PRELIMINARY DRAFT

IMPACT ASSESSMENT TECHNICAL MEMORANDUM

# WATER QUALITY

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# INTRODUCTION

## PURPOSE

This document assesses several water quality issues relative to the proposed upper Susitna River basin hydroelectric development. Since fish species present in the Susitna River drainage are dependent, to a certain degree, on natural instream water quality, studies were initiated (in the beginning phases of Susitna environmental investigations) to address the potential adverse or beneficial effects of water quality parameters on fish.

This report is one in a series on various aquatic impact issues associated with the Susitna Hydroelectric Project. These issues--instream temperature, water quality, turbidity, instream ice, and bedload--will be examined in each of five technical memoranda. These synopses of impacts will ultimately form the foundation for a comprehensive impact assessment report. After each of the five documents has been adequately reviewed, we will integrate them into a draft impact assessment report. The Alaska Power Authority and Harza-Ebasco intend to utilize the impact assessment technical memoranda to discuss issues with agencies and intervenors in the Susitna licensing process.

Impact issues were defined in the course of the Susitna licensing process. After the Federal Energy Regulatory Commission (FERC) reviewed the original license application and the Alaska Power Authority corrected deficiencies and provided supplemental information, the license application was found acceptable. FERC then proceeded with the preparation of an Environmental Impact Statement (EIS). The decision to prepare an EIS set in motion a chain of events in accordance with Council on Environmental Quality mandates (Vide 40 CFR 1500). Scoping meetings were held by FERC staff to determine the significant issues to be analyzed in depth in the environmental impact statement and to identify and eliminate from detailed study issues which were not significant or which were covered by prior environmental review.

Issues deemed important for assessment in the EIS included twelve fishery issues. One of these, Issue No. F-2, identified salmon and resident fish habitats and populations downstream of the dams as topics to be addressed. Sub-issue F-2.6 is the significance of change in water quality parameters (nutrients) on salmon and resident fish habitats and populations downstream of the dams (Sus 472).

Environmental field investigations and analyses of existing published and unpublished information have been conducted in order to provide accurate statements of expected impact of the Susitna project on water quality and fish resources. The data base and the statements of anticipated effects have been scrutinized by agency and intervenor representatives in a series of workshops and discussions. Suggested refinements to the data base and/or the impact statements have been obtained from these discussions. Ultimately, the Alaska Power Authority intends to "settle" each issue with the agencies and intervenors; that is, agreement will be sought on the adequacy of the information base, the impact statements, and the proposed mitigation for undesirable impacts. This agreement or settlement would provide the basis for license articles or stipulations authorizing construction and operation of the Susitna project.

This document, therefore, summarizes work accomplished to date on the water quality issue. It is intended to serve as a discussion document, for it contains a presentation of the issue, a brief synopsis of the relevant information base, the ramifications of altered water quality to aquatic habitats and fish, and the projected effects on fish due to various modes of Susitna project operation.

Finally, this document is intended to be a working tool, a decision-making aid. Other reports containing voluminous data and analyses of water quality changes and effects on fish are heavily referenced. We have not repeated detailed information presented elsewhere unless required for clarity. Presented are statements of effect or no effect and the confidence with which we make those statements.

## SCOPE

This document describes the process of impact assessment; that is, it illustrates how the impact assessment for the water quality issue was conducted. A moderate information base exists with which to assess the effects of the Susitna project on water quality parameters and fish resources. Meteorologic, hydrologic, and water quality data have been collected for nearly five years. With this information and other data, analyses have been forwarded discussing the likelihood of change in water quality due to the project and the effects on fish expected from this change. The mechanisms of impact, or how changes in water quality adversely or beneficially affect fish, are presented. This is done so that reviewers can scrutinize the methods and techniques employed in deriving impact statements from the existing information base and review assumptions used when making predictions of unmeasured events. Also presented are analyses of the degree of control the project will have over water quality parameters.

This report does not delve into flow-related, hydraulic impacts; these are addressed in the Instream Flow Relationships Report Series (Sus 455). However, since water quality is affected to a certain degree by river discharge level, an evaluation of the effects of ~~various~~ flow regimes is presented. Included is an assessment of the adequacy of the existing information base for addressing the issue and, where warranted, suggestions for improving the analysis. The analytical tools available for conducting this impact assessment are discussed, including a presentation of the strengths, weaknesses, and limitations of the models employed for simulating unobserved conditions. Suggestions for mitigating undesirable with-project effects are also provided. However, this is not a mitigation report; substantial information in this vein can be examined in other documents, most notably work accomplished by Woodward-Clyde Consultants (Sus 422).

The significance of the issue and associated impacts, both adverse and beneficial, are discussed. The magnitude of the fish resource to be impacted is quantified to the extent feasible and to the extent that the existing information base would reasonably permit. Since most of the impacts expected from operation of the Susitna project are in the middle river reach, the size of the fish populations there is presented relative to the population size of Susitna River drainage fish stocks as a whole.

## STATEMENT OF THE PROBLEM

Water quality in the impoundment zone will change under with-project conditions from its natural lotic character to an essentially lentic character. The reservoirs (especially Watana) will act as traps for 70-90% of the incoming sediment normally transported by the upper river during the open water season (May-October) and will subject incoming flow to seasonal patterns of thermal stratification and community metabolism which will measurably alter the quality of the outflow. This change in water quality combined with changes in the quantity of downstream flow will alter habitat conditions along the entire length of the middle river during the open water season and in both the middle and lower rivers during the winter months. Thus, a 240-mile reach will be affected by impoundment.

The water quality parameters of greatest biological significance that will likely be changed under with-project conditions include: temperature, total suspended sediment concentration (TSS), turbidity, total recoverable and dissolved metal concentrations (including some heavy metals), macronutrient concentrations, and total organic carbon concentrations. Temperature is addressed in a separate issue paper as are TSS, turbidity, and total organic carbon. This paper will thus focus on the remaining parameters as well as pH, dissolved oxygen concentration, and total dissolved gas supersaturation.

## METHODS AND PROCEDURES

Short of conducting field and laboratory experiments, the principal tools available to assess the water quality impacts associated with impoundment of the Susitna River are: 1) the historical baseline water quality and flow records collected by the USGS; and 2) the body of information in the literature concerning water quality processes in lakes and reservoirs.

The procedure used to prepare this assessment consisted of: 1) reviewing the literature concerning post-impoundment water quality effects elsewhere in the world; 2) identifying the principal physical, chemical, and biological processes which together alter the water quality of an impounded river; 3) deducing on the basis of baseline and forecasted data which processes would likely result in substantial changes in the natural water quality regime of the Susitna River; and 4) identifying which parameters would be most affected in the Susitna River and describing any likely ecological consequences.

