PRELIMINARY DRAFT

IMPACT ASSESSMENT TECHNICAL MEMORANDUM

INSTREAM TEMPERATURE

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

Table No. Page No.

INTRODUCTION

PURPOSE

This document is a comprehensive assessment of instream temperature issues relative to the proposed upper Susitna River basin hydroelectric development. Impoundment of the upper Susitna River will cause a change in the natural instream temperature. River temperatures are generally expected to be cooler in the open water season and warmer in winter. Since fish species present in the Susitna River drainage are dependent, to a certain degree, on the natural instream temperature regime, studies were initiated (in the beginning phases of Susitna environmental investigations) to address the potential adverse or beneficial effects of the expected alteration of river temperatures on fish.

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

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

Issues deemed important for assessment in the EIS included twelve fishery issues. One of these, Issue No. F-2, identified salmon and resident fish habitats and populations downstream of the dams as topics to be addressed. Sub-issue F-2.5 is the significance of changes in water temperature on salmon and resident fish habitats and populations downstream of the dams.

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

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

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

SCOPE

This document describes the process of impact assessment; that is, it illustrates how the impact assessment for the instream temperature issue was conducted. Considerable information exists with which to assess the effects of the Susitna project on instream temperature regimes and fish resources. Meteorologic and hydrologic data as well as instream temperature measurements have been collected for nearly five years. With this information and other data, computer models of streamflow runoff, groundwater dynamics, and instream temperature were constructed to forecast future with-project conditions. The mechanisms of impact, or how changes in instream temperature adversely or beneficially affect fish, are presented. This is done so that reviewers can scrutinize the methods and techniques employed in deriving impact statements from the existing information base and review assumptions used when making predictions of unmeasured events.

Also presented are analyses of the degree of control the project will have over instream temperature regimes. In the case of instream temperature, some control over outflow temperatures could be afforded by installing multiple level intake gates in the outlet works. The degree to which undesirable water temperatures would be mitigated through these multi-level outlet works is discussed.

This report does not delve into flow-related, hydraulic impacts; these are addressed in the Instream Flow Relationships Report Series (E. Woody Trihey and Assoc. and Woodward-Clyde Consultants Inc. 1985). However, since instream temperature is affected to a certain degree by river discharge level, an evaluation of the effects of various flow regimes on instream temperatures is presented here. Included is an assessment of the adequacy of the existing information base for addressing the issue and, where warranted, suggestions for improving the analysis. The analytical tools available for conducting this impact assessment are discussed, including a presentation of the strengths, weaknesses, and limitations of the models employed for simulating unobserved conditions. Suggestions for mitigating undesirable with-project instream temperature effects are also provided. However, this is not a mitigation report; substantial information in this vein can be examined in other documents, most notably work accomplished by Woodward-Clyde Consultants (1985).

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

STATEMENT OF THE PROBLEM

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. The 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 thermal regime of the river. With both dams on-line, the area between Devil Canyon (RM 152) and the Oshentna River (RM 235) would be converted from a lotic to a lentic system. After impoundment, these reservoirs would exhibit thermal characteristics similar to those naturally occurring in deep glacial lakes (ACRES 1983). Such lakes commonly stratify (however, stratification is often weak) during both winter and summer. With-project, mainstem water temperatures downstream from the dams would be cooler in the open water season and warmer in the winter. A change in the ice regime downstream from the project is also expected due to altered temperatures and increased winter flows.

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, downstream 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 will 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 fairly 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.

Fish are ectothermic, meaning that their body temperature is dependent on the environment and closely approximates it. Therefore, a fish inhabiting a stream where the temperature is 10 C has a body temperature close to 10 C. As temperatures cool in winter, fish become increasingly lethargic, and depending on the species, they may cease feeding and growing altogether. As temperatures rise in spring, fish metabolism correspondingly increases. Water temperature regulates fish metabolism and, hence, behavior by influencing intracellular chemical reaction rates. Hoar (1976) argues persuasively that circadian rhythms and other short-term behavioral phenomena clearly indicate that hormone production and utilization are tied to daily and seasonal changes in the environment, especially temperature. Thus, temperature does not induce behavioral and physiological effects directly through neurological pathways, but indirectly through the endocrine system. In short, hormones are the chemical links between fish and the environment, and fish behavioral states are temperature-moderated. Temperature effects on fish vary by species, population, life-stage, and duration of exposure. Each region of the earth is under a relatively unique thermal regime to which indigenous fish have adapted. Generally, fish in more southerly latitudes are adapted to warmer conditions and wider variation in annual temperature cycles than those in northern latitudes like Alaska.

The most critical temperature-influenced behavior is the timing of fry emergence (Miller and Brannon 1982). Fry emergence is precisely synchronized with maximum food availability in the nursery system (Miller and Brannon 1982; Godin 1982; Stearns 1976, 1977). Thus, premature or delayed emergence could influence cohort mortality rates due to inadequate or improper food supply (Miller and Brannon 1982). Early emergence could also lower fitness because fry would experience colder than normal temperatures reducing their growth rates; late emergence might not allow enough time for growth to optimal smolt size the following spring (Miller and Brannon 1982; Godin 1982).

Another concern with the with-project temperature regime rests on the role that stability plays in evolution. Environmental stability and predictability are generally considered to be the major factors influencing evolution of life history traits (Stearns 1976, 1977). For example, the Pacific salmon spawning migration from feeding areas at sea to natal streams is precisely timed to coincide with historical temperature regimes of incubation environments (Brannon 1982). Miller and Brannon (1982) state,

> "Since the incubation period is dictated by temperature, the time at which eggs should be deposited is predetermined for each habitat. In essence, a time-window exists for egg deposition in a specific site. Optimal incubation and emergence depend on how closely adults are able to gain access to that time-space dimension; individuals from other populations...are likely to miss by a factor determined by their own preprogrammed pattern."

Other fish species exhibit similarly linked temperature-behavior patterns. For example, salmonid fry migratory behaviors as a whole appear to be influenced to varying degrees by water temperature (Zaugg 1982; Miller and Brannon 1982; Thomas 1975; Solomon 1982; Northcote 1969; Thorpe 1982). Water temperature also plays an influential role in fish embryo incubation timing, alevin intragravel movement patterns, fry behavior, smoltification, and growth (Solomon 1982; Hoar 1976; Folmar et al. 1982; Clarke et al. 1978; Groot 1982), all of which ultimately influence overall mortality rates.

METHODS AND PROCEDURES

To assess the effects of with-project instream and in-reservoir temperatures on fish, AEIDC first reviewed available information on how fish respond to different thermal conditions. Ideally, information used in an effects analysis should be specific to the water body in question and to its particular community of organisms. Little 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 thermal 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 adaptation 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 many 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 temperature 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 preferred temperature 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 incubation 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 1983c; 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 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.

FISH RESOURCE

Judged against criteria for EIS preparation (40 CFR 1500), existing information on Susitna River fish resources is generally adequate for an assessment of with-project effects. (An EIS is an accounting tool used by decision makers; its chief purpose is to ensure that all elements deemed significant in the scoping process are considered in decision making.) Available information on open water season salmon-life stage activities (distribution, abundance, spawning timing, spawning location, rearing, and migration) is quite complete; the overwinter salmon data base is much less so.

Information on salmon incubation environments is also relatively well known, but data on winter rearing environments and winter juvenile fish behaviors are incomplete. Some of the gaps in the salmon winter data base may be filled by information gathered during the winter of 1984-1985. As with salmon, information on resident species is much more complete for the open water season than it is for winter. Unlike salmon, however, it is heavily weighted toward selected species. Information on the open water season distribution, habits, and habitats of rainbow trout, burbot, and Arctic grayling is more complete than for other residents. With the exception of limited winter radio-tagging data for rainbow trout and burbot, little is known of the life histories of resident fish at this season. A synopsis of available fish resource information follows.

IMPOUNDMENT ZONE

The principal source of information on fish distribution, abundance, habitat use, and life histories in the impoundment zone is ADF&G 1981a and 1983f. Impoundment study area investigations were conducted in 1981 and 1982 by ADF&G Su-Hydro during the open water field season (May-October). These studies concentrated on Arctic grayling, making data on this species the most complete. Data on overwintering activities in this area is particularly scarce for all species. The major objectives of this study were to: 1) determine the seasonal distribution and abundance of fish populations in the proposed impoundment area; 2) identify spawning and rearing areas; and 3) determine the physical and chemical characteristics of these habitats (ADF&G 1981a, 1983f). More specific tasks dealt with determining the distribution, abundance and migratory habits of Arctic grayling; determining the distribution and relative abundance of selected resident fish species;

