ASSESSMENT OF THE EFFECTS OF THE PROPOSED SUSITNA HYDROELECTRIC PROJECT ON INSTREAM TEMPERATURE AND FISHERY RESOURCES IN THE WATANA TO TALKEETNA REACH

DRAFT REPORT

MAIN TEXT

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SUMMARY

This report presents the results of weekly Susitna River instream temperature simulations comparing Watana-only and Watana/Devil Canyon project configurations with natural condition temperature simulations. These simulations were run using historic hydrologic/meteorologic data covering a number of years to bracket the expected range of resultant downriver temperatures. The effect of these temperatures on andromous fish species is assessed by comparison with lifestage-specific temperature tolerance criteria established from the literature.

Operation of either a single- or two-dam hydroelectric project dampens the natural variation in river temperatures. Mean summer temperatures under a Watana-only scheme are approximately 1.0 C cooler than natural at river miles 150 and 130, and 0.6 C cooler at river mile 100. Addition of the Devil Canyon dam, 33 miles downstream from Watana, would increase this mean seasonal temperature deviation to approximately 2.0, 1.7 and 1.2 C cooler at river miles 150, 130 and 100 respectively. Under either project configuration, downstream temperatures would peak later in the summer than normally, and the greatest deviation from natural temperature would occur in September - October.

Winter reservoir releases will range from 0.4 to 6.4 C in waters normally at 0 C from approximately October to April. Consequently, ice formation will be delayed and, in some cases, not reach as far upstream as under natural conditions.

Based on temperature tolerance limits for salmon established from the literature, the cooler simulated summer temperatures should not significantly impact inmigration or spawning. Mainstem water temperatures, which under

natural conditions may be limiting for salmon incubation, would be improved under project operation. Some retardation of juvenile growth may occur due to cooler summer temperatures, even though these operational temperatures are within the established range of tolerance temperatures.

Outmigrants from tributaries and sloughs above Sherman (river mile 131) during late May and early June will confront mainstem temperatures considerably cooler than natural. Whether this change, among the variety of influences triggering outmigration, is sufficient to alter the timing is unknown.

Burbot and whitefish are the only resident species above the Chulitna confluence expected to be adversely affected by project operation. The expected warmer fall and winter river temperatures, could alter both burbot and whitefish spawning and incubation timing to such a degree as to preclude their successful reproduction in the upper river.

INTRODUCTION

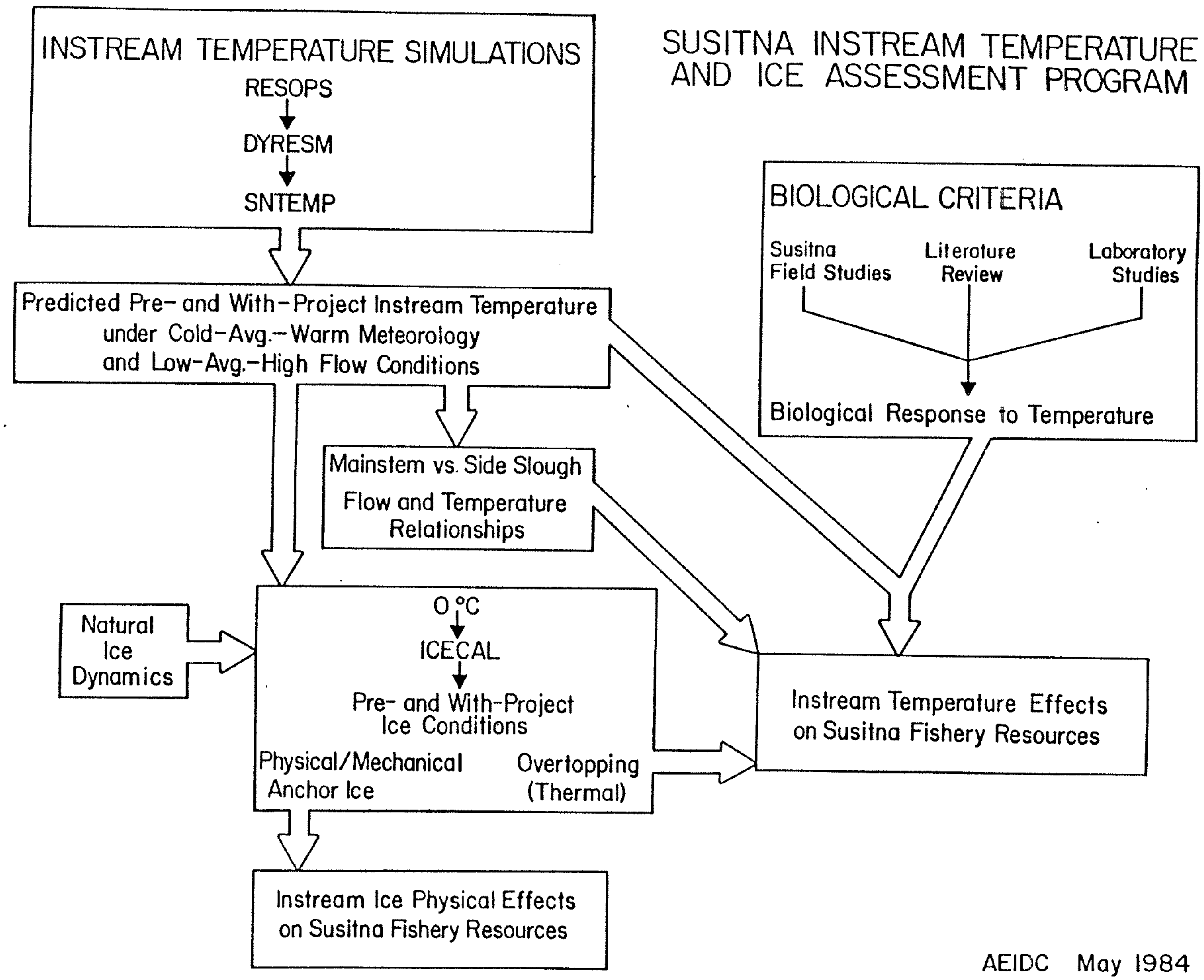
PURPOSE AND SCOPE

PURPOSE

This report summarizes efforts by the Arctic Environmental Information and Data Center (AEIDC) to describe the changes in downstream thermal properties of the Susitna River mainstem resulting from various operational scenarios for the proposed Susitna hydroelectric project. Also examined are potential effects of these temperature changes on instream fishery resources. AEIDC's approach to conducting an assessment of effects of the proposed Susitna project on fishery resources of the Susitna basin was originally described in Alaska, Univ., AEIDC (1983a). Subsequently, a report describing streamflow and temperature modeling conducted by AEIDC was provided in Alaska, Univ., AEIDC (1983b). An initial description of expected changes in downstream temperatures and consequences to instream fishery resources were described in Alaska, Univ., AEIDC (1984a, 1984b). This report is a more refined analysis from that presented in the previous AEIDC reports. As additional reservoir operations and conseqent downstream temperature regimes will be examined in the future, this report should be considered a preliminary draft.

