least to the 0.01 level of significance. Dissolved manganese was not found to correlate with any other variable included in the correlation analysis.

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

Laxen, et al. (1984) have suggested a "decoupling" of the traditional process oriented interpretation of manganese speciation; their observations do not support a link between particulate and soluble manganese 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 manganese, a part of the suspended sediment load. The other source composes the reservoir of dissolved manganese and is largely derived from the influx of reduced, soluble Mn (II) species leached from anoxic soil and groundwaters. Hence, hydrogeological conditions seem to govern manganese speciation in riverine systems. Equilibrium chemistry and biological mediation govern manganese speciation in lakes and reservoirs having relatively longer residence times than lotic systems. The manganese data of preproject conditions may therefore not be of great value in predicting reservoir and downstream manganese levels following river impoundment.

7.6.2 Potential for leaching and bioaccumulation of manganese

A number of laboratory and field studies have defined the speciation dynamics of manganese in lakes and reservoirs. The chemistry of manganese 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 predominantly Mn (IV) phases (Stumm and Morgan 1981). When reservoirs stratify, anaerobiosis may develop in the hypolimnion, and Mn (II) may become the dominate form. This phenomenon is well documented (Hutchinson 1975).

The potential for leaching manganese from inundated soils and rocks is directly related to the potential for anaerobiosis in the proposed reservoirs. The likelihood 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 manganese is predicted. Without elevated concentrations of soluble manganese, levels of manganese in biota are not expected to be above current concentrations.

7.6.3 Risk to the public

Substantial leaching of manganese is not expected to result from impoundment of the Susitna River. As such, the incremental risk to the public is nil.

7.7 IRON (Fe)

7.7.1 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 iron varied from 40 to 42,000 ug/l, averaging 12,816 ug/l. Dissolved iron averaged 103 ug/l and ranged from not detectable to 250 ug/l. The concentrations of dissolved iron are within natural ranges for surface waters, and, considering the suspended solids load, the total iron levels are not unexpected. Large amounts of iron are present in the Susitna River as magnetite, hematite, pyroxenes and other minerals which are present as fine particulates (R & M Consultants Inc. 1984b). Edmundson and Koenings (1985) also found substantial percentages (88 to 94 percent) of the total iron to be present as a particulate form in nearby glacial lakes of south central Alaska.

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

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

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

In studies on non-glacial systems, Gibbs (1977) showed a similar iron speciation for the Amazon River. Tessier et al. (1980) found similar iron speciation in two Quebec rivers. Eisenreich et al. (1980) found about 68% of total iron to be crystalline particles in suspension at nonurban sites on the upper Mississippi River (19% was the dissolved specie). Numerous authors have found dissolved iron 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).

7.7.2 Potential for leaching and bioaccumulation of iron

Four published studies relating to changes in iron concentration 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 iron levels which continued until a time (about 25 days) when iron began to coagulate with tannin and lignin compounds and precipitate. Following impoundment, a slight rise occurred in iron 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 iron 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 iron in the leachates (which were oxygen deficient or anaerobic) to increase with time in soils with substantial organic mats.

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

It appears reasonable to predict that iron 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.

7.7.3 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 iron and dissolved iron. This discrepancy necessitated that total iron must meet the criterion, an unrealistic expectation for streams carrying glacial flour. Generally, about 99 percent of the iron in the Susitna River is carried in the suspended sediment load. The dissolved iron concentrations do not exceed the 1 mg/l limit (Table 7.1), presenting little health risk to the public. The total iron concentrations in the river downstream of the project will decease following impoundment since the suspended sediment load will decrease substantially (APA 1983).

7.8 ALUMINUM (Al)

7.8.1 Occurrence in the Susitna River

Sampling for aluminum has been performed in the Susitna River. Data provided by USGS is given in Table 7.1. R and M Consultants, Inc. (1982) also provided data on dissolved aluminum concentrations. Total and dissolved aluminum data are presented in the original License Application as Figures E.2.104 and E.2.105. Total aluminum levels are relatively high, but not unexpected for glacial rivers such as the Susitna. Aluminum is likely associated with the large suspended sediment loads. Dissolved aluminum levels are higher than 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).

7.8.2 Potential for Leaching and Bioaccumulation of Aluminum

Aluminum is a practically ubiquitous element on earth, but surprisingly, its environmental behavior, toxicity and bioavailability are not completely understood. No reports have been found indicating aluminum leaching occurs following reservoir impoundment, nor is aluminum leaching likely. Aluminum minerals are not very soluble. Humic acids do bind aluminum but concentrations of 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 aluminum in aquatic animals. Aluminum can be found at trace levels in the tissues of almost every organism (Burrows 1977). Little evidence exists to indicate an aluminum bioaccumulation problem in the potential reservoirs.

7.9 LEAD (Pb)

7.9.1 Occurrence in the Susitna River

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

The high levels of lead in the Susitna River are probably due to the high suspended sediment load. Total recoverable lead correlated with suspended solids (r=0.4709), and total recoverable copper (r=0.4998), total recoverable iron (r=0.4994), total recoverable mercury (r=0.4406) at least to the 0.05 level of significance (Appendix A).

7.9.2 Potential for Leaching and Bioaccumulation of Lead

There is very little potential for lead 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 lead concentrations in newly impounded reservoirs.

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

7.10 NICKEL (Ni)

7.10.1 Occurrence in the Susitna River

Total recoverable nickel concentrations in the Susitna River are shown in Table 7.1. Averaging 27 ug/l, the concentrations range from 1 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 nickel in North American rivers 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 nickel in the Susitna River correlated with total recoverable manganese ($r=0.8482$) and total recoverable zinc ($r=0.8123$) at least to the 0.01 level of significance (Appendix A). Total nickel also significantly correlated to dissolved zinc ($r=0.6158$, $P<0.05$).

7.10.2 Potential for Leaching and Bioaccumulation of Nickel

No evidence has been found to indicate that elevated nickel concentrations occur in new reservoirs. Humic acids can leach limited amounts of nickel 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 nickel in sediments, invertebrates, and in the muscle of omnivorous and carnivorous fish were 27, 11, 0.18, and 0.13 mg/kg respectively (Mathis and Cummings 1973 as cited by Moore and Ramamoorthy 1984). Little health risk from nickel exists for consumers of resident fishes following impoundment of the Susitna River.

7.11 BISMUTH (Bi)

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 bismuth exceeded the recommended criterion of 3.5 ug Bi/l. However, the detection limit for the analytical method was 50 ug/l (R & M Consultants, Inc. 1982 as cited by APA 1983a, b). The original License Application contained information on 26 analyses of bismuth in Susitna River water, of these 26, dissolved bismuth was detected three times. Data on bismuth 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 bismuth-related ecological problems in water development projects.

7.12 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 or 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 transport 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 metals 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.

8.0 THE POTENTIAL FOR DISSOLVED 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 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.

Dissolved 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 may, depending on the level of excess gas within their tissues, 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 (Wolke et al.1975; Fickeison and Schneider 1976).

