PRELIMINARY DRAFT

IMPACT ASSESSMENT TECHNICAL MEMORANDUM

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INTRODUCTION

PURPOSE

This document is a comprehensive assessment of with-project sediment transport, instream temperature, water quality, turbidity, and instream ice effects on fish with the proposed upper Susitna River basin hydroelectric development. Impoundment of the upper Susitna River and reservoir operation would cause a change in the natural pattern of stream discharge and temperature effecting habitat for Susitna River drainage fish. Impact issues addressed in this report were defined in the course of the Susitna licensing process. Following Federal Energy Regulatory Commission (FERC) acceptance of the Alaska Power Authority license application FERC initiated preparation of an Environmental Impact Statement (EIS). This decision set in motion a chain of events in accordance with Council on Environmental Quality mandates on EIS preparation (40 CFR 1500). Significant issues to be analyzed in depth in the EIS were identified during scoping meetings; twelve of these pertained to fish (issues F-1 through F-12, inclusive).

Since 1980, APA has commissioned a series of field and literature investigations to provide accurate statements of the expected with-project environment as an aid for conducting an impact assessment. Over the years these products have been repeatedly scrutinized by agency and intervenor representatives in a series of workshops and discussions. This process of peer review has refined the data base and predictions of environmental change thereby enhancing their reliability.

This document is intended to serve as a discussion document and as an aid to decision-making. It contains a presentation of the issues, brief synopses of the relevant information bases, and the projected effects on fish due to various modes of Susitna project operation. It does not contain voluminous data and analyses of sediment and river morphology. Statements of effect or of no effect and the confidence with which those statements are made are provided.

STATEMENT OF THE PROBLEM

The proposed project is sited in the upper Susitna River drainage basin and consists of two dams to be constructed over a period of about 15 years. The first dam, known as the Watana Dam, would be completed near RM 184 at a site three miles upstream from Tsusena Creek. It would include an underground powerhouse and an 885 ft high earthfill dam and a reservoir approximately 50 miles in length. This reservoir would have a surface area of 38,000 acres and a usable storage capacity of 3.7 million acre-feet (maf). The second dam, named Devil Canyon, would be built near RM 152 at a site 33 miles downstream of the Watana dam site. It would be 645 ft high and would impound a 26-mile-long reservoir, having a surface area of 7,800 acres and a usable storage capacity of 0.36 maf (Acres American, 1983).

Construction and subsequent operation of the two Susitna hydroelectric dams is expected to alter the normal sediment transport and temperature regimes of the river, thereby influencing its fish resource. With both dams on-line, the area between Devil Canyon (RM 152) and the Oshetna River (RM 235) would be converted from a lotic to a lentic system. After impoundment, these reservoirs would resemble naturally occurring, deep, glacial lakes (Acres 1983). Sediment trap efficiencies of the Watana Dam alone and of the Watana and Devil Canyon dams together have been estimated by modeling and by fitting data to two different reservoir sedimentation curves (Harza-Ebasco Susitna Joint Venture 1984a). Results indicate that the dams would trap between 78 to

100% of all sediment entering the reservoirs (Harza-Ebasco Susitna Joint Venture 1984a). This, coupled with regulated with-project flows, would noticeably affect instream environments downstream of the dams in several ways.

Suspended load and bedload would be markedly reduced from those seen naturally. This situation would prevail to a point downstream of the Talkeetna and Chulitna rivers respective confluences with the Susitna. Because of their very large sediment loads relative to the mainstem, input from the Talkeetna and Chulitna rivers with-project would dominate the Susitna's sediment load in a manner analogous to present (R&M 1982a; Harza-Ebasco Susitna Joint Venture 1984a). Partly as a consequence of reduced sediment load and partly because of the with-project flow regime, the main channel of the Susitna River above the confluence with the Talkeetna would have a tendency to narrow and, in spots, degrade (R&M 1982a; Harza-Ebasco Susitna Joint Venture 1985). Some sloughs and tributary streams would become perched and some mainstem habitats could become dewatered as a result (R&M 1982a; Harza-Ebasco Susitna Joint Venture 1885; R&M and EWT&A 1985). In time, the river bed would also dampen the effects of freshets, reducing instances of flood waters entering sloughs. These changes could effect fish population numbers.

Water quality in the impoundment zone will change under with-project conditions from its natural lotic character to an essentially lentic character. As indicated, the reservoirs (especially Watana) would trap most incoming sediment transported by the upper river during the open water season (May-October). They would also subject incoming flow to seasonal patterns of thermal stratification which would measurably alter the quality of the outflow. This change in water quality combined with changes in the quantity of downstream flow would 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 would be affected by with-project.

The water quality parameters of greatest biological significance that would 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.

Operation of either a single- or two-dam hydroelectric project would reduce the natural variation in river temperatures. Mean summer river temperatures under a Watana-only scheme would be approximately 1.0 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, 33 miles downstream from Watana, would increase this mean seasonal temperature deviation at RM 150, 130, and 100 to approximately 2.0, 1.7, and 1.2 C cooler, respectively (AEIDC 1984). Under either project configuration, downstram temperatures would peak later in the summer than at present, with the greatest deviation from natural conditions occurring in September and October. Winter reservoir releases would range from 0.4 to 6.4 C in waters normally at 0 C from approximately October to April (AEIDC 1984). Consequently, river ice formation would be delayed and, in some cases, would not reach as far upstream as under natural conditions.

Inflows from tributaries below the dam would buffer the effect of the project, with larger tributaries having a greater effect. The Chulitna and Talkeetna rivers, which join the Susitna River within two miles of each other near RM 98, add a combined flow that is greater than that of the middle Susitna River alone (on an annual basis). Thus, these two rivers have a considerable buffering effect on Susitna water temperatures below their confluences. There is a faily large temperature difference within a cross-sectional transect below the juncture of these three rivers. This apparently results from delayed mixing of the plumes of each of the three rivers for a distance of nearly 25 miles downstream. Downstream of this mixing area, little change in the natural regime would be expected from with-project releases.

Construction and subsequent operation of the two Susitna hydroelectric dams is expected to alter the normal ice regime of the river, thereby influencing fish and their habitats. With both dams on-line, the area between Devil Canyon (RM 152) and the Oshetna River (RM 235) would be converted from a lotic to a lentic system. After impoundment, these reservoirs would resemble naturally occurring, deep, glacial lakes (Acres 1983).

Winter reservoir drawdown would cause ice to fracture and drape over exposed banks, thereby destablizing nearshore environments. In the with-project middle river, formation timing of a contiguous river ice cover would be delayed; an extensive reach of ice-free water would occur below Devil Canyon; winter river flow volumes would be four to five times greater than natural; and ice meltout would occur earlier than normal. Portions of the river near the ice front would be subject to freezeup staging, a natural phenomena which often leads to overtopping of slough berms. With-project, however, staging would be of shorter duration than occurs naturally. With-project increased winter flows relative to natural could lower the temperature of upwelled water in sloughs; natural upwelled water temperature is believed to be an important variable of salmon incubation habitat. Breakup would no longer occur in springtime with-project because of higher than normal water temperatures and steadier stream flows. Ice would instead melt gradually in place; this would lower the potential for ice jam formation.

OVERVIEW OF ENVIRONMENTAL ASSESSMENT TECHNIQUES

Over the past 30 or so years, a variety of methods have been developed for use in evaluating environmental impacts. The impetus behind this effort was, and remains, federal resource management law. Prominent federal environmental acts (table 1) were reviewed to identify fish and wildlife impact assessment requirements. Four broad areas of public interest form common themes in environmental law: species-populations, biological integrity, environmental values, and habitat. Common methods of addressing these themes are reviewed below, as is the methodology used in this analysis.

The first class of environmental assessment techniques examined addresses the theme of species-populations. Notable federal acts calling for this type of approach include the Endangered Species Act, the Federal Nonnuclear Energy Research and Development Act, the Surface Mining Control and Reclamation Act, and the Federal Water Pollution Control Act (table 1).

Many and diverse schemes exist for estimating population numbers and density. The simplest technique, and possibly the one in widest use by managers, is the index. Population assessment indices are of two distinctly different types. The first is a count of animals made in a manner which does not allow direct population estimation by application of sampling theory. This technique employs a sample survey in the absence of known sampling probabilities. Many ADF&G fish escapement surveys are of this type. The second kind of index is one based on complete counts of some known portion of a population, e.g., salmon on redds in a given reach of river. This approach allows one to conduct a relatively intensive and statistically valid analysis by incoporating basic knowledge of a species life history with the count data. Multiple regression analysis is the most frequently used tool in this regard.

Table 1. Federal acts which independently and collectively establish minimum standards for environment impact assessment.

Archeological and Historic Preservation Act, 16 U.S.C. 469, _et seq_.
Clean Air Act, as amended, 42 U.S.C. 7401, _et seq_.
Coastal Zone Management Act, 16 U.S.C. 1451, _et seq_.
Endangered Species Act, 16 U.S. C 1531, _et seq_.
Estuary Protection Act, 16 U.S.C. 1221, _et seq_.
Federal Land Policy and Management Act, 43 U.S.C. 1701, _et seq_.
Federal Nonnuclear Energy Research and Development Act, 42 U.S.C. 5901 _et seq_.
Federal Water Pollution Control Act, 33 U.S.C. 1251, _et seq_.
Federal Water Project Recreation Act, 16 U.S.C. 460-1(12), _et seq_.
Fish and Wildlife Coordination Act, 16 U.S.C. 661, _et seq_.
Forest and Rangeland Renewable Resources Planning Act, 16 U.S.C. 1601, _et seq_.
Land and Water Conservation Fund Act, 16 U.S.C. 4601 - 4601-11, _et seq_.
Marine Protection, Research and Sanctuary Act, 33 U.S.C. 1401, _et seq_.
National Environmental Policy Act, 42 U.S.C. 4321m _et seq_,
National Historic Preservation Act, 16 U.S.C. 470a, _et seq_.
National Forest Management Act, 16 U.S.C. 472, _et seq_.
Rivers and Harbors Act, 33 U.S.C. 403, _et seq_.
Soil and Water Resources Conservation Act, 16 U.S.C. 2001, _et seq_.
Surface Mining Control and Reclamation Act, 30 U.S.C. 1201, _et seq_.
Water Resources Planning Act, 42 U.S.C. 1962, _et seq_.
Watershed Protection and Flood Prevention Act, 16 U.S.C. 1001, _et seq_.

More involved methods of population assessment include direct counts and variants of the mark, release, and subsequent recapture technique. Direct counts are best in terms of validity, but naturally turbid conditions in the Susitna drainage hamper its use there. Over the last decade, the ADF&G and the USFWS have expended much effort in improving electronic fish counters for use in turbid conditions. This work has greatly influenced census work in many glacially-moderated systems.

Mark-recapture techniques have a relatively long history of use in the United States. However, while widely used and under continual evolution, none of them produce overly satisfying results in a statistical sense. This is because all mark-recapture techniques rely on a range of assumptions which are difficult to meet in the wild (e.g., one common assumption is that there exists a well defined population of animals; another is that the average probability of observing a marked animal is equal to the average probability of observing an unmarked animal).