AEIDC's temperature assessment program provides information necessary for describing the effects of the Susitna project on instream fishery resources. Our investigations are part of a larger instream temperature and ice assessment program (Figure 1). This program, which was presented to various state and federal agency personnel and interested individuals during a Susitna workshop on May 15, 1984, involves various elements of the environmental study program sponsored by the Alaska Power Authority. A reservoir operations model, operated by Harza-Ebasco, in conjunction with a reservoir temperature simulation model, DYRESM, also operated by Harza-Ebasco, are used to predict reservoir outflow discharge and temperature conditions for various power load demands for both dam configurations. These data are then transferred to AEIDC as input data to an instream temperature simulation model, SNTEMP. The SNTEMP model predicts either natural or with-project instream temperature conditions. Currently, temperature simulations are run using average weekly time steps. Various combinations of meteorological and flow conditions are imposed on the reservoir operations, reservoir temperature, and instream temperature models in order to examine diverse climatic conditions and their effects on instream temperature.

Figure 1. Components of the instream temperature study.



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In order to evaluate effects of altered temperature conditions on fish, AEIDC has combined the results of field studies conducted in the Susitna basin with available literature and laboratory investigations to develop temperature criteria. These criteria are used in combination with the instream temperature predictions to prepare descriptions of project effects on Susitna fishery resources.

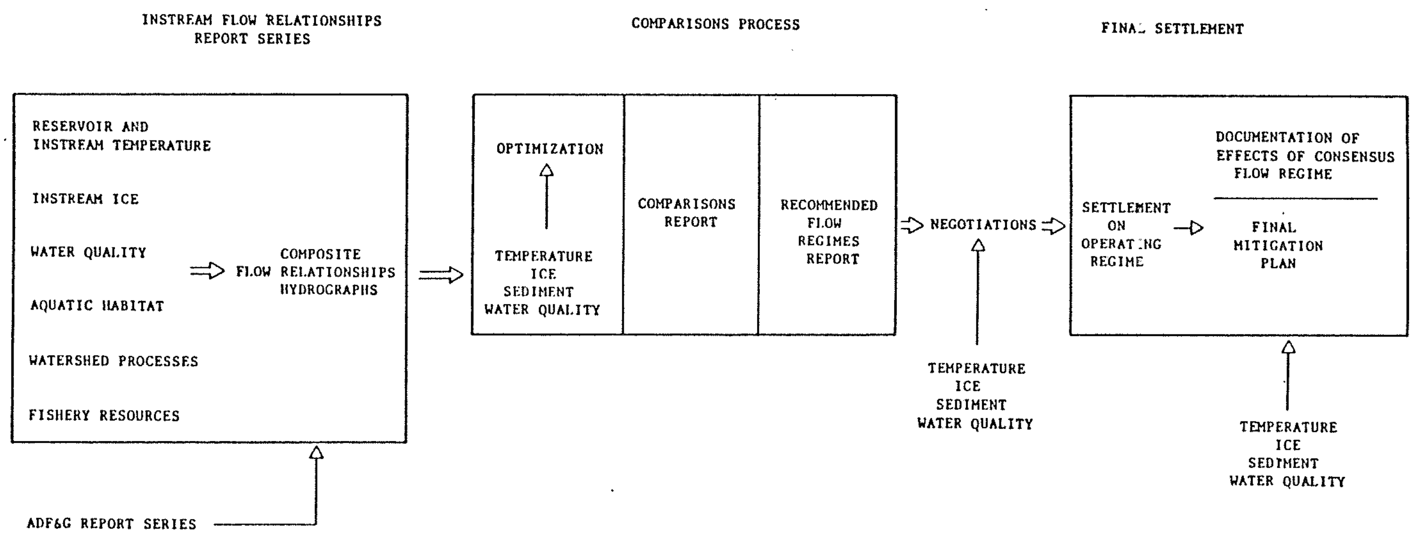
Since a significant portion of the instream salmonid resource in the Susitna basin utilizes side sloughs for spawning and egg incubation as well as extensive rearing, the relationship between mainstem and side slough flow and temperature conditions is being examined by Harza-Ebasco. While a description of these relationships is not currently available, a future report by AEIDC will examine the consequences of downstream thermal change on side slough habitats and their fishery populations.

An additional element of the instream temperature and ice program is the prediction of downstream ice conditions resulting from various project operations. AEIDC's SNTEMP model predicts the downstream location of the instream 0° C isotherm. These predictions are transferred to Harza-Ebasco, for use as input to the instream ice simulation model, ICECAL. ICECAL predicts natural and with-project ice conditions under the same climatology and hydrology utilized for the reservoir and instream temperature simulations. The calibration of ICECAL was accomplished from information developed by R&M Consultants on the natural ice dynamics of the Susitna River (Harza-Ebasco 1984). Again, in future reports, AEIDC will utilize the predictions from the ICECAL model to generate descriptions of the effects of various project operating scenarios on instream ice conditions and on fishery resources.

A series of reports are scheduled for the Susitna instream temperature and ice assessment program. This report will be augmented and refined, with another draft submitted for review in November 1984. Included with the November report will be a chapter discussing the implications of various operating scenarios and resultant temperature regimes on instream ice conditions. Additional thermal analyses will be conducted and a final assessment of all reservoir operation scenarios will be compiled into a March 1985 final report. This report is intended to be an element of the Instream Flow Relationships Report Series.