8.1.1 Causes of Supersaturation

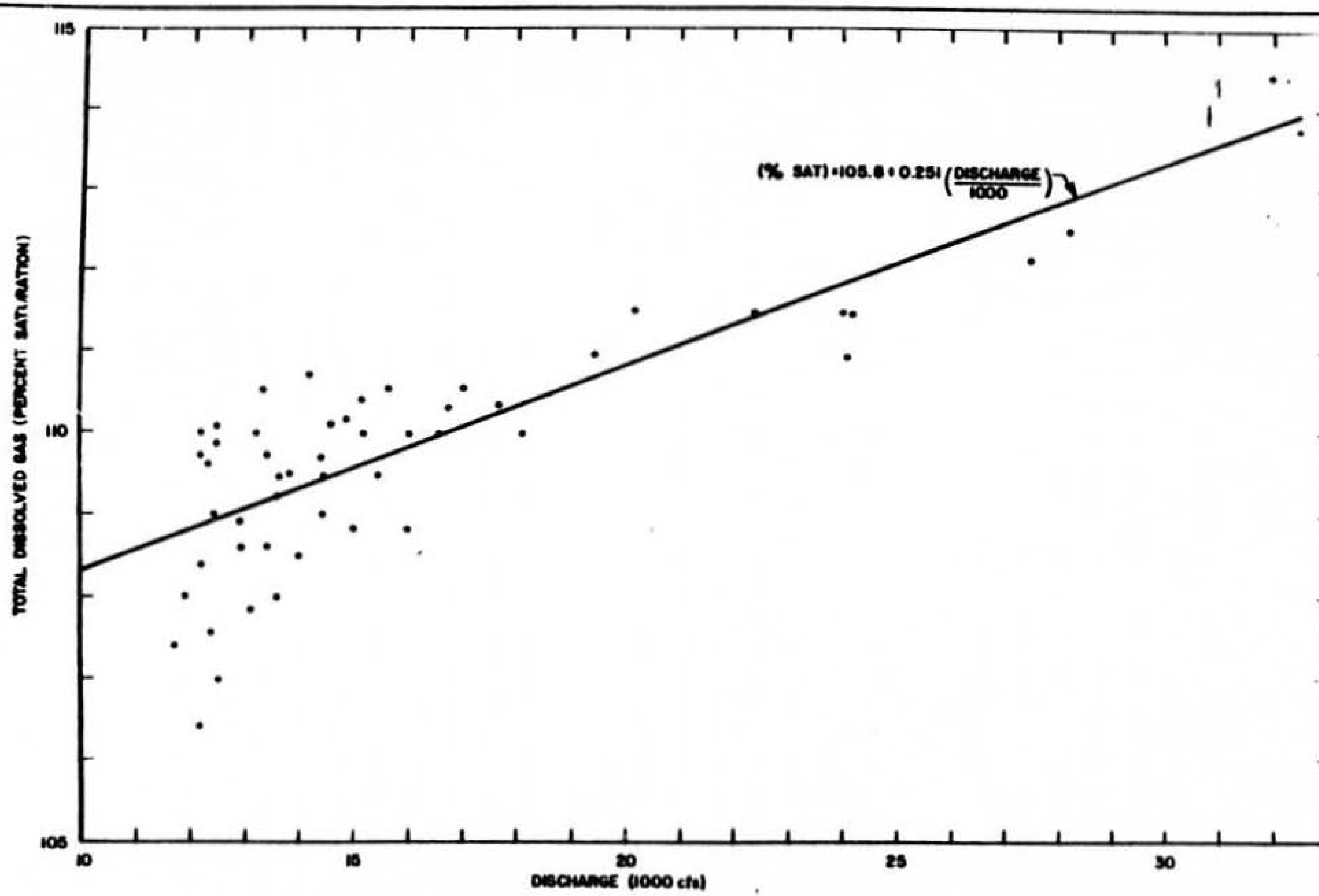
Supersaturated dissolved gas concentrations may occur at dams and hydroelectric facilities by any of the following mechanisms:

1. Spillway discharges entering the receiving stream can cause entrainment of air bubbles to a depth where the change in hydrostatic pressure forces the gas in the bubbles into solution.

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 miles 150 to 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 the 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



TOTAL DISSOLVED GAS (PERCENT SATURATION) VS. DISCHARGE

SOURCE: APA 1983

FIGURE 8.1

flowing through the canyon, within the discharge ranges observed to date (i.e. 10,000 to 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 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.

The time period of late summer and early fall is the period when high volume flows are most likely to occur under planned project operating scenarios (APA 1983 a,b; Harza-Ebasco 1984 f; APA 1985; Harza-Ebasco 1985 a,e). This time period is also the period when adult salmon will be using the middle river mainstem channel as a migratory route to spawning habitats. Also during this time period, juvenile salmon and resident fish are utilizing peripheral habitats (and presumably mainstem habitats to an unknown extent) for rearing. Therefore, under with-project conditions and without mitigation measures, high volume controlled releases would have a potential to cause high gas supersaturation levels and potential biological effects which might involve disruptions of adult salmon inmigrations to spawning areas, and possible detrimental effects to rearing juvenile salmonids and/or resident fish.

Potential disruptions of adult salmonid inmigrations are perhaps among the more serious project impacts which could result from high levels of dissolved gas supersaturation. The effects of dissolved gas supersaturation are often less severe and less prolonged on smaller organisms (Fickeison and

Schneider 1976; Dawley et al. 1976). In addition, during high flow events highly mobile aquatic organisms such as juvenile salmonids are more likely to be in relatively shallow, peripheral habitats where velocities and water quality characteristics would likely be more suitable for them. Dissolved gas levels in shallow, peripheral habitats will likely be closer to equilibrium with the atmosphere than will gas levels in mainstem waters.

In any case, high flow events will be smaller in amplitude, shorter in duration, and will occur less frequently with the project in place when compared to natural conditions. Each of these latter project effects would potentially benefit the fisheries in the middle river, even without the planned mitigation measures.

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 reservoir storage capacity coupled with specialized 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 will be discharged through a 34 foot diameter tunnel beneath the surface of the river at the downstream toe of the dam. A second 34-foot diameter tunnel will be utilized for Watana Stage III. 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 an intake located at el. 1,930 ft. The discharges will be released through one or more of six, 78-inch fixed cone valves located approximately 105 feet above tailwater downstream 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 depth in tailwaters, thus preventing 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 discharge flows up to those anticipated for the 50-year flood. Supersaturation will still occur in Devil Canyon (below the project), 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.

An independent 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 12,000 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. Reservoir operation simulations indicated a maximum outflow from Watana of 33,000 cfs during the 50-year flood. This outflow was composed of 24,000 cfs from the outlet works and 9000 cfs from the powerhouse (Harza-Ebasco 1985a).

Fixed cone valves have also 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, 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 about 15,000 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.

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 will be increased to about 22,000 cfs.

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

In addition to the use of 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 minimize any downstream gas supersaturation conditions.

9.0 AQUATIC NUTRIENT CHANGES RELATED TO THE PROJECT

The significance of changes 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 (i.e., 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 observed and 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. 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, the organic material produced in the river, serves as a very important, high quality food source for microbial populations as well as for invertebrate and vertebrate herbivores and detritus feeders (Cummins, 1979). These detritivores and herbivores, in turn, may become food for vertebrate predators such as juvenile salmonids and resident fishes which, in turn, may become food for other fish, 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 epilithon, and periodic high velocities which can mechanically dislodge attached organisms,
- 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 on 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 low and stable and the negative effects of suspended sediments and turbidity 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 to 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 temperate latitude lake.