Biological integrity analyses are the next class of environmental assessment techniques examined. The chief pieces of legislation calling for their use are the Federal Water Pollution Control Act and the National Environmental Policy Act (table 1). If fully applied, a biological integrity, i.e. ecosystem, approach would document energy flow through the system allowing one to precisely predict overall effects of change. In practice this is never done because it is very labor intensive and, thus, too costly. Instead, it is common to narrow the scope of work by singling out a few representative species and/or relationships for study. Field study is typically undertaken to document seasonal numbers of target species in the study (often without regard to their relationship to local or regional populations), their habits (e.g., special use areas), and food resources.

Such assessments have increasingly made use of models (some elaborate, some not) to predict with-project effects. A number of factors limit the veracity of conclusions reached by this approach. Chief among these is that conclusions reached are subjectively applied ad hoc to the system as a whole.

Consideration of economic and environmental values (the third of the four areas of public interest addressed by federal law) is the essence of the National Environmental Policy Act. This approach to impact assessment usually entails estimating the monetary and nonmonetary values of the resources to be affected. A relatively large number of techniques for this purpose exist; none are overly satisfying. Implementation of a values approach to impact assessment is (and will continue to be) limited by the difficulty (some would say the impossibility) of setting values on often intangible environmental components such as aesthetics.

The fourth environmental impact assessment theme recognized by federal law is habitat analysis. The principal laws legitimizing this approach are the Federal Land Policy and Management Act, the Fish and Wildlife Coordination Act, the Forest and Rangeland Renewable Resources Planning Act, the Endangered Species Act, and the Surface Mining Control and Reclamation Act (table 1).

Various techniques are available for characterizing habitat quality. For example, species diversity is often used as an index of habitat quality. This type of index accounts for both numbers of species and numbers of individuals of each species in each habitat type. The species diversity approach has been challenged on a number of grounds. For example Wiens (1978) points out that it is insensitive to which species are present (i.e., it treats rare and common species alike), while Inhaber (1976) notes the absence of a standard of comparison (a problem of all biological indices).

Another habitat based impact assessment approach is the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures (HEP). HEP is a species-habitat approach; habitat quality is denoted through use of an index derived by evaluating the ability of key habitat components to supply the life requisites of the subject species. Its chief limitation is that predictions made are applicable only for the species being evaluated, i.e., it does not directly relate that species to other ecosystem components.

The U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM), another habitat based approach, is closely related to HEP in logic. It too focuses on target species relationships with their habitat, defined as Weighted Usable Area (WUA). Water depth, velocity, and substrate data are coupled with habitat suitability curves to compute WUA. The chief limitation of this approach is that it fails to take into account the effects of with-project change on factors such as growth, competition, mortality, and movement. These limitations are at the heart of a recent benchmark judicial ruling (Energy Management 1984) against use of the IFIM and in favor of a less rigorous, more qualitative, approach.

METHODS AND PROCEDURES

The existing Susitna River Information base consists of a mix of quantitative and qualitative data and model results: some is compatible, some is not. It is strongly biased towards habitat descriptors. Natural and with-project environmental parameters are well known, as are the likely responses of aquatic organisms to changes of the types predicted. Given this, a habitat based impact assessment is the logical technique of choice for the Susitna River study.

The sediment transport analysis was accomplished by comparing predictions of the with-project environment with information on fish distribution, abundance, and habits and on known fish and invertebrate response to perturbations of the types predicted. Professional judgement was used as necessary to interpret the relationship between various data base components, i.e., the relative comparability and utility of quantitative information vs. qualitative information vs. model runs.

To assess effects of with-project changes in sediment transport on instream biota, AEIDC first reviewed the information base on how sediment affects aquatic organisms (Appendix E). Pertinent Susitna River specific information (i.e., data on sediment effects on the biota) is not broad in scope, consisting only of preliminary primary production data and ocular estimates of the appearance of in-slough spawning gravels following floods. Where necessary, information from other areas and latitudes was used to aid in the analysis. This factor imposed no constraint on conclusions reached because organisms respond to sediments in similar ways worldwide. Next, information on Susitna River fish stocks was assembled and synthesized (Appendix A). Following this, estimates of with-project environmental changes (and the information and procedures used in deriving them) were reviewed. These are based on sediment transport studies. Both the information base on fish stocks and that on the with-project sediment regime are adequate for use in an effects analysis. These three steps (determining how various life forms are affected by sediment, compiling information on the fish resource, and reviewing project sediment studies) provided the basis for predicting effects of the with-project sediment transport regime on aquatic organisms.

To assess the effects of with-project instream and in-reservoir temperatures, on fish, AEIDC firs reviewed available information on how fish respond to different thermal conditions (Appendix C). Ideally, information used in an effects analysis should be specific to the water body in question and to its particular community of organisms. Little site specific information exists on the effects of temperature changes on Susitna River fish necessitating the use of information from other areas and latitudes. Professional judgement was used to ascertain the applicability of each piece of information to the area of concern. Generally, information proximal to the Susitna River was judged to be more pertinent than data from other areas of Alaska, which in turn was usually more useful than information from more southerly latitudes. Once the information was assembled it was synthesized to evolve a number of evaluation criteria. These criteria included temperature ranges believed to be capable of supporting adult spawning migrations, spawning, incubation, rearing, and smolt migrations. This process is described in detail in a 1984 AEIDC report.

A number of terms used in this analysis need definition. The term "selected" or "preferred" temperature is defined as that range of temperatures in which fish naturally congregate (or spend the most time), given a free choice situation (reynolds 1977; Alabaster and Lloyd 1982). Each life stage of every fish species has a characteristic temperature tolerance range as a consequence of acclimatization -- the physical adaption to environmental conditions. The tolerance range of fish changes as they become acclimatized to warmer or cooler waters. The acclimation process is moderated by temporal and thermal factors; fish require relatively more time to acclimatize to large shifts in temperature than to small ones. Thus, this process spans a period of hours or days depending on the magnitude of the temperature shift. It involves a "biophysical and biochemical restructuring of may cellular and tissue components for operation under the new thermal regime imposed on the organism" (Fry and Hochachka 1970). Once a new rate of metabolism has been established, the fish is considered acclimatized. Temperatures beyond the tolerance range are referred to as incipient lethal temperatures, upper and lower thresholds where temperatuer begins to have a lethal effect. Above or below incipient lethal temperatures, survival depends on the duration of exposure with mortality occurring more rapidly with greater deviation from the threshold. An upper boundary above which survival is virtually zero is often referred to as the critical thermal maximum (CTM). No critical thermal minimum short of freezing has been established for salmon.

Thermal tolerance and preference ranges were established during the course of this study for the five Pacific salmon species found in the Susitna Drainage (AEIDC 1984). These limits were based on the literature, laboratory studies, field studies, and observed Susitna Drainage temperatures. Tolerance zones were established for each life phase activity excluding incubation (see below for our method of addressing incubation). Within this range fish can expect to live and function free from the lethal effects of temperature. Insufficient information exists to adequately describe the tolerance and preference ranges of the other species found in the study basin. Susitna

River fish are acclimatized to a temperature range between 0 and approximately 18 C. The preferreed temeprature within this range for most salmonid life phases is between 6 and 12 C. The upper and lower incipient lethal temperatures for the salmon life phases, excluding incubation, fall between 13 and 18 C and 1 to 7 C, respectively.

Embryo incubaton rates rise with increasing intragravel water temperature. Accumulated temperature units, or degree-days to hatching and emergence, were determined and used as criteria for incubation. Development times were computed and plotted from Susitna-specific incubation data (ADF&G 1983e; Wangaard and Burger 1983). A regression analysis was performed; it showed that a linear relationship existed between mean incubation temperature and development rate (the inverse of the time to emergence) for chum and sockeye. A nomograph capable of predicting the date of emergence was then developed, given the date of spawning and the average temperature (AEIDC 1984).

The temperature effects analysis was performed by comparing predicted with-project temperatures to the tolerance ranges identified for the various fish life stages considered. In cases where the tolerance range was not fully determined (e.g. Arctic grayling, burbot, etc). existing knowledge was compared to predicted with-project temperatures. Because information on resident fish is incomplete, assessment of with-project effects on them is less rigorous than that for anadromous species.

The procedure used in the water quality effects analysis 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, conclusions reached are mostly 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 of the Susitna River.

To assess effects of with-project changes of the altered ice regime on instream biota, AEIDC first reviewed the information base on how instream ice affects aquatic organisms. Next, information on Susitna River fish stocks was assembled and synthesized. Following this, estimates of with-project environmental changes (and the information and procedures used in deriving them) were reviewed. These changes are based on ICECAL simulations, DYRESM reservoir ice simulations, groundwater analysis, intragravel flow and temperature analysis and sediment transport studies. Both the information base on fish stocks and that on the with-project ice regime are adequate for use in an effects analysis. These three steps (determining how various life forms are affected by different ice conditions, compiling information on the fish resource, and reviewing project ice studies) provided the basis for predicting effects of the with-project sediment transport regime on aquatic organisms.

Available information is sufficient to address with-project effects on 13 of the 19 fish species present in the project area. These are all five salmon species, eulachon, Bering cisco, burbot, round and humpback whitefish, rainbow trout, Arctic grayling, and lake trout. Tables 2, 3, and 4 summarize predicted with-project negative sediment transport-related effects on fish; tables 6 and 7 summarize negative temperature effects. Collectively, they provide an overview of anticipated negative effects by species, location, and time of year for both the Watana Dam and Watana and Devil Canyon dams together. A dimensionless ordinal scale identifies the relative severity of anticipated temperature and sediment transport effects on fish. Its values range from:

0 - given predictions of the with-project environment and availavle knowledge of the fish specis in question, no negative effects are likely.

1 - the with-project environment could negatively influence a species life stage, but the effects should be relatively minor.

2 - given available information, the with-project sediment transport regime would negatively affect fish productivity.

3 - available information indicates that the with-project sediment transport regime may negatively affect a species productivity, but more data re needed to so state with certainty.

The veracity of conclusions reached varies by species and by river reach in consequence of differences in available information and type.

ANALYSIS

SEDIMENT TRANSPORT

ANTICIPATED NEGATIVE EFFECTS

Impoundment Zone

The following discussion explains predictions summarized in table 2. Predicted with-project sedimentation and suspended sediment levels in the impoundments would negatively influence to varying degrees all fish species present. Anticipated with-project suspended sediment loads in the reservoirs vary seasonally from a summer high of between 200 to 400 mg/L (50 NTU's) to a winter low of between 30 to 70 mg/L (10 NTU's) (Peratovich, Nottingham, and Drage 1982). Summer levels could occasionally be higher than this, especially nearshore, as storm runoff is expected to re-entrain sediment deposited during winter drawdown (Peratovich, Nottingham and Drage 1982). Following extensive review of sediment effects on North American benthic and planktonic communities and on population, reproduction, and species composition of fish, Newport and Moyer (1974) concluded that water bodies having suspended sediment concentrations above 100 mg/L year round were unlikely to support a viable year round sport fishery. The reasons for this are many but chiefly concern the effects of sediment on aquatic organism respiration efficiency. Suspended inorganic sediment can mechanically damage and interfere with oxygen transport across membranes (McCart and DeGraaf 1974; Cordone and Kelley 1961).

Table 2. Anticipated relative negative with-project sediment transport effects on impoundment zone fish.