Exhaustive literature reviews conducted by AEIDC and Harza-Ebasco (Tom Stuart, H-E, Anchorage, pers. comm.) revealed no studies concerning the impoundment of glacial rivers and relatively few studies on downstream water quality effects. Thus, most of the conclusions presented here are based on qualitative analogies drawn from documented events associated with reservoirs studied for the most part in temperature latitudes, taking into account the glacial character and lower water temperatures displayed by the Susitna River. Impacts are assessed for both the one- and two-dam scenarios as well as for the construction and filling phases of the proposed projects.

# THE INFORMATION BASE

## BASELINE DATA

The main body of data describing the natural water quality characteristics of the Susitna River is found in the U.S. Geological Survey (USGS) "Water Resources Data for Alaska" annual report series. This information is summarized through 1981 in R&M Consultants, Inc. and L.A. Peterson and Assoc. (1981a, b). These data are collected routinely on a monthly basis by the USGS at its gauging stations located at Denali (1957-), Vee Canyon (1962-), and Gold Creek (1949-) on the upper and middle Susitna River; the Chulitna River (1958-); the Talkeetna River (1954-); and at its Sunshine (1971-) and Susitna stations (1955-) on the lower Susitna River. Data collected by R&M Consultants at Vee Canyon and Gold Creek from 1980-82 are summarized in R&M Consultants, Inc. (1982). Limited additional data for mainstem, slough, and tributary sites can be found in various Alaska Department of Fish and Game reports (ADF&G, Su-Hydro 1981).

Water quality data collected at Vee Canyon can be used to describe some of the chemical characteristics of the water that will flow into Watana reservoir (Table 1). The basic pattern these data present for the upper river is similar in most respects to the annual cycle displayed in the middle river for which a much more complete and longer data record is available. The most significant difference is the absence of dissolved gas supersaturation at Vee Canyon. Other minor differences (e.g., higher mean pH, potassium, and chemical oxygen demand levels in summer and a lower mean turbidity) can be attributed either to the influence of clearwater tributaries entering upstream of the station or to the relatively small number of data points available for analysis.

Table 1. Mean baseline water quality characteristics for upper Susitna River at Vee Canyon under summer (May-August) and winter (October-April) conditions.

| Parameter (Symbol of Abbreviation) | Units of Measure | Summer USGS[1] | Summer R&M[2] | Winter USGS[1] | Winter R&M[2] |
|---|---|---|---|---|---|
| Total Suspended Solids (TSS) | mg/1 | 799 | 358 | 14 | 6.0 |
| Turbidity | NTU | 70 | 156 | 0 | 1.3 |
| Total Dissolved Solids (TDS) | mg/1 | 94 | 98 | 136 | 141 |
| Conductivity | ($\mu$mhos $cm^{-1}$, 25°C) | 146 | 129 | 250 | 212 |
| pH | pH Units | 7.7 | 7.6 | 7.4 | 7.1 |
| Alkalinity | mg/1 as Ca $CO_3$ | 52 | 61 | 112 | 81 |
| Hardness | mg/1 as Ca $CO_3$ | 63 | 58 | 96 | 103 |
| Sulfate ($SO_4^{-2}$) | mg/1 | 14 | 6 | 13 | 14 |
| Chloride (Cl) | mg/1 | 5.3 | 6.7 | 17 | 17.5 |
| Dissolved Calcium ($Ca^{+2}$) | mg/1 | 21 | 18 | 30 | 33 |
| Dissolved Magnesium ($Mg^{+2}$) | mg/1 | 2.7 | 2.4 | 3.8 | 5.2 |
| Sodium ($Na^{+}$) | mg/1 | 3.8 | 3.4 | 6.5 | 8.0 |
| Dissolved Potassium ($K^{+}$) | mg/1 | 3.5 | 2.3 | 3.7 | 5.2 |
| Dissolved Oxygen (DO) | mg/1 | 11.5 | 11.9 | 12.6 | 13.1 |
| DO (% Saturation) | % | 99 | 101 | 97 | 98 |
| Chemical Oxygen Demand (COD) | mg/1 | 20 | 20 | 9 | 10 |
| Total Organic Carbon (TOC) | mg/1 | -- | -- | -- | 2 |
| True Color | pcu | 10 | 70 | -- | 15 |
| | | Dissolved | | | Dissolved |
| Total Phosphorus | $\mu$g/1 | 60 | 140 | 40 | 50 |
| Nitrate-Nitrogen as N ($NO_3$-N) | mg/1 | 0.20 | 0.14 | 0 | 0.30 |
| Dissolved Cadmium (Cd) | $\mu$g/1 | -- | -- | -- | -- |
| Dissolved Copper (Cu) | $\mu$g/1 | -- | -- | -- | -- |
| Dissolved Iron (Fe) | $\mu$g/1 | -- | 1.10 | -- | 0.37 |
| Dissolved Lead (Pb) | $\mu$g/1 | -- | -- | -- | -- |
| Dissolved Mercury (Hg) | $\mu$g/1 | -- | -- | -- | -- |
| Dissolved Nickel (Ni) | $\mu$g/1 | -- | -- | -- | -- |
| Dissolved Zinc (Zn) | $\mu$g/1 | -- | .07 | -- | -- |

1 R&M Consultants, Inc. 1982; R&M Consultants L.A. Peterson and Assoc. 1981.
2 R&M Consultants, Inc. 1982.

The water quality records for Gold Creek (RM 136) provide the best possible description of baseline conditions in the middle river and can also be used to approximate many characteristics of the Watana reservoir inflow (Table 2).

Natural water quality conditions in the middle river change seasonally as a result of changes in mainstem flow and sediment content. During winter, surface flows average less than 2,000 cfs and are derived almost entirely from groundwater or outflow from the Tyone River system. Thus, total dissolved solids (TDS) and alkalinity, for example, are at their highest annual levels, while temperature, total gas concentrations, total suspended solids (TSS), turbidity, and the trace metals and phosphorus associated with inorganic particulates are at their lowest levels of the year. The maximum observed dissolved Cd, Cu, Hg, and Zn concentrations recorded at Gold Creek were 1, 5, 0.2, and 14 µg/l, respectively. Most of the riverbed surface area is covered in winter by thick ice and deep snow with the exception of peripheral channels bearing upwelling groundwater and channels carrying very fast moving mainstem water (velocity leads).