Instream temperature and ice assessments will be required during various phases of the overall Susitna environmental studies program and settlement process (Figure 2). Currently, these studies are part of the Instream Flow Relationships Report Series (IFRS). The temperature and ice assessment results will be used in the Alaska Power Authority's comparison process to examine the effects of selected flow regimes on power production and downstream fishery resources. Various flow regimes will be examined based upon their on discharge-related consequences, then later examined in terms of effects on temperature and ice conditions. The Alaska Power Authority intends to develop a recommended flow regime, the effects of which will be described in a future report. This report would be used as a basis for a negotiations phase with state and federal agencies in order to arrive at a settlement on the operating regime for the Susitna project. During negotiations, various additional alternative flow regimes may be discussed, the temperature and ice consequences of which will be examined from AEIDC's temperature and ice assessment reports. Finally, temperature and ice assessments will be required to describe the environmental effects of the final

Figure 2. Susitna environmental studies program and settlement process.



consensus flow regime in order to quantify the effect in terms of needed mitigation facilities.

SCOPE OF THE REPORT

This report describes the expected temperature changes and effects on fishery resources for the Watana to Talkeetna mainstem reach of the Susitna River. Although temperature predictions will be provided downstream to the Parks Highway bridge crossing of the mainstem Susitna at Sunshine, fishery assessments are only provided to Talkeetna due to the lack of Susitna-specific habitat information below the confluence of the Talkeetna and Chulitna Rivers. Statements of effect which are discussed herein, however, could be valid to fishery populations in this confluence area. Until quantitative flow and temperature relationships between mainstem and side slough habitats become available, effects of the project in terms of temperature change in side slough habitats cannot be provided.

Examined in this report are 50 cases, nine natural and 41 with-project. For simulation purposes, the year has been divided into two segments, winter and summer. The winter period extends from September through April, while the summer period includes the months of May through September. Figure 3 presents the simulations discussed. AEIDC examined four summer and five winter seasons comparing natural temperature conditions with single- and two-dam scenarios. Three summer and three winter seasons under Watana-filling conditions are also examined.

This report also describes the process of developing temperature assessment criteria. Field investigations by the Alaska Department of Fish and Game (ADF&G) have been ongoing since the 1970s. Also, in 1982 the Alaska Power Authority contracted with the U.S. Fish and Wildlife Service (USFWS) to conduct laboratory investigations of the effects of different temperature regimes on Susitna sockeye and chum salmon fertilized egg development. The results of the USFWS laboratory and ADF&G field investigations have been combined with literature references to prepare criteria used to judge the nature of effect of each with-project simulation. This report presents the results of these efforts conducted to date.

Figure 3. Temperature simulations discussed in this report

	Natural Conditions	Watana Only 1996 Demand	Watana Only 2001 Demand	Watana/Devil Canyon 2002 Demand	Watana/Devil Canyon 2020 Demand	Watana Filling
Summer Season:	X	X	X	X	X	X
1971	X	X	X	X	X	
1974	X	X	X	X	X	X
1981	X	X	X	X	X	X
1982	X	X	X	X	X	X
Winter Season:						
1971-72	X	X	X	X	X	X
1974-75	X	X	X	X	X	
1976-77	X	X		X	X	
1981-82	X	X	X	X	X	X
1982-83	X	X	X	X	X	X

X denotes that scheme has been simulated.