Fish Species	Watana Operation Effects Scale[1]	Watana Operation Date	Devil Canyon Operation Effects Scale	Devil Canyon Operation Date
Chinook salmon	--	--	0[2]	--
Arctic Grayling				
adult migration	0	--	0	--
spawning	0		0	
incubation	0	--	0	--
rearing	1	Oct-Apr	1	Oct-Apr
Lake Trout				
adult migration	0	--	0	--
spawning	2	Aug-Dec	2	Aug-Dec
incubation	2	--	2	--
rearing	1	Oct-Apr	1	Oct-Apr
Whitefish[3]				
adult migration	0	--	0	--
spawning	0	--	0	--
incubation	0		0	
rearing	1	Oct-Apr	1	Oct-Apr
Rainbow Trout				
adult migration	0	--	0	--
spawning	0	--	0	--
incubation	0	--	0	--
rearing	1	Oct-Apr	1	Oct-Apr
Burbot				
adult migration	0	--	0	--
spawning	1	Jan-Feb	1	Jan-Feb
Incubation	3	--	3	--
rearing	1	--	1	--
Longnose Sucker				
adult migration	0	--	0	--
spawning	0	--	0	--
incubation	0		0	
rearing	1	Oct-Apr	1	Oct-Apr

[1] 0 - no concern
1 - low
2 - moderate to severe
3 - possible

[2] The Devil Canyon dam would block upstream passage of chinook salmon, a few of which spawn in Cheechako Creek (RM 152.5) and Chinook Creek (RM 156.8); with-project sediment transport would not negatively influence habitats there.

[3] This table is applicable to both humpback and round whitefish.

The with-project sediment transport regime would most affect lake trout and burbot, the only two impoundment zone species which naturally reproduce in lake environments. Lake trout normally spawn in fall over the gravel substrates of clearwater lakes. The combined effects of lake drawdown and winter sedimentation would generally limit in-reservoir reproduction rates by this species. Embryos which were not dehydrated by receding reservoir water levels in winter (i.e., those spawned below the lower low water level) would face the consequences of sediment build-up on natal beds (i.e., oxygen deprivation). Burbot spawn in winter under the ice and over gravel in either lakes or streams. This species population could be held in check by the anticipated pattern of winter sedimentation also, but too little is known of the precise pattern of sedimentation to allow an accurate assessment of the degree, or magnitude, of its effects on burbot embyros. Burbot are broadcast spawners and can spawn in a wide range of depths. It may be that some embryos in some areas might find favorable conditions for reproduction and growth (e.g., local hydraulic conditions might produce eddies where sedimentation rates were relatively low).

Reservoir rearing habitat quality for all species would be low (table 2). Given the predicted reservoir environment in winter, it is likely that invertebrate populations there would become dominated by infauna capable of living in low oxygenated environments (see Appendix E), rather than by epifaunal fish foods such as caddis fly larvae. This would translate into lowered food availability for fish. Sedimentation would also reduce available cover afforded by cobbles and boulders making fry somewhat more susceptible to predation.

Middle River Zone

Tables 3 and 4 summarize anticipated with-project negative sediment transport effects on middle river zone anadromous and resident fish. These effects can be placed into one of two categories; those centered on the mainstem proper and those centered on slough spawning habitats. Immediately after project startup and regardless of whether one or two dams are on-line, the mainstem between Devil Canyon and its confluence with both the Talkeetna and Chulitna rivers would begin to degrade (R&M, Woodward-Clyde Consultants, and Harza Ebasco Susitna Joint Venture 1985). Mainstem degradation would continue until the bed adjusted to the new (regulated) flow volume. The river's channel would narrow as it entrenched (R&M 1982; Harza-Ebasco Susitna Joint Venture 1985). With-project mainstem degradation (coupled with regulated flows) would accelerate the natural process of slough senescence noted by AEIDC (1985). Sloughs in the natural (i.e., unregulated) environment are continually created and destroyed over time as a consequence of the slow but continuous process of river bed degradation. In its essence, the process of slough senescence begins with the perching of slough mouths by the degrading river (AEIDC 1985). In time the slough is left behind by the river and eventually it evolves into dry land (AEIDC 1985). Under natural conditions new sloughs are constantly and coincidentally created as entrained bed material is redeposited (AEIDC 1985).

Unlike natural, with-project sloughs would not complete their life cycle, nor would new sloughs be created. With-project, the effect of freshets necessary to entrain bed material for slough building would be greatly diminished. Once the bed achieved equilibrium with with-project flows, the process of slough perching would cease (Harza-Ebasco Susitna Joint Venture 1985). With-project sloughs, following a period of environmental adjustment delimited by the period of mainstem degradation, would superficially appear to be in stasis with the environment (i.e., they would not gradually make the transition to dry land). Change would be occurring, however. The dams would reduce the incidence of freshet-induced overtopping of slough berms (Harza-Ebasco Susitna Joint Venture 1984a). This would lead to a build-up of fines and coarser bed material (Harza-Ebasco Susitna Joint Venture 1984a; Blakely et al., 1985).

Immediately downstream of the Chulitna confluence with the mainstem, a zone of with-project aggradation is predicted to occur (R&M 1982, Harza-Ebasco Susitna Joint Venture 1984a). Aggradation here is likely to be significant and it may have consequence to the built as well as natural environment (R&M 1982). However, natural flow from the Talkeetna River is believed sufficient to maintain a distinct channel through this zone (R&M 1982; Harza-Ebasco Susitna Joint Venture 1984a).

The chief sediment transport problem concerns degradation of traditional slough spawning habitats for chum, pink, and sockeye salmon (table 2). As indicated above, the with-project rate of flood-induced overtopping of slough berms would be greatly diminished over natural conditions. This is predicted to result in both a buildup of intragravel fines (floods are necessary to re-entrain deposited fines thereby rehabilitating spawning beds) and a buildup of larger, coarser material deposited during each flood event (Harza-Ebasco Susitna Joint Venture 1984a, 1985). Unless mitigated, this process would eventually destroy all in-slough salmon spawning habitats by filling in gravel interstices and by altering the character of spawning substrates. Since no new sloughs would be created under the with-project sediment transport regime, this means that unless mitigated, the annual average drainagewide escapements would in time be reduced by as many as 20,000 adult chum (eight-year average

Table 3. Anticipated relative negative with-project sediment transport effects on middle river zone anadromous fish.

Fish Species	Watana Operation Effects Scale[1]	Watana Operation Location	Watana Operation Date	Devil Canyon Operation Effects Scale	Devil Canyon Operation Location	Devil Canyon Operation Date
Chinook salmon						
adult inmigration	0	--	--	--	--	--
spawning	0	--	--	0	--	--
incubation	0	--	--	0	--	--
rearing/smolting	1	sloughs	year-round	1	sloughs	year-round
outmigration	0	--	--	0	--	--
Chum salmon						
adult inmigration	0	--	--	0	--	--
spawning	1	sloughs	Aug-Sep	1	sloughs	Aug-Sep
incubation	2	sloughs	Sep-May	2	sloughs	Sep-May
rearing/smolting	1	sloughs	May-Jun	1	sloughs	May-Jun
outmigration	0	--	--	0	--	--
Pink salmon						
adult inmigration	0	--	--	0	--	--
spawning	1	sloughs	Aug	1	sloughs	
incubation	2	sloughs	Sep-May	2	sloughs	Sep-May
rearing/smolting	0	--	--	0	--	--
outmigration	0	--	--	0	--	--
Coho salmon						
adult inmigration	0	--	--	0	--	--
spawning	0	--	--	0	--	--
incubation	0	--	--	0	--	--
rearing/smolting	1	sloughs	year-round	1	sloughs	year-round
outmigration	0	--	--	0	--	--
Sockeye salmon						
adult inmigration	0	--	--	0	--	--
spawning	1	sloughs	Aug-Sep	1	sloughs	Aug-Sep
incubation	2	sloughs	Sep-May	2	sloughs	Sep-May
rearing/smolting	1	sloughs	year-round	1	sloughs	year-round
outmigration	0	--	--	0	--	--

[1] 0 - no concern
1 - low
2 - moderate
3 - possible

See text for a complete description of the effects scale.

from table 5), 500 adult sockeye (eight-year average from table 5), and 270 adult pink salmon (six-year average from table 5) unless mitigated. These numbers represent 2.4%, .08%, and .007% respectively of all chum, sockeye, and pink salmon spawning in the Susitna drainage basin in 1984.

Stream degradation at the mouths of all major middle river salmon spawning sloughs is predicted to be slight (Appendix D). Taken by itself, this can be interpreted to mean that there would be no with-project access problems for salmon. However, comparison of existing information on minimum mainstem flows necessary to allow passage of adult spawners into natal habitats (Blakely et al., 1985; Sautner, Vining, and Rundquist 1984) and knowledge of the ability of salmon to traverse stream reaches under given flows (Blakely et al., 1985; Sautner, Vining, and Rundquist 1984; Trihey 1982) to predictions of Case E-VI flows (Harza-Ebasco Susitna Joint Venture 1984b) and with-project mainstem degradation patterns (Harza-Ebasco Susitna Joint Venture 1985) leads to the conclusion that in some years some pink, chum, and sockeye salmon would not be able to reach traditional natal slough environments (table 2). With present information, it is impossible to accurately predict which sloughs would be most affected, and hence, the number of fish affected. Additional study is not likely to improve this situation. Variables affecting flow estimates (e.g., climate and energy demand) and the lack of a clear relationship between flow volume and sediment transport, make it unlikely that materially greater predictive precision is achievable, regardless of whether additional study effort is expended.

Predicted with-project aggradation at the mouths of Deadhorse (RM 120.8), Sherman (RM 130.8), and Jack Long (RM 144.5) creeks would likely restrict access to spawning habitats for some salmon (R&M 1982a, 1985). Escapement counts made to evolve indices of abundance indicate that relatively few salmon spawn in these streams (Appendix A). Based on the 1984 count (the highest on record), 399 adult pink, 10 chum, 6 coho, and 7 chinook salmon could be displaced from traditional natal grounds as a result of with-project aggradation. This represents .01%, .001%, .003%, and .003% respectively of all pink, chum, coho, and chinook salmon spawning in the Susitna River basin in 1984. These counts are not direct censuses, so numbers reported under-estimate salmon use to some extent. However, as table 4 shows, relatively few salmon of any species have been tallied over the years in any of the subject streams.

Unless mitigated, slough rearing habitat quality for chinook, chum, sockeye, and coho salmon would diminish as a result of the with-project sediment transport regime (table 3). Reduction in the number of yearly floods would result in a change in character of in-slough substrates. The change would be away from heterogeneity, as irregularly sized gravel and cobble material, was gradually covered by fines and sand. The net result would be a diminishment in cover (EWT&A and Milner 1985) and, ultimately, food availability (the invertebrate fauna would predictably shift towards one dominated by infauna -- Appendix E). Again, existing information does not permit an estimate of how many fish would be affected or of their ultimate fates.

The with-project sediment transport regime would pose no problems to any of the resident middle river fish species (table 4), because with-project sediment loads would be lower than natural (cf. Knott and Lipscomb 1983 to the predictions of Harza-Ebasco Susitna Joint Venture 1984a, 1985). This would be true even in the early years of project operation when scouring of the mainstem is predicted to occur. Potential with-project beneficial effects are discussed on pages 57 to 58 of this report.

Table 4. Anticipated relative negative with-project sediment transport effects on middle river zone resident fish species.