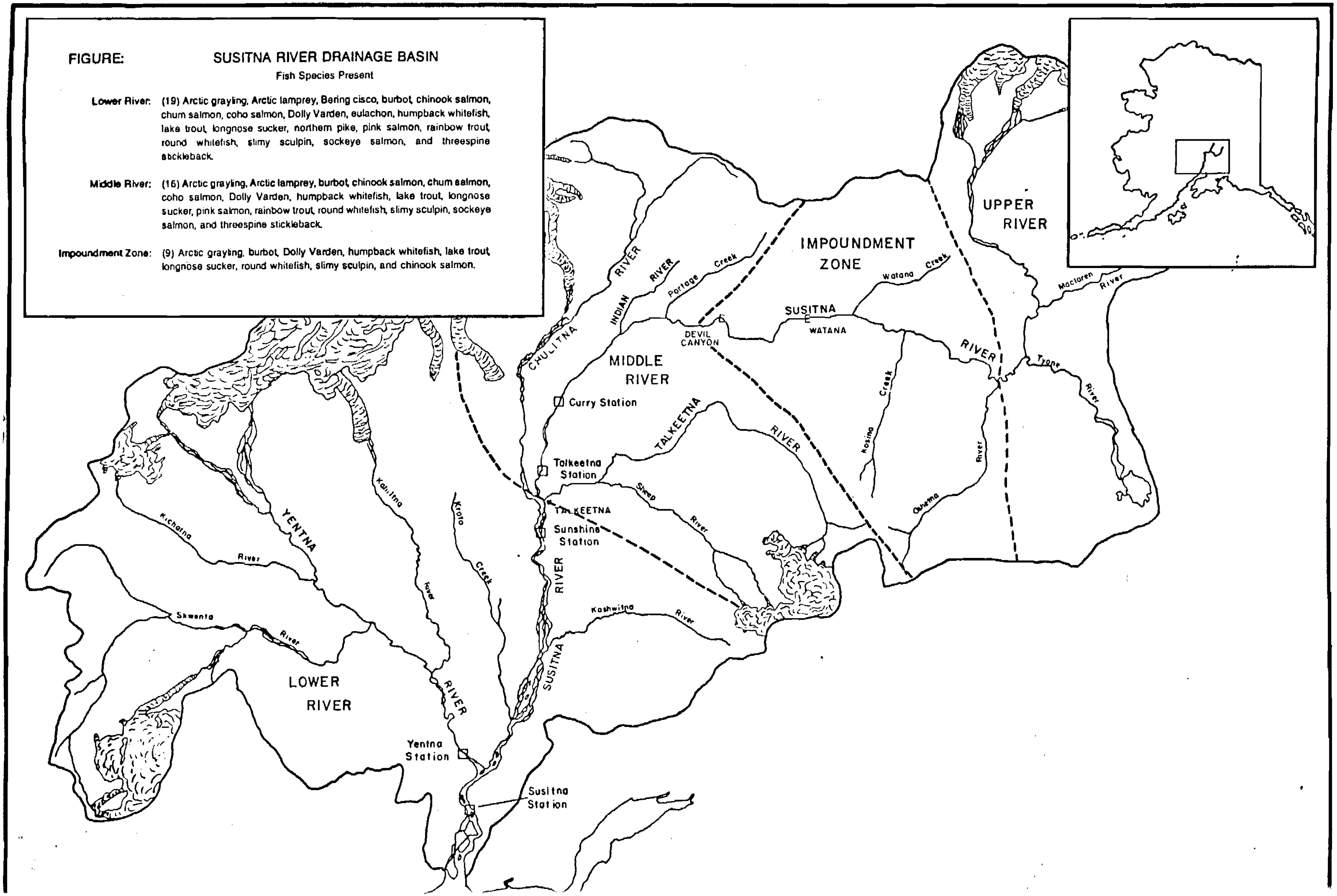
determining the abundance of lake trout and Arctic grayling in Sally Lake; recording biological information on selected resident fish populations to provide information on survival and growth; and identifying Arctic grayling spawning and rearing locations within and adjacent to the with-project impoundment areas (ADF&G 1983).

Prior to initiation of the 1981 ADF&G Su-Hydro studies, fish resource data for this area were collected by the U.S. Fish & Wildlife Service (1952, 1954, 1957, 1959a, 1959b, 1960, 1965) and ADF&G (1978). These studies were preliminary Susitna environmental assessments and primarily defined species composition. They also highlighted selected habitat locations of particular interest. Additional information on the fish resource in this area is found in the transmission corridor studies of Schmidt et al. 1984.

The natural environment between Devil Canyon and the upstream end of the proposed Watana Reservoir provides habitats for nine fish species (ADF&G 1983b); eight are year-round residents and one (chinook salmon) is anadromous (Figure 1). Within Devil Canyon, Cheechako Creek (RM 152.5) and Chinook Creek (RM 156.8) mark the upstream limit of salmon in the mainstem Susitna River. Devil Canyon's constricted river channel apparently creates a velocity barrier to upstream salmon migrants. In total, fewer than 100 salmon utilize these two tributary habitats for reproductive purposes (Barrett, Thompson & Wick 1985).

Arctic grayling are the most widely distributed and abundant species utilizing habitats above the canyon. The total 1982 Arctic grayling population in the impoundment zone was estimated to be over 16,000 (ADF&G 1983b). Mainstem impoundment areas above the canyon provide essential overwintering habitat for Arctic grayling, which move into its tributaries to spawn following breakup in late May or early June (ADF&G 1983b). Arctic

Figure 5 Susitna River drainage Basin fish Species by study zone



grayling migrate out of natal tributaries in September as water levels begin to drop. They overwinter in mainstem environments which become less turbid following freeze-up (ADF&G 1983b).

Except for documentation of their presence, little is known of the life histories or relative abundance of other species resident in the impoundment zone. Based on limited capture data, it seems that both burbot and longnose sucker are relatively abundant there (ADF&G 1983b). Elsewhere in the mainstem Susitna River, burbot spawn under the ice from January to February over gravel near tributary stream mouths (R. Sundet, pers. comm.). During the rest of the year, they apparently distribute themselves throughout the deeper portions of aquatic environments. Susitna River longnose sucker are spring spawners which move from overwinter habitats in the mainstem to tributary natal areas from late May to early June (ADF&G 1983). Small numbers of round and humpback whitefish have been captured (at two locations) within the impoundment areas, but there are no estimates of their relative abundances (ADF&G 1983). If they behave similarly to lower river and middle river whitefish, they overwinter in mainstem environments. Although available information is scant, it appears that this species spawns in early October in clearwater tributary streams.

Although not present in mainstem impoundment areas, some lake trout and rainbow trout might gain access to them as a result of the project. Sally Lake, which supports a lake trout population of undetermined size, would be inundated by the Watana Reservoir (ADF&G 1983b). Lake trout generally spawn from August through December and require stable lake shore gravel substrates for reproduction. High lake (located immediately north of Devil Canyon) is a tributary system to Devil Creek which has a resident population of rainbow trout. Although this lake is outside of the original study area, should the project be completed, we believe that some rainbows might outmigrate down

Devil Creek to the Devil Canyon Reservoir. Elsewhere in the basin, rainbow trout typically overwinter in lakes and mainstem habitats, returning in the spring following breakup to spawn in tributary streams. Most rainbow trout spawn in moderate velocity clearwater streams, which are paved with relatively small cobbles (ADF&G 1983c).

DEVIL CANYON TO LOWER RIVER

Fish and aquatic habitat investigations have been conducted on the Susitna River since the 1950's to evaluate the proposed hydroelectric project [U.S. Fish and Wildlife Service 1952, 1954, 1957, 1959a, 1959b, 1960, 1965; Barrett (1974); ADF&G (1976, 1978), 1981a, 1983a, 1983b, 1983d, 1985; Barrett, Thompson, and Wick (1984, 1985); Riis (1977); Schmidt et al. (1984a, 1984b); and Wangaard and Burger (1983)]. In 1980, the Susitna Hydroelectric Aquatic Studies Program was initiated to collect data on the fish and aquatic habitat resources of the basin.

Extant Susitna River basin data on fish distribution, abundance and habitat use focuses on salmon and are temporarily and spatially limited. The studies, and therefore the information available, is more complete for the open water season and for the area upstream of the Chulitna River influence. A complete summary of ADF&G's Su-Hydro studies of the fish resources downstream of Devil Canyon is available in a report by Woodward Clyde Consultants and Entrix (1985). ADF&G's Su-Hydro studies have: documented migration timing of salmon runs in the Susitna River; estimated the population size and relative abundance of salmon in various sub-basins of the Susitna River; estimated the total salmon escapements into sloughs and tributaries upstream of RM 98.6; quantified selected biological characteristics of Susitna River salmon stocks (e.g., sex ratio, fecundity, length at age); identified important spawning areas for some resident species; documented timing and estimated the relative utilization of macrohabitat types by juvenile and adult salmon and some resident species; developed habitat suitability criteria for adult and juvenile salmon, eulachon, Bering cisco, and some resident species; estimated population size and survival for juvenile chum and sockeye; documented outmigration timing of juvenile salmon; collected baseline physical and chemical water quality data in identified macrohabitat types; developed understanding of site-specific habitat responses to various mainstem discharges; evaluated the capability of adult salmon to pass into selected sloughs; and confirmed the importance of ground water upwelling for spawning salmon in sloughs.

At least nineteen species of fish are known to inhabit the Susitna Drainage (Table 1), all of which are dependent to some extent on mainstem environments to fulfill aspects of their respective life histories. Seven of these species are anadromous; they include five species of Pacific salmon, eulachon, and Bering cisco.

The Susitna River drainage is the largest watershed in Upper Cook Inlet and is the inlet's largest salmon-producing system (CIRPT 1981). The basin provides reproductive and rearing habitat for millions of salmon (Table 2), more than 99% of which spawn in its tributaries. Salmon utilize mainstem river environments for migration, rearing, overwintering, and to a lesser extent spawning (Woodward Clyde Consultants & Entrix 1985). Adult migration timing varies by species, but in general the peak inmigration time is from mid-June to the end of September (Table 3).

Above the Chulitna River confluence (RM 98.5) salmon spawn in a variety of tributaries, sloughs, and a few mainstem sites. In this river reach, coho and chinook have only been found to spawn in tributary stream environments,

Table 1. Common and Scientific Names of Fish Species Recorded in the Susitna River Basin.

Arctic lamprey	Lampetra japonica (Martens)
Eulachon (hooligan)	Thaleichthys pacificus (Richardson)
Arctic grayling	Thymallus arcticus (Pallas)
Bering cisco	Coregonus laurettae Bean
Round whitefish	Prosopium cylindraceum (Pallas)
Humpback whitefish	Coregonus pidschian (Gmelin)
Rainbow trout	Salmo gairdneri Richardson
Lake trout	Salvelinus namaycush (Walbaum)
Dolly Varden	Salvelinus malma (Walbaum)
Pink (humpback) salmon	Oncorhynchus gorbuscha (Walbaum)
Sockeye (red) salmon	Oncorhynchus nerka (Walbaum)
Chinook (king) salmon	Oncorhynchus tshawytscha (Walbaum)
Coho (silver) salmon	Oncorhynchus kisutch (Walbaum)
Chum (dog) salmon	Oncorhynchus keta (Walbaum)
Northern pike	Esox lucius Linnaeus
Longnose sucker	Catostomus catostomus (Forster)
Threespine stickleback	Gasterosteus aculeatus Linnaeus
Burbot	Lota lota (Linnaeus)
Slimy sculpin	Cottus cognatus Richardson

Table 2. Susitna River Salmon Escapement Estimates, 1981-1984.