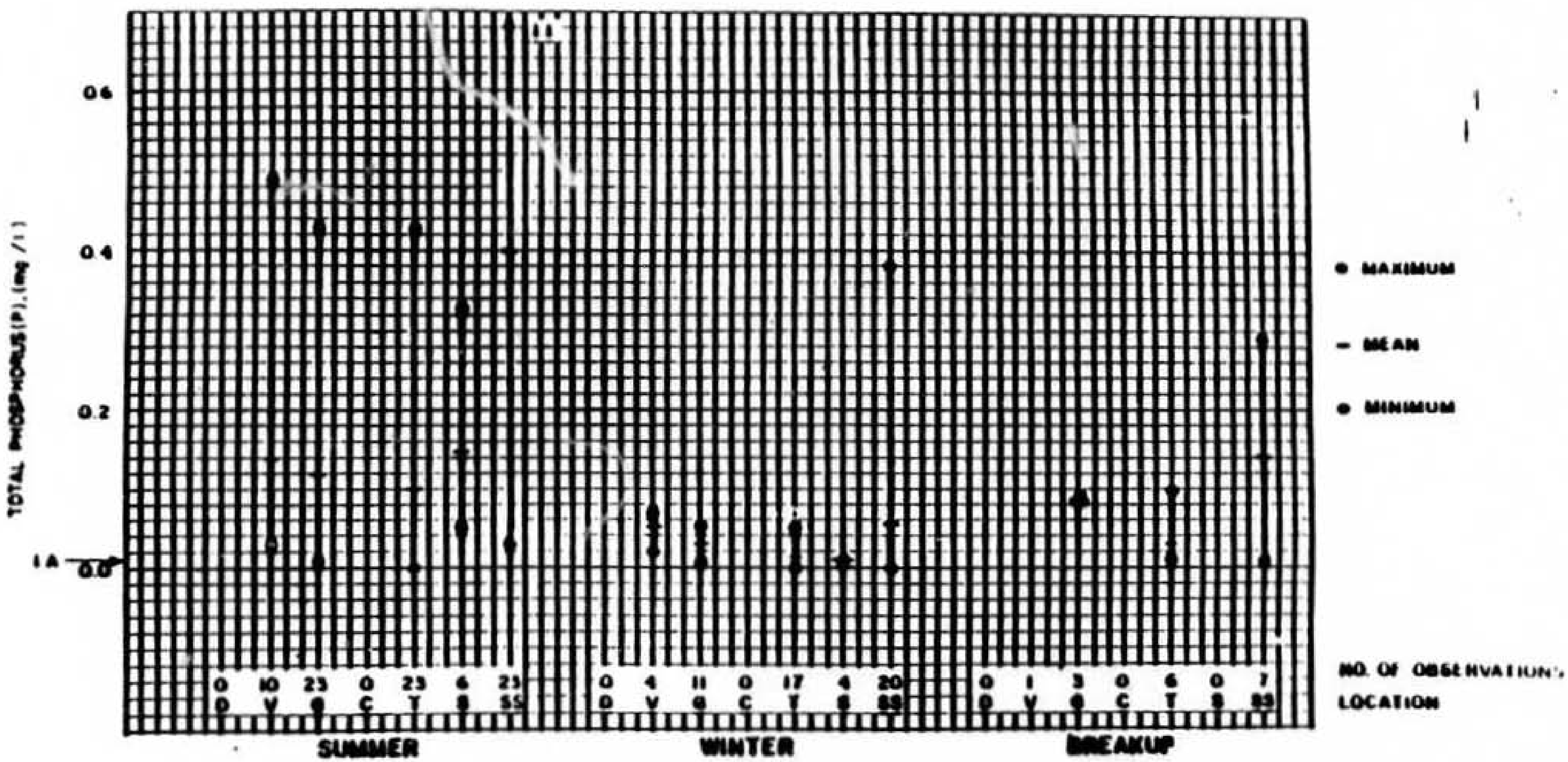
Although concentrations of total nitrogen and phosphorus which are generally representative of any given trophic status of subarctic rivers have not been

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.

SOURCE: USGS AND R&M

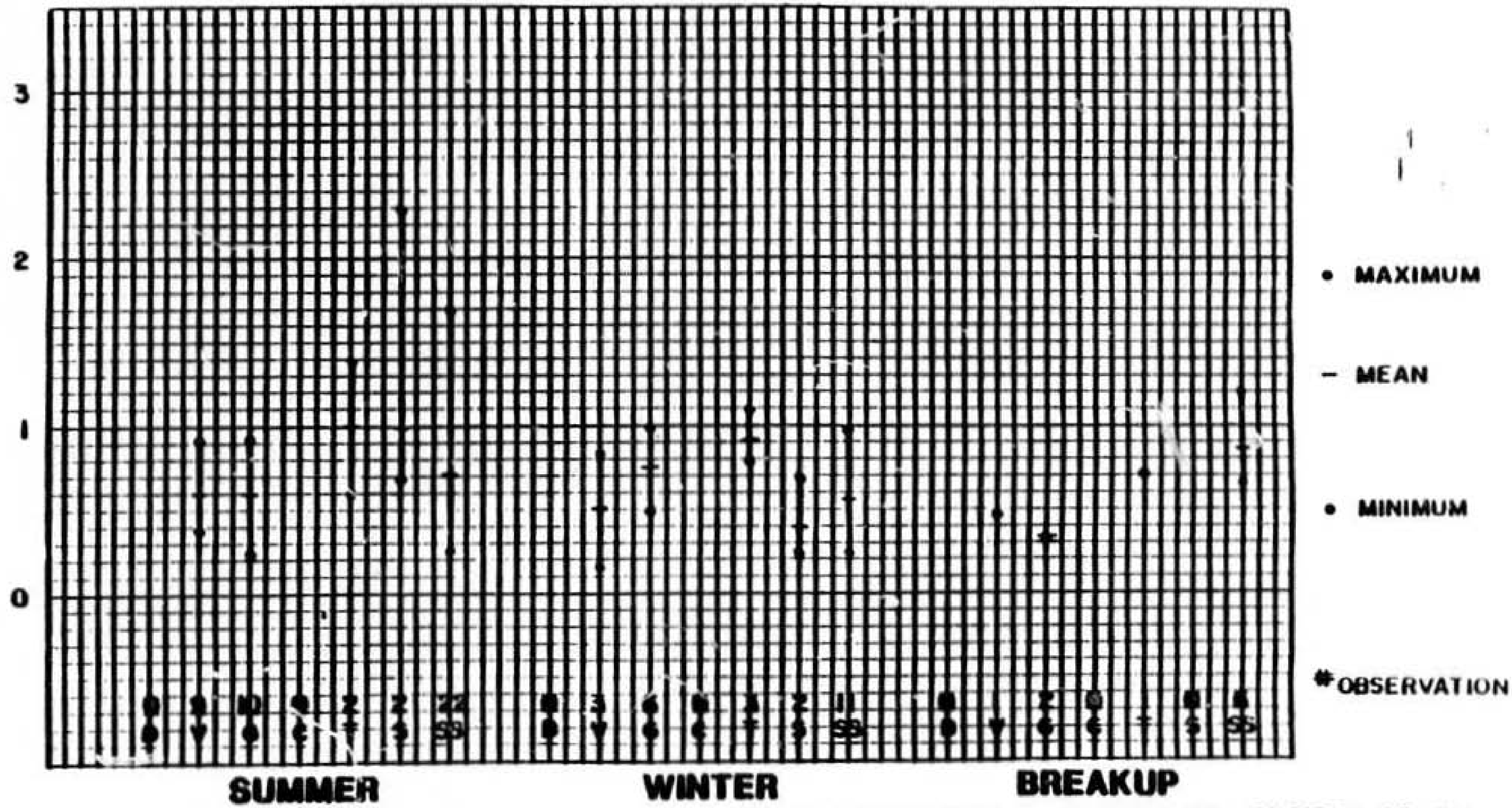
FIGURE 9.1

SUSITNA HYDROELECTRIC PROJECT

DATA SUMMARY - TOTAL PHOSPHORUS

Source: APA 1981

PARAMETER: TOTAL NITROGEN, as N, (mg./l.)



