PRELIMINARY DRAFT

IMPACT ASSESSMENT TECHNICAL MEMORANDUM

INSTREAM ICE

Prepared By:

Arctic Environmental Information and Data Center
University of Alaska-Fairbanks
707 "A" Street
Anchorage, Alaska 99501

Submitted to:

Harza-Ebasco Susitna Joint Venture
711 "H" Street
Anchorage, Alaska 99501

1985

TABLE OF CONTENTS

INTRODUCTION

PURPOSE

Impoundment of the upper Susitna River would cause a change in the natural pattern of instream ice formation and breakup. This document is a comprehensive assessment of the effect of the with-project ice regime on fish associated with the proposed upper Susitna River basin hydroelectric development. Since Instream ice and breakup phenology are important variables affecting habitat for Susitna River drainage fish, studies were initiated in the beginning phases of Susitna environmental investigations to identify potential adverse or beneficial with-project effects of the expected alteration.

This report is one in a series on aquatic impact issues associated with the Susitna Hydroelectric Project. These issues -- instream temperature, water quality, turbidity, instream ice, and bedload -- are examined separately in five separate technical memoranda. Following review they will be integrated into a single draft impact assessment report. The Alaska Power Authority and Harza-Ebasco intends to utilize the final impact assessment technical memorandum to discuss issues with agencies and intervenors in the Susitna licensing process.

Impact issues addressed in this series of reports were defined in the course of the Susitna licensing process. Following Federal Energy Regulatory Commission (FERC) review of the original license application, the Alaska Power Authority corrected noted deficiencies and provided supplemental information. The license application was subsequently ruled acceptable. FERC then proceeded with the preparation of an Environmental Impact Statement (EIS). This decision set in motion a chain of events in accordance with Council on

Environmental Quality mandates on EIS preparation (Vide 40 CFR 1500). Significant issues to be analyzed in depth in the EIS were identified during scoping meetings. Twelve fishery were identified to this process; of these, Issues F-3 and F-5, addressed with-project ice related phenomena on salmon and resident fish habitats and populations.

APA commissioned a series of environmental field investigations and analyses of existing published and unpublished information to provide accurate statements of expected impact of the Susitna project on the natural ice regime and subsequently, on fish resources. Over the years the data base and statements of anticipated effects have been scrutinized by agency and intervenor representatives in a series of workshops and discussions. This process has refined the data base and impact statements based on it.

This document is intended to serve as a discussion document and as an aid to decision-making. It contains a presentation of the instream ice issue, a brief synopsis of the relevant information base, the ramifications of ice related phenomena to aquatic habitats and fish, and the projected effects on fish due to various modes of Susitna project operation. It does not contain voluminous data and analyses of ice related issues. Statements of effect or of no effect and the confidence with which those statements are made are provided.

STATEMENT OF THE PROBLEM

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

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

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

OVERVIEW OF ENVIRONMENTAL ASSESSMENT TECHNIQUES

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

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

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

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

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

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

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

The second class of environemtal assessment techniques examined addresses the theme of biological (i.e. ecological) integrity. The chief pieces of legislation calling for this approach are the Federal Water Pollution Control Act and the National Environmental Policy Act (table 1). If fully applied, such an approach would document energy flow through the system allowing one to precisely predict overall effects of change. In practice this is never done because it is very labor intensive and, thus too costly. Instead, it is common for a few representative species and/or relationships to be singled out for study, thereby narrowing its scope. Field study is typically undertaken to document seasonal numbers of target species in the study (often without regard to their relationship to local or regional populations), their habits (e.g., special use areas), and food resources. Biologically based assessments have increasingly made use of models (some elaborate, some not) to predict with-project effects. Two factors limit the veracity of conclusions reached by this approach. First, a given model's ability to predict the future depends heavily on whether it is multidimensional or not and on the assumptions used. Most models used are one dimensional limiting their utility. Second, conclusions reached in this approach are subjectively applied ad hoc to the system as a whole.

Consideration of economic and environmental values (the third of the four areas of public interest addressed by federal law) is the essence of the National Environmental Policy Act. This approach to impact assessment usually entails estimating the monetary and nonmonetary values of the resources to be affected. Implementation of a values approach to impact assessment is (and will continue to be) limited by the difficulty (some would say the impossibility) of setting values on often intangible environmental components such as aesthetics.