Year	Chinook	Sockeye[1]	Pink	Chum	Coho	Total[2]
1981	-	272,500	85,600	282,700	36,800	677,600
1982	-	265,200	890,500	458,200	79,800	1,693,700
1983	-	176,200	101,300	276,800	24,100	578,400
1984	250,000	605,800	3,629,900	812,700	190,100	5,488,500

[1] Second run sockeye only.

[2] Total 1984 drainage escapement estimate. Escapement counts for 1981 through 1983 do not include chinooks or any escapements into tributaries downstream of RM 77, with the exception of those into the Yentna River.

Source: ADF&G 1983a; Barrett, Thompson & Wick 1984 and 1985.

Table 3. Susitna River Salmon Phenology.

	HABITAT	DATE RANGE	DATE PEAK
CHINOOK (KING) SALMON			
Adult Inmigration	Cook Inlet - Talkeetna	May 25 - Aug 18	Jun 18 - Jun 30
	Talkeetna - D.C.	Jun 07 - Aug 20	Jun 24 - Jul 04
	Middle River Tributaries	Jul 01 - Aug 06	
Juvenile Migration	Middle River	May 18 - Oct 03[1&3]	
Spawning	Middle River Tributaries	Jul 01 - Aug 26	Jul 20 - Jul 27
	Lower River Tributaries	Jul 07 - Aug 20	Jul 20 - Jul 27
COHO (SILVER) SALMON			
Adult Inmigration	Cook Inlet - Talkeetna	Jul 07 - Sep 28	Jul 27 - Aug 20
	Talkeetna - D.C.	Jul 18 - Sep 19	Aug 12 - Aug 26
	Middle River Tributaries	Aug 08 - Sep 27	
Juvenile Migration	Middle River	May 18 - Oct 12[1&3]	May 28 - Aug 21
Spawning	Middle River Tributaries	Sep 01 - Oct 08	Sep 05 - Sep 24
	Lower River Tributaries	Aug 08 - Oct 01	
CHUM (DOG) SALMON			
Adult Inmigration	Cook Inlet - Talkeetna	Jun 24 - Sep 28	Jul 27 - Aug 02
	Talkeetna - D.C.	Jul 10 - Sep 15	Aug 01 - Aug 17
	Middle River Tributaries	Jul 27 - Sep 06	
	Middle River Sloughs	Aug 06 - Sep 05	
Juvenile Migration	Middle River	May 18[3] - Aug 20	May 28 - Jul 17

Table 3. Susitna River Salmon Phenology.
(cont'd)

	HABITAT	DATE RANGE	DATE PEAK
Spawning	Middle River Tributaries	Jul 27 - Oct 01	Aug 05 - Sep 10
	Middle River Sloughs	Aug 05 - Oct 11	Aug 20 - Sep 25
	Middle River Mainstem	Sep 02 - Sep 19	
	Lower River Tributaries	Jul 27 - Sep 09	Aug 06 - Aug 14
SOCKEYE (RED) SALMON[2]			
Adult Inmigration	Cook Inlet - Talkeetna	Jul 04 - Aug 08	Jul 18 - Jul 27
	Talkeetna - D.C.	Jul 16 - Sep 18	Jul 31 - Aug 05
Juvenile Migration	Middle River	May 18 - Oct 11[1&3]	Jun 22 - Jul 17
Spawning	Middle River Sloughs	Aug 05 - Oct 11	Aug 25 - Sep 25
PINK (HUMPBACK) SALMON			
Adult Inmigration	Cook Inlet - Talkeetna	Jun 28 - Sep 10	Jul 26 - Aug 03
	Talkeetna - D.C.	Jul 10 - Aug 30	Aug 01 - Aug 08
	Middle River Tributaries	Jul 27 - Aug 23	
	Middle River Sloughs	Aug 04 - Aug 17	
Juvenile Migration	Middle River	May 18[3] - Jul 24	May 29 - Jun 08
Spawning	Middle River Tributaries	Jul 27 - Aug 30	Aug 10 - Aug 25
	Middle River Sloughs	Aug 04 - Aug 30	Aug 15 - Aug 30
	Lower River Tributaries	Jul 27 - Sep 09	Aug 06 - Aug 09

1 All migration includes migration to and between habitat, not just outmigration.
2 Second run sockeye only.
3 No data available for pre-ice movement; earlier date of range refers to initiation of outmigrant trap operation.

Source: Barrett, Thompson and Wick 1984, 1985; Schmidt et al. 1984; ADF&G 1983a,c.

33RC1/007h

pink salmon primarily in tributary streams (with a small number utilizing slough habitats), chum salmon in tributary, slough, and mainstem environments, and sockeye almost exclusively in sloughs (Barrett, Thompson & Wick 1985). Over 90% of salmon spawning in this reach occurs in tributaries (Barrett, Thompson & Wick 1985).

At least eighteen tributary streams in the middle river provide salmon spawning habitats (Table 4). Over 96% of the total chinook escapement above the Chulitna confluence spawn in two streams; Portage Creek (RM 148.9) and Indian River (RM 138.6) (Table 4). In 1984, these two streams had a combined escapement of over 13,000 fish which represented a little over 5% of the basin's total chinook resource (Barrett, Thompson & Wick 1985). Only about 10% of Susitna River coho salmon spawn above the Chulitna confluence; they apparently spawn only in tributaries in this reach. (Barrett, Thompson & Wick 1985). Indian River (RM 138.6) is the most important tributary for them, providing a little over 30% of the reproductive habitat available here (Table 4). Portage and 4th of July (RM 131.1) creeks and Indian River provide reproductive habitats for over 80% of middle river pink salmon; this represents about 1% of the total Susitna escapement for pink salmon (Barrett, Thompson & Wick 1985). The same three streams provide over 98% of tributary spawning habitat for chum salmon (Barrett, Thompson & Wick 1985). In 1984, these tributaries accounted for about 1% of the total Susitna chum salmon escapement.

Based on escapement counts for 1984, 34 middle river sloughs collectively provided habitat for approximately 5.5% of all salmon migrating above Talkeetna station (Barrett, Thompson & Wick 1985). These sloughs are of particular importance to chum and sockeye salmon. About 50% of the chum and almost all of the sockeye spawning above the Chulitna confluence occurs in

Table 4. Peak Salmon Survey Counts Above Talkeetna for Susitna River Tributary Streams.

STREAM	SURVEY DISTANCE	Coho						Chinook								
		1974	1976	1981	1982	1983	1984	1975	1976	1977	1978	1979	1981	1982	1983	1984
Whiskers Creek (RM 101.4)	0.25	27		70	176	115	301	22	8						3	67
Chase Creek (RM 106.9)	0.25	40		80	36	12	239							15		3
Slash Creek (RM 111.2)	0.75				6	2	5									
Gash Creek (RM 111.6)	1.0			141	74	19	234									
Lane Creek (RM 113.6)	0.5			3	5	2	24						40	47	12	23
Lower McKenzie (RM 116.2)	1.5			56	133	18	24									
McKenzie Creek (RM 116.7)	0.25															
Little Portage (RM 117.7)	0.25				8											
Fifth of July (RM 123.7)	0.25													3		17
Skull Creek (RM 124.7)	0.25															
Sherman Creek (RM 130.8)	0.25													3		
Fourth of July (RM 131.0)	0.25	26	17	1	4	3	8	1	14					56	6	92
Gold Creek (RM 136.7)	0.25				1									21	23	23
Indian River (RM 138.6)	15.0	64	30	85	101	53	465	10	537	393	114	285	422	1,053	1,193	1,456
Jack Long (RM 144.5)	0.25				1	1	6							2	6	7
Portage Creek (RM 148.9)	15.0	150	100	22	88	15	128	29	702	374	140	140	659	1,253	3,140	5,446
Cheechako Creek (RM 152.5)	3.0													16	25	29
Chinook Creek (RM 156.8)	2.0													4	8	15
TOTAL		307	147	458	633	240	1,434	62	1,261	767	254	425	1,121	2,473	4,416	7,178

Table 4. Peak Salmon Survey Counts Above Talkeetna for Susitna River Tributary Streams. (cont'd)

STREAM	SURVEY DISTANCE	Chum 1974	Chum 1975	Chum 1976	Chum 1977	Chum 1981	Chum 1982	Chum 1983	Chum 1984	Sockeye 1974	Sockeye 1975	Sockeye 1976	Sockeye 1977	Sockeye 1981	Sockeye 1982	Sockeye 1983	Sockeye 1984
Whiskers Creek (RM 101.4)	0.25					1											
Chase Creek (RM 106.9)	0.25					1			1								
Slash Creek (RM 111.2)	0.75																
Gash Creek (RM 111.6)	1.0																
Lane Creek (RM 113.6)	0.5		3		2	76	11		31								
Lower McKenzie (RM 116.2)	1.5					14		1	23					1			
McKenzie Creek (RM 116.7)	0.25										46						
Little Portage (RM 117.7)	0.25						31		18								
Fifth of July (RM 123.7)	0.25							6	2								
Skull Creek (RM 124.7)	0.25					10	1		4								
Sherman Creek (RM 130.8)	0.25					9			6								
Fourth of July (RM 131.0)	0.25	594		78	11	90	191	148	193		1						
Gold Creek (RM 136.7)	0.25																
Indian River (RM 138.6)	15.0	531	70	134	776	40	1,346	811	2,247		1	2	1			1	1
Jack Long (RM 144.5)	0.25						3	2	4								
Portage Creek (RM 148.9)	15.0	276		300			153	526	1,285								12
Cheechako Creek (RM 152.5)	3.0																
Chinook Creek (RM 156.8)	2.0																
TOTAL		1,401	73	512	789	241	1,736	1,494	3,814		48	2	1	1		1	13