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 198?

established, it is reasonable to assume that concentrations generally accepted as indicators of lake trophic status, and possibly even lower 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:

- Mainstem river, tributary and groundwater influents;
- Surface runoff from eroding reservoir sidewalls and reservoir drawdown zones;
- Liberation of nutrients due to microbial decay of inundated organic material;
- Leaching of nutrients from newly inundated soils by chemical and biochemical processes;
- Treated secondary sewag effluents from construction-related facilities;
- Particulate fallout from atmospheric sources;
- 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 (Wetzel 1975, Hannan 1979, 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 sites 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, and organic detritus (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 internal nutrient flow during their entire lifetimes primarily because autochthonous productivity will be strongly limited by highly turbid conditions and the remaining community metabolism will be dominated by heterotrophic catabolism of relatively refractile organic detritus. Both reservoirs 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 in downstream flows 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 total suspended solids (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 to 13 percent of the TP, while the orthophosphate (FRP) content was 8 to 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 at 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.

Table 9.2

SUSITNA HYDROELECTRIC PROJECT
PHOSPHORUS IN SUSITNA RIVER SAMPLES

All values are reported as ug/l (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.

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 to 10 percent by weight, while 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 that they are, to a limited extent, biologically 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. Cyanophyta, with the capacity to fix their own nitrogen source and secrete copius mucilage, may have a competitive advantage compared to some types of periphyton in such habitats. Filamentous chlorophyceae (Zygnema sp. Spirogyra sp.) are also known to occur in large, continuously turbid, subarctic habitats (e.g. the Kasilof River, Alaska). (Smith 1950; Prescott 1962; 1970; Hobbie 1980).

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

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).

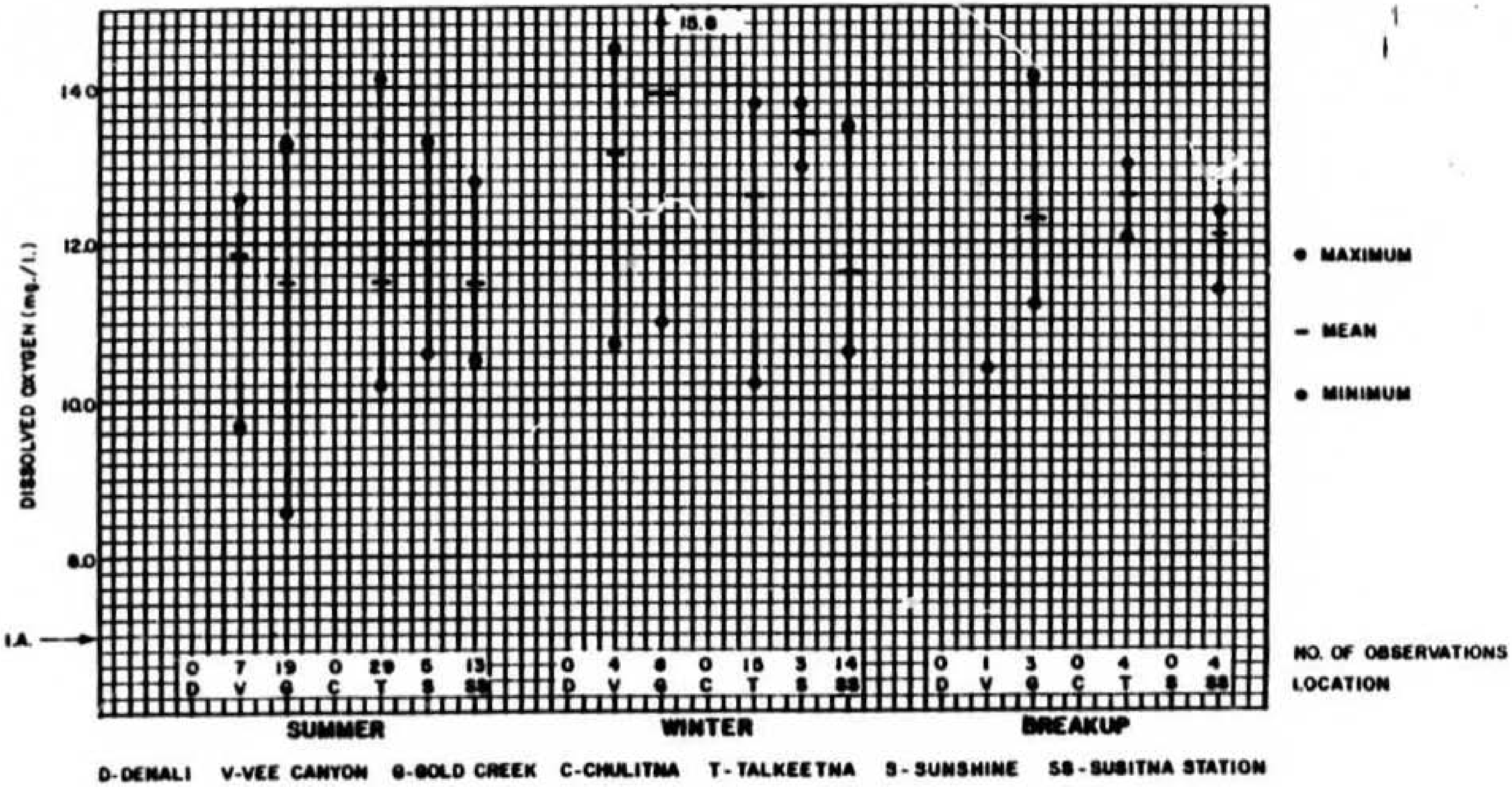
The trophic status of the middle river mainstem is presumed to be relatively impoverished at present, especially relative to non-glacial rivers at the same latitude. Project-induced changes in macronutrients are not expected to change the middle river trophic status. Periodic high turbidity and suspended sediment levels presently act to limit middle river aquatic productivity at all trophic levels. Continuous, 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, Alaska. Peripheral riverine habitats that will 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

10.1 EXISTING CONDITIONS IN THE SUSITNA RIVER

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. Average winter dissolved oxygen concentrations have been approximately 98 percent saturation at Gold Creek, and 80 percent saturation 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 equate to summer saturation levels of approximately 97 to 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. 1981, 1982a; R & M Consultants, Inc. and L.A. Peterson and Associates 1982). Most measured TOC values have been less than 5 mg/l at various Susitna River stations during both winter and summer seasons (USGS 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 (e.g. Yukon, Kuskokwim, Tanana and Copper Rivers) (R & M Consultants, Inc. and Peterson and Assoc. 1982; USGS 1980, 1981, 1982, 1983). The majority of the TOC is composed of dissolved organic carbon (DOC), with the remainder being found in the particulate form (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:

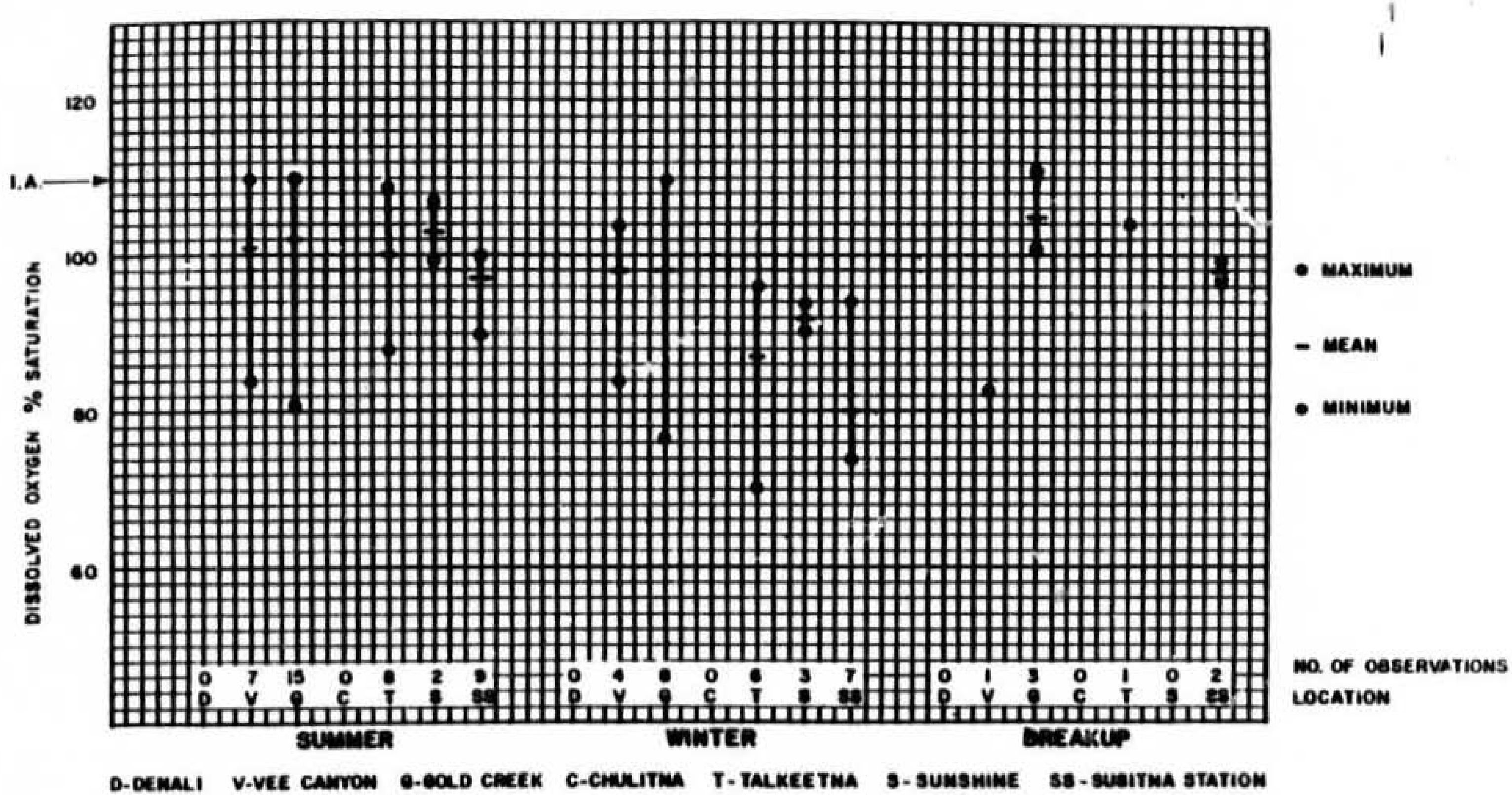
I. A. CRITERIA: GREATER THAN 7mg./l. BUT IN NO CASE SHALL DISSOLVED OXYGEN EXCEED 17mg./l. (ADEC 1979).

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

DATA SUMMARY - DISSOLVED OXYGEN

SOURCE: USGS AND R & M

FIGURE 10.1



NOTES:

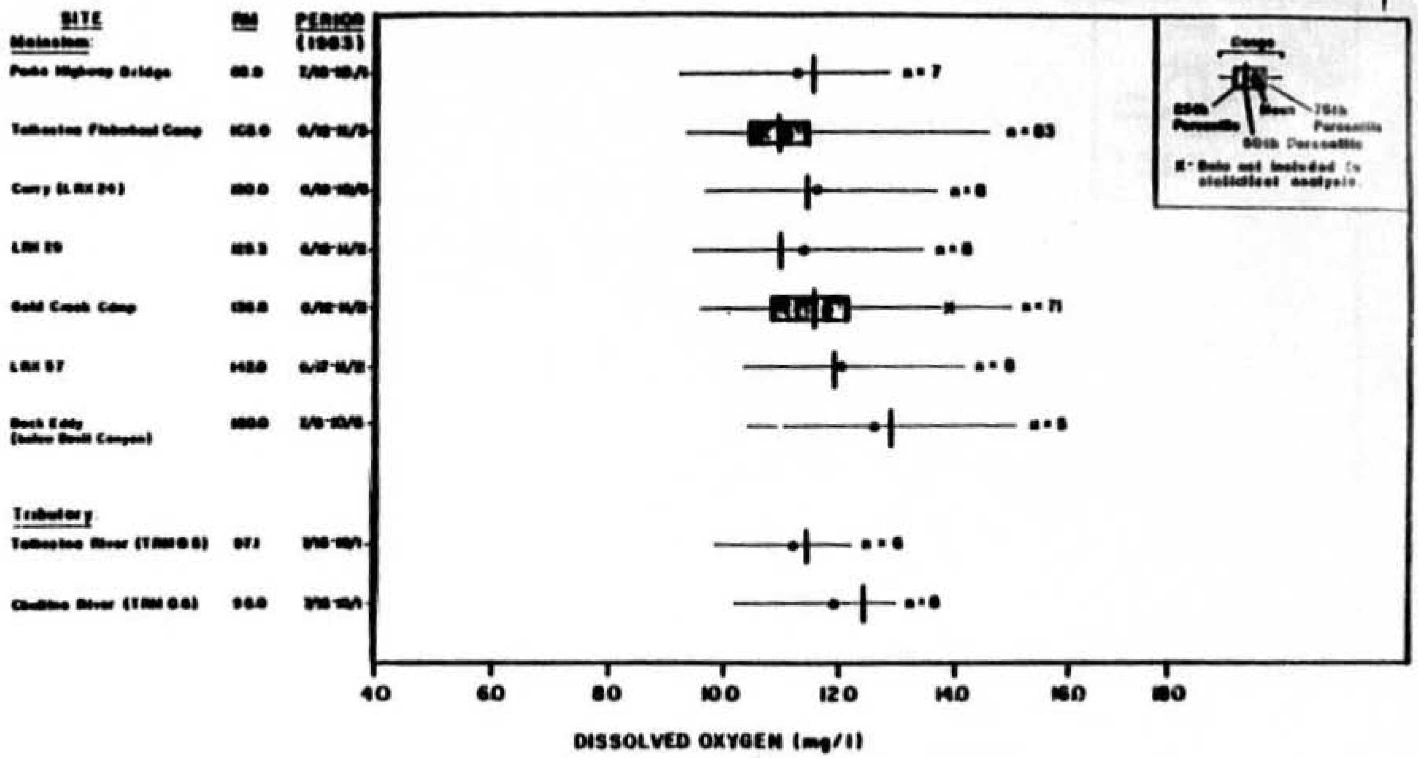
I. A. CRITERION: THE CONCENTRATION OF TOTAL DISSOLVED GAS SHALL NOT EXCEED 110 % SATURATION AT ANY POINT. (ADEC, 1979).