Fish Species	Watana Operation			Devil Canyon Operation		
	Effects[1] Scale	Location	Date	Effects[1] Scale	Location	Date
Burbot						
adult migration	0	--	--	0	--	--
spawning	0	--	--	0	--	--
incubation	0	--	--	0	--	--
rearing	0	--	--	0	--	--
Whitefish[2]						
adult migration	0	--	--	0	--	--
Rainbow trout						
adult migration	0	--	--	0	--	--
spawning	0	--	--	0	--	--
incubation	0	--	--	0	--	--
rearing	0	--	--	0	--	--
Arctic grayling						
adult migration	0	--	--	0	--	--
spawning	0	--	--	0	--	--
incubation	0	--	--	0	--	--
rearing	0	--	--	0	--	--

[1]
0 - no concern
1 - low
2 - moderate
3 - possible

See text for a complete description of the effects scale

[2] This table is applicable to both broad and humpback whitefish.

Lower River Zone

With-project sediment transport effects in the lower river are more difficult to predict than elsewhere in the study area. This is due to the braided nature of the mainstem (braided streams are difficult to model) and to the fact that relatively little study effort has been directed there. Project team members believe that more data are required to define with-project effects on the lower river (Bredthauer 1985). Prominent data gaps are listed in table 5.

Based on USGS data (Knott and Lipscomb 1983, 1985) the with-project sediment transport regime would be moderated below RM 97 by tributary input, especially those from the Talkeetna, Chulitna, and Yentna rivers (R&M and EWT&A 1985). As indicated earlier (see Appendix D), a significant zone of aggradation is predicted to occur near the Chulitna River's confluence with the mainstem ((Harza-Ebasco Susitna Joint Venture 1984a). Downstream of that point, little else is known of with-project effects on sediment transport, and hence, its effect on fish.

R&M and EWT&A (1985) believe that tributary mouths in this reach should become more stable as a result of with-project regulated flows. R&M and EWT&A (1985) estimate that with-project summer flows of around 25,000 to 30,000 cfs would be sufficient to allow passage into all lower river tributaries. However, they note that the mouths of Rolly (RM 39.0), Caswell (RM 64.0), Goose (RM 72.0), Montana (RM 77.0), Rabiduex (RM 83.1) and Trapper (RM 91.5) creeks have possible inherent access problems which might become manifest under some with-project flows (R&M and EWT&A 1985). They further note that due to the braided nature of the mainstem in this reach, quantification of change would be difficult (R&M and EWT&A 1985). Salmon index counts were made by ADF&G in these streams in 1984; around 3,000 chinook, 300 sockeye, 900

Table 5. Prominent data gaps in the lower Susitna River information base.

Sediment aggradation/morphology
Backwater effects at tributary mouths
Turbidity regime (local, plumes)
Relationship of flow and fish access to streams, sloughs, side-channels
Survey of mainstream spawning sites found in 1984
Timing and magnitude of ice staging and relationship to upwelling
Timing of flows - increased spawning area, later dewatering
Relate flows to rearing areas, spawning areas, access consideration
Fish abundance, rearing curves
Fisheries use of tributaries
Effect of with-project flows on salt-water intrusion

Source: Bredthauer 1985

pink, 590 chum, and 700 coho were counted (Barrett, Thompson, and Wick 1985). Although these counts do not indicate total escapement, they do provide some measure of the relative importance of each stream to each species. From this perspective, Montana Creek is the most important of the six streams for chinook (total count of 2,309) and pink (total count of 469) salmon, Trapper Creek is the most important of the group for sockeye salmon (total count of 200), Goose Creek is the most important of the six for chum salmon (total count of 383), and Rabideux Creek is the most important of the group for coho (total count of 480) (Barrett, Thompson, and Wick 1985).

The with-project sediment transport regime probably would not negatively affect any species spawning or overwintering in the mainstem lower river proper. This conclusion is based on the fact that overall sediment loads would be diminished with-project (although only slightly) from natural, thereby somewhat enhancing the quality of the environment. A discussion of the with-project beneficial effects is found in the next section.

POTENTIAL WITH-PROJECT BENEFICIAL EFFECTS OF THE SEDIMENT TRANSPORT REGIME

The with-project in-reservoir sediment transport process would not convey or otherwise impart any beneficial effects to fish or their food organisms. However, with-project sediment transport in the middle river might lead to an increase in primary productivity. Once the bed restabilized, sediment load in this reach would be less than natural (Appendix D). An increase in aquatic primary production could lead to an increase in consumers which, in turn, might equate with an incremental gain in fish habitat quality. Existing information is insufficient to gauge or even to characterize the magnitude of this effect. With-project turbidity in the middle river would still be substantial due to suspended glacial flour (the reservoirs could not trap all sizes of fines, some of which are present as colloids). Also unknown is whether natural invertebrate numbers and kinds limit present fish numbers. This latter point is central to a determination of whether there would be a gain in fish habitat quality. An ongoing AEIDC study seeks to understand natural primary rates of production in this reach; its results may shed light on the question of with-project primary productivity, but not necessarily on its effect on fish.

The with-project reduction in sediment load could lead to an increase in available mainstem salmon spawning habitats. The with-project sediment transport regime is predicted to keep the bed downstream of Devil Canyon relatively free of fines. This effect would diminish with distance downstream as tributaries added their sediment loads to the mainstem. It would not be noticeable below the Talkeetna and Chulitna confluence with the mainstem due to their moderating influence. Present information does not allow estimation of the magnitude of this.

No major (i.e., demonstrable) beneficial gains in primary production are likely to occur as a result of the with-project sediment regime in the lower river. This is due to the moderating influence of sediment inputs from the Talkeetna, Chulitna, and Yentna rivers (Appendix D). Existing information is insufficient to assess whether any other sediment transport associated beneficial effects could occur in the lower river. However, the slight reduction in suspended load and bed load caused by the dams might improve fish habitat quality somewhat.

SUMMARY OF WITH-PROJECT SEDIMENT TRANSPORT EFFECTS ON FISH

Based on existing data (sediment transport calculations and model runs and life history information) and professional judgement, with-project sediment transport phenomena (unless mitigated for) would limit fish numbers in the impoundment zone and in the middle river. Reservoir sedimentation (coupled with winter drawdown) would limit reproduction by lake trout and possibly burbot. In the middle river, with-project reduction of the number and intensity of floods would eventually diminish slough spawning habitats for salmon. Unless action was periodically taken to clean slough spawning beds, sedimentation attendant to periodic floods would eventually lead to a loss of these habitats. Comparison of estimates of released water flow variability and estimates of with-project mainstem degradation to salmon life history data and information on minimum water depth necessary at slough mouths to provide salmon access, leads to the conclusion that in some years some sloughs would be blocked to salmon. However, given the relatively small amount of with-project channel degradation predicted for the mouths of the principal spawning sloughs, this should not be a major problem. Potential with-project beneficial effects in the middle river are limited to a possible increase in primary production and an increase in salmon spawning habitat. An ongoing study may shed light on the primary production question. With-project sediment loads below the Devil Canyon dam would be markedly reduced over those occuring naturally. Following bed stabilization, it is possible that portions of the mainstem could function as salmon spawning habitat (the bed should be swept relatively clean of fines). Present information does not allow a prediction of the degree of this type of change, so no estimate of effected fish numbers is possible. Information is also too scant to allow an accurate appraisal of the effects of the lower river with-project sediment regime on fish. It is generally believed by APA's contractors that regulated with-project flows should help stabilize stream mouths in this reach. Although unquantifiable, the slight reduction over natural conditions of with-project mainstem sediment loads should improve habitat quality for fish somewhat; natural suspended sediment loads generally exceed the limits thought minimally acceptable for maintenance of vigorous resident fish populations.

INSTREAM TEMPERATURE

ANTICIPATED NEGATIVE EFFECTS OF THE WITH-PROJECT INSTREAM TEMPERATURE REGIME ON FISH

As noted earlier, available information for this analysis ranges from sufficient to scant to altogether lacking. Consequently, only 13 of the drainage's 19 species are addressed. These are all five salmon species, eulachon, Bering cisco, burbot, round and humpback whitefish, rainbow trout, Arctic grayling, and lake trout. Based on temperature model runs and current knowledge of fish response to ambient temperature change, no direct temperature-induced mortality is anticipated to occur with-project.

Tables 6 and 7 summarize anticipated with-project negative temperature-related effects on anadromous and resident fish. They provide an overview of anticipated negative effects by species, life stage, location, and time of year for both the Watana Dam and Watana and Devil Canyon dams together.

Chinook Salmon

With-project water temperatures could negatively affect four of five chinook salmon life stages (table 6); the two-dam option would negatively affect more life stages than the Watana Dam alone. Given present understanding of how temperature moderates adult chinook migration behavior, predicted June water temperatures above Talkeetna under the two-dam scenario could slightly retard the migration front. This would be a chronic problem, recurring on a yearly basis. Modeling results indicate that this cold temperature problem would be most severe near RM 150. The only chinook spawning habitat known to occur in this area is found in Portage Creek (RM 148.9); average chinook salmon escapement to this stream for the years 1981 to 1984 was over 2600 fish (Barrett, Thompson & Wick 1984). Depending on meteorological conditions, the duration of cold temperatures sufficient to interfere with migration would be between one and two weeks. Taken by itself, a delay in spawning of this duration might be sufficient to noticeably depress reproductive success by ultimately delaying fry emergence. Since emergence timing is keyed to maximal food availability (Godin 1982; Miller and Brannon 1982), it is expected that late emerging fry would encounter less than optimal growth conditions.

Table 6. Anticipated relative negative with-project temperature effects on anadromous species.

Fish Species	Watana Operation			Devil Canyon Operation		
	Effects Scale[1]	Location[2]	Date[2]	Effects Scale[1]	Location[2]	Date[2]
Chinook Salmon						
Adult Inmigration	0			1	Near RM 150	Jun
Spawning	0			1	Above RM 130	Jul
Incubation	0			0		
Rearing/Smolting	2	Devil Canyon to Mixing Zone	Jun-Sep	2	Devil Canyon to Mixing Zone	Jun-Sep
Outmigration	0			1	Near RM 150	May-Jun
Chum Salmon						
Adult Inmigration	0			0		
Spawning	0			0		
Incubation	0			0		
Rearing/Smolting	1	Devil Canyon to Mixing Zone	Jun-Jul	1	Devil Canyon to Mixing Zone	Jun-Jul
Outmigration	0			0		
Pink Salmon						
Adult Inmigration	0			2	Above RM 130	Jul
Spawning	0			1	Above RM 130	Jul
Incubation	0			0		
Rearing/Smolting	0			0		
Outmigration	0			1	Near RM 150	May-Jun

Table 6. Anticipated relative negative with-project temperature effects on anadromous species. (cont'd)

Fish Species	Watana Operation			Devil Canyon Operation		
	Effects Scale[1]	Location[2]	Date[2]	Effects Scale[1]	Location[2]	Date[2]
Coho Salmon						
Adult Inmigration	0			0		
Spawning	0			0		
Incubation	0			0		
Rearing/Smolting	1	Devil Canyon to Mixing Zone	Jun-Sep	1	Devil Canyon to Mixing Zone	Jun-Sep
Outmigration	0			0		
Sockeye Salmon						
Adult Inmigration	0			0		
Spawning	0			0		
Incubation	0			0		
Rearing/Smolting	1	Devil Canyon to Mixing Zone	Jun-Sep	1	Devil Canyon to Mixing Zone	Jun-Sep
Outmigration	0			0		
Eulachon						
Adult Inmigration	0			0		
Spawning	0			0		
Incubation	0			0		
Rearing/Smolting	0			0		
Outmigration	0			0		

Table 6. Anticipated relative negative with-project temperature effects on anadromous species. (cont'd)

Fish Species	Watana Operation			Devil Canyon Operation		
	Effects Scale[1]	Location[2]	Date[2]	Effects Scale[1]	Location[2]	Date[2]
Bering Cisco						
Adult Inmigration	0			0		
Spawning	3	Near RM 75	Oct	3	Near RM 75	Oct
Incubation	0			0		
Rearing/Smolting	0			0		
Outmigration	0			0		

[1]
0 No concern
1 Low
2 Moderate
3 Possible

See text for a complete description of the effects scale.