Table 4. Peak Salmon Survey Counts Above Talkeetna for Susitna River Tributary Streams. (cont'd)

STREAM	SURVEY DISTANCE	Pink							
		1974	1975	1976	1977	1981	1982	1983	1984
Whiskers Creek (RM 101.4)	0.25			75		1	138		293
Chase Creek (RM 106.9)	0.25			50		38	107	6	438
Slash Creek (RM 111.2)	0.75								3
Gash Creek (RM 111.6)	1.0								6
Lane Creek (RM 113.6)	0.5	82	106		1,103	291	640	28	1,184
Maggot Creek (RM 115.6)	0.25								107
Lower McKenzie (RM 116.2)	1.5						23	17	585
McKenzie Creek (RM 116.7)	0.25						17		11
Little Portage (RM 117.7)	0.25						140	7	162
Deadhorse Creek (RM 120.8)	0.25								337
Fifth of July (RM 123.7)	0.25					2	113	9	411
Skull Creek (RM 124.7)	0.25					8	12	1	121
Sherman Creek (RM 130.8)	0.25					6	24		48
Fourth of July (RM 131.0)	0.25	159	148	4,000	612	29	702	78	1,842
Gold Creek (RM 136.7)	0.25			32			11	7	82
Indian River (RM 138.6)	15.0	577	321	5,000	1,611	2	738	886	9,066
Jack Long (RM 144.5)	0.25					1		5	14
Portage Creek (RM 148.9)	15.0	218		3,000			169	285	2,707
Cheechako Creek (RM 152.5)	3.0						21		
Chinook Creek (RM 156.8)	2.0								
TOTAL		1,036	575	12,157	3,326	378	2,855	1,329	17,417

Source: Barrett 1974; Barrett, Thompson and Wick 1984, 1985; Riis 1977; ADF&G 1976, 1978, 1981, 1983a.

sloughs. This represents about 2% of all chum and less than 0.5% of all sockeye spawning in the Susitna Drainage (Barrett, Thompson & Wick 1985).

Spawning habitat quality apparently varies greatly between sloughs as, in the last four years, the majority of chum salmon spawners counted were in 10 of the 34 (Tables 5 and 6). Three of the 10 most used sloughs (8A, 11, 21) have added significance in that they also accommodated over 90% of all sockeye spawning in the middle river (Table 5).

Relatively few salmon spawn in mainstem non-slough habitats; of those which do, chum salmon predominate. Generally, spawning habitats within the mainstem proper are small areally and widely distributed. In 1984, ADF&G made a concerted effort to identify mainstem middle river spawning habitats; they identified 36 spawning sites. Numbers of spawning fish counted at each of these sites varied from one to 131 with an average of 35 (Barrett, Thompson, & Wick 1985). The estimated total mainstem escapement was approximately 3,000 chum salmon (Barrett, Thompson & Wick 1985). This is less than 0.5% of the total Susitna escapement.

Four of the five salmon species use middle river waters for rearing purposes (Schmidt et al. 1984a). At this time insufficient information exists to characterize the relative importance of individual mainstem rearing habitats. From May to September juvenile chinook rear in tributary and side channel environments, coho mostly rear in tributary and upland sloughs, and sockeye are evenly distributed between upland and side sloughs. From May to July rearing chum juveniles are distributed throughout side slough and tributary stream environments (Dugan et al. 1984).

Of the five salmon species present, only two have been captured in winter in the middle river (ADF&G 1983c). Preliminary studies indicate that significant numbers (perhaps 25 to 50%) of chinook and coho juveniles reared

Table 5. Peak Slough Escapement Counts Above Talkeetna.

		CHUM								SOCKEYE								PINK					
SLOUGH NO.	RIVER MILE	1974	1975	1976	1977	1981	1982	1983	1984	1974	1975	1976	1977	1981	1982	1983	1984	1976	1977	1981	1982	1983	1984
1	99.6					6			12								10						
2	100.4					27		49	129								7						2
3B	101.4		50					3	56		15			7		5	20			1			28
3A	101.9								17					1			11						56
Talkeetna St.	103.0																						
4	105.2																						
5	107.2						2	1									1						4
6	108.2	1																					
6A	112.3					11	2							1							35		
7	113.2																						
8	113.7					302			65								2			25			1
Bushrod	117.8								90														10
Curry St.	120.0																						
8D	121.8						23		49														
8C	121.9						48	4	121						2								1
8B	122.2					1	80	104	400				2		5		1						68
Moose	123.5					167	23	68	76						8	22	8				8		25
A'	124.6					140		77	111														24
A	124.7					34		2	2											2			
8A	125.1				51	620	336	37	917				70	177	68	66	128				28		134
B	126.3						58	7	108						8	2	9				32		
9	128.3	511	181		36	260	300	169	350	8			6	10	5	2	6				12		1
9B	129.2					90	5		73					81	1		7						
9A	133.3					182	118	105	303					2	1	1							
10	133.8				2		2	1	36							1							
11	135.3	33		66	116	411	459	238	1,586	79	84	78	214	893	456	248	564	1			131		121
12	135.4																						
13	135.7		1			4		4	13														
14	135.9	2							1														
15	137.2		1			1	1		100			1					1				132	1	500
16	137.3	2	12		4	3			15										13				
17	138.9	24				38	21	90	66					6		6	16						1
18	139.1								11														
19	139.7	4				3		3	45	3		32	8	23		5	11				1	1	
20	140.0	107		2	28	14	30	63	280		20			2							64	7	85
21	141.1	668	250	30	304	274	736	319	2,354	13	75	23		38	53	197	122				64		8
21A	145.5								10														
22	144.5					8		114	151								2						
TOTAL		1,352	495	98	541	2,596	2,244	1,458	7,547	103	194	134	300	1,241	607	555	926	1	13	28	507	9	1,069

Source: Barrett 1974; Barrett, Thompson and Wick 1984, 1985; Riis, 1977; ADF&G 1976, 1978, 1981, 1983a.

Table 6. Chum Salmon Escapement for the Ten Most Productive Sloughs Above RM 98.6, 1981-83.

Slough	River Mile	1981	1982	1983	3-Year Average	Percent of Total Escapement
8	113.7	695	0	0	232	5.6
8B	122.2	0	99	261	120	2.9
Moose	123.5	222	59	86	122	2.9
A'	124.6	200	0	155	118	2.8
8A	125.1	480	1,062	112	551	13.2
9	128.3	368	603	430	467	11.2
9A	133.8	140	86	231	152	3.6
11	135.3	1,119	1,078	674	957	23.0
17	138.9	135	23	166	108	2.6
21	141.1	657	1,737	481	958	23.0

Source: Barrett, Thompson and Wick 1984.

in this zone overwinter in side slough and tributary stream environments (ADF&G 1985a). Perhaps significantly, preliminary evidence indicates that few juvenile salmon utilize the mainstem proper for overwintering purposes (ADF&G 1985a).

Two studies to determine the timing of emergence and yolk absorption for Susitna chum and sockeye salmon have been conducted. Wangaard & Burger (1983) incubated Susitna chum and sockeye eggs in a laboratory experiment under four separate temperature regimes until complete yolk absorption. In a related study, ADF&G (1983c) determined the timing to 50 percent emergence for chum and sockeye salmon under natural conditions. A study was also carried out by ADF&G in 1984 to evaluate the incubation life-phase of chum salmon in the middle Susitna River. Upwelling was found to be the most significant factor required for successful development and survival of salmon embryos in sloughs and mainstem habitats in the middle Susitna River (ADF&G 1985). Dewatering and freezing of redds was identified as the major factor contributing to embryo mortality (ADF&G 1985).

LOWER RIVER

At least 17 tributary streams and six sloughs provide salmon reproductive habitats downstream of the Chulitna confluence. Tributary systems in this reach support more than 99% of all salmon spawning. To date, no chinook, sockeye, or pink salmon have been observed spawning in lower river mainstem waters; all apparently use tributary streams exclusively for this purpose (Barrett, Thompson & Wick 1985). Small numbers of chum and coho salmon have been seen spawning in 13 separate mainstem sites and six side sloughs; most members of these two species also spawn in tributary environments. ADF&G estimates that, in aggregate, the number of chum salmon spawning within mainstem environments in this reach represents roughly 0.3% of 1984 escapement to the basin. The estimated number of spawning coho in the mainstem represents roughly 0.2% of the 1984 escapement (Barrett, Thompson & Wick 1985). Chum salmon were the principal users of side slough spawning environments, being present in five of the six sloughs used. Their estimated numbers represent roughly 0.1% of the total 1984 escapement. Only six coho were seen spawning in sloughs in 1984; all were in one of the six sloughs (Barrett, Thompson & Wick 1985). This indicates that lower river sloughs are less important than middle river sloughs for spawning purposes.

Less is known of salmon rearing and overwintering habitats in lower river mainstem environments than in the middle river. Given their respective life history requirements and the natural hydrologic conditions occurring in winter, it is possible that some chinook, coho, and sockeye salmon overwinter in the mainstem and that some chum, chinook, and coho rear there. A few coho and chinook have been captured during winter in mainstem environments in this river reach (ADF&G 1983c).

Several million eulachon spawn in late May to early June in the lower 50 miles of the mainstem Susitna River. Most of these fish spawn below RM 29 in main channel habitats near cut banks over loose sand and gravel substrates (Barrett, Thompson & Wick 1984). Bering cisco return to the Susitna River in late August and spawning takes place from September through October. In 1981 and 1982, spawning activity peaked in the second week of October. Bering cisco are known to spawn only in main channel environments; the majority of spawning apparently takes place between RM 75 and RM 85 (Barrett, Thompson & Wick 1984).