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

DATA SUMMARY – DISSOLVED OXYGEN % SATURATION

SOURCE USGS AND R&M

FIGURE 10

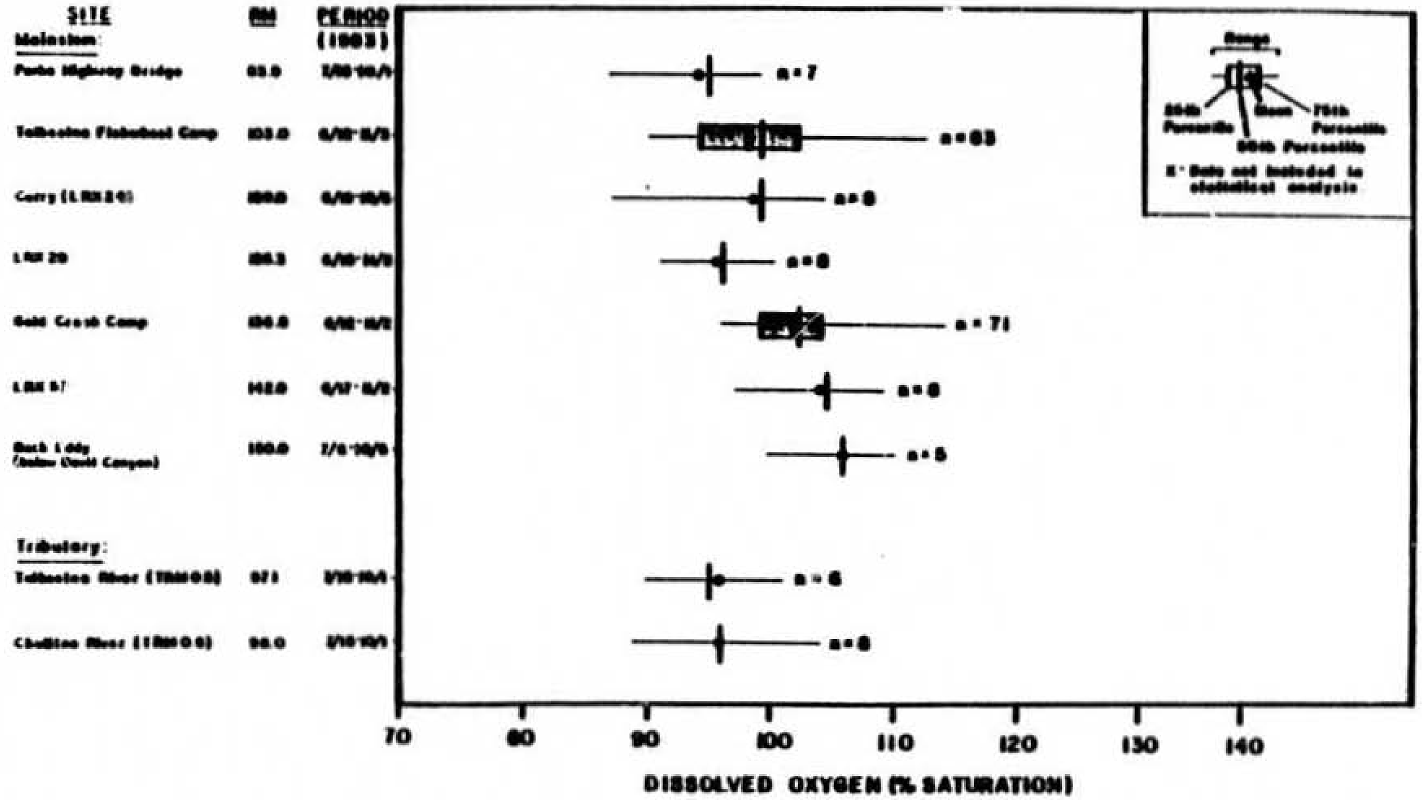


Dissolved oxygen data summary showing range, 25th, 50th (median), and 75th percentile for mainstem and tributary water quality study sites

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 from 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 (USGS 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 (e.g. <20 mg/l).

As previously discussed, much of the organic carbon recruited from allochthonous sources into lotic habitats is expected to have relatively poor food quality (Cummins 1979) and is expected to be relatively refractory to microbial degradation (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 sorption 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 metabolism 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 the Kuparuk River, an Alaskan arctic stream (Peterson, et al. 1985b) indicated that the biological productivity of this naturally heterotrophic open-canopied, tundra 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.

10.2 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 important 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 remain and may create some localized oxygen depletion. The process of decomposition will be relatively slow at the prevailing cold temperatures, however, and any waters experiencing oxygen depletion are expected to be substantially diluted by mixing with 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 long term problems due to oxygen deficits in epilimnion release waters of large reservoirs. Some short term water quality problems related to oxygen deficiency have been reported from some subarctic reservoirs, but most studies indicated that water qualtiy problems related to oxygen deficiency were alleviated within three to five years. (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).

Stratification that is anticipated in the reservoirs is expected to limit oxygen replenishment to the hypolimnion, but this is expected to be most important during the ice covered periods. Spring and fall turnover, together with the large freshet inflow of highly oxygenated (probably O_2

saturated) water is expected to cause mixing and substantial reoxygenation of most oxygen deficicient waters which may occur. It is anticipated that the surficial layers of the impoundments will maintain high enough oxygen concentrations (>8.0 mg/l) to avoid any biological problems for native fish.

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 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 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, heterotrophic 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 can be assumed that a decrease in biological productivity in downstream mainstem riverine habitats may occur due to: 1) reservoir trapping of an undefinable amount 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 EXPECTED TRENDS IN BIOLOGICAL LIMNOLOGY

11.1 RESERVOIR PHYSIOLOGICAL LIMNOLOGY AND TROPHIC STATUS

It is anticipated that the Susitna Hydroelectric Project reservoirs will have low levels of productivity. Rates of community metabolism will be relatively slow due to a cold mean annual thermal regime. Water quality characteristics in the new lentic habitats will likely limit the types and numbers of organisms which occur there. Both the numbers and the biomass of planktonic populations will be dominated by organisms able to exist for long periods of time by heterotrophic means. The dominant form of biologically important food will be low concentrations of dissolved and particulate organic detritus derived from allochthonous sources. Heterotrophic recycling of organic detritus will be the most important form of biological energy transfer between trophic levels.

The water column within these reservoirs, as in most relatively deep water bodies, will be a most important site of biological activity. The reservoir floors and sidewalls, although expected to make important contributions to short term fluctuations in community metabolism when new soils and organic detritus are inundated, will be minimally important with respect to long term reservoir community metabolism trends. The importance of biological activity associated with flooded reservoir substrates is expected to decline as the reservoirs age due to gradually decreasing releases of organic and inorganic nutrients into the overlying water column (Grimas 1961; Nilsson 1965; Rodhe 1964; Grimas and Nilsson 1965; Lindstrom 1973; Ostrofsky and Duthie 1975; Ostrofsky and Duthie 1978; Duthie 1979; Hannan 1979; Baxter and Glaude 1980; Ostrofsky and Duthie 1980; Grimard and Jones 1982; Peterson and Associates and R & M Consultants, Inc. 1982; Hecky et al. 1984).

Basic limnological characteristics will strongly influence the reservoir biology so as to maintain the average annual primary productivity rates within the lower half of a range of values expected to stay between 1 to 20 g-carbon/m^2/yr. Among the primary limnological characteristics which will act to minimize the potential biological productivity of the project reservoirs are:

- o moderate to high suspended sediment concentrations;
- o moderate to high turbidity values and consequent very shallow euphotic zones;
- o low to moderate mean annual temperatures;
- o moderate to large maximum and mean depths;
- o short average hydraulic residence times;
- o large total reservoir volume per unit of reservoir surface area;
- o large total reservoir volume for dilution of any nutrient leachates resulting from inundation of new soils and organic detritus;
- o retardation of nutrient leaching due to high rates of inorganic particulate sedimentation;
- o withdrawal and discharge of water and entrained plankters from the zone of greatest water column productivity (i.e. near surface waters);
- o possibilities of a relatively unstable vertical density structure, and the consequent potential for a relatively deep mixed surface layer in combination with a shallow euphotic zone.

Assignment of a trophic status classification to a body of water can be a fairly subjective exercise. Different investigators may not always concur about the trophic status classification of a water body.

It is frequently useful to consider the trophic status of a water body within the larger continuum of trophic states extending from extremely unproductive to extremely productive systems. An important trophic state indicator of large, lentic systems is their annual rate of primary productivity (e.g. see Table 11.1). In addition to primary productivity rates, however, there are a wide variety of other water quality descriptors which are frequently used to help define trophic status. Such descriptors frequently include, but are not limited to: phytoplankton standing crops; phytoplankton biomass densities; dominant phytoplankton categories; chlorophyll a concentrations; light extinction coefficients; total organic carbon concentrations; total phosphorus and nitrogen concentrations (Wetzel 1975).