[2] Location and date of anticipated effects comes from temperature modeling results (AEIDC 1984).

However, it is possible that chinook inmigration to Portage Creek would not be noticeably affected by with-project temperatures. Importantly, the potential temperature block would occur early in the spawning migrational period and it would end before peak inmigration. Also, the potential temperature barrier would (according to model results) be proximal to natal habitats in Portage Creek; the biological imperative of reproduction might alone be sufficient to overcome it. Lastly, inflow from Portage Creek should breach the cold temperature zone, providing an avenue of access.

Predicted July mainstem water temperatures for the two-dam scenario above RM 130 fall below established spawning tolerance criteria for chinook salmon. This is not believed to be significant since no chinook have yet been found spawning in the mainstem. Given the level of effort researchers have spent identifying spawning areas, if any do spawn in mainstem environments, their numbers are probably very low.

Predicted with-project temperatures for both the one and two-dam options would negatively affect rearing juvenile chinook growth rates and smoltification. Modeling indicates that, depending on climate and the temperature of reservoir-released waters, growth rates of juveniles rearing in affected mainstem areas (above RM 130) could be reduced by 8 to 29% (AEIDC 1984). These growth-reduction rate estimates are based in part on the assumption that effected juvenile fish would eat to satiation. Since this probably does not happen in the wild, these estimates should be viewed as the worst case possible.

Reduced growth rates could affect productivity in terms of smolt ocean survival rates and outmigration patterns. Ocean survival rates of chinook smolts might be reduced because size is an indirect indicator of physiological readiness for life at sea (Wedemeyer 1980). Since the minimum threshold size necessary for successful smoltification of Susitna River chinook is unknown, it is impossible to gauge the magnitude of effects of predicted growth reduction on ocean survival. Based on capture data (Schmidt et al. 1984), approximately 20% of all chinook juveniles rearing in mainstem environments above the Chulitna confluence would be affected. Under a worst case scenario where unfit smolts outmigrated, all could conceivably perish. Average escapement data for the last four years indicates that this represents a potential loss of around 1,500 returning adult fish (assuming that fry reared in existing natural environments all have the same probability of survival). This estimate is based on peak escapement counts which represent less than 52 percent of a spawning population (Barrett, Thompson and Wick 1984)

Alternatively, affected smolts might not outmigrate for an additional year. This should be of less concern than if unfit smolts outmigrated, since smoltification is a reversible process (Wedemeyer 1980; Groot 1982; Clarke et al. 1978). Thus, affected smolts might successfully outmigrate after an additional year in freshwater. If this occurred, productivity would expectedly be slightly reduced due to an extra year of naturally-induced freshwater mortality.

Finally, affected smolts might outmigrate later in the year than normal. This could result in high mortality since outmigration of individual Pacific salmon stocks is known to be keyed to maximum ocean food productivity (Groot 1982; Godin 1982). As with the first concern discussed above (outmigration of unfit smolts), mortality rates of chinook rearing in colder with-project mainstem water would be significant.

The last with-project temperature issue concerning chinook salmon is that of potential delay of fry and smolt outmigration near RM 150. Under the coldest two-dam scenarios modeled, unfavorable temperatures for outmigration would occur for one to two weeks from late May to early June. The affected habitat would be near Portage Creek. This issue is not as potentially serious as some of the others because, according to model results, it would not be a chronic problem (i.e., it occurs infrequently) and the delay would be of relatively short duration. Also, it would occur early in the outmigration cycle so there would probably be sufficient time available for successful outmigration. Given the problems short duration, its expected frequency, and the natural wide variation in chinook survival rates, it is doubtful that any difference in productivity could be detected from this circumstance.

Chum Salmon

With-project June to July temperatures for both the one-dam and the two-dam scenarios would reduce chum fry and smolt growth rates. This is not as important an issue with chum salmon as with chinook, because they generally spend little time rearing in freshwater following emergence. Some stocks outmigrate immediately after emergence, providing indirect evidence that the freshwater growth stage is not as crucial for chum salmon as it is for some other species.

The small amount of chum rearing that takes place upstream of the Chulitna confluence (the primary affected area) occurs primarily in sloughs (Schmidt et al. 1984). The sloughs' mean annual temperatures mimic mean annual mainstem temperatures; however, mainstem temperatures fluctuate more than those in the sloughs. With-project mean annual river temperatures are not predicted to vary significantly from those occurring naturally. Given the above, the effect of with-project temperatures on chum salmon productivity would be minimal. This conclusion is severely constrained by inherent limitations of the model used; at present, it is impossible to accurately predict with-project slough temperatures in narrow time frames such as those defining the duration of chum salmon rearing. Ongoing analysis by Harza-Ebasco may shed new light on this question.

Pink Salmon

Based on model runs to date, there would be no temperature-related problems confronting pink salmon if only the Watana Dam was constructed. With both dams operating; however, three pink salmon life stages would be negatively affected to some extent. Temperature-related problems, though chronic, would be most manifest in even-numbered years when pink escapement is highest. The chief concern is a potential delay of inmigration timing (by one to three weeks depending on meteorology) above RM 130. Principal spawning areas above RM 130 are in Indian River (RM 138.6) and Portage Creek; in 1984 these two streams supported approximately 65% of all pink salmon spawning above Talkeetna (about 12,000 fish).

Potential with-project temperature effects on pink salmon inmigration timing are greater than those on chinook salmon inmigration timing for three reasons. First, the potential temperature block could preclude access to a greater amount of habitat. Second, predicted timing of the event would occur slightly later and nearer the peak of inmigration, so more fish would be involved. Finally, the period of exposure to temperatures below the thermal tolerance level would be of longer duration.

As with chinook salmon, several factors could lessen potential effects. Spawning habitats (especially Indian River) are relatively close to the problem area, so it is conceivable that fish, being physiologically ready to spawn, might be compelled to surmount the obstacle. Also, at least for Indian River, tributary inflow might create an avenue of access for upstream migrants.

With present knowledge it is impossible to quantify the overall influence with-project temperatures would have on pink salmon inmigration timing. It is important to note that even under a worst case scenario, model results indicate that the temperature block would disappear slightly before peak inmigration occurred (last week of July to first two weeks of August). Thus, the majority of fish would continue to reach their natal beds in synchrony with endogenous biological clocks.

Predicted with-project July water temperatures above RM 130 fall below thermal tolerance criteria for successful pink salmon spawning (see AEIDC 1984). However, no pink salmon have been found spawning in mainstem areas above RM 130, lessening the significance of potential negative effects.

With both dams operating and only under the coldest scenarios modeled, late May to early June mainstem water temperatures near RM 150 are predicted to be below pink salmon outmigration thermal tolerance criteria. However, this should not seriously affect long-term productivity, since the predicted low temperatures occur early in the outmigration period. Considering the rapidity with which pink salmon outmigrate, the anticipated delay should not impede their timely access to the estuary.

Coho and Sockeye Salmon

Predicted June to September with-project mainstem temperatures for both the one and two-dam options would negatively effect coho and sockeye salmon juvenile growth and smoltification rates. Judged against thermal tolerance criteria, anticipated effects would be significantly more troublesome with the two-dam option. The anticipated reduction in growth rate is identical to that reported for chinook salmon (see above). However, to date relatively few coho or sockeye salmon (4% and 8% respectively of all rearing salmon captured)

(Schmidt et al. 1984) have been found rearing in waters which would be influenced by with-project temperatures.

Eulachon and Bering Cisco

It appears that all eulachon spawning activity takes place far below the area likely to be influenced by temperature change. The maximum upstream limit of eulachon spawning occurs around RM 30. Since tributary inflow and climatic influence should dampen with-project temperatures considerably upstream of RM 30, with-project temperatures should exert no effect on eulachon. Bering cisco spawning grounds roughly coincide with the downstream limit of the temperature effects zone (at RM 75). Too little is known of how temperature affects Bering cisco life history stages to allow a prediction of their fate to be made. Further, temperature modeling has not been done for the subject area.

RESIDENT SPECIES

The following discussion addresses the anticipated with-project negative temperature effects on resident fish, which are summarized in table 12.

Burbot

Depending on whether one or two dams were operating and also on climatic factors, an open water area would occur with-project during winter from Devil Canyon downstream between RM 140 and 120 (Harza-Ebasco Susitna Joint Venture 1984). Susitna River burbot reportedly spawn under the ice at temperatures colder than 3 C. Winter with-project temperatures could negatively affect

Table 7. Anticipated relative negative with-project temperature effects on resident species.

Fish Species	Watana Operation			Devil Canyon Operation		
	Effects Scale[1]	Location[2]	Date[2]	Effects Scale[1]	Location[2]	Date[2]
Burbot						
Adult Migration	0			0		
Spawning	3	Upstream of the Ice Front (RM 120-140)	Jan-Mar	3	Upstream of the Ice Front (RM 120-140)	Jan-Mar
Incubation	0			0		
Rearing	0			0		
Whitefish[3]						
Adult Migration	0			0		
Spawning	1	Upstream of RM 100	Oct	1	Upstream of RM 100	Oct
Incubation	1	Upstream of RM 100	Oct-Apr	1	Upstream of RM 100	Oct-Apr
Rearing	0			0		
Rainbow Trout						
Adult Migration	0			3	Upstream of RM 100	May-Jun
Spawning	0			0		
Incubation	0			0		
Rearing	0			0		

Table 7. Anticipated relative negative with-project temperature effects on resident species. (cont'd)

Fish Species	Watana Operation			Devil Canyon Operation		
	Effects Scale[1]	Location[2]	Date[2]	Effects Scale[1]	Location[2]	Date[2]
Arctic Grayling						
Adult Migration	3	Impoundment	May-Jun	3	Impoundment & Upstream of RM 100	May-Jun
Spawning	0			0		
Incubation	0			0		
Rearing	0			0		
Lake Trout						
Adult Migration	0			0		
Spawning	0			0		
Incubation	0			0		
Rearing	0			0		

1
0 No concern
1 Low
2 Moderate
3 Possible

See text for a complete description of the effects scale.

2 Location and date of anticipated effects comes from temperature modeling results (AEIDC 1984).

3 This table is applicable to both broad and humpback whitefish.

burbot spawning in the ice-free zone cause they are predicted to be warmer than natural there. This means that with-project conditions (no ice cover and warmer than normal water) would be less than optimal for spawning. However, a number of uncertainties constrain this conclusion. First, although all observations of burbot spawning have been made under an ice mantle, it is unclear whether ice cover is a requisite for this behavior. Second, winter water temperatures in the ice-free zone are predicted to decline in a linear fashion downstream from the reservoir until reaching the 0 C isotherm proximal to the ice front. Depending on climate and dam operational scenario, the predicted range of water temperatures in this zone varies and, therefore, the amount of potential affected habitat varies. Third, to date no burbot have been found spawning in the area of the predicted ice-free zone. Because of these points, it is difficult to predict the influence of with-project temperatures on burbot spawning with any certainty. It does appear, however, that few fish are involved.