Of the 12 resident Susitna Drainage fish species (Figure 1), capture data indicate that only rainbow trout, Arctic grayling, burbot, round whitefish, longnose sucker, and slimy sculpin are common in the middle river (ADF&G 1983c). Dolly Varden, humpback whitefish, threespine stickleback, and Arctic lamprey also occur, but all appear to be more abundant downstream of the Chulitna confluence (Schmidt, et al. 1984). Lake trout are found only in surrounding area lakes, none of which would be influenced by the project. Northern pike occur in the lower river but are not common (Schmidt, et al. 1984).

Little is known of either the numbers or the life histories (especially during the winter) of any fish species residing year-round in the Susitna River. Given the naturally reduced flow regimes of tributary streams in winter, it is probable that the majority of these resident fish (with the exception of lake trout) overwinter somewhere in the mainstem. It is generally believed, however, that most resident fish overwinter in the lower river (ADF&G 1983c). A forthcoming ADF&G report (due to be released in late April), reportedly will contain a synopsis of available information on resident species. Rainbow trout, Arctic grayling, and Dolly Varden probably spend most of the open water season in tributaries, using the mainstem principally for migration and overwintering (ADF&G 1983c). Rainbow trout and Arctic grayling move into tributaries to spawn in the spring after breakup. Whiskers, Lane, and 4th of July creeks are the primary tributaries above the Chulitna confluence used by spawning rainbows (Schmidt, et al. 1984). Burbot, whitefish, longnose sucker, sculpin, stickleback, and Arctic lamprey are found in both the mainstem and tributaries during the open water season. Round whitefish are believed to spawn in October at either mainstem, tributary mouth, or tributary locations (Schmidt, et al. 1984). Burbot spawning generally occurs between January and March under the ice in areas influenced by the mainstem or in tributary mouths like the Deshka.

Based on ongoing radio-telemetry studies, it appears that favored mainstem overwinter habitats for adult rainbow trout and burbot differ principally by depth and location. Tagged rainbows are most frequently relocated in mainstem side channels near tributaries in waters generally less than five feet (Rich Sundet, pers. comm.). They are often found close to open leads. Tagged burbot are most frequently located in winter in pools greater than six feet deep along river bends (Rich Sundet, pers. comm.). Both species seem to favor low velocity environments. Only one Arctic grayling has been successfully radio-tagged; it was frequently relocated in close association with rainbow trout (Rich Sundet, pers. comm.). No other resident species have been radio-tagged. It may be that other resident salmonids with habits like rainbow trout also frequent relatively shallow low velocity environments in winter; the same type of relationship may exist between burbot and other bottom feeders such as longnose sucker.

SYNOPSIS OF SALMON LIFE HISTORY WITH RESPECT TO TEMPERATURE

As an aid to defining the extent of possible effects on fish from with-project temperature changes, the literature was searched for pertinent information on the influence of temperature on migration spawning, alevin and juvenile behaviors and on incubation success and the smoltification process. Interpretation and subsequent application of the very large body of information on Pacific salmon to this analysis is confounded by the fact that it is specific to a vast number of drainages stretching over nearly 20 degrees of latitude. Timing of major physiological and behavioral characteristics are shaped by genetic selection and are specific to individual drainages (and, often, portions of given drainages) somewhat constraining the applicability of this information to the Susitna Drainage. A synopsis of this information follows.

ADULT INMIGRATION

Upstream migration of salmon is closely related to the temperature regime characteristic of each spawning stream (Sheridan 1962). The reported temperatures at which natural migration occurs vary between species and location but appear to be influenced by latitude. In general, average annual freshwater temperatures are progressively cooler with increasing latitude (Wetzel 1975). At latitudes above 55°N, inmigrating chinook, coho, sockeye, and chum salmon have been observed in streams having water temperatures of 4 C or colder (Bell 1983).

Temperatures above the upper tolerance range have been reported to stop fish migration (Bell 1980). The upper tolerance range for Pacific salmon is reported to be between 20 to 24 C (Bell 1980; Reiser and Bjornn 1979). Temperatures between 6 and 6.5 C reported by stopped pink salmon inmigration to the Main Bay Hatchery in Prince William Sound (Krasnowski 1984). At these temperatures, pink salmon were seen milling in seawater which was at a temperature between 10 and 12 C (Krasnowski 1984). When the hatcheries raceway water temperature was artificially raised to 8.5 C, the salmon quickly entered the holding pond (Krasnowski 1984).

Adult salmon throughout the Talkeetna to Devil Canyon reach experience natural water temperatures ranging from approximately 2.5 to 16 C during the chinook inmigration, 4 to 15 C during the coho inmigration, and 5 to 16 C during the pink, chum, and sockeye inmigration (AEIDC 1984).

ADULT SPAWNING

Spawning of adult Pacific salmon has been reported to occur in water temperatures ranging from approximately 4 to 18 C, although the preferred temperature range for all five North American species is reported by McNeil and Bailey (1975) to be between 7 to 13 C. Chum salmon have been observed spawning in upper Susitna mainstem habitats at temperatures as cold as 3.3 C (ADF&G 1983b).

Burbot and round whitefish are the most numerous species using mainstem habitats for spawning. Burbot is one of the few species of freshwater fish to spawn in winter. Elsewhere, burbot spawning has been observed to take place in water between 0.5 to 1.5 C (Scott and Crossman 1973; Alabaster and Lloyd 1982). Temperatures between 0 and 0.7 C were observed in Susitna River mainstem burbot spawning areas in 1983 (ADF&G 1983c). Round whitefish spawning has been observed at temperatures between 0 and 4.5 C (Scott and Crossman 1973; Bryan and Kato 1975). This species is believed to spawn in the Susitna River during October while water temperatures are dropping rapidly.

EMBRYO DEVELOPMENT

Compared to other life history phases, embryo development is perhaps the most influenced by water temperature. Temperature ranges that cause no increased embryo mortality are much narrower than those for adults (Alabaster and Lloyd 1982). In the freshwater species for which data on embryonic development are available, the preferred range of temperatures is 3.5 to 11.1 C (Alabaster and Lloyd 1982). Generally, the lower and upper temperature limits for successful initial incubation of salmon embryos are 4.5 and 14.5 C, respectively (Reiser and Bjornn 1979). In laboratory studies conducted in Washington (Combs 1965) and from a literature review conducted by Bams (1967), salmon embryos are reportedly most vulnerable to temperature stress before closure of the blastopore, which occurs at about 140 accumulated Celsius temperature units. (A temperature unit is one degree above freezing experienced by developing fish embryos per day.) After the period of initial sensitivity to low temperatures has passed (approximately 30 days at 4.5 C), embryos and alevins can tolerate temperatures near 0 C (McNeil and Bailey 1975).

From his work on Sashin Creek in southeast Alaska, Merrell (1962) suggested that pink salmon embryo survival may be related to water temperatures during spawning. McNeil (1969) further examined Sashin Creek data and discussed the relationship between initial incubation temperature and survival. These two investigations determined that embryos exposed to cooler spawning temperature experienced greater incubation mortality than embryos which began incubation at warmer temperatures. Abnormal embryonic development could occur if, during initial stages of development, embryos are exposed to temperatures below 6 C (Bailey 1983). Bailey and Evans (1971) reported an increase in pink salmon embryo mortalities when initial incubation water temperatures were held below 2 C during this initial incubation period.

Of the species found in the Susitna River, the most sensitive embryos to temperature change are those of burbot with a tolerance range of only 0 to 3 C and a preferred range of 0.5 to 1.0 C (Alabaster and Lloyd 1982). The next most sensitive would be the coregonids followed by the salmonids, of which the most sensitive appear to be pink salmon. The most tolerant species would be those spawning in quite shallow waters experiencing diurnal fluctuations of temperature (Alabaster and Lloyd 1982).

ALEVINS

Alevin intragravel movement rates are known to be influenced by environmental temperatures. Early in their development, alevins move downward in their natal redds where they remain until shortly before emerging (Dill 1967). Both the descending and ascending rates of movement are primarily influenced by temperature (Bams 1969); size of gravel interstices, dissolved gases, gravel size, and sedimentation also effect movement rates (Bams 1967; Hausle and Coble 1976; Witzel and MacCrimmon 1981; Fast et al. 1982), but temperature is the chief determinant (Bams 1967).

REARING

Water temperature affects immature fish metabolism, growth, food capture, swimming performance, and disease resistance. Juvenile salmonids can usually tolerate a wider range of water temperatures than embryos. They can also survive short exposure to temperatures which would be ultimately lethal, and can live for longer periods at temperatures at which they abstain from feeding (Alabaster and Lloyd 1982).

Juvenile salmon activity slows at water temperatures lower than 4 C; at these temperatures, fish tend to be less active and spend more time resting in secluded, covered habitats (Chapman and Bjornn 1969). In Carnation Creek, British Columbia, Bustard and Narver (1975) reported that at water temperatures below 7 C, fish stopped feeding and moved into deeper water or closer to objects providing cover. In Grant Creek near Seward, Alaska, juvenile salmonids were inactive at water temperatures of 1.0 to 4.5 C inhabiting cover afforded by streambed cobbles and other large gravels (AEIDC 1982).

Generally, the tolerable temperature range for rearing salmonids is between 4 and 16 C. However, rearing juvenile salmonids have been observed in side sloughs in the upper Susitna River where, from June through September, water temperatures were between 2.4 and 15.5 C (ADF&G 1983d), a slightly wider range. Juvenile coho and chinook salmon have been successfully reared in Alaska hatcheries at temperatures between 2 and 4 C (Pratt 1984). In an experiment at the U.S. National Marine Fisheries Service Auke Bay Laboratory, coho salmon grew temperatures of 0.2, 2 and 4 C. No mortality was seen in unfed fish held at these temperatures except for those at 4 C (Koski 1984). This suggests that at temperatures at and above 4 C, coho are sufficiently active to require food, whereas below this temperatures they are inactive and do not require food.