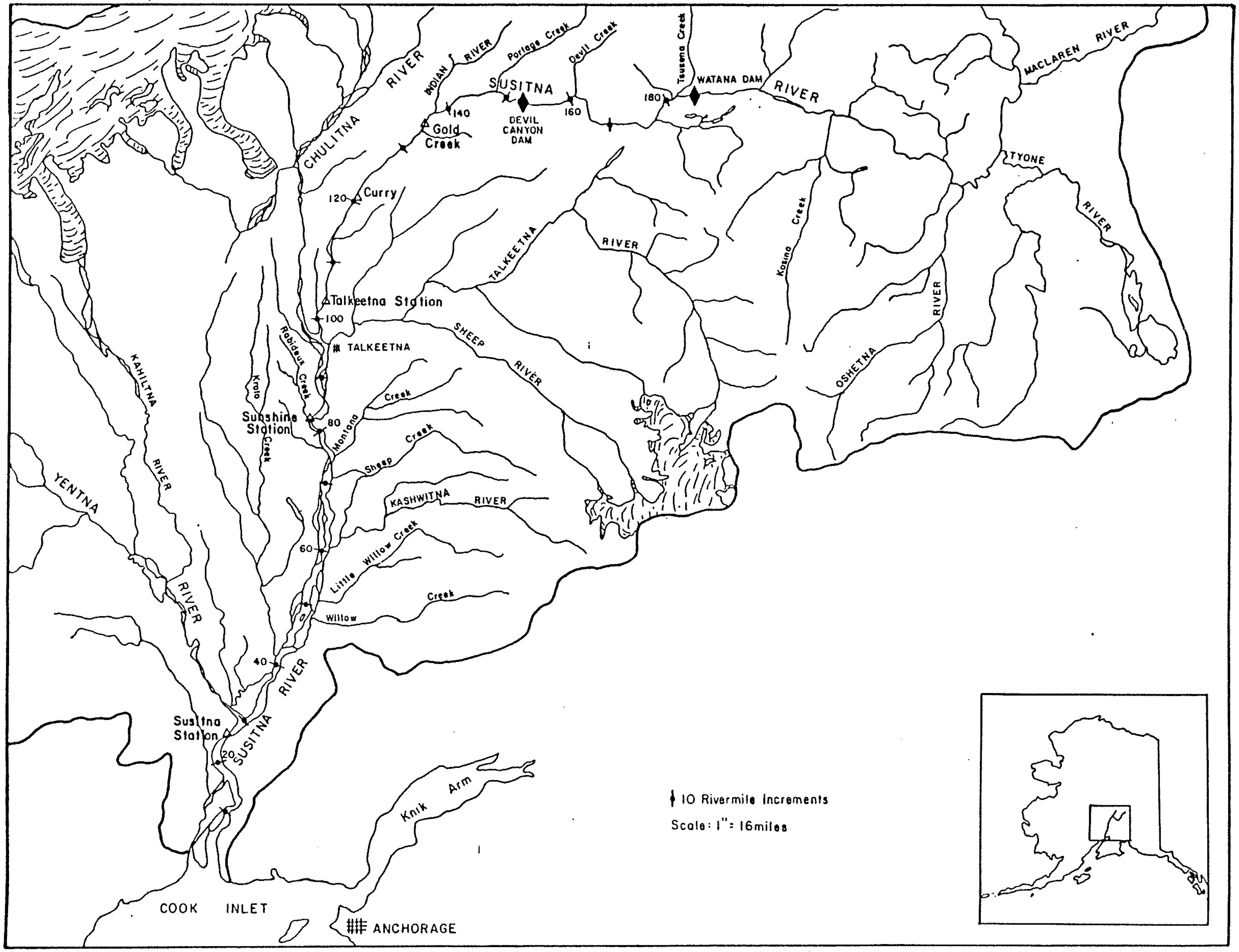
BACKGROUND

The Susitna River drains an area of 19,600 sq mi, the sixth largest river basin in Alaska. The Susitna flows 320 mi from its origin at Susitna Glacier to the Cook Inlet estuary. Its basin is bordered by the Alaska Range to the north, the Chulitna and Talkeetna mountains to the west and south, and the northern Talkeetna plateau and Gulkana uplands to the east. This area is largely within the coastal trough of Southcentral Alaska, a belt of lowlands extending the length of the Pacific mountain system and interrupted by the Talkeetna, Clearwater, and Wrangell mountains.

Major Susitna tributaries include the Talkeetna, Chulitna, and Yentna Rivers (Figure 4). The Yentna River enters the Susitna at river mile (RM) 28 (28 mi from the Susitna confluence with the Cook Inlet estuary). The Chulitna River rises in the glaciers on the south slope of Mount McKinley and flows south, entering the Susitna near Talkeetna (RM 99). The Talkeetna River rises in the Talkeetna Mountains, flows west, and joins the Susitna near Talkeetna.

Tributaries in northern portions of the Susitna basin originate in the glaciers of the eastern Alaska Range. The east and west forks of the Susitna and the McClaren Rivers join the mainstem Susitna River above RM 260. Below the glaciers the braided channel traverses a high plateau and continues south to the Oshetna River confluence near RM 233. There it takes a sharp turn west and flows through a steeply cut canyon which contains the Watana (RM 184.4) and Devil Canyon (RM 151.6) dam sites. In this predominantly single channel reach the gradient is quite steep, approximately 10 ft/mi (Acres American, 1983). Below Gold Creek (RM 137) the river alternates between single and multiple channels until the confluence with the Chulitna

Figure 4. Map of the Susitna basin study region.



and Talkeetna rivers (RM 97), below which the Susitna broadens into widely braided channels for 97 miles to Cook Inlet.

The proposed project consists of two dams to be constructed over a period of about 15 years. The Watana dam would be completed in 1994 at a site 3 mi upstream from Tsusena Creek (RM 184.4). This development would include an underground powerhouse and 885 ft high earthfill dam, which would impound a reservoir 48 mi long with a surface area of 38,000 acres and a usable storage capacity of 3.7 million acre feet (maf). The dam would house multiple level intakes and cone valves. Installed generating capacity would be 1020 megawatts (mw), with an estimated average annual energy output of 3460 gigawatt hours (gwh).

The concrete arch Devil Canyon dam would be completed by 2002 at a site 32 mi downstream of the Watana dam site. It would be 645 ft high and would impound a 26 mile-long reservoir with 7,800 surface acres and a storage capacity of .36 maf (Acres American, 1983). Installed generating capacity would be about 600 mw, with an average annual energy output of 3450 gwh. Both reservoirs would be drawn down during the high energy demand winter months and filled during the summer months when energy requirements are lowest.

Seven anadromous and twelve resident fish species are known to inhabit the Susitna drainage. From the Watana Dam site to the Parks Highway Bridge, five anadromous (the five Pacific salmon species) and ten resident species are found.

Construction and subsequent operation of the Susitna dams are expected to affect the aquatic resources in the basin by altering the normal thermal regime of the river. Mainstem water temperatures downstream from the project will be cooler in the summer and warmer in the winter than those currently found. A change in the ice regime downstream from the project is also expected due to altered temperatures and increased winter flows.

METHODS

INSTREAM TEMPERATURE MODELING

DESCRIPTION OF MODEL, ASSUMPTIONS, LIMITATIONS

A computer version of the Instream Water Temperature model developed by the Instream Flow and Aquatic Systems Group (IFG), U.S. Fish and Wildlife Service (Theurer et al. 1983) has been used to analyze the downstream temperature changes associated with the Susitna Hydroelectric Project. Estimates of the Watana dam release temperatures and flows were used to initiate the stream temperature model.

The instream water temperature model (SNTEMP) predicts longitudinal, cross-section averaged, mean daily temperatures throughout a stream network. SNTEMP consists of several submodels:

1. A solar model which predicts solar radiation based on the latitude of the stream basin, time of year, basin topographic characteristics, and prevailing meteorologic conditions;
2. A meteorologic correction model accounting for changes in air temperature, relative humidity, and atmospheric pressure with elevation;
3. A heat flux model accounting for all significant heat sources and sinks;
4. A heat transport model to move the water and its associated heat content downstream;
5. A flow mixing model for merging tributary flows and heat content with those of the mainstem.

A complete description of each of these components is provided in the model description/documentation available from the U.S. Fish and Wildlife service (Theurer et al. 1983). Application of this model to the Susitna basin has been previously discussed in Alaska, Univ., AEIDC (1984b, 1983b). A brief description of the heat transport model will be provided since it is this component, more than any other, which determines the model's limitations. The heat transport model used in SNTEMP is based on the following dynamic temperature-steady flow equation:

$$(A/Q)\ (\partial T/\partial t) + \partial T/\partial x = (q_d/Q)\ (T_d - T) + (B\Sigma H)/(Q\rho c_p)$$

|<--dynamic term-->|<------steady state equation----------->|

|<------dynamic temperature - steady flow equation-------->|

where:

A = flow area, L^2

Q = flow, L^3/t

T = temperature, T

t = time, t

x = distance, L

q_d = distributed inflow, L^2/t

T_d = distributed inflow temperature, T

B = stream top width, L

SH = net heat flux, $(E/L^2)/t$

ρ = density of water, M/L^3

c_p = specific heat of water, $(E/M)/T$

and dimensions are:

M - mass

T - temperature

L - length

t - time

E - energy

The net heat flux is the sum of atmospheric, topographic, and vegetative radiation; solar radiation; evaporation; free and forced convection; stream friction; stream bed conduction; and water back radiation.