Whitefish

Both species of whitefish naturally spawn in October under conditions of rapidly decreasing water temperatures. Under the Watana Dam-only scenario, predicted October temperatures between RM 100 and RM 150 would be 2.1 to 4.1 C warmer than normal. Under the two-dam scenario, they would be 3.1 to 6.2 C warmer (AEIDC 1984). These warmer temperatures would expectedly accelerate whitefish embryo development rates, resulting in earlier than normal emerging fry. Early emerging fry survival rates would expectedly be less than natural; fry would encounter a colder and more hostile environment, with an inadequate number of seasonal food items. Alternately, predicted warmer October temperatures could delay whitefish spawning until temperatures dropped in

November. Although effects of this delay cannot be quantified, resulting fry would emerge later than normal. Given that salmonid emergence times are correlated with maximal food availability (Groot 1982), fry would experience less than optimal rearing conditions.

A number of factors complicate the conclusions reached concerning whitefish. Spawning locations and number of spawners in the area to be effected with-project are unknown. Therefore, it is impossible to predict the magnitude of with-project temperature effects on Susitna River whitefish stocks as a whole.

Rainbow Trout

Susitna River rainbow trout occupy the northernmost limit of their natural range; and thus, may be more susceptible to temperature deviation than any other resident fish. Rainbow trout naturally spawn on the ascending phase of the yearly temperature cycle. Very few rainbow trout have been captured in mainstem, or slough environments in spring. With-project water temperatures under the two-dam scenario may be too cold to stimulate migration from mainstem overwintering habitats to tributaries, thereby negatively affecting productivity. Several factors make this conclusion tentative. Most apparently spend the ice-free seasons in tributaries. First, capture data, although preliminary, indicate that outmigrants from lakes may significantly contribute to the population (M. Stratton pers. comm.) Second, the location of overwintering mainstem habitats is not completely known and this has consequence to the analysis. If overwintering habitats are proximal to tributary mouths (and, thus under the influence of tributary inflow), with-project mainstem water temperatures would not affect migration behavior. If, however, overwintering habitats are removed from tributary inflow influence, the concern is relevant; colder than normal temperature could impede upstream movement. Present knowledge is clearly insufficient to allow accurate predictions, but it does appear that relatively few adult rainbow trout could be affected.

Arctic Grayling

With-project May to June temperatures could negatively affect the timing of Arctic grayling spawning migrations. This would be a problem under either the one or two-dam scenario. With the Watana Dam alone, the concern focuses solely on the impoundment; with both dams on-line, concerns focus on the Watana reservoir and the area upstream of RM 100 to Devil Canyon. Arctic grayling spawning migrations are keyed to ascending water temperatures (like rainbow trout). Since the with-project environment would be colder than normal, it is possible that a delay in migration may occur. If so, it could negatively affect productivity by delaying spawning. However, insufficient information exists on the influence of cold temperatures on Arctic grayling migratory behavior to state this with certainty. Perhaps significantly, predicted with-project temperatures are within the range naturally experienced by the species in Alaska as a whole.

Lake Trout

Lake trout naturally inhabit waters whose temperatures are within the range of those predicted with-project. Therefore, no temperature-related negative effects are anticipated.

POTENTIAL BENEFICIAL WITH-PROJECT TEMPERATURE EFFECTS

As reported earlier, with-project released water temperatures for both the one and two-dam scenario are predicted to be warmer than natural in winter and cooler than natural in summer (See Appendix B). This effect is predicted to be more pronounced with the two-dam option and would be manifest only from the Devil Canyon Dam face to, at most, RM 120 (i.e.,the area of open water). Given that predicted released water temperatures are in the range of those supporting successful salmon spawning and incubation activities in the Susitna basin, it is conceivable that the subject area could afford additional reproductive habitat provided that suitable substrates occur there. Predicted winter water temperatures in the open area are also within the range of those seen in natural slough overwintering habitats. Provided that cover was available, it is conceivable that the subject reach could provide ten to thirty miles (depending on reservoir operational scenarios) of additional overwintering habitat. Given existing information, it is impossible to accurately gauge the scope of potential beneficial with-project effects.

SUMMARY OF WITH-PROJECT TEMPERATURE EFFECTS ON FISH

Based on existing data, model runs, thermal tolerance criteria, life history information, and professional judgement, no <u>direct</u> mortality on fish is anticipated to occur from with-project temperatures. Indirect mortality to some fish species may occur, however, and depending on operational scenario, these effects may be significant. Although unquantifiable, effects on rearing chinook salmon (in the mainstem from Devil Canyon to about the Chulitna confluence) are predicted to be the most severe of all. Regardless of operating scenario, juvenile chinook salmon growth rates would be retarded; effects would be more acute with both reservoirs than with one. This would result in <u>smaller than normal</u> smolts and/or a delay in outmigration, both of which are known to result in reduced survivorship. Based on four years of escapement data, this could maximally result in the loss of about 1,500 adult chinook salmon. Next in severity, with-project water temperatures (for the two-dam scenario only) could delay adult pink and chinook salmon inmigration (and hence, spawning) above RM 130. This would offset the normal timing of incubation, emergence, and outmigration. This, too, has been shown to reduce survivorship. Given the wide natural variation in pink salmon escapements, it is difficult to estimate the number of fish which would be effected. In 1984, this would have been approximately 12,000 fish. Of lesser concern, with-project water temperatures (for the two-dam coldest climate scenarios only) could delay pink and chinook salmon outmigration near RM 150. A fairly wide range of other relatively minor negative effects are predicted to occur from with-project temperatures. These vary from reductions in chum, coho, and sockeye salmon juvenile growth rates, to possible interruption of spawning behaviors by Bering cisco, whitefish, and burbot, to delay of inmigration of adult rainbow and Arctic grayling to spawning habitats.

Potential beneficial effects of the altered with-project temperature regime on fish are limited to the creation of some overwintering and incubation habitats. These would occur in the 10- to 30-mile stretch of open water which would annually occur each winter immediately below the Devil Canyon dam face. Given present knowledge, it is impossible to gauge the scope of these effects with-project.

WATER QUALITY

OVERVIEW

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. 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 section of this report;

the focus here is 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.

ANTICIPATED EFFECTS

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 causing 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. 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 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 would be discharged beneath the tailwater surface to prevent entrainment of air. Controlled releases designed to fulfill environmental stipulations or to pass flood flows would be routed through six Howell-Bunger cone valves with a combined capacity of 24,000 cfs. These cone valves are designed to release water in a spray, thus preventing plunging and gas supersaturation. Without Devil Canyon Dam, the releases from Watana Dam would 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 would 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. 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 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 would be oligotrophic and would 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 would be much more stabilized under with-project conditions, so too would annual patterns of primary productivity. Thus, the large pulses of productivity observed in the spring and especially in the fall, under natural circumstances, would 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 would 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 would affect both its middle and lower reaches.

The main concern is not that elevated heavy metal concentrations would 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 would 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 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 the dissolved Hg 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 ranges from weak (physical adsorption) to strong (chelation). 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 would 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 would 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 would 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 would 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 would rise sharply during the first 5 to 10 years after closure and would then decline gradually over the life of the project. Concentrations downstream, however, would 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 would be significantly accelerated under with-project conditions. If acceleration does occur for Cd, it would 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 would likely increase somewhat after impoundment, but given its high affinity for humic substances (Schnitzer and Khan 1982), almost all of the dissolved Cu would 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 OF ANTICIPATED WITH-PROJECT WATER QUALITY

Impoundment of the Susitna River at Watana and Devil Canyon would 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 would, 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 would 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 would have any noticeable positive impact on downstream fish production. Likewise, since winter levels would be below 110%, no harmful effects are likely to result from the relative increases anticipated for winter months.

The reservoirs created by impoundment would be relatively unproductive (oligotrophic) and phytoplankton growth would be limited year-round by prevailing turbidity levels other than macronutrient concentrations. The net reduction of macronutrient transport downstream would 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 would 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 would likely be higher than baseline levels throughout the life of the project, however.

INSTREAM ICE

ANTICIPATED EFFECTS

Watana Reservoir

Ice processes attendant to winter reservoir drawdown would affect reservoir fish spawning and rearing habitat quality. The littoral habitat would experience periodic dehydration, substrate freezing, and possibly some ice gouging, and erosion. Reservoir drawdown, ice draping, and ice gouging would preclude evolution of a stable littoral zone conducive to lake trout (from Sally Lake) reproductive and rearing success. Lake trout reaching the impoundment, however, would likely live out a normal life span. The effects on other salmonids would be less severe, because they can spawn in tributary streams. Thus, only their rearing and overwintering life stages would be affected. Rearing habitats for Arctic grayling and whitefish within the impoundment would probably be less than ideal since lake drawdown, ice draping, ice gouging, erosion, and associated effects would likely limit cover and food availability. Taken together these events would preclude establishment of riparian vegetation, limit invertebrate productivity, and dewater the habitat.

The effects of the Watana Reservoir ice regime on burbot are more difficult to predict, because they have more generalized habitat requirements. Burbot often inhabit deep, cold, and turbid environments. Burbot found in lakes often utilize lake shore gravels for spawning, however, most of those found in the Susitna River spawn in tributary stream environments. Due to the disruptions in the impoundment's littoral zone, it would not afford any additional viable reproductive habitat because of its unstable nature. Because of their ability to use either lake shoreline or tributary areas for spawning, available habitat would still remain for them in the tributaries to the reservoir. Thus, the impoundment's ice regime probably would not exert discernible negative effects on this reaches burbot population.

Ice blockage of tributary stream mouths by stranded ice may be a problem for fish in extremely cold years, when spring ice meltout is retarded. However, if climatic conditions match long-term averages, the tributary mouths should be ice free before late May or early June when Arctic grayling and longnose sucker migrate to tributary stream spawning habitats. Blockage of stream mouths by ice is very unlikely, as snowmelt runoff has to go somewhere, and meltout in the tributaries should be similar to natural conditions. If the spring meltout did not occur until after early June, both grayling and longnose sucker could fail to access the tributaries and experience reproductive failure for that year. From a fish population biology standpoint loss of a single-year class is not particularly troubling unless the loss is to a dominant year-class or the population is being simultaneously stressed by other factors such as epidemics or sport fishing. In Alaska, some local fish populations commonly have certain year classes predominate while others are absent or nearly so.

Once the Devil Canyon Dam was on-line, Watana Reservoir operations could have less influence on fish habitats because the expected drawdown would be less. However, since predicted drawdown exceeds 40 ft it would still severely limit establishment of a stable littoral zone.

Devil Canyon Reservoir

Because of its smaller scale, winter drawdown of the Devil Canyon Reservoir would be less influential on impoundment littoral zone habitats than that predicted for the Watana Reservoir. Ice draping would be minimal (if it occurred at all) and ice gouging negligible given the bedrock substrate and lack of ice fracturing from extensive drawdown. Perhaps importantly, impoundment area geomorphology and geology are such that they naturally limit the availability of potential lentic spawning habitat. The canyon's steep side walls and bedrock substrate severely limits potential use by spawning fish, and for this reason the reservoir would be an unproductive environment for fish.