The fourth approach to environmental impact assessment recognized by federal law is habitat analysis. The principal laws legitimizing this approach are the Federal Land Policy and Management Act, the Fish and Wildlife Coordination Act, the Forest and Rangeland Renewable Resources Planning Act, the Endangered Species Act, and the Surface Mining Control and Reclamation Act (table 1). Various techniques are available for characterizing habitat quality. For example, species diversity is often used as an index of habitat quality. This type of index accounts for both numbers of species and numbers of individuals of each species in each habitat type. The approach has been challenged on a number of grounds. For example Wiens (1978) points out that it is insensitive to which species are present (i.e., it treats rare and common species alike), while Inhaber (1976) notes the absence of a standard of comparison (a problem of all biological indices).

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

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

METHODS AND PROCEDURES

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

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

To assess effects of with-project changes in the ice regime on instream biota, AEIDC first reviewed the information base on how ice related phenomena affects aquatic organisms. Next, information on Susitna River fish stocks was assembled and synthesized. Following this, estimates of with-project environmental changes (and the information and procedures used in deriving them) were reviewed. These changes are based on ICECAL simulations, DYRESM reservoir ice simulations, groundwater analysis, intragravel fow and temperature analysis, and sediment transport studies.

These three steps (determining how various life forms are affected by different ice conditions, compiling information on the fish resource, and reviewing project ice studies) provided the basis for predicting effects of the with-project ice regime on aquatic organisms.

Both the information base on fish stocks and that on the with-project ice regime are adequate for use in an effects analysis. Available information is sufficient to address ice effects on 13 of the 19 fish species present in the project area. These are all five salmon species, eulachon, Bering cisco, burbot, round and humpback whitefish, rainbow trout, Arctic grayling, and lake trout.

This analysis was constrained by a number of factors. Chief among these was that the models used were designed primarily to address physical process *per se*, rather than the effects of icing on animals and their habitat. Second, extant Susitna River basin data on fish distribution, abundance, and habitats focus on salmon and are temporally and spatially limited. Third, knowledge of the effects of various winter conditions on fish mortality rates is particularly scant.

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

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 simply an accounting tool whose chief purpose is to ensure that all elements deemed significant by the scoping process are considered in decision making.) Available information on open water season salmon-life stage activities (distribution, abundance, spawning timing and location, rearing, and migration) is quite complete; the overwinter salmon data base is much less so. Nonetheless, it is sufficient for the purposes used. Tables 2 and 3 respectively provide an overview of basinwide salmon escapements and the time of occurrence of their major life phases. 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 towards selected species. It, too, is sufficient for EIS preparation purposes. Information on rainbow trout, burbot, and Arctic grayling in the open water season 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 history in the impoundment zone is ADF&G 1981a and 1983d. 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, 1983d). 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

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] The 1984 drainage wide escapement estimates. 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, and Wick 1984, 1985.

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-breakup movement; earlier date of given 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/2

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

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 1983d).

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 designed primarily to define 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. 1984c.