Three sets of data are required as input to the model: (1) meteorologic, (2) hydrologic, and (3) stream geometry. Meteorologic data consists of solar radiation coefficients (atmospheric dust and ground reflectivity), air temperature, relative humidity, possible sunshine, and wind speed. Hydrologic data consists of discharge data throughout the stream system, initial temperatures of the mainstem and significant tributaries, and estimates of the temperature of distributed inflows (groundwater or overland). Stream geometry consists of a definition of the stream system network (latitudes, elevations, and distances), stream widths, and stream shading.

Simulated stream temperatures in this report represent 24-hour average temperatures. These average daily temperatures were simulated with weekly average hydrologic and meteorologic conditions. Temperature predictions therefore represent the 24-hour average stream temperature which would be expected to occur on the average day of the week.

Water weeks are used as the averaging time period. The first water week begins on October 1. All water weeks are seven days long except the fifty-second week which is eight days long; February 29 is not considered when it occurs. Table 1 is useful for converting between water weeks and calendar days.

Table 1. Water weeks for water year n.

WEEK NUMBER	FROM day	FROM month	FROM year	TO day	TO month	TO year	WEEK NUMBER	FROM day	FROM month	FROM year	TO day	TO month	TO year
1	1	Oct.	n-1	7	Oct.	n-1	27	1	Apr.	n	7	Apr.	n
2	8	Oct.	n-1	14	Oct.	n-1	28	8	Apr.	n	14	Apr.	n
3	15	Oct.	n-1	21	Oct.	n-1	29	15	Apr.	n	21	Apr.	n
4	22	Oct.	n-1	28	Oct.	n-1	30	22	Apr.	n	28	Apr.	n
5	29	Oct.	n-1	4	Nov.	n-1	31	29	Apr.	n	5	May	n
6	5	Nov.	n-1	11	Nov.	n-1	32	6	May	n	12	May	n
7	12	Nov.	n-1	18	Nov.	n-1	33	13	May	n	19	May	n
8	19	Nov.	n-1	25	Nov.	n-1	34	20	May	n	26	May	n
9	26	Nov.	n-1	2	Dec.	n-1	35	27	May	n	2	June	n
10	3	Dec.	n-1	9	Dec.	n-1	36	3	June	n	9	June	n
11	10	Dec.	n-1	16	Dec.	n-1	37	10	June	n	16	June	n
12	17	Dec.	n-1	23	Dec.	n-1	38	17	June	n	23	June	n
13	24	Dec.	n-1	30	Dec.	n-1	39	24	June	n	30	June	n
14	31	Dec.	n-1	6	Jan.	n	40	1	July	n	7	July	n
15	7	Jan.	n	13	Jan.	n	41	8	July	n	14	July	n
16	14	Jan.	n	20	Jan.	n	42	15	July	n	21	July	n
17	21	Jan.	n	27	Jan.	n	43	22	July	n	28	July	n
18	28	Jan.	n	3	Feb.	n	44	29	July	n	4	Aug.	n
19	4	Feb.	n	10	Feb.	n	45	5	Aug.	n	11	Aug.	n
20	11	Feb.	n	17	Feb.	n	46	12	Aug.	n	18	Aug.	n
21	18	Feb.	n	24	Feb.	n	47	19	Aug.	n	25	Aug.	n
22	25	Feb.	n	3	Mar.	n	48	26	Aug.	n	1	Sep.	n
23	4	Mar.	n	10	Mar.	n	49	2	Sep.	n	8	Sep.	n
24	11	Mar.	n	17	Mar.	n	50	9	Sep.	n	15	Sep.	n
25	18	Mar.	n	24	Mar.	n	51	16	Sep.	n	22	Sep.	n
26	25	Mar.	n	31	Mar.	n	52	23	Sep.	n	30	Sep.	n

Seasonal simulations are of two types: 1) winter period (week 49, water year n-1 to week 30, water year n), and 2) summer period (week 31 to week 52).

MODEL LINKAGES TO SNTEMP

With-project stream temperature simulations require the flow and temperature of reservoir releases as input. Harza Engineering Company models the reservoir(s) operation to determine release flows and temperatures, and transmit their results to AEIDC. These results include daily flows and associated temperatures from powerhouse, cone valve and spillway releases.

The daily results are processed by AEIDC to obtain single mean weekly flows and temperatures which incorporate releases from all three outflow structures. These results are then used directly as input to the SNTEMP model.

APPLICATION OF MODEL TO THE SUSITNA RIVER

Stream Structure Data

The stream network is defined for the mainstem Susitna from Watana dam site (RM 184.4) to the Parks Highway bridge (RM 83.8). For simulation of the Watana/Devil Canyon configuration, the upstream end of the study reach is the Devil Canyon dam site (RM 151.6). Major tributaries between Watana and Parks Highway Bridge were included in the Susitna stream network (Figure 5).

The mainstem network was segmented into 10 reaches to account for differences in topographic shading resulting from stream orientation and local topography. The monthly sunrise/sunset altitude angles (Alaska, Univ., AEIDC, 1983b) were interpolated into weekly values (Table 2).

Stream widths are simulated as a function of flow. These width functions were determined from Susitna River cross-section plots prepared by

Figure 5. Flow balance sub-basins, Cantwell gage to Sunshine gage.