Arctic grayling, burbot, longnose sucker, and possibly rainbow trout could access the Devil Canyon Reservoir and become residents. None depend exclusively on lentic littoral zones for reproductive purposes. Lake trout are not resident within the Devil Canyon impoundment area. They would have to gain access from the Watana Reservoir either by passing through the turbines, over the spillway, or through the gate valves.

With-project ice blockage of tributary stream mouths should not be a problem in this reservoir. The two main tributaries capable of providing reproductive habitats for the subject species, Fog Creek (RM 177) and Tsusena Creek (RM 181) are located in the upper end of the reservoir where open water is more likely. Normal spring tributary meltout in this area should easily wash out ice allowing timely access to spawning and rearing habitats for all reservoir residents.

Middle River Zone

The chief ice related concerns in the middle river are over slough incubation and rearing habitat quality. One deals with the potential introduction of near-freezing water to slough incubation and rearing environments through ice-induced overtopping. Another slough related issue concerns the potential of with-project flows altering the character of upwelling waters. Other issues in this vein pertain to the with-project end of the natural cycle of breakup-induced flooding of slough habitats and the amount of with-project anchor ice. Natural breakup-induced floods are necessary to flush fines from slough spawning gravels.

There are few nonslough ice related concerns in the middle river. One concerns a potential gain in primary productivity in the ice-free reach (as more light penetrates the ice-free water surface). Another, is the potential for there being more overwinter habitat with-project than naturally occurs (as a result of higher than natural with-project flows). The last non-slough issue pertains to anchor ice; when anchor ice breaks up, melts, or otherwise disperses, it dislodges considerable amounts of substrate which can be life threatening to developing embryos. Each of these issues are addressed below.

Overtopping of slough berms occurs naturally during freeze-up as a result of ice-induced staging and during breakup as a consequence of ice dam formation. It can directly influence overwinter embryo mortality in the middle river (ADF&G 1983d, 1985b). Overtopping from freeze-up-induced staging is the most troublesome to salmon, because it could introduce mainstem water which is colder than ambient groundwater to developing embryos, for relatively long periods of times.

During the incubation period, embryo survival naturally varies greatly and is dependent on several factors. The principal natural phenomena inducing embryo mortality are freezing of the spawning habitat, redd desiccation from dropping water levels, changes in the thermal and chemical characteristics of groundwater, and silting of redds (Buklis and Barton 1984, Canada Department of Fisheries & Oceans 1984). Dewatering and freezing of salmon redds have been identified as the principal natural factors inducing chum salmon embryo mortality in the middle Susitna River (ADF&G 1985b). Natural mortality is generally high during incubation; reported survival rates from North America and Asia range between 1.5% to 30% (Buklis and Barton 1984; McNeil 1980). Preliminary survival estimates for eggs deposited in 1985 in the middle Susitna drainage averaged 30%, 22%, and 16% for chinook, sockeye, and chum salmon respectively (Roth and Stratton 1985).

Embryo temperature tolerance ranges are much narrower than those for adults (Alabaster and Lloyd 1982). Generally, the lower and upper temperature limits for successful initial incubation of Pacific salmon eggs fall between 4.5 C and 14.5 C (Reiser and Bjornn 1979). Salmon embryos are most vulnerable to temperature stress in their early development stages, before closure of the blastopore. Closure occurs at about 140 accumulated Celsius temperature units (Combs 1965; Bams 1967). (A temperature unit is one degree above freezing experienced by developing fish embryos per day).

Merrell (1962) suggested that pink salmon embryo survival in Sashin Creek, southeastern Alaska, may be related to water temperature during spawning. Embryos exposed to cooler spawning environmental temperatures have been shown to experience greater incubation mortality than those which began incubation at warmer temperatures (McNeil 1969). Bailey and Evans (1971) reported an increase in pink salmon mortality when water temperatures were held below 2 C during the initial incubation period. Laboratory experiments with developing Susitna chum and sockeye salmon embryos resulted in increased mortality and alevin abnormality when average temperatures were maintained at a level less than 3.4 C (Wangaard and Burger 1983). However, these increases were relatively slight. Following the period of initial sensitivity to low temperatures, i.e., after blastopore closure (approximately 30 days at 4.5 C), embryos and alevins can survive temperatures near 0 C (McNeil and Bailey 1975), but their development is slowed. During the incubation period, mean intragravel water temperatures in the primary middle river spawning sloughs range from 2.0 C to 4.3 C (ADF&G 1983d). Since peak chum salmon spawning in sloughs occurs between late August and September (table 11), it follows that blastopore closure occurs by October.

Slough 8A was naturally overtopped in late November 1982 by cold mainstem water (near 0 C), providing some insight into potential effects of with-project overtopping events. Slough 8A intragravel water temperature and dissolved oxygen were depressed during this event. Subsequently, embryo development and emergence was delayed, and large numbers of dead embryos were seen (ADF&G 1983d). This suggests that increased mortality occurred.

The significance of with-project overtopping to developing salmon varies between sloughs, being more problematic in those downstream of the predicted ice front. As noted above, the predicted ice front location with the Watana Reservoir would occur between RM 124 and RM 142 (table 18). When it is at RM 124 (the farthest downstream ice front location predicted with the Watana Reservoir), sloughs upstream of this point would be subject to overtopping. Of the most productive chum salmon sloughs in the middle river, only sloughs 8, 8B, and Moose are located downstream of RM 124 and would be subject to overtopping. An average of 696 chum salmon spawned in these sloughs between 1981 and 1984 (table 14). This represents approximately 10.4% of the total chum salmon escapement to middle river sloughs for those four years (table 14). At the other extreme, when the predicted ice front is RM 142, all of the top chum salmon producing sloughs would be subject to overtopping. From 1981 to 1984, these sloughs supported an aggregate average of 6,004 spawning chum salmon, approximately 88.5% of those spawning in middle river sloughs (table 14).

Predicted river freezeup dates with the Watana Reservoir only range from November 28 to December 30 (Harza-Ebasco Susitna Joint Venture 1984). Ice formation in all model simulations is assumed to begin at the confluence of the Chulitna and Susitna rivers and progress upstream from there. The expected rate of ice front progression upstream from the Chulitna River confluence varies annually due to climatic influence and temperature of the outflow. With the Watana Reservoir on-line, ice front advance is predicted to take up to six weeks (Harza-Ebasco Susitna Joint Venture 1984).

Given the predicted start of river freezeup (late November) and the predicted rate of ice front advance, the earliest an overtopping event could occur is early December, which is generally after blastopore closure. Most model runs indicate that freeze-up start dates would be later, occurring in mid to late December (table 18). Therefore, the majority of predicted overtopping events from ice staging could not occur before late December and perhaps not until January.

According to ICECAL simulations, sloughs 8, 8A, 9, 9A, and 11 would be overtopped in some winters due to ice staging with Watana only (Harza-Ebasco Susitna Joint Venture 1984). Together, these sloughs accounted for about 51% of all chum and 79% of all sockeye salmon spawning in middle river sloughs from 1981 to 1984 (table 13 and 14).

Based on ICECAL simulations of river freezeup timing, subsequent ice front advance, and what is known of the relationship between temperature and chum salmon embryo development, some with-project ice-induced overtopping events could lead to widespread embryo mortality in affected sloughs. While the likelihood of any direct embryo mortality from thermal stress diminishes after October following blastopore closure, some ICECAL simulations predict that staging induced overtopping events could last until spring meltout. If this were to occur, indirect mortality could be significant given that cold temperatures of this severity (near 0 C) and duration should delay embryo development and fry emergence to such an extent that they would be unable to complete their life cycle. This problem could be exacerbated in slough 8A where a direct linkage between mainstem temperature and intragravel water temperature has been posited. Staging, even in the absence of overtopping, could lead to colder than natural upwelled water temperatures in slough incubation environments (this temperature linkage is also believed to exist in portions of slough 21, but should not produce a similar problem because of the warmer with-project winter water temperatures there).

The environmental consequences of ice-staging overtopping events appear to be less with both dams on-line. This is because initial freezeup dates are predicted to be later, meltout dates are expected earlier, and ice thickness would be less. Further, the predicted duration of overtopping events is shorter, and they would occur later in winter.

According to ICECAL simulations, only sloughs 8, 8A, 9, and 9A would be overtopped in cold winters due to ice staging with two-dam scenarios (Harza-Ebasco Susitna Joint Venture 1984). Together, these four sloughs accounted for about 28% of all chum and 14% of all sockeye salmon spawning in middle river sloughs from 1981 to 1984 (table 13 and 14). Importantly, only the "cold winter" simulations, which represent environmental extremes, predicted overtopping.

Overtopping of slough berms by colder mainstem waters could also affect overwintering fish, as water temperature affects fish metabolism, growth, food capture, swimming, and disease resistance (see temperature memorandum). Juvenile salmonids are tolerant of a wider range of water temperatures than embryos and can survive short exposures to temperatures which could ultimately be lethal. They can live for long periods at relatively low temperatures, at which time they abstain from feeding, are less active, and spend more time resting in secluded habitats (Alabaster and Lloyd 1982; Chapman and Bjornn 1969). For example, in Carnation Creek, British Columbia, fish stopped feeding and moved into deeper water or closer to objects providing cover at temperatures below 7 C (Bustard and Narver 1975). Similarly, in Grant Creek, near Seward, Alaska, juvenile salmonids were inactive at water temperatures between 1.0 C to 4.5 C and inhabited cover afforded by streambed cobbles (AEIDC 1982). Regardless of whether one or two dams are on-line, some fish overwintering in sloughs would be exposed to colder overflow waters. As mentioned above, the chief difference between the one and two-dam options in this regard lies in the number of sloughs subject to overtopping and the duration of overtopping events.

Overwintering salmonids exposed to cold overflow waters (near 0 C) could respond in one of two ways, given that a critical thermal minimum has not been demonstrated short of actual freezing (AEIDC 1984). They conceivably might simply seek cover within the slough, becoming relatively inactive until temperatures once again rise following the end of the overtopping event. Alternately, since they are mobile they might elect to leave or be forced out by high velocities during large overtopping events. Given that overflow water temperature would be identical to mainstem temperature, it is arguable whether given a choice they would flee. If they did emigrate, their survival would ultimately depend on availability of replacement habitat which appears limited in this reach.

Overtopping of slough berms from breakup-driven ice jams is not expected to be a with- project issue, given ICECAL predictions, as river ice would melt in place rather than breakup. Thus, no ice jams are predicted to form at this time and no flooding of slough environments would occur.

The second middle river addressed issue concerns the effect of with-project ice- staging on upwelling rates in middle river spawning sloughs (see list in Appendix A). Maximum winter river stages upstream of the with-project ice front are predicted to be lower than corresponding natural conditions, because freezeup staging would not occur (Harza-Ebasco Susitna Joint Venture 1984). Since upwelling rates are believed to be a function of river flow volumes, there is concern that this lower stage could reduce the amount of slough upwelling. This should be of minimal concern since with-project winter flows upstream of the ice front (with either dam scenario) are predicted to be similar to those occurring naturally in September and higher than the minimum with-project summer discharges. As upwelling is presently sufficient for incubation purposes during natural September flows, one could assume that with-project upwelling would also be sufficient. Downstream of the ice-front, with-project river stages with both dams on-line are predicted to be higher than natural. Consequently, concern over project effects on upwelling rates are apparently moot in this zone.