Although surface flow is low and water temperatures are between 0 and 4 C, benthic algal and invertebrate growth is taking place during this five- to six-month period and supporting a large percentage of the overwintering fish community of the system.

Breakup usually occurs in May following a brief (three to four week) spring transition period of increasing temperatures, lengthened photoperiod, and accelerating ice and snow melt. Middle river stream flow rapidly increases from approximately 5,000 cfs to 20,000 cfs, while fluctuating suspended sediment concentrations average approximately 360 mg/l (Peratrovich et al. 1982) generating mean turbidities of less than 50 NTU.

Table 2. Mean baseline water quality characteristics for middle Susitna River at Gold Creek under summer (May - September) and winter (October - April) conditions.

| Parameter (Symbol or Abbreviation) | Units of Measure | Summer | Winter |
|---|---|---|---|
| Total Suspended Solids (TSS) | mg/l | 740 | 12 |
| Turbidity | NTU | 126 | <1 |
| Total Dissolved Solids (TDS) | mg/l | 93 | 154 |
| Conductivity | ($\mu$mhos $cm^{-1}$, 25°C) | 128 | 279 |
| pH | pH units | 7.3 | 7.5 |
| Alkalinity | mg/l as $CaCO_3$ | 51 | 72 |
| Hardness | mg/l as $CaCO_3$ | 64 | 98 |
| Sulfate ($SO_4^{-2}$) | mg/l | 16 | 21 |
| Chloride ($Cl^{-1}$) | mg/l | 5.5 | 22 |
| Dissolved Calcium ($Ca^{+2}$) | mg/l | 20 | 30 |
| Dissolved Magnesium ($Mg^{+2}$) | mg/l | 3.2 | 5.4 |
| Sodium ($Na^{+}$) | mg/l | 4.1 | 11.3 |
| Dissolved Potassium ($K^{+}$) | mg/l | 2.4 | 2.3 |
| Dissolved Oxygen (DO) | mg/l | 11.9 | 13.9 |
| DO (% Saturation) | % | 102 | 97 |
| Chemical Oxygen Demand (COD) | mg/l | 10.9 | 8.4 |
| Total Organic Carbon (TOC) | mg/l | 2.0 | 2.6 |
| True Color | pcu | 10 | 5 |
| Total Phosphorus | $\mu$g/l | 130 | 30 |
| Nitrate-nitrogen as N ($NO_3$-N)[1] | mg/l | 0.12 | 0.16 |

Table 2. (cont'd)

| Parameter (Symbol or Abbreviation) | Units of Measure | Turbid (Summer) | Clear (Winter) |
|---|---|---|---|
| Total Recoverable Cadmium[2] [Cd(t)] | μg/l | 1 | - |
| Total Recoverable Copper [Cu(t)] | μg/l | 65 | ND |
| Total Recoverable Iron [Fe(t)] | μg/l | 16,000 | ND |
| Total Recoverable Lead [Pb(t)] | μg/l | 50 | ND |
| Total Recoverable Mercury [Hg(t)] | μg/l | 0.12 | 0.04 |
| Total Recoverable Nickel [Ni(t)] | μg/l | 65 | 45 |
| Total Recoverable Zinc [Zn(t)] | μg/l | 50 | 50 |

ND = None Detected

Source: U.S. Geological Survey as summarized in R&M Consultants (1982).

1 Data collected by R&M Consultants, 1980-82 (R&M Consultants 1982).

2 All trace metals are U.S.G.S. data as summarized in R&M Consultants (1981); winter values are for Sunshine Station.

Under normal weather conditions, approximately 90% of the total annual streamflow occurs between May and September with maximal discharges in June, July, and August. These summer discharge maxima are typically between 30,000 and 40,000 cfs. These high summer flows, resulting largely from surface runoff and glacial melting in the headwaters, serve to dilute the dissolved solids load derived from bedrock and soil weathering. Thus, such parameters as TDS and alkalinity are at their lowest annual levels, while temperature, TSS, turbidity, total recoverable trace metals, and total phosphorus are at their highest annual levels.

Water entering Devil Canyon in summer is generally nearly saturated with dissolved gases (mostly oxygen, nitrogen, and minute amounts of argon), but becomes supersaturated by the aerating action of rapids and the pressurization which occurs in plunge pools within Devil Canyon. The degree of gas supersaturation increases with discharge. This flow effect has been documented for discharges ranging between 10,000 and 32,500 cfs (ADF&G Su-Hydro 1983 Basic Data Report) and naturally occurring supersaturation conditions as high as 116% have been observed at the mouth of Devil Canyon. Water can remain supersaturated as far downstream as Curry (Dana Schmidt, ADF&G Su-Hydro, personal comm.). No instances of gas bubble disease embolisms in fish have been documented to date, however.

A brief (one-month) fall transition period typically begins in late September and extends through most of October during which mainstem flows average between 6,000-12,000 cfs. TSS concentrations and turbidity levels decline rapidly and the resulting hydraulic and light transmission properties of the river are generally at their most favorable for algal growth wherever suitable substrate exists. Preliminary estimates indicate that the quantity of algal biomass produced daily in the middle river alone during this period may exceed 30,000 metric tons.

The water quality records for Susitna Station (RM 25) provide the best possible description of baseline conditions in the lower river (Table 3). By the time water flowing from the middle river reaches the Susitna gauging station, it has been diluted over fivefold by flows from the glacial Talkeetna, Chulitna, and Yentna Rivers as well as numerous smaller clearwater tributaries. The annual pattern of water quality conditions in the lower river is similar to the pattern displayed by the middle river. Generally, the lower river displays lower TDS concentrations year-round than the middle river, while mean TSS concentrations are approximately the same. Despite the similarity of mean TSS concentration, lower river water tends to be nearly twice as turbid and higher in total phosphorus and most trace metal concentrations than the middle river. This indicates a longitudinal change in the particle size composition of the sediment load as it is transported through the system (i.e., lower river water carries a higher proportion of finer sediment particles which exert a greater turbidity per unit weight and offer more surface area for adsorption of phosphorus and trace metals than the relatively larger particle sizes transported in the middle river). This increase in total recoverable concentrations does not appear to be attended by increased concentrations of dissolved phosphorus or trace metals, either in winter or summer. The maximum observed dissolved Cd, Cu, Hg, and Zn concentrations recorded at Susitna station were 1, 7, 0.2., and 20 μg/l, respectively.