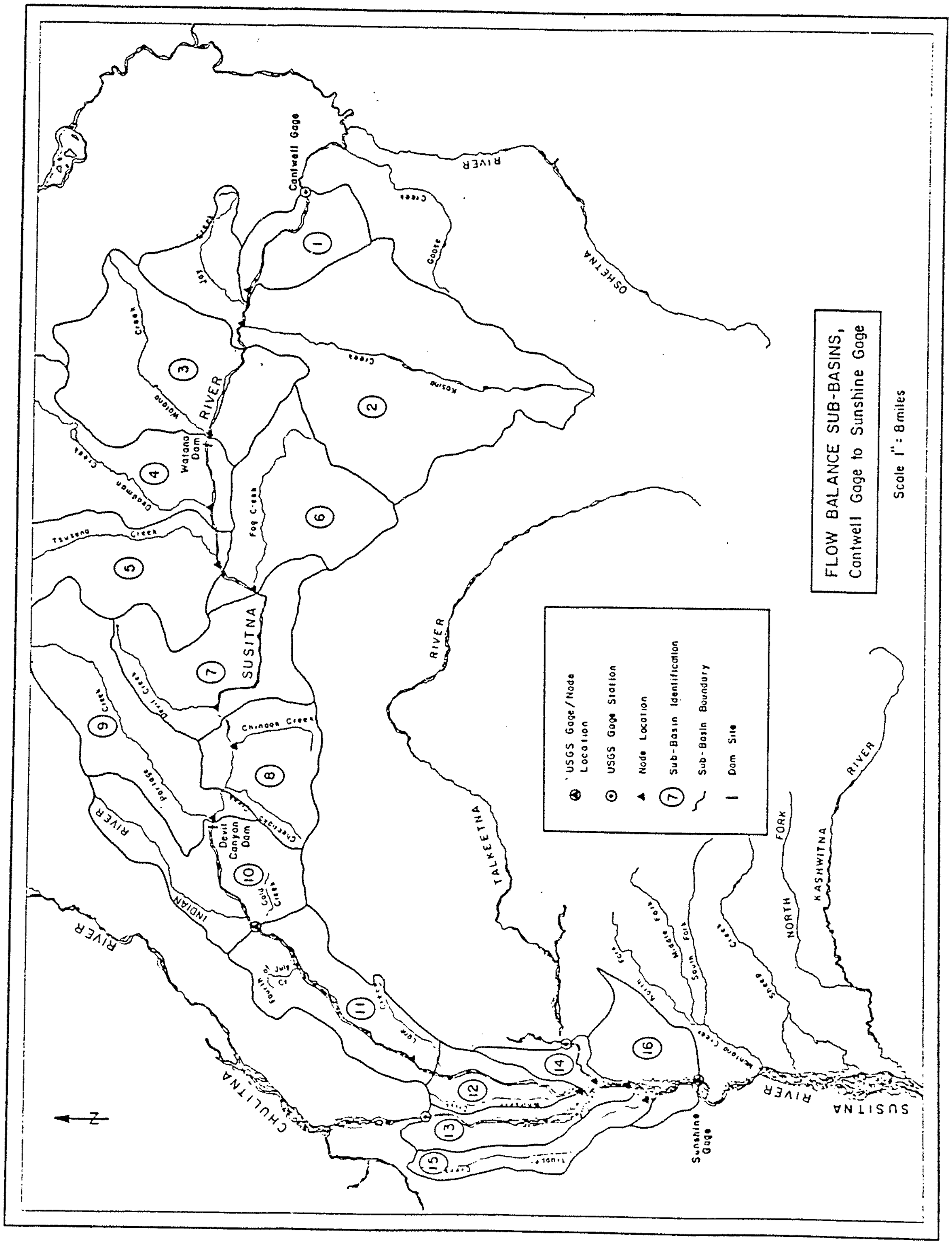


Table 2. Weekly values of Susitna and Chulitna Solar Altitude Angles

	Mainstream Rivermile Range									
WEEK	184.5-179.5	179.5-175.5	175.5-166.0	166.0-163.0	163.0-146.5	146.5-142.5	142.5-124.0	124.0-115.0	115.0-99.5	CHULITNA
1	0.31	0.118	0.265	0.269	0.405	0.077	0.080	0.143	0.00	0.078
2	0.49	0.112	0.265	0.240	0.405	0.093	0.103	0.140	0.00	0.075
3	0.65	0.105	0.265	0.210	0.405	0.108	0.127	0.138	0.00	0.071
4	0.78	0.098	0.265	0.189	0.405	0.114	0.138	0.129	0.00	0.065
5	0.78	0.082	0.265	0.161	0.405	0.114	0.138	0.113	0.00	0.057
6	0.78	0.069	0.265	0.135	0.405	0.114	0.138	0.099	0.00	0.050
7	0.78	0.055	0.265	0.110	0.405	0.114	0.138	0.083	0.00	0.042
8	0.78	0.043	0.265	0.086	0.405	0.114	0.138	0.068	0.00	0.035
9	0.78	0.046	0.265	0.071	0.405	0.114	0.138	0.068	0.00	0.030
10	0.78	0.048	0.265	0.057	0.405	0.114	0.138	0.068	0.00	0.026
11	0.78	0.051	0.265	0.043	0.405	0.114	0.138	0.068	0.00	0.021
12	0.78	0.053	0.265	0.029	0.405	0.114	0.138	0.068	0.00	0.018
13	0.78	0.052	0.265	0.036	0.405	0.114	0.138	0.068	0.00	0.020
14	0.78	0.050	0.265	0.050	0.405	0.114	0.138	0.068	0.00	0.024
15	0.78	0.048	0.265	0.063	0.405	0.114	0.138	0.068	0.00	0.028
16	0.78	0.046	0.265	0.076	0.405	0.114	0.138	0.068	0.00	0.031
17	0.78	0.048	0.265	0.094	0.405	0.114	0.138	0.068	0.00	0.037
18	0.78	0.060	0.265	0.120	0.405	0.114	0.138	0.090	0.00	0.044
19	0.78	0.075	0.265	0.146	0.405	0.114	0.138	0.105	0.00	0.052
20	0.78	0.088	0.265	0.173	0.405	0.114	0.138	0.121	0.00	0.060
21	0.78	0.102	0.265	0.200	0.405	0.114	0.138	0.138	0.00	0.068
22	0.62	0.109	0.265	0.229	0.405	0.099	0.114	0.140	0.00	0.073
23	0.44	0.115	0.350	0.257	0.405	0.071	0.088	0.141	0.00	0.077
24	0.26	0.122	0.210	0.286	0.405	0.063	0.060	0.144	0.00	0.081
25	0.069	0.130	0.068	0.315	0.405	0.045	0.035	0.148	0.00	0.088
26	0.065	0.135	0.058	0.341	0.446	0.043	0.035	0.143	0.00	0.088
27	0.062	0.142	0.049	0.368	0.490	0.041	0.035	0.138	0.00	0.088
28	0.059	0.148	0.039	0.395	0.530	0.038	0.035	0.132	0.00	0.088
29	0.055	0.154	0.030	0.422	0.575	0.036	0.035	0.128	0.00	0.088
30	0.050	0.150	0.032	0.441	0.551	0.041	0.035	0.126	0.00	0.083
31	0.047	0.133	0.040	0.453	0.465	0.053	0.035	0.127	0.00	0.075
32	0.043	0.117	0.054	0.464	0.385	0.065	0.035	0.129	0.00	0.068
33	0.039	0.100	0.080	0.476	0.300	0.076	0.035	0.130	0.00	0.060
34	0.035	0.086	0.095	0.488	0.226	0.087	0.035	0.131	0.00	0.054
35	0.048	0.086	0.102	0.483	0.235	0.092	0.037	0.133	0.00	0.051
36	0.060	0.086	0.109	0.477	0.244	0.097	0.039	0.135	0.00	0.049
37	0.072	0.086	0.115	0.470	0.251	0.100	0.041	0.137	0.00	0.046
38	0.088	0.086	0.121	0.465	0.259	0.103	0.042	0.139	0.00	0.044
39	0.079	0.086	0.118	0.467	0.257	0.103	0.041	0.138	0.00	0.045
40	0.065	0.086	0.111	0.472	0.248	0.099	0.039	0.136	0.00	0.048
41	0.052	0.086	0.105	0.478	0.238	0.093	0.037	0.134	0.00	0.050
42	0.040	0.086	0.099	0.484	0.230	0.089	0.035	0.132	0.00	0.051
43	0.037	0.095	0.088	0.480	0.275	0.080	0.035	0.131	0.00	0.058
44	0.041	0.110	0.073	0.469	0.354	0.070	0.035	0.129	0.00	0.064
45	0.045	0.126	0.057	0.458	0.435	0.059	0.035	0.128	0.00	0.073
46	0.049	0.141	0.041	0.447	0.515	0.048	0.035	0.125	0.00	0.079
47	0.053	0.156	0.025	0.435	0.595	0.035	0.035	0.123	0.00	0.088
48	0.057	0.150	0.034	0.409	0.555	0.037	0.035	0.127	0.00	0.088
49	0.060	0.144	0.044	0.371	0.510	0.040	0.035	0.133	0.00	0.088
50	0.063	0.139	0.053	0.355	0.468	0.041	0.035	0.139	0.00	0.088
51	0.066	0.132	0.062	0.327	0.424	0.044	0.035	0.145	0.00	0.088
52	0.15	0.125	0.135	0.297	0.405	0.062	0.055	0.145	0.00	0.083

R&M Consultants (1982a, 1982b) and, in the lower river, interpolated from USGS maps (Gemperline 1984).