The third issue examined deals with the potential effects of the with-project winter open water zone below Devil Canyon on fish habitat quality. Regardless of whether one or two dams are built, an ice-free zone of open water would occur each winter below Devil Canyon. With Watana Reservoir above, this (predicted by ICECAL) would be 10 to 28 miles long; with both dams operational the zone would be between 15 to 29 miles long. Conceivably, primary productivity could be enhanced in this area because of warmer water temperatures and less snow and ice cover. Taken by itself, ice removal would allow more light to penetrate the water column, stimulating primary production. However, the question is complicated by the fact that there is little sunlight here in the winter and released reservoir waters would be turbid, whereas natural winter flows are relatively clear (Acres American 1983). An ongoing AEIDC study seeks to answer the productivity question. At present, there is no reliable information to use to describe the probable influences of the with-project open water area on winter productivity.

Another aspect of the open water reach lies in its potential to become overwintering habitat. Present juvenile salmon overwintering areas are characterized by the presence of ice cover and by upwelling warmer than ambient water (ADF&G 1985a). Little is known about most resident species overwintering habitats, however, limited data from radio tagged rainbow trout suggests that this species uses areas of upwelling for overwintering (Sundet and Wenger 1984). Many resident species have been found to overwinter in deeper mainstem pools and at tributary mouths (ADF&G 1983c).

The open water reach could conceivably provide some overwinter habitat for juvenile salmon, since released reservoir waters (0.5 C to 5.6 C) would be within the normal range of upwelling temperatures (0.8 C to 4.2 C) and cover could be afforded by the turbid conditions. However, it is premature to speculate on the effectiveness of this type of cover because of the broad range of turbidities forecasted for this time of year (Acres 1983). The open water area could provide more overwintering habitat for resident species than now exists, chiefly because of the combined effects of higher with-project flows (which could create favored deep pool environments) and the relatively warmer temperatures.

The open water area could also provide additional salmon spawning and incubation habitat. Chum salmon have been observed spawning in other mainstem areas influenced by upwelling groundwater (ADF&G 1985b). Although undocumented, it is possible that upwelled mainstem water temperatures at these sites are similar to those seen in sloughs. Given that released water temperatures are predicted to be in the range of upwelled slough water temperatures, and given the proclivity of chum salmon for spawning in mainstem environments, it is conceivable that this area of the middle river could function as reproductive habitat provided that suitable substrate exists there.

Another expressed ice-related concern in the middle river pertains to the natural flushing of beaver dams as well as fines from slough spawning habitats by breakup-induced flooding. Regardless of whether one or two dams are built, ICECAL simulations predict that drastic breakup events would no longer occur; the river ice cover would gradually melt in place and no large flood flows would clean out the sloughs.

Because no sediment samples have been taken before and after breakup floods, the issue remains founded on subjective appraisal of environmental conditions. While it is conceivable that breakup flooding is necessary for the maintenance of slough spawning substrates (at least in some locations), it is also possible that hydraulic upwelling pressure (coupled with the actions of redd building adults) is sufficient for this purpose. Given the lack of information on the amount and size of intragravel fines before and after floods, no clear conclusions can be drawn.

The last question analyzed concerns the effect of with-project anchor ice on fish and their habitats. Mechanisms of anchor ice formation are poorly understood, but it is known to form most often in supercooled reaches over gravel substrates (Michel 1971; Mason 1958). While anchor ice is relatively common in the mainstem middle river, none has been found to date in either mainstem or slough upwelling areas.

Little is known about the influence of anchor ice on Susitna River fish habitats. Benson (1955) studied anchor ice effects on trout stream ecology in Michigan. There, anchor ice was not found to affect trout eggs buried in the gravel. However, trout fry were apparently vulnerable if they were emerging at the same time as anchor ice was forming. In California, Needham and Jones (1959) noticed that dispersing anchor ice dislodged substrates carrying away considerable numbers of invertebrates. In the middle river, anchor ice can carry gravel substrates away in a similar manner (R&M Consultants Inc. 1984). This could be a concern to fall and winter mainstem spawners like burbot and whitefish if they happen to be using areas subject to anchor ice formation.

Since little is known about the mechanics of anchor ice formation, it is not simulated in the ICECAL model. However, the extent of anchor ice would be limited to the reach between the 0 C isotherm and the ice front. It is believed that there would be less anchor ice with-project in the middle river. Upstream of the 0 C isotherm, in the open water lead below Devil Canyon, no anchor ice formation is likely due to the influence of warmer than natural released water. This could have a stabilizing effect on instream invertebrate habitats. Anchor ice would form with-project between the upstream edge of the ice-front and the 0 C isotherm in a manner similar to that seen naturally. More anchor ice would form with the Watana Reservoir than with both dams on-line because of the greater amount of open water at 0 C. It is probable that no anchor ice would form in areas influenced by relatively warm upwelled water. Thus, with-project anchor ice should not influence those salmon reproductive habitats in areas of upwelling.

Lower River

As indicated earlier, no ice modeling has been done for the lower river; thus, conclusions presented are tentative. Two ice related issues are apparent in the lower river. One relates to staging and the other to the influence of ice cover on primary production and on cover.

With regard to staging, it is thought likely that freezeup would occur later than normal with either one or two dams operating. Subsequent overtopping would also occur, but would likely be later than under natural conditions. The consequence to the salmon resource as a whole from overtopping would be minimal. Even if 100% mortality occurred, lower river slough reproductive habitats are severely limited in area and are utilized by only a small number of chum salmon. Consequently, their collective contribution to maintenance of Susitna River salmon stocks is very small.

As in the middle river, the question of ice-related effects on upwelling pertains to salmon reproductive habitat quality. In essence, the question rests with two points: the rate of upstream migration of the ice front and the assumption that mainstem upwelling has a controlling influence on embryo survival. Salmon spawning naturally occurs in the mainstem at a time when river flow is decreasing. Successful salmon reproduction in the mainstem is partly dependent on freezeup staging, which raises the water level and assures that upwelling is not diminished. This concern is more acute near the confluence of the Chulitna and Susitna rivers than further downstream for two reasons; it would take longer for the ice front to arrive and more fish spawn in this area.

With the project ice front advance would be slower than natural but flows would be greater than those now occurring. These two factors seem to offset each other. If so, effects to incubating embryos would be minimal, because flows should be sufficient to maintain upwelling. However, it is important to point out that, to date, there is no direct evidence that mainstem upwelling in the lower river exerts a controlling influence on incubation environments there.

The last lower river ice-related issue raised pertains to the question of how the with-project ice cover would affect primary productivity and the amount of overwinter fish habitat. It is believed that regardless of whether one or two dams is built, there would be more ice in the lower river with-project than naturally. However, the exact morphology of the ice cover is unknown. Provided that extensive lead systems did not develop, instream primary production with-project should be reduced in rough proportion to the increase in ice cover seen. Due to the low gradient and high porosity of the ice under with-project conditions, it is more likely that open leads will occur in a manner similar to natural conditions. If this is true, then an extensive system of open water leads would develop, and primary productivity could increase.

It is possible that winter habitat availability could increase with-project, given the combined effects of ice-induced staging and greater flows. However, overwinter habitat is comprised of more components than just water volume. Numerous other variables, such as bed morphology, water depth, water velocity, temperature, and cover are at play. So, the belief that overwinter habitat might increase with-project is provisional.

SUMMARY OF INSTREAM ICE EFFECTS ON FISH

Winter drawdown of the Watana Reservoir would have a destabilizing influence on its littoral zone, making it unproductive for salmonids. Some species would be more affected than others. In all likelihood, winter drawdown would preclude successful fall and winter reproduction. This could effect lake trout, whitefish, and burbot spawning and if it took place at all, eggs would desiccate or freeze. Ice draping, gouging, and associated erosion would probably limit invertebrate productivity and cover availability, which in turn would diminish rearing habitat quality for Arctic grayling and whitefish. In some extremely cold years, ice blockage of tributary stream mouths could delay Arctic grayling and longnose sucker natal migrations. At such times, it is likely that reproductive failure could occur. This is not considered unlikely and even if it occurred at all should not be a major problem, since loss of a single year class is not overly threatening to relatively long-lived and fecund organisms like fish.

The environment of the Devil Canyon impoundment would be much more stable, given its winter drawdown schedule. However, the canyon's geomorphology and substrate geology limit establishment of a productive littoral zone. Fish reproductive habitats near the mouths of Fog and Tsusena creeks may not be influenced by with-project icing events. Both are located in the upper end of the reservoir where open water is more likely.

The chief ice concern with-project lies in potential altering of slough incubation habitat quality. Ice staging downstream of the ice front could cause overtopping of slough berms with colder than ambient mainstem water. This would have consequence to natal habitats.

ICECAL simulations predict that all with-project ice-induced overtopping events would occur after blastopore closure. Thus, there is little likelihood that direct mortality of embryos would ensue. However, indirect mortality would be significant given the predicted duration of most overtopping events ($\geq$ one month). This would delay development to such a degree that it is unlikely that the embryos could complete their life cycles. Overtopping waters could also affect overwintering juvenile fish. Effects would be more severe the longer the cold exposure lasted. Overtopping events would be more frequent and severe with the Watana Reservoir alone than with both dams on-line.

Concern has been raised that the absence of with-project ice staging in the area upstream of the ice front would alter slough upwelling rates. This does not seem likely as with-project winter flows are forecast to be between 8,000 and 12,000 cfs. This is similar to flows occurring naturally in September. Since September upwelling rates are apparently sufficient to maintain salmon natal habitat quality, it seems likely that with-project winter flows should also be adequate. The with-project 10 to 29 mile long open water zone in winter below Devil Canyon could enhance primary productivity in the mainstem. Theoretically, more light would penetrate the open water column, thereby stimulating photosynthesis. However, there is little light at this time of year and winter flows would be somewhat turbid confounding the issue.

A more likely effect of this open water zone could be the creation of additional overwinter habitat due to the combined influence of higher flows and warmer than natural water temperatures. Higher flow volumes could create deep pool overwinter habitats for resident species. Since released reservoir waters are predicted to be about the same temperature as that of upwelled slough groundwater, this area might also provide some salmon overwinter and spawning habitat. The with-project flow regime would eliminate breakup-induced flooding of slough habitats. This process may be necessary for maintenance of slough natal habitats (through flushing of beaver dams and fines from interstitial gravel spaces). Given present knowledge, it is impossible to predict the long term consequences of elimination of breakup-induced flooding on these habitats.

Anchor ice has been shown to have a destabilizing influence on invertebrate and fish embryo habitats by dislodging substrates during melting or breakup. No anchor ice is expected to form with-project in the open water lead upstream of the 0 C isotherm; however, it would form between the ice front and the 0 C isotherm in a manner analogous to that seen naturally. Cessation of anchor ice formation in the open water zone could stabilize incubation habitats.

Less physical and biological information exists on the lower river than for the other two reaches. No temperature or ice modeling has been attempted for this reach, making evaluation of with-project effects completely subjective. Overtopping is still expected to occur in the lower river although somewhat later than natural. Because of the very small number of salmon spawning in the area its effect on the Susitna stocks should be minor. With-project winter icing probably would not negatively influence upwelling rates, given that the effects of the predicted slower than normal ice front advance and the higher than natural flows would likely offset each other. Higher with-project winter flows coupled with ice-induced staging could increase the amount of overwinter fish habitat (since wetted area would be increased). Since overwinter habitat is comprised of more than just water volume, it is impossible to speculate on whether new wetted areas would be utilized.

TURBIDITY

(To be written pending completion of field work).

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