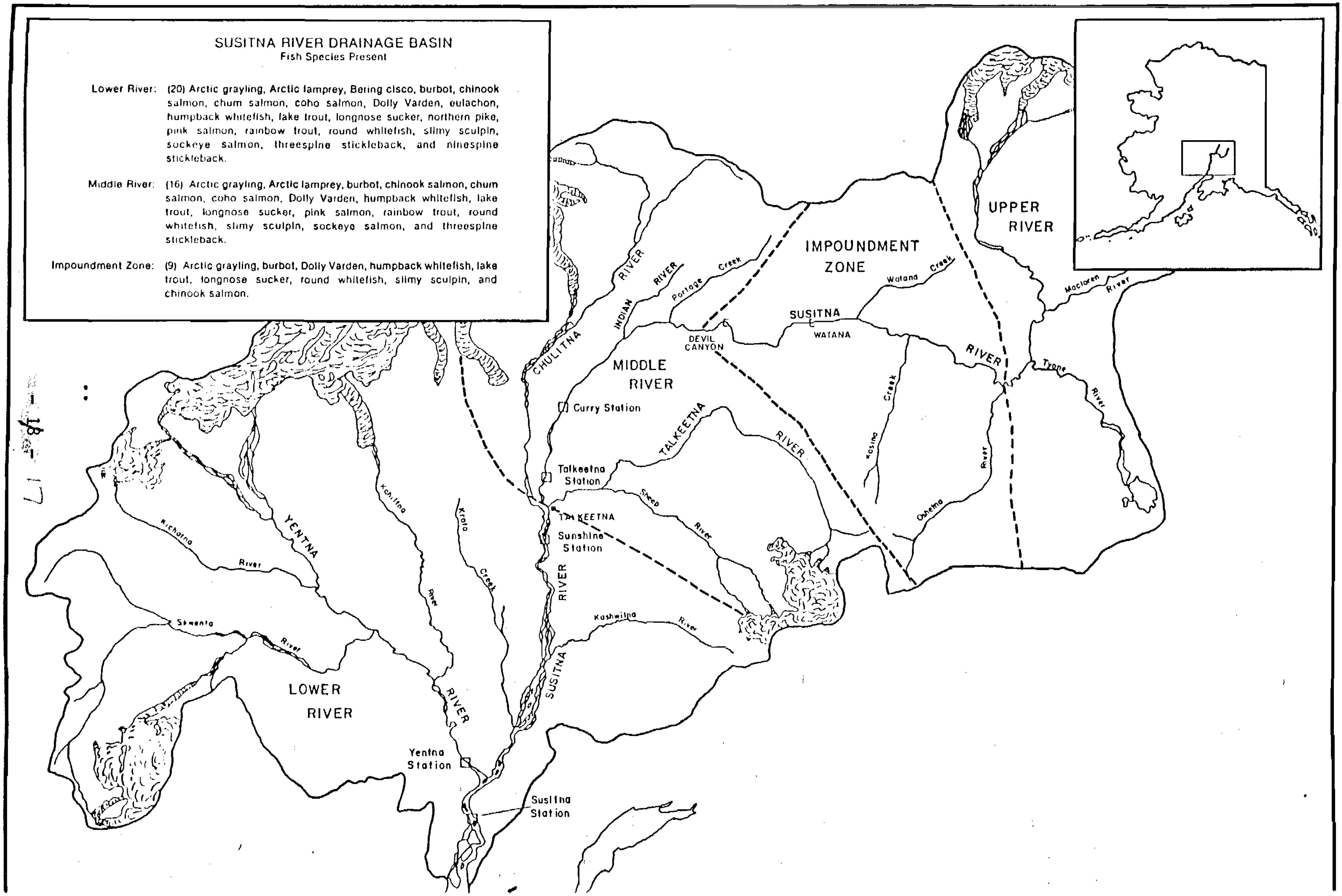
The natural environment between Devil Canyon and the upstream end of the proposed Watana Reservoir provides habitats for nine fish species (ADF&G 1983d); eight are year-round residents and one (chinook salmon) is anadromous (Figure 1). Within Devil Canyon, Fog Creek (RM 176.7) marks the upstream limit of salmon migration in the mainstem Susitna River. Only three streams, in the canyon had salmon observed in them during 1984. These streams, (Cheechako, Chinook, and Fog creeks) had, in total, fewer than 100 chinook salmon observed using them for spawning (Barrett, Thompson and Wick 1985).

Arctic grayling are the most widely distributed and abundant species utilizing habitats above the canyon. The total 1982 Arctic grayling population above 15 cm in length in eight of the impoundment zone streams was estimated to be over 16,000 (ADF&G 1983b). Mainstem areas above the canyon provide essential overwintering habitat for Arctic grayling, which move into tributaries to spawn following breakup in late May or early June (ADF&G 1983d). Arctic grayling migrate out of natal tributaries in September as water levels and temperatures begin to drop. They overwinter in mainstem environments which become less turbid following freeze-up (ADF&G 1983d).

Except for documentation of their presence, little is known of the relative abundance of other species resident in the environments of the proposed impoundment zone. Based on limited capture data, it seems that both burbot and longnose sucker are relatively common there (ADF&G 1983d). Elsewhere in the Susitna River, burbot spawn under the ice in tributaries (such as the Deshka River) over gravel substrates from January to February, and radio tagged fish data suggests they also spawn in the mainstem (ADF&G 1983b). 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 1983d). 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 1983d). If they behave similarly to lower river and middle river whitefish, they also overwinter in mainstem environments. Although available information is scant, it appears that these two white fish species spawn in early October in clearwater tributary streams.