Table 3. Mean baseline water quality characteristics for lower Susitna River at Susitna Station under summer (May - September) and winter (October - April) conditions.

| Parameter | Units | Summer | Winter |
|---|---|---|---|
| Total Suspended Solids (TSS) | mg/l | 745 | 5 |
| Turbidity | NTU | 233 | 1.5 |
| Total Dissolved Solids (TDS) | mg/l | 73 | 123 |
| Conductivity | μmhos $cm^{-1}$, 25°C | 122 | 205 |
| pH | pH units | 7.7 | 7.3 |
| Alkalinity | mg/l as $CaCO_3$ | 44 | 69 |
| Hardness | mg/l as $CaCO_3$ | 54 | 85 |
| Sulfate ($SO_4^{-2}$) | mg/l | 13.2 | 17.3 |
| Chloride (Cl) | mg/l | 2.7 | 13 |
| Dissolved Calcium ($Ca^{+2}$) | mg/l | 17 | 27 |
| Dissolved Magnesium ($Mg^{+2}$) | mg/l | 2.5 | 4.3 |
| Sodium ($Na^{+}$) | mg/l | 2.7 | 7.7 |
| Dissolved Potassium ($K^{+}$) | mg/l | 1.4 | 1.7 |
| Dissolved Oxygen (DO) | mg/l | 11.5 | 11.6 |
| DO (% Saturation) | % | 97 | 80 |
| Chemical Oxygen Demand (COD) | mg/l | - | - |
| Total Organic Carbon (TOC) | mg/l | 4.4 | 1.6 |
| True Color | pcu | 10 | 0 |
| Total Phosphorus | μg/l | 400 | 50 |
| Nitrate-nitrogen as N ($NO_3$-N) | mg/l | .0 | 0.19 |
| Total Recoverable Cadmium [Cd(t)] | μg/l | 9 | 8 |
| Total Recoverable Copper [Cu(t)] | μg/l | 50 | 30 |
| Total Recoverable Iron [Fe(t)] | μg/l | 20,000 | 500 |
| Total Recoverable Lead (Pb(t)] | μg/l | 100 | 80 |
| Total Recoverable Mercury [Ng(t)] | μg/l | 0.12 | 0.04 |
| Total Recoverable Nickel (Ni(t)] | μg/l | 75 | 13 |
| Total Recoverable Zinc [Zn(t)] | μg/l | 50 | 50 |

## FORECASTED DATA

Few quantitative forecasts of with-project water quality conditions in the impoundment zone or downstream are presently available. Detailed, quantitative predictions regarding reservoir temperature profiles and middle river temperatures under a wide range of meteorological and hydrological scenarios are found in APA (1984) and AEIDC (1984). The results of these intensive modeling efforts and a discussion of environmental consequences are presented in a separate issue paper and will only be briefly summarized here.

The temperature profile of any reservoir varies with hydrologic and meteorologic conditions as well as the morphology of the reservoir and its operational schedule for any given year. The Watana reservoir will be long, narrow, and deep with a relatively short hydraulic residence time (Table 4). The topography of the impoundment area will provide little opportunity for the development of an extensive littoral zone. The general annual temperature profile pattern for Watana Reservoir will be characterized by a fall turnover in November roughly coincident with the formation of an ice cover during which isothermal conditions of approximately 4 C will prevail. This will be followed by inverse stratification in which epilimnetic temperatures will drop from near 0 C at the surface to approximately 2.5 C near the metalimnion. Hypolimnetic temperatures will approach 4 C. This condition will usually persist until May or June. During the summer, the epilimnion will gradually warm with maximal surface temperatures of 10-13 C occurring in August and September. Stratification will remain in place until the turnover in November. Available forecasts indicate that a spring turnover might also occur in June during unusually dry years (e.g., 1974-75).

Table 4. Selected morphometric and hydrologic features of the Watana and Devil Canyon reservoirs.

| Parameter | Watana | Devil Canyon |
|---|---|---|
| Maximum Length (l) | 48 mi (77 km) | 26 mi (42 km) |
| Mean Width ($\bar{b}$) | 1.25 mi | 0.46 mi |
| Maximum Surface Area ($A_m$) | 60 $mi^2$ | 12 $mi^2$ |
| Volume (V) | $9.5 \times 10^6$ ac ft ($11.7 \times 10^9 m^3$) | $1.1 \times 10^6$ ac ft ($1.4 \times 10^9 m^3$) |
| Maximum Depth ($Z_m$) | 735 ft (223 m) | 565 ft (171 m) |
| Mean Depth ($\bar{Z}$) | 250 ft (76 m) | 140 ft (42 m) |
| Relative Depth (Zr) | 1.6% | 2.7% |
| Shoreline (L) | 183 mi (295 km) | 76 mi (123 km) |
| Shoreline Development ($D_L$) | 6.7 | 6.2 |
| Mean Hydraulic Residence Time | 1.65 yrs | 60 days |
| Normal Drawdown | 120 ft (36.6 m) | 50 ft (15.2 m) |

Based on: Acres American 1983.

(Sus. Hydro Project, Fed. Energy Reg. Comm. License App, Exhibit F, Supporting Design Report, (Preliminary), Feb. 1983, by Acres.)

Model forecasts for downstream river temperatures show a general dampening of the variations that occur naturally and this will affect conditions as far downstream as Talkeetna. Mean summer river temperatures under Watana only would be approximately 1 C cooler than natural at river miles (RM) 150 and 130, and 0.6 C cooler at RM 100. Addition of the Devil Canyon dam would increase this seasonal change to approximately 2.0, 1.7, and 1.2 C cooler at RM 150, 130, and 100, respectively. Under both scenarios, downstream temperatures would peak later in the summer with the greatest deviation from natural temperatures occurring in September-October. Winter releases would range from 0.4 to 6.4 C from October to April. Natural winter temperatures are 0 C. These alterations in the natural temperature regime are well within the tolerance limits for adult and juvenile salmon and are not expected to significantly impact migration or spawning activity with the exception of a possible delay in chinook inmigration to Portage Creek. Some reduction of juvenile growth might occur due to cooler summer temperatures. The anticipated warmer fall and winter river temperatures could sufficiently alter both burbot and whitefish spawning and incubation timing to eliminate these species from the middle river.

A preliminary, crude estimate of with-project TSS concentrations and turbidity levels can be found in Peratrovich, et al. (1982) and a discussion of their potential ecological consequences appears in EWTA and WCC (1984). A formal reservoir modelling effort is currently underway to provide more precise estimates of anticipated TSS concentrations (Tom Stuart, Harza-Ebasco, personal communication).

Predictions regarding some of the parameters addressed in this paper are found in the original license application and these are based largely on a study conducted by L.A. Peterson and Assoc. and R&M Consultants (1982).