Obviously, no measurements of the previously mentioned water quality descriptors can be made in non-existent project reservoirs. But, subjective estimates of the values of many of these entities can be made based on knowledge of similar measurements from other temperate and subarctic systems (e.g. see Table 4.2), especially when several key limnological characteristics of the proposed reservoirs can be fairly reliably estimated. A rather complex and subjective synthesis of the water quality descriptors that can be estimated for the proposed project reservoirs results in a one word trophic status prediction for them; they will likely be ultraoligotrophic (Table 11.1).

The estimated turbidity level of the project reservoirs is a key limnological characteristic. The primary productivity of the project reservoirs is expected to be strongly light limited because of moderate to high turbidity levels. A somewhat analagous situation of a continuously turbid, subarctic reservoir exhibiting light limited primary productivity has been observed at Southern Indian Lake, in northern Manitoba, Canada

Table 11.1

SUSITNA HYDROELECTRIC PROJECT
APPROXIMATE 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]	<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 (N.W.T., Canada)	Ultra-Oligotrophic	11	74°
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[3]	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[1]	5-20	60°
LaGrande Lake-Reservoir (Quebec, Canada)	Ultra-Oligotrophic	<30	53°
Southern Indian LK Reservoir (Manitoba, Canada)	Oligotrophic	55	57°
Koocanusa Reservoir (Montana-British Columbia)	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°
Harding Lake (Alaska)	Oligotrophic	48	64°
Big Lake (Alaska)	Oligo-Mesotrophic	50	61°
Superior (USA-Canada)	Oligotrophic	50	48°
Brooks (Alaska)	Oligotrophic[1]	<57	59°
Naknek (Alaska)	Oligotrophic[1]	<62	59°
Tahoe (Nevada-California)	Oligotrophic	70	39°
Cresent Lake (Alaska)	Oligotrophic[1]	<90	61°
George (New York)	Oligo-Mesotrophic	72	48°
Huron (USA-Canada)	Oligo-Mesotrophic	100	48°
Flathead (Montana)	Oligo-Mesotrophic	123	48°

1/ Estimated from information describing partial year (summer only) studies.
2/ Primarily composed of phytoplankton studies.
3/ Prediction

Source: (MODIFIED AFTER STUART, 1983)

Table 11.1 (Cont'd)

Water Body	Trophic Classification	Annual Primary Productivity $gCm^{-2}\ yr^{-1}$ Approximate Estimates	Latitude
Michigan (USA)	Mesotrophic	130-150	45°
Clear (California)	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 Slotsso (Denmark)	Eutrophic	376	56°
Wintergreen (Michigan)	Eutrophic	369	43°
Sollerod 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°

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(Hecky and Guildford 1984; Planas and Hecky 1984; Hecky 1984; Hecky et. al. 1984). Due to the expected turbidity in the project reservoirs, the standard types of empirically derived models for predicting reservoir trophic response from nutrient loading and nutrient concentration relationships (e.g. Vollenweider 1975; Dillon 1975; Jones and Bachman 1976; and Larcen and Mercier 1976) are not expected to be applicable for predicting the trophic status of the project reservoirs (Rast and Lee 1978; Kerekes 1982; Mueller 1982; Walker 1982; Soballe and Bachman 1984; Edmundson, J. A. and Koenings 1985a).

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 relatively clear. However, their estimate is conservatively low since the effects of low light penetration were neglected in their analysis.

Reduction of riverine-borne suspended sediments by settling within the reservoir will result in a sediment blanket effect. Much organic material on the reservoir floor and side walls will eventually become coated and/or buried by settled (most 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 McCullough 1984).

Development of a small but viable phytoplankton population composed of primarily Bacillariophyceae, Crysophaeceae, Dinofyceae and Chlorophyceae with a microplankton community of photosynthetic bacteria and mostly unicellular Cyanophyceae is expected to be formed within the project reservoirs. 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 protozoa, bacteria, fungi and actinomycetes are expected to dominate the metabolism of 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 Insecta, Protozoa, Rotifera, and Copepoda but very low densities of Cladocera and are 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, Edmundson and Koenings 1985b).

A macrobenthic community with relatively low densities of Crustacea, Insecta, Oligochaeta, and Mollusca is expected to form immediately after impoundment. Macrobenthos densities will probably decrease after the first 5 to 10 years of reservoir aging (Wetzel 1975, Grimas 1965, Hutchinson 1967, Grimas and Nilsson 1965, Wiens and 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 lifetime. Southern Indian Lake, a subarctic Canadian reservoir, became very turbid due to increased suspended sediment concentrations when it was impounded and expanded as part of a hydroelectric project. Its fish population was seriously disrupted as a consequence of the higher suspended sediment concentration (Hecky et al. 1984; Bodaly et al. 1984; Fudge and Bodaly 1984; Bodaly and Lesack 1984). Bradley Lake, on Alaska's Kenai Pennisula, is a naturally turbid lake which is strongly affected by glacial flour at concentrations comparable to those expected for the Watana and Devil Canyon Reservoirs. It is thought to be devoid of fish, perhaps partly due to its high suspended sediment concentration (Ott Water Engineers, Inc. et al. 1981).

11.2 Biological Limnology in the Middle River Reach

Most biological activity in the middle river will occur in a different habitat location from where it occurs in the project reservoirs. While the most important site of biological activity in the reservoirs will be the water column, the most important site of biological activity in the river habitats will be the substrate and interstitial spaces of the streambed. The water column above the streambed is expected to be of minimal importance to the overall riverine biological productivity and trophic status (Hynes 1970; Cummins 1974; Moore 1977; Kawecka et al. 1978; Barton and Lock 1979; Ward and Stanford 1979; Cushing et al. 1980; Vannote et al. 1980; Newbold et al. 1981; Murphy et al. 1981; Ward et al. 1982; Minshall et al. 1983; Conners and Naiman 1984; Soballe and Bachmann 1984; Lloyd 1985; Peterson et al. 1985b; Reub et al. 1985).

Studies of lower trophic levels (ADF&G 1985b; Richards et al. 1985; Van Nieuwenhuyse 1985), rearing juvenile salmonids (e.g. ADF&G 1985 a and c), and observations by many biologists concur that biological productivity in the middle river is relatively low at all trophic levels. These observations are in agreement with those made on several other lotic habitats having the characteristics of glacial streams or on streams strongly affected by fine sediments (Hynes 1970; Steffan 1971; Ward and Stanford 1979; Ward et al. 1982; Milner 1983; Van Stappen 1984; Lloyd 1985).

Apparent reasons for the relatively low productivity of the middle river are that a combination of natural factors are currently producing less than optimum habitat conditions for many types of organisms suited to live there. Among the more important natural factors which currently help to minimize biological productivity in the middle reach and which will be altered by the project are: an unfavorable hydrologic regime involving large discharge fluctuations; and a natural sediment transport regime which causes substantial habitat degradation. Alterations of the natural sediment transport regime are among the more biologically important changes expected to be induced by the project.

The natural cycle of primary production in the middle river appears to have two periods of maximal activity: during spring (April - May), and during fall (October - November) (Van Nieuwenhuyse 1985). Both of these periods of high primary production and buildup of epilithic standing crops (periphyton biomass is dominated by Hydrarus sp., Spirogyra sp., Zygnemas sp., and a variety of mobile and sessile pennate diatoms) appear to be inversely related to the natural cycle of sediment transport. Three substantial effects of the extant sediment regime are among the primary factors which minimize the metabolic activity and standing crop accumulation of epilithic communities during the summer: 1) particulate scour; 2) sedimentation of streambed substrates; and 3) light limitation due to high turbidity. Were it not for the latter effects, the June - September season would probably also be a period of high primary production accompanied by accumulation of large standing crops of epilithon, thus creating a more productive river habitat at the primary producer and higher trophic levels.