Although not currently present in mainstem areas, some lake trout might gain access to the reservoirs as a result of the project. Sally Lake, which supports a lake trout population of undetermined number, would be inundated by the Watana Reservoir (ADF&G 1983d). 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. Should the project be completed, it is possible that some rainbows might gain access to the Devil Canyon reservoir by outmigrating down Devil

Figure 1. Fish of the impoundment zone.



Creek. 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 clearwater streams whose beds are covered with relatively small cobbles and have relatively moderate velocities (ADF&G 1983b).

MIDDLE 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, 1983c, 1985b; 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 temporally 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 confluence. A 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 groundwater upwelling for salmon spawning in sloughs.

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; 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 and 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 and 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 and Wick

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

STREAM	SURVEY DISTANCE	Coho 1974	Coho 1976	Coho 1981	Coho 1982	Coho 1983	Coho 1984	Chinook 1975	Chinook 1976	Chinook 1977	Chinook 1978	Chinook 1979	Chinook 1981	Chinook 1982	Chinook 1983	Chinook 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.

1985). Indian River (RM 138.6) is the most important tributary for coho, providing a little over 30% of the reproductive habitat available here (table 5). 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 in this reach (Barrett, Thompson and 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 and Wick 1985). These sloughs are of particular importance to middle river chum and sockeye salmon. About 50% of the chum and almost all of the sockeye spawning above the Chulitna confluence occurs in sloughs. This represents about 2% of all chum and less than 0.5% of all sockeye spawning in the Susitna drainage (Barrett, Thompson and Wick 1985).

Spawning habitat quality apparently varies greatly between sloughs as, in the last four years, the majority (>88%) of chum salmon spawners counted were in 10 of the 34 (tables 5 and 6). Three of these 10 (8A, 11, 21) have added significance in that they also accommodated over 90% of all sockeye spawning in the middle river (table 5).

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, 1981-84.

Slough	River Mile	1981	1982	1983	1984	4-Year Average	Percent of Total Escapement
8	113.7	695	0	0	217	228	3.4
8B	122.2	0	99	261	860	305	4.5
Moose	123.5	222	59	86	284	163	2.4
A'	124.6	200	0	155	217	143	2.1
8A	125.1	480	1,062	112	2,383	1,009	14.9
9	128.3	368	603	430	304	426	6.3
9A	133.8	140	86	231	528	246	3.6
11	135.3	1,119	1,078	674	3,418	1,572	23.2
17	138.9	135	23	166	204	132	1.9
21	141.1	657	1,737	481	4,245	1,780	26.2

Source: Barrett, Thompson, and Wick, 1984, 1985.

Relatively few salmon spawn in mainstem nonslough 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 fish counted at each of these sites varied from one to 131 with an average of 35 (Barrett, Thompson, and Wick 1985). The estimated total mainstem escapement was approximately 3,000 chum salmon (Barrett, Thompson and Wick 1985). This is less than 0.5% of the total Susitna escapement.

Four of the five salmon species (all but pink) use middle river waters for rearing purposes (Schmidt et al. 1984b). At this time insufficient information exists to characterize the relative importance of mainstem rearing habitats relative to each other. From May to September juvenile chinook rear in tributary and side channel environments, coho mostly rear in tributary and upland sloughs, and sockeye move from noted side sloughs to upland sloughs for rearing. From May to July rearing chum juveniles are distributed throughout side slough and tributary stream environments (Dugan, Sterritt, and Stratton 1984).

Of the five salmon species present, only chinook and coho were captured in the middle river during the 1981-82 winter field season (ADF&G 1983c). Preliminary studies indicate that significant numbers (perhaps 25 to 50%) of chinook and coho juveniles reared in this zone overwinter in side slough and tributary stream environments (ADF&G 1985a). Provisional capture data for the 1984-85 winter field season show that a few sockeye are also overwintering in this area of the river (Crawford 1985). Preliminary evidence indicates that few juvenile salmon utilize the mainstem proper for overwintering purposes (ADF&G 1985a).