This study concluded that:

1. Both the Devil Canyon and Watana reservoirs will be oligotrophic based on the results obtained from the Vollenweider phosphorus loading model (Vollenweider 1976).
2. A short-term unquantifiable increase in dissolved solids, conductivity, and most of the major ions may occur after closure due to inundation and leaching of rocks and soils in the impoundment area.
3. Approximately 70-97 percent of the suspended sediment load carried into the Watana reservoir by the inflow will settle, resulting in significantly less turbid conditions in summer, but higher turbidity levels in winter.
4. Evaporative losses from both reservoirs will not exceed 1 percent of their total volume and will thus not produce a significant increase in dissolved solids concentrations.
5. The amplitude and phase of the river's annual temperature cycle will change under with-project conditions.
6. The concentrations of "many" metals will be reduced in Watana Reservoir due to precipitation and settling.
7. Both reservoirs will maintain relatively high oxygen levels because existing oxygen demand is low.
8. The reservoirs will support only low levels of phytoplankton production which will be limited by high turbidities and the presence of an ice and snow cover during the winter.

Field studies are currently being conducted by AEIDC and EWTA to develop a model that will provide quantitative estimates of the trophic status of the middle river under with-project conditions. Preliminary results will be available in June 1985.

## DATA GAPS

The USGS water quality records for the Susitna River and some of its major tributaries provide the best available information with which to perform a rigorous hydrochemical analysis. To date, this has not been done. However, the data summaries conducted by R&M Consultants do provide mean, maximum, and minimum values for a large number of water quality parameters. These values are grouped according to three seasons: winter, summer, and breakup. The use of such seasonal means, however, does not provide the best possible level of resolution for the purposes of biological interpretation and can lead to distortions. For example, R&M Consultants (1982) reports a summer mean TSS concentration for Gold Creek of 740 mg/1 based on the USGS data records and a mean of 268 mg/1 based on its own field work conducted during 1980-82. The much higher value obtained from the USGS records reflects the fact that during the glacial surges which occurred in the 1950s, USGS gathered water samples almost daily, while in later years sampling frequency dropped to just a few each year (Jim Knott, USGS, Anchorage, personal communication). Also, the use of means unaccompanied by any statistical measure of confidence interval is highly irregular.

The lack of a formal hydrochemical analysis in which the water chemistry characteristics of the Susitna River are interpreted in the context of the vegetation, soils, geology, and hydrology of its watershed makes it difficult to provide quantitative estimates of project impacts on water quality. This is exacerbated by the relative paucity of heavy metal data (especially for Vee Canyon and at all stations during the winter months) and by the lack of any quantitative baseline information on the trophic dynamics of the river. Another important data gap is the absence of any data on baseline tissue Hg levels for resident fish and land otters inhabiting the middle river or on Hg speciation. Also, only very limited water chemistry data are available for middle river sloughs and tributaries where most of the fish production of this reach originates.

For the most part these shortcomings, however, do not prevent qualitative estimates which should provide a reasonable degree of certainty regarding potential ecological impacts.

# IMPACT ANALYSIS

## BASIC CONSIDERATIONS

A variety of complex interactions determine the seasonal and spatial variations in water quality frequently observed during and long after impoundment of a river, but the most significant for forecasting general conditions in the Susitna reservoirs are temperature, trophic status, volume, and residence time. This is true because most of the negative impacts on water quality normally associated with reservoirs (e.g., oxygen deficits and winter fish kills, lowered pH and higher metals and carbon dioxide concentrations in the hypolimnion, releases of hydrogen sulfide gas, etc.) are biologically induced, either directly or indirectly, and are thus highly dependent on temperature and on the amounts and rates of organic carbon supply to the hypolimnion. A large volume ensures that products of hypolimnetic decomposition or chemical reduction are highly diluted, while a short residence time limits the amount of time available for such processes to take place.

The Watana Reservoir will have a large volume, a short residence time, low temperatures, and low levels of autochthonous productivity. These factors, combined with the high levels of suspended sediment that will be carried in by the inflow to blanket the inundated soils and vegetation on the reservoir bottom, will be conducive to relatively good reservoir water quality conditions compared to many reservoirs and lakes located in temperate latitudes. Thus, while the morphology and glacial character of the Susitna River essentially eliminate many of the problems normally associated with reservoirs (affecting such parameters as pH, dissolved oxygen, dissolved solids, phosphorus, nitrogen, and total organic carbon), they also pose new, largely unmitigable problems, especially with respect to potential downstream impacts. The most important among these relates to downstream suspended sediment concentrations.

A common problem from which the Susitna River will perhaps not be exempt is elevated trace metal concentrations. The implications of an altered sediment transport regime are discussed in a separate issue paper so this paper will focus largely on questions concerning with-project trace metal concentrations and related parameters. Another water quality concern is the potential for releasing supersaturated water below the dams. This topic will be addressed first.

## NITROGEN SUPERSATURATION

Dissolved gas supersaturation occurs downstream of some hydroelectric facilities and, if at sufficiently high levels (generally >115%), can have chronic or lethal effects on aquatic organisms (Boyer 1973, Fickeison and Schneider 1976). When aquatic organisms encounter supersaturated water, the dissolved air diffuses through their respiratory organs and its concentration within the body approaches an equilibrium dictated largely by ambient water temperature and pressure. When the organism moves to an area of lower pressure or higher temperature, the gases dissolved in the blood and other body fluids, come out of solution resulting in embolisms that block circulation and disrupt normal tissue structure. Even though dissolved gas concentrations in excess of 115% supersaturation have been measured below Devil Canyon (ADF&G 1982), no detrimental biological effects have ever been observed. As we have seen, gas supersaturation does not naturally occur upstream of Devil Canyon (Table 1).

High head dams produce gas supersaturation by one or more of three mechanisms:

1. Spillway releases plunging into stilling basins entrain air bubbles to sufficient depths to force excess gas into solution.

2. Withdrawal of cold (4 C) $N_2$- saturated water from the high pressures prevailing in the hypolimnion of a reservoir, exposes the water to the warmer, lower pressure conditions existing at the surface, thus causing supersaturation.

3. Leakage of air into power turbines exerts sufficient pressure to force excess air into solution.

The potential for disruption of downstream aquatic communities depends on the level, duration, timing, and downstream extent of supersaturation events, as well as on the species, age, and condition of the organisms exposed. For example, smaller organisms (e.g., macroinvertebrates and juvenile fish) are less sensitive to the harmful effects of gas supersaturation than larger organisms (Fickeison and Schneider 1976; Dawley et al. 1975). Large releases of supersaturated water during the period of adult salmon inmigration (midsummer to fall) would, thus, presumably have greater negative effects on fish production than similar releases occurring at other times of the year.