Spring freshets in the middle river initiate the summer period of prolonged, severe scour and sedimentation of streambed substrates. Much of the organic detritus and recent growths of epilithon left over from the previous spring, winter and fall are presumably flushed from riverine habitats, and perhaps swept from the river altogether. Fresh supplies of living or detrital organic particulates which may serve as food for detritivores and benthic invertebrates are practically prohibited from accumulating or from growing in most mainstem affected habitats because of the harsh environmental conditions.

During freshets and summer runoff, the largest and most stable exposed substrates (which make the best spots for microbial colonization) are in zones of major channels that are associated with relatively high water velocities. They are also in very low light zones, are frequently embedded

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APPENDIX

APPENDIX A - 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  200001001003700 40 2  50 00
 20000 656          50  10000        320100 3    00
  8500  22                 050 40     20  0 2    30
 17500 327  20 0    31 415000 90 10250  4 40 23 60 6
 42600 600100 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 012      1   56 714000120 15200  0    36 90 5
  3000   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 300012 0  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
 140000149000110  1 90 142000 70   070 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 560011 0 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
 86800 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 16500  4 10     00
  9360   3      0  0  5 2  450150  2 30 30 10  4 20
 144000 450 59 0    26 216000 20  4270  5 10 19 50
 2070001450 37 0  0 75 330000140 16700 10 10 40140 7
  7700   4 21  0     3 0  390160  1 30 20 10  6 60
 88600 326 34  2    20 715000 90 33410  6 30 22 5020
 173000 920 29 0    90 520000 50 96500  7 02 36160 6
  4000   9           2 1  300 65    30 17     1 10
 54000 526          20 5 990000190 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

PROBLEM CODE....................METALS
NUMBER OF VARIABLES.............. 17
NUMBER OF CASES.................. 38
NUMBER OF TRANSGENERATION CARDS.. 0
NUMBER OF VARIABLES ADDED........ 0
NUMBER OF VARIABLE FORMAT CARD(S) 01

TRANSGENERATION (IF ANY) OCCURS BEFORE ITEM DELETION

VARIABLE FORMAT CARD(S)
(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)

MEANS AND STANDARD DEVIATIONS

VARIABLE	MEAN	STANDARD DEVIATION	NUMBER OF ITEMS
01	58606.8421	51892.5819	38
02	500.9722	450.7574	36
03	3.0450	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	12015.5263	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	38
17	10.0000	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\$	0.44120	0.04265	0.77120	0.02150	0.32017

		(38)	(36)	(20)	(14)	(09)	(35)	(33)	(38)	(36)	(25)
02	*	0.73130 (36)	1.00000 (36)	-0.01270 (19)	0.04017 (14)	0.00000$ (08)	0.65045 (34)	0.30078 (31)	0.92403 (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)	0.04017 (14)	0.05444 (08)	1.00000 (14)	0.00000$ (07)	0.10410 (14)	-0.14007 (14)	0.12954 (14)	-0.20064 (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	*	0.44120 (35)	0.65045 (34)	0.59737 (20)	0.10410 (14)	0.00000$ (09)	1.00000 (35)	0.30420 (31)	0.66341 (35)	0.11400 (33)	0.49978 (25)
07	*	0.04265 (33)	0.30078 (31)	0.32106 (19)	-0.14007 (14)	0.00000$ (09)	0.30420 (31)	1.00000 (33)	0.15007 (33)	0.46336 (32)	0.34319 (23)
08	*	0.77120 (30)	0.92403 (36)	-0.02258 (20)	0.12954 (14)	0.00000$ (09)	0.66341 (35)	0.15007 (33)	1.00000 (38)	0.10005 (36)	0.49939 (25)
09	*	0.02150 (36)	0.25354 (34)	0.23073 (19)	-0.20064 (13)	0.00000$ (08)	0.11400 (33)	0.46336 (32)	0.10005 (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 (30)	0.09967 (36)	-0.12569 (20)	0.11304 (14)	0.00000$ (09)	0.60253 (35)	0.14932 (33)	0.93063 (30)	0.11033 (36)	0.34512 (25)
12	*	-0.20690 (33)	0.03250 (31)	-0.09270 (19)	0.60729 (12)	0.00000$ (07)	0.04009 (32)	-0.10662 (30)	0.01737 (33)	0.01053 (31)	0.26635 (23)
13	*	0.10239 (20)	0.16927 (27)	0.07706 (17)	-0.01641 (09)	0.00000$ (06)	0.39350 (26)	0.21490 (23)	0.34104 (20)	-0.01249 (26)	0.55377 (20)
14	*	-0.04309 (10)	-0.22467 (10)	0.59114 (05)	0.12051 (06)	0.00000$ (02)	0.43691 (09)	-0.20377 (10)	-0.23560 (10)	-0.30749 (10)	0.34272 (06)
15	*	0.50199 (20)	0.70963 (20)	0.20899 (12)	-0.22745 (06)	0.00000$ (02)	0.47731 (20)	0.44943 (10)	0.71090 (20)	0.24232 (20)	0.40101 (16)
16	*	0.63750 (30)	0.04020 (36)	0.07415 (20)	0.12444 (14)	0.00000$ (09)	0.70529 (35)	0.19044 (33)	0.07219 (30)	0.24179 (36)	0.44061 (25)
17	*	-0.10303	-0.23705	-0.09301	-0.30320	0.00000$	-0.21700	0.10434	-0.20206	0.13000	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)	0.10239 (28)	-0.04309 (10)	0.50199 (20)	0.63750 (30)	-0.10303 (25)	(
02 *	0.09967 (36)	0.03250 (31)	0.16927 (27)	-0.22467 (10)	0.78963 (20)	0.84028 (36)	-0.23705 (23)	(
03 *	-0.12569 (20)	-0.09270 (19)	0.07706 (17)	0.59114 (05)	0.20899 (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$ (00)	(
06 *	0.60253 (35)	0.04009 (32)	0.39350 (26)	0.43691 (09)	0.47731 (20)	0.70529 (35)	-0.21700 (23)	(
07 *	0.14932 (33)	-0.10662 (30)	0.21498 (23)	-0.20377 (10)	0.44943 (10)	0.19044 (33)	0.10434 (25)	(
08 *	0.93063 (30)	0.01737 (33)	0.34104 (20)	-0.23560 (10)	0.71090 (20)	0.07219 (30)	-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 (30)	-0.02005 (33)	0.32706 (28)	-0.17112 (10)	0.04022 (20)	0.00396 (30)	-0.22300 (25)	(
12 *	-0.02005 (33)	1.00000 (33)	0.04130 (24)	-0.41120 (00)	-0.00155 (20)	-0.00477 (33)	-0.10760 (23)	(
13 *	0.32706	0.04130	1.00000	0.23965	0.39794	0.54714	-0.20915	

```
          (   20)  (   24)  (   20)  (   09)  (   16)  (   20)  (   19)  (

14  *  -0.17112 -0.41120  0.23965  1.00000  0.47602 -0.13975 -0.49931
          (   10)  (   08)  (   09)  (   10)  (   06)  (   10)  (   09)  (

15  *   0.04822 -0.00155  0.39794  0.47602  1.00000  0.01230 -0.61577
          (   20)  (   20)  (   16)  (   06)  (   20)  (   20)  (   13)  (

16  *   0.00396 -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
===>
===>
===>
===>
===> LI
===>
===>
===>
===>
===>
===> FLUSH
===> HARD0
 MAP:      1563X492*OUT       00 OF=4    P=3    C=36
```