Stream width functions for the Chulitna and Talkeetna Rivers were developed from stream width data collected by the USGS (1980, 1981). The stream width functions for the Susitna, Chulitna, and Talkeetna Rivers are presented in Appendix C.

Hydrologic Data

Estimates of significant tributary flow contributions are necessary for simulating mainstem temperatures. Since few tributaries in the basin have gaged flow records, flow contributions from most of these sub-basins must be estimated. To assure consistency among the various project engineering programs, flow to the mainstem from tributary sub-basins are estimated as proportional to the sub-basin area.

The present modeling effort considers the basin between the Watana dam site and the Parks Highway bridge at Sunshine. Chulitna and Talkeetna River flows are incorporated into this system at the USGS gage station on each river near the town of Talkeetna. This basin is further divided into thirteen sub-basins. These sub-basins are defined by drainage divides and are centered around the larger tributaries. Flow from each sub-basin is added to the mainstem Susitna as point inflow at a model node location generally near the major tributary mouth. Figure 5 (discussed previously) provides a map of the basin under consideration, the sub-basins and the node locations where sub-basin inflows are assigned.

A water balance program, H2OBAL, (Alaska, Univ., AEIDC 1983b) is used to provide SNTEMP with flows at each node for each simulated timestep. H2OBAL requires a time series of input flows at four locations: the Susitna

River at the Watana dam site, the Susitna at the Gold Creek USGS gage, and the Chulitna and Talkeetna rivers at the USGS gage stations on each. For simulating the operation of the Devil Canyon dam, Devil Canyon release flows are used in place of the Watana data.

Simulations discussed in this report consider seasons within water years 1971 through 1983. Continuous flow data for this period are available from USGS records at Gold Creek and Talkeetna. Flows at Watana and Chulitna are not available for all periods, and are determined as follows:

Watana. Although R&M Consultants have been collecting flow data at this location during the open water season since July 1980, an equal area contribution relationship is used for all periods. When flow data are available at the Susitna River USGS gage near Cantwell (Station #15291500), the following relationship is used:

$$Q_W = 0.515\ (Q_{GC} - Q_{CA}) + Q_{CA}$$

where Q is the mean flow for a given period and subscripts W, CA and GC refer to Watana, Cantwell and Gold Creek respectively. The factor 0.515 is the drainage area ratio between the Cantwell to Watana and Cantwell to Gold Creek Basins. When flow data are not available at the Cantwell gage, the following relationship is used:

$$Q_W = 0.841\ Q_{GC}$$

where 0.841 is the drainage area ratio of the entire basin at Watana to that defined at Gold Creek.

Chulitna. Streamflow data at the Chulitna River USGS gage were not collected from October 1972 until May 1980. Simulations of this period used the weekly flow formula:

$$Q_{WK,CH} = Q_{M,CH} \times \frac{Q_{wk,GC}}{Q_{M,GC}}$$

where subscripts WK and M denote weekly and monthly periods of flow, and CH refers to the Chulitna gage location. This relationship is based on the assumption that the Chulitna basin responds similarly within a month to the Susitna basin defined at Gold Creek. The Chulitna monthly flow data were synthesized using the Texas Water Development Board's FILLIN program (Acres American 1983).