SMOLTIFICATION

Salmon fry are physiologically adapted to life in fresh water environments, and before they can successfully undertake life at sea (and, hence, mature) they must undergo a complex physiological and morphological transformation. This process is termed smoltification. The overall controlling force is endogenous and has the characteristics of a circannual rhythm (Hoar 1976; Wedemeyer et al. 1980). Timing of transformation is dependent on numerous environmental factors which influence metabolism and which act as behavioral releasers (Schreck 1982).

Photoperiod is the major environmental factor influencing smolt transformation in Atlantic salmon, steelhead trout, and coho and sockeye salmon (Wagner 1974; Wedemeyer et al. 1980). Photoperiod is apparently subordinate to other as yet unidentified environmental factors in chinook salmon (Clarke et al. 1981). In species where photoperiod is controlling, its chief influence appears to be that of synchronizing endogenous rhythm with natural seasonal change (Groot 1982). Temperature affects the smoltification process by regulating physiological response to photoperiod; it causes effects to occur sooner the higher the temperature or later the lower the temperature (Clarke et al. 1981). In short, temperature exerts influence on the smolting process by controlling growth, and it regulates both the magnitude and duration of the smolting process (Clarke et al. 1978; Grau 1982; cf. Groot 1982).

Na^+K^+ATPase gill activity has been associated with the smolt transformation process and is believed to be an indicator of physiological readiness for life at sea (Wedemeyer et al. 1980). This activity can be correlated with smolt size, but, large smolts do not necessarily display the highest level of activity (Wedemeyer et al. 1980). However, there does appear to be a minimum threshold size necessary for initiating the gill ATPase cycle (e.g. 80 to 90mm in spring run chinook and 90mm in coho) (Wedemeyer et al. 1980).

FRY/SMOLT OUTMIGRATION

Dispersal (migratory) movements of salmon fry may be categorized into one of three types: dispersal within their natal reproductive habitat, dispersal to nursery lakes, or dispersal to an estuary (Godin 1982). Natural incident light intensity appears to be the most important environmental variable influencing daily onset and termination of salmonid migratory movements (Godin 1982), but water temperature has at times been correlated with peak migration rates (Sano 1966; Coburn and McHart 1967; Thomas 1975). Presumably, this is due to increased fry mobility at higher temperatures (Godin 1982).

Northcote (1962, 1969) has shown experimentally that temperature determines the direction of rainbow trout fry movements and Raymond (1979) has correlated juvenile chinook outmigrations from the Salmon River with sudden rises in water temperature. Temperature may interact with genetic factors to determine sockeye salmon (Raleigh 1971) and cutthroat trout (Raleigh and Chapman 1971) upstream movement rates. Temperatures at or below 6 C seem to slow instream migrations of coho, cutthroat, and steelhead fry (Cederholm and Scarlett 1982); temperatures above 7 C stimulate chinook salmon to migrate (Raymond 1979).

Godin (1982) hypothesizes that the annual timing of gravel emergence and subsequent dispersal of salmonid fry to initial feeding habitats is determined genetically as a result of natural selection determined by predictable annual changes in environmental variables which include water temperature. Godin (1982) further argues that annual timing of dispersal is "...optimized evolutionarily by natural selection to maximize the fitness of individual fish." Solomon (1982) suggests that the role of increasing water temperatures in the ice-free season is in enhancing the physiological readiness of the fish for migration through stimulation of the endocrine system.

In the Susitna River, salmon smolt outmigration generally occurs from mid-May through August (Schmidt et al. 1984). River ice breakup generally precedes a large part of the initial chum and pink salmon fry outmigration period. There are few data available on pink salmon outmigration, but this activity is believed to occur between mid-May and mid-June, peaking in early June. Outmigrating chum fry occur in the river mainstem from mid-May to mid-August, peaking in June. Coho, chinook, and sockeye juveniles outmigrate from mid-May to early October, with peaks occurring from June through August.

In addition to salmon smolt outmigration, there is also a migration between habitats as both resident and juvenile anadromous fish redistribute themselves into slough, side channel and mainstem habitats for overwintering. These emigrations generally peak in August for chinook and coho salmon (Schmidt et al. 1984). Rainbow trout and Arctic grayling generally move out of tributaries to overwintering areas in late August through September (Sundet and Wenger 1984).

Timing of smolt entrance to the sea is believed to influence survival rates. Several hatchery studies (Bilton 1978; Washington 1982) found that optimal size varied with time of release; e.g., maximum return of adult salmon in one study resulted when smolts weighing about 20g. a piece were released just prior to the summer solstice (Bilton 1978). Bilton (1978) found very large male smolts did not migrate at all, becoming jacks.

WATER TEMPERATURE

OVERVIEW

Temperature data for waters in the Susitna Basin have been collected by three different groups: the U.S. Geological Survey (USGS), Alaska Department of Fish and Game (ADF&G), and R&M Consultants. Prior to the 1980 field season, the only continuous temperature recorders were at three mainstem Susitna sites operated by the USGS since the mid-1970s. Of the new sites added specifically for the Susitna hydroelectric project, the majority are concentrated in the Watana-to-Sunshine reach of the river. Temperature data collection below the Parks Highway bridge (RM 83.5) was increased during the 1984 field season by ADF&G on request from AEIDC to provide additional data in the event that lower river temperature simulations were undertaken. Table 7, showing the available temperature data used for initial monthly stream

Table 7. Monthly stream temperatures, available data June to September 1980, 1982, 1982. (From AEIDC 1983).

Mainstem/Tributary River Mile	River Name/Description	Number of Days 1980 J	J	A	S	1981 J	J	A	S	1982 J	J	A	S
10.1/0.5	Alexander Cr.					25	31	31	30				
10.1	Susitna above Alexander Cr.					25	31	31	1				
25.8	Susitna R., Su Station	30	31	31	30					10	--	--	--
28.0/2.0	Yentna R.					26	31	31	14				
28.0/4.0	Yentna R.									23	31	31	27
29.5	Susitna R. above Yentna R.									20	31	31	30
32.3	Susitna R. above Yentna R.					25	31	31	12				
40.6/1.2	Deshka R.					21	31	31	30				
49.8/4.9	**Deception Cr. near Willow	5	8	--	8								
49.8/11.6	**Willow Cr. near Willow	5	18	--	22								
50.5/1.0	Little Willow Cr.					7	31	31	30				
50.5	Susitna R. above Little Willow Cr.					7	31	31	24				
61.2	Susitna R. above Kashwitna R.					--	--	2	27				
77.2/0.0	Montana Creek					19	24	--	1				
77.5	Susitna R. above Montana Cr.					19	3	2	30				
83.8	Susitna R., east shore--Parks Hwy.					20	14	--	--	--	--	--	30
83.9	Susitna R., west shore--Parks Hwy.									23	9	10	30
97.0	Susitna R.--LRX1									17	--	--	--
97.2/5.0	**Talkeetna R. near Talkeetna	--	1	--	--								
97.0/1.0	Talkeetna R.					10	31	31	30				
97.2/1.5	Talkeetna R.									17	1	31	30
98.5/18.0	**Chulitna R. near Talkeetna	1	1	1	--					27	30	3	20
98.6/0.5	Chulitna R.					11	17	--	20				
98.6/0.6	Chulitna R.									17	--	10	25
103.0	Susitna R.--TKA fishwheel					11	10	19	22	7	28	31	25
113.0	Susitna R.--LRX 18									--	25	31	30
120.7	Susitna R.--Curry									--	25	31	30
126.0	Susitna R.--Slough 8A									--	4	31	30
126.1	Susitna R.--LRX 29									--	22	31	30
129.2	Susitna R.--Slough 9									--	4	31	24
130.8	Susitna R.--LRX 35									--	23	4	17
131.3	Susitna R. above 4th of July Cr.					15	31	30	26				
136.5	**Susitna R. near Gold Cr.	30	31	31	30	--	8	25	29	--	--	12	30
136.8/0.0	Gold Creek					11	7	3	--				
138.6/1.0	Indian R.									23	31	4	28
138.6/0.1	Indian R.					--	10	25	14				
138.7	Susitna R. above Indian R.					--	11	29	16				
140.0	Susitna R.--Slough 19					--	--	5	13				
140.1	Susitna R.--LRX 53									--	--	23	--
142.0	Susitna R.--Slough 21					--	--	4	29	--	4	31	30
148.8	Susitna R. above Portage Cr.					--	13	31	29				
148.8/0.1	Portage Cr.									13	26	28	--
181.3/0.0	Tsusena Cr.									12	7	31	30
184.4	*Susitna R. at Watana dam site					30	--	31	30				
194.1/0.0	Watana Cr.									11	31	15	16
206.8/0.0	Kosina Cr.									4	31	17	12
223.7	**Susitna R. near Cantwell	--	--	--	--					27	31	31	22
231.3/0.0	Goose Creek									--	31	31	30
233.4/0.0	Oshetna Creek									--	31	31	30

*R&M gages
**USGS gages
All others are ADF&G gages

Table 7: Monthly stream temperatures, ~~available~~ usable data June to September 1980, 1982, 1982. (From AEIDC 1983).