Of the 11 resident middle river fish species (figure 1), capture data indicate that rainbow trout, Arctic grayling, round whitefish, longnose sucker, and slimy sculpin are common (ADF&G 1983c). Dolly Varden, burbot, humpback whitefish, threespine stickleback, and Arctic lamprey also occur, but all appear to be more abundant in the lower river (Sundet and Wenger 1984). Lake trout are found only in surrounding area lakes, none of which would be influenced by the project.

Less is known about most resident fish species in the middle river than about salmon. Rough population estimates made in 1983 showed there to be about 4,000 adult rainbow trout in the middle river. Catch data from 1981-84 in the middle river show round whitefish to be the most abundant species and that Arctic grayling and longnose sucker are more abundant than rainbow trout which are more common than burbot (Sundet and Wenger 1984). Lakes in the Portage Creek and Fourth of July drainages where rainbow trout are abundant probably contribute heavily to middle river rainbow populations (Crawford, Hale, and Schmidt 1985).

Given the naturally reduced winter flow regimes of tributary streams, the majority of resident fish (with the exception of lake trout) probably overwinter somewhere in the mainstem. It is generally believed that most resident fish which migrate to tributaries in the summer overwinter downstream of their natal tributaries in the mainstem (Sundet and Wenger 1984). Of the most common resident species, three (round whitefish, longnose sucker, and slimy sculpin) can occur year-round in the mainstem. Rainbow trout and Arctic grayling migrate out of tributaries by early October and most overwinter in the mainstem slightly downstream of these tributaries (Crawford, Hale, and Schmidt 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 spawning salmon. 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 and 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 the 1984 basinwide escapement. The estimated number of spawning coho in the mainstem represents roughly 0.2% of the 1984 escapement (Barrett, Thompson and 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 slough (Barrett, Thompson and Wick 1985). Thus, 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. Coho, chinook, chum and sockeye juveniles primarily rear in tributaries; chinook, chum, and sockeye juveniles also make use of side channels. Sloughs are limited in occurrence and are not used heavily by any salmon species (Crawford, Hale, and Schmidt 1985). 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 and 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 and Wick 1984).

Little is known about most resident fish life histories in the lower river. The 13 resident fish species found in the lower river, with the exception of lake trout, northern pike, and ninespine stickleback, are generally believed to be common (Sundet and Wenger 1984). As elsewhere in the drainage rainbow trout, Arctic grayling, and Dolly Varden spend most of the open water season in tributaries, using the mainstem principally for migration and overwintering (ADF&G 1983b). These species move into tributaries to spawn in the spring after breakup. Rainbow trout and Arctic grayling outmigrate from most eastside tributaries in September (Crawford, Hale, and Schmidt 1985). Burbot, whitefish, longnose sucker, sculpin, stickleback, and Arctic lamprey are found in both the mainstem and tributaries during the open water season. All of these species are believed to overwinter in the mainstem, but only rainbow trout, burbot, and slimy sculpin were captured there during 1982 winter sampling (ADF&G 1983b). Round whitefish are believed to spawn in October at either mainstem, tributary mouth, or tributary locations (Schmidt, et al. 1984b). Burbot spawning generally occurs between January and March under the ice in areas influenced by the mainstem or in tributaries 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 (Crawford 1985). Tagged rainbows are most frequently relocated in mainstem side channels, near tributaries, in waters generally less than five feet in depth. Tagged burbot are frequently located in winter in mainstem pools greater than six feet deep along river bends. However, most of the tagged burbot were found in the Deshka River. Both species seem to favor low velocity environments.

THE WITH PROJECT ICE REGIME

The following is a synopsis of selected aspects of the with-project environment that have relevance to an effects analysis of the with-project ice regime on fish. (A detailed description of with-project ice processes is found in R&M et at. 1985.) The Watana Reservoir would inundate roughly 48 linear miles of the mainstem Susitna River and about 30 miles of tributary stream environments, thereby converting them to a lentic system. The Watana Reservoir would generally begin to freeze over sometime in mid-November, with probable maximum ice thicknesses ranging from 3 to 5 ft. Winter reservoir drawdown would cause nearshore ice to fracture and drape over exposed banks. While on-line alone, the Watana reservoir's winter drawdown would average about 90 ft. With both dams constructed drawdown in Watana would average about 40 ft. In midwinter, grounded ice could form barricades at tributary mouths. Based on observations of natural ice processes within the upper basin, however, it is believed that tributary flows would downcut grounded ice before reservoir ice meltout which would generally occur between May and early June.