The activities associated with construction of the proposed dams will not result in unnaturally high levels of gas supersaturation. The present design for Watana Dam calls for multilevel intakes that will withdraw water only from the top 120 ft. of Watana Reservoir. These levels are well above the hypolimnion, but should deeper intake structures be added, they would likely only be used during the winter in an effort to increase downstream water temperatures above the natural winter level of 0 C. Powerhouse flows will be discharged beneath the tailwater surface to prevent entrainment of air. Controlled releases designed to fulfill environmental stipulations or to pass flood flows will be routed through six Howell-Bunger cone valves with a combined capacity of 24,000 cfs. These cone valves will release water in a spray, thus preventing plunging and gas supersaturation. Without Devil Canyon Dam, the releases from Watana Dam will still pass through the entire length of Devil Canyon, resulting in supersaturation. The levels of supersaturation, however, should not exceed natural levels except possibly when spillway releases become necessary during 1-in-50-year flood events. Natural dissolved gas concentrations under such flood conditions are not known so it is not possible to determine to what extent, if any, entrainment of air into spillway plunge pools might increase gas supersaturation levels downstream of Devil Canyon or whether the length of the downstream reach affected would be significantly greater. Under such extreme circumstances, the possible negative effects associated with gas supersaturation would pale in comparison to the disruptions caused by strictly physical processes.

Devil Canyon Dam will withdraw water from the upper 50 ft. of the reservoir via two intake structures. Four turbines with a rated capacity of 3,680 cfs will discharge powerhouse flows via a 6,000-foot-long tailrace tunnel that will bypass the lower portion of Devil Canyon rapids and release water below the tailwater level. With both dams in place, the amount of water released downstream from the proposed project will exceed the mean annual flood of 50,000 cfs only during 1-in-50-year flood events. Thus, except on rare occasions, dissolved gas concentrations below Devil Canyon will always be lower than under natural conditions.

## DISSOLVED OXYGEN, pH, AND MACRONUTRIENTS

Whether or not the impoundment zones are cleared of vegetation prior to inundation, both Watana and Devil Canyon Reservoirs are likely to experience some decline in hypolimnetic dissolved oxygen concentration (Campbell et al. 1975; Smith and Justice 1975; Therien et al. 1982). Given the relatively large volumes and short residence times of the reservoirs, however, the potential for discharging oxygen deficient (<5 mg/l) water downstream is minimal. If it should occur, the reaerating action of the cone valves and the Devil Canyon rapids will quickly eliminate any saturation deficit and thus preclude potential negative impacts on downstream aquatic communities.

The buffering capacity afforded by its moderate alkalinity levels presently maintains a slightly alkaline pH in the Susitna River (Tables 1-3). Seasonal fluctuations naturally range between 6.0 and 8.1, a range typical of North American freshwater (Wetzel 1975). Approximately 8,300 acres of wetland vegetation will be flooded by impoundment with both dams in place. Of this, less than 1,200 acres (or about 2.7 percent of the total impounded area) all classified as "bog-like" by the U.S. Fish & Wildlife Service. Flooding of such a relatively small area of acidic bog habitat is unlikely to produce any perceptible change in pH levels, either in the reservoirs or in downstream riverine habitats (see Allan 1978; Baxter and Glaude 1980; Campbell et al. 1975; Duffer and Harlin 1971; Duthie 1979; Geen 1975; Gunnison et al. 1983; L.A. Peterson et al. 1982; Smith and Justice 1975).

The concentrations of either biologically available phosphorus or nitrogen (or both) typically limit the basic biological productivity or trophic status of an inland water body. In the case of clearwater lakes, the relationship between macronutrient concentrations and trophic status is fairly well established (Wetzel 1975). For glacial lakes and for river in general, however, other regulating factors often take precedence, thus complicating efforts to classify their trophic status strictly in terms of macronutrient concentrations. In the case of the Susitna River, the principal "complicating factor" is the seasonal pattern of light limitation imposed by the river's natural turbidity regime.

However, to evaluate the extent to which existing or with-project macronutrient concentrations might limit the productivity of the Susitna River, it is reasonable to adopt the trophic classification scheme for clearwater lakes as a lower limit.

Natural phosphorus and nitrogen concentrations in the Susitna River display great seasonal variability ranging from below detection to levels more than ample to support moderate algal biomass (10-20 µg/l total P and <500 µg/l total N) or even high biomass (>20 µg/l total P and >500 µg/l total N). However, substantial amounts of algal growth occur throughout most of the river only during periods of moderate flow and low (<20 NTU) turbidity (i.e., during transition periods in the fall and spring). This information strongly suggests that productivity is not limited by macronutrient concentrations throughout most of the open water season, but rather by lack of light and by scour and sedimentation of the streambed. Likewise, based on the fact that algal blooms in streams frequently occur below sewage outfalls and the results of recent studies in Iowa indicating nutrient limitation in streams (Bushong and Bachman 1985), it is likely that the productivity of the Susitna River during these transition periods is limited by concentrations of biologically available phosphorus and nitrogen. Without further study, however, it is impossible to state how much of the total P measured in Susitna River water at any given time becomes biologically available and thus to predict what the lower limit of primary productivity might be under such circumstances.

Since the bulk of the macronutrient load of the Susitna River is presently associated with suspended sediment particles, the project reservoirs will act as nutrient sinks and phosphorus and nitrogen exports to downstream areas should be reduced (Hannan 1979; Wetzel 1975). Based on available data for glacial lakes, however, it can be expected that the trophic status of both Watana and Devil Canyon reservoirs will be oligotrophic and will be limited by turbidity rather than nutrient levels (Koenings 1985).

Predictions regarding the trophic status of downstream habitats are less easy to make. Just as downstream flow and turbidity levels will be much more stabilized under with-project conditions, so too will annual patterns of primary productivity. Thus, the large pulses of productivity observed in the spring and especially in the fall, under natural circumstances, will likely be attenuated; while summer levels may increase, producing a steadier, but lower level pulse of longer duration. If downstream with-project turbidities are greater than 20-30 NTU, it is extremely likely that the magnitude of this productivity will be limited (as in the reservoirs) by light and not by with-project macronutrient concentrations.