Mainstem/Tributary River Mile	River Name/Description	Number of Days 1980				1981				1982			
		J	J	A	S	J	J	A	S	J	J	A	S
10.1/0.5	Alexander Cr.					18	31	31	26				
10.1	Susitna above Alexander Cr.					18	31	27	--				
25.8	Susitna R., Su Station	30	31	31	30					--	--	--	--
28.0/2.0	Yentna R.					20	31	31	--				
28.0/4.0	Yentna R.									14	31	31	24
29.5	Susitna R. above Yentna R.									10	31	31	30
32.3	Susitna R. above Yentna R.					18	31	29	6				
40.6/1.2	Deshka R.					10	31	31	30				
49.8/4.9	**Deception Cr. near Willow	--	--	--	2								
49.8/11.6	**Willow Cr. near Willow	--	13	--	4								
50.5/1.0	Little Willow Cr.					--	31	31	28				
50.5	Susitna R. above Little Willow Cr.					--	31	31	10				
61.2	Susitna R. above Kashwitna R.					--	--	--	22				
77.2/0.0	Montana Creek					6	17	--	--				
77.5	Susitna R. above Montana Cr.					8	--	--	30				
83.8	Susitna R., east shore--Parks Hwy.					8	--	--	--	--	--	--	30
83.9	Susitna R., west shore--Parks Hwy.									14	--	--	30
97.0	Susitna R.--LRX 1									14	--	--	--
97.2/5.0	**Talkeetna R. near Talkeetna	--	--	--	--								
97.0/1.0	Talkeetna R.					--	31	31	30				
97.2/1.5	Talkeetna R.									14	--	31	30
98.5/18.0	**Chulitna R. near Talkeetna	--	--	--	--					24	30	--	10
98.6/0.5	Chulitna R.					--	3	--	12				
98.6/0.6	Chulitna R.									14	--	--	18
103.0	Susitna R.--TKA fishwheel					--	--	17	13	--	21	31	16
113.0	Susitna R.--LRX 18									--	17	31	30
120.7	Susitna R.--Curry									--	17	31	30
126.0	Susitna R.--Slough 8A									--	--	29	30
126.1	Susitna R.--LRX 29									--	13	31	30
129.2	Susitna R.--Slough 9									--	--	31	20
130.8	Susitna R.--LRX 35									--	--	--	6
131.3	Susitna R. above 4th of July Cr.					--	31	26	22				
136.5	**Susitna R. above Gold Cr.	30	31	31	30	--	--	24	24	--	--	--	30
136.8/0.0	Gold Creek					--	--	--	--				
138.6/1.0	Indian R.									16	31	--	--
138.6/0.1	Indian R.					--	--	17	8				
138.7	Susitna R. above Indian R.					--	--	21	10				
140.0	Susitna R.--Slough 19					--	--	--	--				
140.1	Susitna R.--LRX 53									--	--	23	--
142.0	Susitna R.--Slough 21					--	--	--	28	--	--	31	30
148.8	Susitna R. above Portage Cr.					--	--	31	28				
148.8/0.1	Portage Cr.									--	15	25	--
181.3/0.0	Tsusena Cr.									--	31	31	30
184.4	*Susitna R. at Watana dam site					30	--	31	30				
194.1/0.0	Watana Cr.									--	31	--	6
206.8/0.0	Kosina Cr.									--	31	3	--
223.7	**Susitna R. near Cantwell	--	--	--	--					24	31	31	15
231.3/0.0	Goose Creek									--	31	31	30
233.4/0.0	Oshetna Creek									--	15	31	24

*R&M gages
**USGS gages
All others are ADF&G gages

temperature simulations (summers 1980 to 1982), illustrates the density and temporal consistency of these data.

There are a number of problems in the available water temperature data set with regard to its usefulness for temperature modeling. These primarily lie with the short period of record available and in the reliability of some of these data. These problems are discussed below.

Short length of record - Collection of most of the data needed for temperature modeling began in 1980. In order to predict instream temperatures covering a large range of meteorologic conditions, representative years were selected for simulation, some preceding 1980. For these early years, temperature data were synthesized using regression techniques (AEIDC 1983, 1984).

Discontinuous records - Most of the temperature recorders used for the Susitna project are self-contained units, Omnidata Datapods and Ryan Thermographs. These instruments are designed for infrequent service, and thus are infrequently visited once they are in service. When these units malfunction, data may be lost for periods of two weeks or more. Throughout the study there were instances of data gaps resulting both from instrument failure and from tampering by people and wildlife.

Inaccurate data - There are a number of errors inherent in the data itself. The first is associated with the instrument. The accuracy of Datapods and Thermographs is ± 0.1 and ± 0.6 C respectively, provided the instruments are properly calibrated. Improper recorder placement may also lead to error. The USGS mainstem Susitna temperature recorder at Gold Creek was initially located in the plume of Gold Creek, inaccurately recording mainstem temperatures. The probe was later moved.

Further problems result from the fact that the recorders must be anchored to the shore. Thus, they lie close to shore possibly in the plume of a tributary or in a quiescent area unrepresentative of true mainstem temperatures. Even under the best conditions, when a recorder is properly calibrated and not located in a quiescent area or in a tributary plume, it is only recording the temperature at a single location. Temperatures across a river transect often show large variation; Schmidt (1984) found differences as high as 2.8 C across transects below the Talkeetna River confluence (RM 92.7), while the USGS (Bigelow, pers. comm.) reports deferences as high as 3.3 C across a transect at Sunshine (RM 83.5).

TEMPERATURE MODELS

DYRESM

The reservoir temperature simulation model, DYRESM, is used to predict the thermal stratification of both reservoirs under various meteorologic and power load demand conditions. The original model (Imberger and Patterson 1981) has been modified with the inclusion of an ice cover subroutine developed for Canadian lakes (Harza-Ebasco 1984). Results from DYRESM, coupled with those from the reservoir operations model, provide predictions of reservoir release volumes and temperatures at the downstream-most dam. These values serve as upstream boundary conditions for the stream temperature model.

Calibration.

The DYRESM model was calibrated for Alaska climatic conditions using Eklutna Lake data for the period June through December 1982 (Harza-Ebasco 1984). Eklutna is a glacial lake tapped for hydroelectric power. The main differences between it and the proposed reservoirs are the design of the intake structures, bathymetric shape near the intakes, and local meteorology.

Results from the Eklutna Lake study (Harza-Ebasco 1984) show accurate prediction of both summer and winter outflow temperatures to ± 1 C. Some instances of temporal differences of approximately 2 C were seen during periods of high summer winds. These differences were attributed to difficulty in modeling wind-induced mixing and internal wave motion near the intake structure using a one-dimensional model (Harza-Ebasco 1984).

Reliability.

DYRESM is a one-dimensional model, predicting only a vertical temperature distribution. This assumption is most seriously taxed during periods of high wind which induce mixing in the epilimion. It is treated in the model by corrections which affect deeper surface mixing (APA 1984). This problem is of some concern with both reservoir simulations, as wind speed predictions at the proposed reservoir surface level are somewhat speculative.

In order to maintain the ability for selected reservoir temperature releases, it is essential that the reservoirs' thermal stratification remain intact in the face of both wind-induced surface mixing and hydraulic mixing near the intake structures. The Federal Energy Regulatory Commission (FERC) (1984) predicted a weak thermal stratification of the Watana reservoir and questioned the ability of the intake structure to allow selective temperature withdrawal. FERC noted the same concern with the Devil Canyon reservoir, estimating cooler summer temperatures than those predicted by DYRESM. APA (1984) acknowledges that the stratification of both reservoirs would be weak relative to those in temperate climes, but maintains that the stratification should be strong enough around the intake structures to maintain stratification except during spring and fall turnover periods.

In the event that the thermal stratification could not be maintained, the ability to release the warmest available summer and coldest winter waters (i.e., those in the uppermost thermal strata) would be lost. Release temperatures throughout the year would be closer to the mean annual reservoir temperature, approximately 4 C, limiting its effectiveness as a mitigation measure.

Synopsis of Results.

DYRESM has been run for both a one- and two-dam configuration for myriad combinations of power demand, flow requirements, meteorology, intake operating rules and intake design. Consequently, generalizing these results is difficult and possibly misleading. Results from these DYRESM simulations are available in AEIDC (1984) for Case C simulations under the "inflow matching" operating rule. Results under Case E-VI flow requirements have not been published; however, river water temperatures immediately below the proposed Devil Canyon dam face (RM 150) are available in AEIDC (1985).

The ranges of outflow temperatures under the various combinations are shown for summer (here defined as water weeks 36-52, June 3 - September 30) and winter (weeks 5-30, October 29 - April 28) in Tables 8 and 9. Note that weeks during the spring and fall transitional periods are not represented in these tables. The number of simulations run for each of the categories vary. As few as one and as many as five seasons of meteorologic data have been run for some categories; different intake structure designs are represented in the table as well. Consequently, making direct comparisons between runs is not recommended.

Table ~~8~~ 9. Synopsis of simulated summer (weeks 36-52) release temperature ranges (C).

Case C

Intake Operation	Watana		Devil Canyon	
	1996	2001	2002	2020
Warmest Water	--	2.1 - 12.6	4.6 - 10.0	--
Inflow Matching	2.4 - 11.2	2.4 - 11.1	3.2 - 10.2	3.0 - 11.2

Case E-VI

Intake Operation	Watana		Devil Canyon	
	1996	2001	2002	2020
Warmest Water	--	6.1 - 12.1	4.3 - 8.8	--
Inflow Matching	--	5.4 - 11.5	4.3 - 8.6	--

10

Table 9. Synopsis of simulated winter (weeks 5-30) release temperature ranges (C).

Case C

Intake Operation	Watana		Devil Canyon	
	1996	2001	2002	2020
Warmest Water	1.0 - 3.5	0.7 - 4.2	2.7 - 5.8	--
Inflow Matching	0.3 - 4.2	0.3 - 4.3	0.5 - 5.6	0.6 - 2.2

Case E-VI (winter of 1981-82 only)

Intake Operation	Watana		Devil Canyon	
	1996	2001	2002	2020
Warmest Water	--	2.8 - 4.1	2.7 - 5.5	--
Inflow Matching	--	2.3 - 4.1	2.2 - 5.5	--

In general terms, simulated summer release temperatures are cooler from the Devil Canyon reservoir than from the Watana reservoir. In later demand years under two-dam operation (represented by the year 2020); however, cone valves are used less frequently and warmer summer release temperatures result. During winter, the reverse occurs with warmer release temperatures resulting from two-dam operation.

<u>SNTEMP</u>

The SNTEMP instream temperature model has been used to simulate mainstem Susitna River temperatures in the Watana-to-Sunshine reach. Discussions of the model and its application to this project are available in Theurer et al. (1983) and AEIDC (1983, 1984).

As with all simulation models, SNTEMP is governed by a large set of assumptions (AEIDC 1983, 1984). Three of these are especially important when considering the applicability of model results.