The Devil Canyon Reservoir would inundate a maximum of 32 linear miles of mainstem Susitna River environments. Freeze-up times would be similar to those of the Watana Reservoir, but probable maximum ice thickness would not exceed 4 ft. Yearly winter reservoir drawdown would be slight if it occurred at all. Consequently, less ice draping would occur than in the Watana Reservoir. A few miles of open water may occur in the upper part of Devil Canyon Reservoir due to the warm water released from the Watana Reservoir.

The with-project middle river ice environment would differ dramatically from natural conditions. Formation timing of a contiguous river ice cover would be delayed, there would be an extensive reach of ice-free water below Devil Canyon, winter river flows would be four to five times greater, and ice meltout would occur earlier. These changes would occur as a consequence of dam interception of mainstem frazil ice, increased winter flows due to the reservoir's operating schedule(s), and warmer than normal instream winter temperatures (the reservoirs would function as heat sinks).

During the winter, with-project water temperature is predicted to range between 0.4 C to 5.6 C at the dam outlet (AEIDC 1984). Water temperatures are predicted to decline relatively uniformly with increasing distance downstream, until reaching 0 C.

Middle river freeze-up is predicted to be delayed between 2 to 6 weeks with Watana Dam and 4 to 7 weeks with both dams in place. Depending on the weather and with only Watana Dam on-line, the ice front is predicted to range somewhere between RM 124 and RM 142 and ice thickness below the front would be similar to or slightly thinner than natural. With both dams operating, the ice front is expected to range between RM 123 to RM 137 and ice thickness is expected to be less than for natural conditions. The ice front would likely be dynamic, changing location in some winters more than others in response to changes in weather conditions and with-project flows. Upstream of the ice front, the river would not be completely ice covered, open water with temperatures often above 0 C would occur throughout the winter. Between the 0 C isotherm and the upstream edge of the ice front, a zone of anchor ice and border ice formation would occur; neither anchor ice nor border ice would form upstream of this zone.

Portions of the river near the ice front would be subject to freeze-up staging, due to displacement by the developing ice cover and additional friction at the rough bottom surface of the ice cover. When this happens, water velocity slows and the water level rises. This would lead to periodic flooding of sloughs and side channels, a phenomena seen naturally. Staging can last all winter under natural conditions. However, there is a gradual reduction in water levels as discharges drop and the cover erodes. Staging would occur for a shorter period with-project since the ice cover would form later and melt out earlier. There would, however, be much more flow in the river with-project.

Intragravel temperatures in many sloughs and side channels during winter are believed to be moderated by groundwater flows, except for periods of overtopping of upstream berms as a result of ice staging or ice breakup. The mean annual mainstem temperature is not expected to change significantly with-project, and the temperature of that component of groundwater flow which is directly related to mainstem flows should not be changed. (Sloughs 8A and 21 appear to be more directly influenced by mainstem temperature variations than others. The increased winter flows relative to natural conditions and increased mainstem water levels resulting from ice formation could produce colder than natural upwelling groundwater and, thus, colder intragravel temperatures here.)

Regardless of the final reservoir operation regime adopted, winter flow rates would increase significantly with-project. Consequently, the aquatic instream environment would be substantially greater in extent (i.e., the wetted area would be increased). Because no ice staging would occur in the open water reaches immediately below Devil Canyon, no winter flooding is anticipated in this area. However, localized flooding would occur within ice-mantled river reaches, since higher than natural flows would be coupled with ice-induced staging. Higher flow rates might also increase the length of open leads in ice-mantled areas downstream of the ice front.

The with-project springtime environment would differ from natural conditions chiefly in breakup phenology. Predicted higher than normal stream temperatures and steadier stream flows would cause a gradual in-place melting of the ice cover and the potential for breakup jamming would be reduced. Ice meltout is expected to occur four to seven weeks earlier than natural with the Watana Dam and seven to eight weeks earlier with both dams operating.