## TRACE METAL CONCENTRATIONS

The potential for increased trace metal concentrations following impoundment and any likely ecological consequences within the resulting reservoirs or downstream have not previously been addressed, either in the license application or in subsequently published project documents. The nature and extent of these potential changes are of considerable importance, especially for downstream salmon and resident fish populations since fish densities in the reservoirs themselves are likely to be very low and largely unexploited by man. As in the case of with-project suspended sediment transport, the potential change in the seasonal pattern of trace metal transport in the Susitna River will affect both its middle and lower reaches.

The main concern is not that elevated heavy metal concentrations will result in fish kills or even impede growth and propagation, but rather that even small increases in bioavailable heavy metal concentrations in reservoir and riverine water will cause sufficiently large increases in fish tissue heavy metal (especially mercury) contents to render the meat unfit for human (or other animal) consumption.

Under natural conditions, the Susitna River has displayed concentrations of aluminum (Al), bismuth (Bi), cadmium (Cd), copper (Cu), iron (Fe), manganese (Mn), mercury (Hg), nickel (Ni), and zinc (Zn), that exceed water quality criteria established for the protection of freshwater organisms (R&M Consultants and L.A. Peterson and Assoc. 1981). Of these, only Fe can be considered relatively nontoxic, while Cd, Cu, Hg, and Zn are known to be highly toxic to aquatic organisms depending on the forms and concentrations in which they are present, the species, condition, and age of the exposed organisms, and a variety of physiochemical properties of the water (e.g., temperature, hardness, dissolved oxygen concentration, pH) (Welch 1980, Forstner and Wittmann 1979).

No data are available at this time which could be used to determine what proportion of these naturally high metal concentrations is bioavailable nor what their background levels are in the tissues of fish, invertebrates, or benthic algae inhabiting the Susitna River. Muscle tissue in rainbow trout collected from Nancy Lake, however, contained very high levels (1000 ppb) of mercury (presumably methylmercury) (Tom Stuart, Harza-Ebasco, pers. comm.). The meat in a can of tuna averages 250 ppb (EPA 1980).

Of the four heavy metals of concern here, biomagnification has been documented only for Hg as a direct result of impoundment (Bodaly et al. 1984, Abernathy and Cumbie 1977, Cox et al. 1979, Meister et al. 1979). This metal will thus be addressed first.

## MERCURY

An examination of the USGS Water Resource Data reports reveals that total Hg concentrations in the Susitna River naturally range from zero to 0.8 µg/l while dissolved Hg varied between 0 and <0.5 µg/l. The latter are on the high end of the range of dissolved Hg concentrations found in unpolluted North American surface waters (Moore and Ramamoorthy 1984) and well above the 0.01 µg/l global average for freshwater (Forstner and Wittmann 1979). Approximately 25 to 50% of the total Hg transported by the river is in dissolved form. Typically, this percentage is less than ten (Jackson et al. 1978, Lockwood and Chen 1973, Moore and Ramamoorthy 1984, Rudd et al. 1983). Presumably, the bulk of this dissolved Hg load is bound to humic substances (i.e., humics, humic acids, fulvic acids, and yellow organic acids) which have been shown to contribute about 60% to 80% of the dissolved organic carbon of freshwaters (Reuter and Perdue 1977). The attractive forces between Hg and these humic substances range from weak (physical adsorption) to strong (chelation). This mobilization of Hg by organic matter facilitates the transformation of elemental Hg to mercuric ion ($Hg^{+2}$) which in turn is the substrate for microbial methylation. It is in the methylated form that Hg is most toxic. A variety of bacteria and fungi are capable of transforming $Hg^{+2}$ (both in organic and inorganic form) to methylmercury even in well oxygenated water (Forstner and Wittmann 1979) thus releasing it to the water itself and into the food chain. Fish become contaminated with methylmercury either directly, by absorbing it through their skin and gills, or indirectly from the food they consume (EPA 1980). Once absorbed or ingested, the uptake rate is very fast, while excretion is extremely slow. Thus, bioconcentration factors for fish can be as high as 10,000 times ambient levels in the water (EPA 1980).

Available literature strongly suggests that mercury levels in resident fish inhabiting Watana and Devil Canyon reservoirs will increase by an unquantifiable amount within one to three years after closure of the dams (Abernathy and Cumbie 1977, Bodaly et al. 1984). With aging of the reservoirs, and recruitment and mortality within reservoir fish populations, Hg concentrations in fish tissue should decline, but may always remain higher than baseline levels. The release of methylmercury through microbial action in the inundated organic soils of the reservoirs should be slowed to some extent (perhaps as much as 50%) by the prevailing cold (4 C) water temperatures (Wright and Hamilton 1982) and by the blanketing action of inflowing sediment settling to the reservoir bottoms (L.A. Peterson and Assoc. 1982). The cold temperatures may, however, also act to extend the length of the reservoir aging process compared to reservoirs located in warmer regions (Bodaly et al. 1984). Also, the low level of primary productivity anticipated for the limited phytoplankton community of the reservoirs should act to minimize increases in methylmercury bioaccumulation in fishes (Rudd and Turner 1983b).

No information is available in the literature concerning Hg enrichment in fish downstream of newly impounded reservoirs. Whether or not this process will be enhanced downstream of the Susitna reservoirs depends largely on which form of Hg is exported from the reservoirs and in what concentrations. Another important factor will be the with-project trophic status of the river after impoundment.

After impoundment, as now, most of the Hg transported by the river will be adsorbed to suspended sediment particles in an inorganic form. Some reduction in this inorganic Hg load can be expected as a result of settling in the reservoirs, but the amount of this reduction will not be directly proportional to the mass of sediment lost to the reservoirs. This is because the finer particles transported by the river after impoundment offer a greater surface area for adsorption in proportion to their mass than the larger particles (>5-10μ) that will settle out in the reservoirs.

The concentrations of methylmercury that might be released by the reservoirs cannot be quantified at this time. It is likely that releases will rise sharply during the first 5 to 10 years after closure and will then decline gradually over the life of the project. Concentrations downstream, however, will reflect not only the quantities released by the reservoirs, but in situ mobilization as well. The latter process could be greatly accelerated by an increase in primary productivity levels brought on by reduced with-project turbidities downstream. By increasing the amount of organic carbon available for microbial decomposition, methylmercury formation would increase. Because of its high enrichment capacity, even a small increase in ambient methylmercury concentrations could result in very high concentrations in the tissues of downstream fish, especially resident species. Assuming these fish are presently safe to eat, such an increase could make them unfit for human consumption in the future. The only way to mitigate for such an event would be to monitor Hg content in fish tissues after impoundment and inform the public if any danger exists.