1. One-dimensionality. The temperature at any given cross-section is represented by a single value, presumed to be the mean temperature along that cross-section. As mentioned previously, thermal variation across a transect may be greater than 2 C.

2. Instantaneous mixing of tributaries. The mass and associated heat content of influent tributaries are instantaneously mixed by the model at the tributary confluences. There is no accounting for the temperature plumes from influent tributaries found in the river system.

3. No ice cover. SNTEMP simulates openwater conditions throughout the year. This is of concern in the spring when simulated water temperatures rise in response to increased solar radiation and warmer air temperatures. Under an ice cover, water temperatures would warm much slower. Thus, simulated temperatures during this period are warmer than realistic until after breakup occurs.

Additional note should be made of the estimation methods employed for influent tributary temperatures. A temperature regression function for middle river tributaries was developed using data from three tributary sites (AEIDC 1984). Likewise, regression functions are used to predict water temperatures of the large tributaries (the Talkeetna and Chulitna rivers) when data are not available. As these two rivers contribute large volumes of flow to the mainstem Susitna, predicted temperatures below the three-river confluence must be given careful scrutiny.

The influence of mainstem river temperatures on the temperature of groundwater influent to adjacent sloughs has not been fully resolved at this time. Mean river temperatures are believed to drive nearby groundwater temperatures; thus, changes in mean annual mainstem temperatures (expected to be slight) may also be felt in sloughs. Of special concern is whether the timing of mainstem temperature changes would be felt in sloughs during key fish use periods, notably egg incubation. Hydrology studies on these sloughs note the variation in response between different sloughs; variation in temperature changes would likewise be expected. Additional study on this topic is presently being done by Harza-Ebasco.

Calibration.

SNTEMP was calibrated for the period of June through September 1981 and 1982 (AEIDC 1983). Calibration during the winter period is moot, as natural water temperatures are uniformly 0 C. Model validation was done on a monthly (AEIDC 1983) and weekly basis (AEIDC 1984). The 90% confidence interval (using the Z - statistic) for weekly water temperatures for water years 1981-1983 is -1.0 to 0.8 C.

Reliability.

To predict mainstem water temperatures, SNTEMP relies on upstream boundary conditions predicted by another simulation model (DYRESM), influent tributary temperatures estimated using regression techniques on short records of data, and meteorologic data extrapolated from the record at Talkeetna. The model has been calibrated using published data which is representative, but not infallible. Consequently, the resultant temperature predictions include the possibility of a variety of combined errors.

While the ability of SNTEMP to predict absolute temperatures is uncertain, much greater reliance may be placed on the relative temperature differences resulting between different simulation scenarios. Thus, the ability to assess the temperature changes resulting from operation of the project remains good.

Synopsis of Results.

SNTEMP results are summarized for Case C simulations ("inflow matching" intake operation only) in AEIDC (1984) and for Case E-VI and Case C ("warmest water" intake operation) in AEIDC (1985). These results are presented at three mainstem locations (RM 150, 130, and 100) in tabular and graphical form, comparing methods of powerhouse intake operation and power load demands. The reader is referred to these sources in lieu of extensive discussion here. A brief summary of simulation results and a table of mean summer temperatures (Table 10), both at a representative middle river location (RM 130) are included here. As these results are included to show relative differences between methods of operation, a single summer season (1982) is used, which represents normal air temperatures and hydrologic conditions.

Two general observations should first be noted concerning river temperatures under with-project conditions relative to natural conditions. First, the magnitude of variation between winter and summer temperatures would be lessened; winter temperatures would be warmer than natural and summer temperatures cooler. Second, there would be a general delay of the normal temperature variation pattern; cooling would occur later than normal in the fall, and warming would occur later in the spring/summer. A synopsis of summer and winter simulation results follow.

As noted previously, no temperature simulation has been done downstream of the Parks Highway bridge. This is largely due to the impracticality of modeling the lower river with the limited available data and the limitation of a one-dimensional model in a region of river with very distinct temperature plumes resulting from the inflowing Chulitna and Talkeetna rivers.

Under natural conditions, flows from the three rivers remain relatively distinct, mixing slowly until approximately RM 75.0 (Schmidt 1987). The effect of lower with-project flows on the rate of mixing is uncertain; however, slightly cooler summer temperatures from the Susitna will probably not substantially alter the mainstem temperatures below RM 75.0.

Table 10. Simulated mean summer 1982 river temperatures for water weeks 31-52 at RM 130.

		Case C		Case E-VI	
Dam Configuration	Load Demand	Inflow Matching	Warmest Water	Inflow Matching	Warrant Water
Watana Only	1996	7.8	NR	NR	NR
	2001	7.7	8.3	7.7	8.3
Watana/ Devil Canyon	2002	7.0	6.9	6.6	6.7
	2020	7.2	NR	NR	NR
Natural		8.8			

NR = not run for this case

Summer. Simulated summer temperatures are cooler then natural temperatures under all project configurations, flow requirements, and methods of intake operations. Simulated river temperatures under two-dam operation are cooler than under Watana only. This is a result of two conditions: generally cooler reservoir release temperatures, and 30 miles less river available for reservoir releases to warm through normal heat-transfer processes.

Simulated mean summer river temperatures tend to be cooler under increased load demands. This trend, however, is contradicted under the Devil Canyon operation scenario for 2020, as the higher power demand results in fewer cold-water non-power releases through the cone valve structures. There is an additional tendency with increasing load demands for delaying both summer warming and fall cooling. Differences in mean summer temperatures between Case C and Case E-VI simulations are negligible under a Watana-only configuration and only slightly cooler (less than 0.5 C for any set of conditions at RM 130) for Case E-VI under the two-dam project.

Winter. The simulated selection of water from the thermally stratified reservoirs during the winter is based in part on meeting desired ice conditions downriver. While releasing near 0 C water during the winter may be an option in some cases, resulting ice conditions with the ten-fold increased flow may be devastating. In such cases, releasing the warmest available water in order to suppress ice formation may be desirable. Thus, the gauge of judging with-project summer temperatures, deviation from natural temperatures, is not applicable during the winter. For a complete discussion of river temperature/ice simulations, the reader is referred to Harza-Ebasco (1984, 1985a, 1985b).

In most general terms, reservoir releases during the winter (water weeks 5 through 30) range from 0.3 C to 5.8 C. Release waters begin cooling immediately once exposed to the cold air temperatures. With increased load demands in later years of operation, larger amounts of water would be released requiring longer distances to cool to 0 C. Under a single-dam configuration, 30 additional miles of river are available for this cooling process to occur.

ANALYSIS

ANTICIPATED NEGATIVE EFFECTS

As noted earlier, available information for this analysis ranges from sufficient to scant to altogether lacking. Consequently, only 13 of the drainage's nineteen 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 <u>direct</u> temperature-induced mortality is anticipated to occur with-project.

Tables 11 and 12 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. Anticipated negative effects are indicated by a dimensionless ordinal scale, which identifies the relative severity of anticipated effects. Its values range from:

0 - given predictions of with-project temperatures and available knowledge of a species life stage, no negative effects are likely.

1 - available information indicates that with-project temperatures could negatively effect a species life stage, but the effects should be relatively minor.

2 - available information indicates that with-project temperatures could chronically affect a life stage, thereby reducing productivity.

3 - available information indicates that predicted with-project temperatures <u>may</u> negatively affect a species life stage, but more data is needed to so state with certainty.

ANADROMOUS SPECIES

The following discussion addresses the anticipated with-project negative temperature effects on anadromous fish, which are summarized in Table 11.

Chinook Salmon

With-project water temperatures could negatively affect four of five chinook salmon life stages; 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.

12

Table 11. 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 11. 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		

12

Table 11. 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 1~~2~~3. 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 1~~2~~3. 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 With-Project Beneficial 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. 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 (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.

Mitigation

Effective mitigation for anticipated minor negative effects (1's in Tables 12 and 13) is difficult to propose because the numbers of fish involved are relatively small compared with Susitna stocks as a whole. Monitoring of these species is not feasible since, given present census capabilities, it is doubtful that a change in population numbers could be attributed to with-project effects. It is equally difficult to propose mitigation for Category 3 species in Tables 12 and 13. Far too little is known of these species life histories, their numbers, or their response to altered thermal regimes to accurately state whether they would or would not be affected by with-project conditions. All that can be said is that some potential for negative change in their respective populations is possible.

Thus, it is premature to suggest mitigation for species in this category. For species in Category 2 (Tables ___ and ___), anticipated population effects could be monitored by current techniques and, if warranted, these should be mitigated. As indicated earlier in this report, the model used to predict chinook salmon growth rates tends to over estimate with-project negative effects. The model could be modified to more accurately predict with-project conditions. This could be done by either incorporating unpublished data on chinook growth rates purported to be kept in the files of J.R. Brett, Canadian Fisheries biologist with the Nanaimo Pacific Biological Station or by conducting in situ growth studies of Susitna chinook salmon.

SUMMARY

In summary, this report presents the results of an analysis of existing information of with-project temperature effects on Susitna River fish. It is based on a comparison of available predictions from simulation models of reservoir and instream temperatures with either fish thermal tolerance criteria or (in their absence) information on fish response to thermal gradients. Together, several factors complicated this analysis. First, the temperature data base as a whole is temporarily limited and its accuracy varies between stations. Because of this, model calibrations were in part performed with synthesized data, adding an unknown level of imprecision to results. Second, both temperature models used (DYRESM and SNTEMP) are one dimensional, so they cannot account for all of the variables influencing water temperature. Generally, model runs are better predictors of temperature ranges (between with-project and natural conditions) then they are of specific with-project temperatures. Third, available fish thermal tolerance information, while of sufficient scope for use in gauging effects on salmonids, is biased to lower latitudes necessitating professional interpretation. Fourth, little relevant thermal tolerance information exists for the other species present. Fifth, the model used to estimate temperature effects on salmon growth rates incorporates several assumptions which collectively make conclusions reached more representative of worst case situations.

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 smaller than normal 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.

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