ICECAL simulations have not been run for the lower river because of the complexity of the system; the following is based wholly on subjective input provided by the Harza-Ebasco ice modeling team. Ice would probably begin forming with-project in early November about the same time as it does naturally. Decreased ice contribution from the middle river is expected to delay upstream movement of the ice front by 2 to 6 weeks with Watana Reservoir and 4 to 7 weeks with both dams on-line. Increased winter flows might produce somewhat more ice than now occurs. Overtopping of slough berms occurs naturally in this reach and, as in the middle river, increased with-project water levels may increase the incidence of overtopping. Lower river ice meltout could be advanced over natural conditions due to the expected earlier than normal meltout of the middle river. The beginning of the lower river meltout would be closely coincidental to the completion of the middle river meltout. The lower river breakup is expected to begin earlier and be somewhat milder than natural.

ANALYSIS

ANTICIPATED WITH-PROJECT EFFECTS

WATANA RESERVOIR

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

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

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

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

DEVIL CANYON RESERVOIR

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

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

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

MIDDLE RIVER

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The second middle river addressed issue concerns the effect of with-project ice- staging on upwelling rates in middle river spawning sloughs (table 19). Maximum winter river stages upstream of the with-project ice front are predicted to be lower than corresponding natural conditions, because freezeup staging would not occur (Harza-Ebasco Susitna Joint Venture 1984). Since upwelling rates are believed to be a function of river flow volumes, there is concern that this lower stage could reduce the amount of slough upwelling. This should be of minimal concern since with-project winter flows upstream of the ice front (with either dam scenario) are predicted to be similar to those occurring naturally in September and higher than the minimum with-project summer discharges. As upwelling is presently sufficient for incubation purposes during natural September flows, one could assume that with-project upwelling would also be sufficient. Downstream of the ice-front, with-project river stages with both dams on-line are predicted to be higher than natural. Consequently, concern over project effects on upwelling rates are apparently moot in this zone.

The third issue examined deals with the potential effects of the with-project winter open water zone below Devil Canyon on fish habitat quality (table 19). Regardless of whether one or two dams are built, an ice-free zone of open water would occur each winter below Devil Canyon. With Watana Reservoir above, this (predicted by ICECAL) would be 10 to 28 miles long; with both dams operational the zone would be between 15 to 29 miles long (table 18). Conceivably, primary productivity could be enhanced in this area because of warmer water temperatures and less snow and ice cover. Taken by itself, ice removal would allow more light to penetrate the water column, stimulating primary production. However, the question is complicated by the fact that there is little sunlight here in the winter and released reservoir waters would be turbid, whereas natural winter flows are relatively clear (Acres American 1983). An ongoing AEIDC study seeks to answer the productivity question. At present, there is no reliable information to use to describe the probable influences of the with-project open water area on winter productivity.

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

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

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

Another expressed ice-related concern in the middle river pertains to the natural flushing of beaver dams as well as fines from slough spawning habitats by breakup-induced flooding (table 19). Regardless of whether one or two dams are built, ICECAL simulations predict that drastic breakup events would no longer occur; the river ice cover would gradually melt in place and no large flood flows would clean out the sloughs.

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

The last question analyzed concerns the effect of with-project anchor ice on fish and their habitats (table 19). Mechanisms of anchor ice formation are poorly understood, but it is known to form most often in supercooled reaches over gravel substrates (Michel 1971; Mason 1958). While anchor ice is relatively common in the mainstem middle river, none has been found to date in either mainstem or slough upwelling areas.

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

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

LOWER RIVER

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

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

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

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

The last lower river ice-related issue raised pertains to the question of how the with-project ice cover would affect primary productivity and the amount of overwinter fish habitat (table 19). It is believed that regardless of whether one or two dams is built, there would be more ice in the lower river with-project than naturally. However, the exact morphology of the ice cover is unknown. Provided that extensive lead systems did not develop, instream primary production with-project should be reduced in rough proportion to the increase in ice cover seen. Due to the low gradient and high porosity of the ice under with-project conditions, it is more likely that open leads will occur in a manner similar to natural conditions. If this is true, then an extensive system of open water leads would develop, and primary productivity could increase.

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

SUMMARY

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

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

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

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

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

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

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

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