CADMIUM

Cadmium (Cd) concentrations in the Susitna River are presently relatively low. Total Cd ranges from 0 to 10 μg/l and dissolved concentrations greater than 3 μg/l have never been recorded (R&M 1982). The global average for dissolved Cd in freshwater is 0.07 μg/l (Forstner and Wittmann 1979).

No documented instances of Cd leaching from soils inundated by impoundments exist, but it could occur. However, given its low natural levels in the Susitna drainage, it does not seem likely that its enrichment in fish inhabiting the reservoirs or downstream habitats will be significantly accelerated under with-project conditions. If acceleration does occur for Cd, it will most certainly occur for Hg as well.

COPPER

Copper (Cu) is an essential micronutrient for plants which performs several vital enzymatic functions and plays a major role in chlorophyll syntheses. It is also important in invertebrate blood chemistry and the synthesis of hemoglobin. Natural total Cu concentrations in the Susitna River range from <10 μ/l to 190 μg/l; dissolved concentrations range from 0 to 12 μg/l (R&M 1982). The average concentration of soluble Cu in U.S. freshwater is 15 μg/l (EPA 1976). Holland (1960) reports a dissolved Cu concentration of 178 μg/l as producing acute toxicity in juvenile chinook salmon tested in water of similar temperature, pH, alkalinity, and hardness as Susitna River water.

Copper concentrations will likely increase somewhat after impoundment, but given its high affinity for humic substances (Schnitzer and Khan 1982), almost all of the dissolved Cu will be in the organocomplexed form which is significantly less toxic to aquatic organisms than either free Cu ions or hydroxocopper. No studies have revealed any biomagnification of Cu following impoundment so the risk of negative impacts to Susitna River fish stocks is low. It is possible that increases in Cu concentrations might be offset to some extent by increased uptake by a more productive, with-project benthic algal community.

## ZINC

Zinc (Zn) is also a micronutrient which becomes toxic when present in excess concentrations. Total Zn levels in the Susitna River vary from 10 to 200 μg/l; dissolved levels from 0 to 30 μg/l. The world average for freshwater is 10 μg/l dissolved Zn (Forstner and Wittmann 1979). As for Cu, the toxicity of Zn to aquatic organisms depends on the form in which it is present and on the pH, temperature, alkalinity, and hardness of the ambient water. The TL50 (the concentration of dissolved Zn lethal to 50% of the organisms tested after 96 h of exposure) is reported by Herbert and Shurben (1964) as 910 μg/l for juvenile rainbow trout tested in water of comparable summertime alkalinities and pH levels to the Susitna River (although water temperature was 17.7 C).

No reports of elevated Zn concentrations either in or downstream of newly impounded reservoirs are available. If this were to occur in the Susitna River, it is doubtful that they would be of sufficient magnitude to impair the growth and propagation of aquatic organisms. As in the case of Cu, almost all of the dissolved Zn would be chelated or otherwise bound to humic substances.

## SUMMARY AND RECOMMENDATIONS

Impoundment of the Susitna River at Watana and Devil Canyon will substantially alter the annual water quality regime of approximately 240 miles of the river. In addition to changing the annual pattern of sediment transport (discussed in a separate issue paper), impoundment will, under both the one- and two-dam scenarios, result in:

1. reduced nitrogen supersaturation levels below Devil Canyon during the summer months, and increased levels during the winter months that in either case will exceed 110% only under extreme (1-in-50-year) flood conditions;

2. a net reduction in downstream macronutrient transport by virtue of the settling action of the reservoirs on suspended sediment particles >10-15μ in beta diameter;

3. essentially no change in dissolved oxygen and pH levels, except perhaps in the hypolimnion of the reservoirs in winter; and

4. potentially higher concentrations of bioavailable mercury, cadmium, copper, and zinc with the strong possibility of biomagnification of methylated mercury both in the reservoirs and downstream.

Since no incidents of gas bubble disease have been observed in the Susitna River in over five years of intensive study, it is unlikely that reductions in summer nitrogen supersaturation levels will have any noticeable positive impact on downstream fish production. Likewise, since winter levels will be below 110%, no harmful effects are likely to result from the relative increases anticipated for winter months.

The reservoirs created by impoundment will be relatively unproductive (oligotrophic) and phytoplankton growth will be limited year-round by prevailing turbidity levels other than macronutrient concentrations. The net reduction of macronutrient transport downstream will probably not effect downstream trophic status unless with-project turbidity levels approach 20-30 NTU. Even under these circumstances, the supply of bioavailable nitrogen and phosphorus could very well exceed the demand.

The potential for increased mercury bioaccumulation in reservoir and downstream aquatic organisms will not likely threaten fish production, but could render the meat of resident species unfit for human (or other animal) consumption. This negative impact should be most acute during the first 1-10 years after closure and should decline thereafter. Resident fish tissue mercury levels will likely be higher than baseline levels throughout the life of the project, however.

The chain of events leading to fish production in any waterbody is only as strong as its weakest link. For the Susitna River, the "weakest link" appears to be fish food production which in turn is based largely on primary (benthic algal) production. Algal productivity in the Susitna River is regulated by a host of physical factors (e.g., desiccation, freezing, temperature, unstable substrate, scour, and sedimentation) and by water quality, especially turbidity and macronutrient concentrations. Under natural conditions, the river appears to alternate between light limitation and nutrient (and perhaps temperature) limitation on a roughly six-month cycle.

Based on field observations, the transition between the two phases apparently occurs when turbidities reach 20-30 NTU.

The "weakest links" in the chain of studies conducted to assess the potential impact of the proposed Susitna Hydroelectric Project are the lack of any baseline primary productivity data and the failure to perform any formal hydrochemical analyses. Field studies designed to address the relationship between primary productivity and the factors that presently limit it (and will likely limit it under with-project conditions) are presently underway. Final results will be available in December 1985. The need for a formal hydrochemical analysis, combined with baseline assessments of heavy metal speciation and mercury levels in resident fish tissues should be obvious, especially in light of the fact that <u>all</u> water quality impacts (with the exception of nitrogen supersaturation) are entirely unmitigable. It is therefore recommended that:

1. a formal analysis of the water chemistry characteristics of the Susitna River be performed by a reputable chemical hydrologist as soon as possible, and that the results be made available to the Aquatic Studies Team in time for the FERC hearings scheduled to begin in ~~the fall of~~ 1985;

2. data on baseline levels of mercury in resident fish tissues be gathered and that this effort be incorporated into any with-project monitoring plan; and

3. primary productivity in middle river habitats be monitored for at least five years after closure of the dams in order to assist in the interpretation of any with-project changes in fish production (as measured by an outmigrant monitoring program).

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