Flow data are also required at Sunshine, the downstream end of the present region of temperature simulation. The USGS began collecting flow data at that site in May 1981. However, on occasion, recorded flows at Sunshine were less than the sum of recorded flows upbasin at the Gold Creek, Chulitna and Talkeetna gages. While the reasons for this discrepancy remain unclear, we decided to use a simple basin area relationship to estimate flows at Sunshine, thus avoiding negative tributary contributions. This relationship is:

$$Q_S = 1.070\ (Q_{GC} + Q_{CH} + Q_T)$$

where subscripts S and T refer to the Sunshine and Talkeetna gage sites, and the factor 1.070 is the ratio of the drainage area defined at Sunshine to the combined area of the Gold Creek, Chulitna and Talkeetna drainage basins.

Estimates of tributary inflow temperatures are necessary for all natural and with-project simulations. Additionally, pre-project stream temperatures are required at the Watana dam site for natural stream temperature simulations.

ADF&G tributary temperature observations at Tsusena Creek, Portage Creek, and Indian River (ADF&G 1983; Quane 1984) were used to develop a tributary temperature regression function (Figure 6). This function is used to estimate weekly temperatures of all the middle river tributaries between the Watana dam site and the Chulitna confluence for all pre- and with-project simulations (observed Tsusena Creek, Portage Creek, and Indian River temperatures were used when available for water year 1981, 1982 and 1983 simulations).

Observed temperatures on the Chulitna and Talkeetna Rivers (ADF&G 1983; Quane 1984) were used to develop equilibrium temperature regression models (Alaska, Univ., AEIDC 1983b). These regression models (Figure 7) were used to synthesize Chulitna and Talkeetna stream temperatures for all simulations for which observed data were not available.

Actual or estimated pre-project Watana dam site temperatures are required for natural condition simulations. These natural condition simulations are used for base line comparisons and for model validation simulations. An equilibrium temperature regression model was developed for the Watana site using data collected during water year 1981 (R&M Consultants 1982c)(Figure 8). The regression analysis was limited to observed temperatures greater than 0 C.

Meteorologic Data

The SNTEMP model is designed for climatic data input from only one representative meteorologic data station per stream network. The only long-term meteorologic data station within the middle river Susitna Basin is the US National Weather Service Station located in Talkeetna. This station has daily air temperature, wind speed, relative humidity, and percent cloud

Figure 6. Tributary temperature regression function.

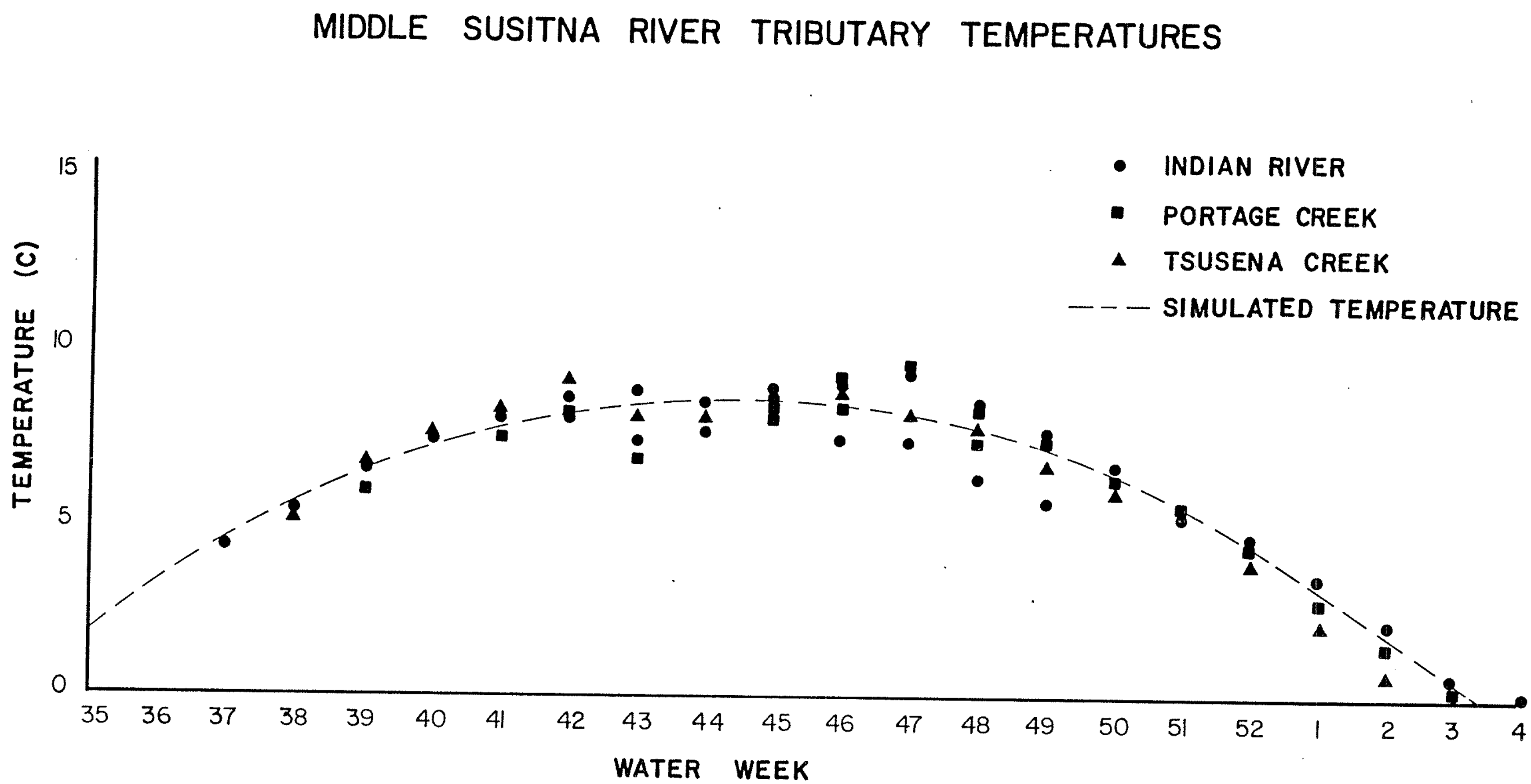


Figure 7. Chulitna and Talkeetna Rivers temperature regression functions.

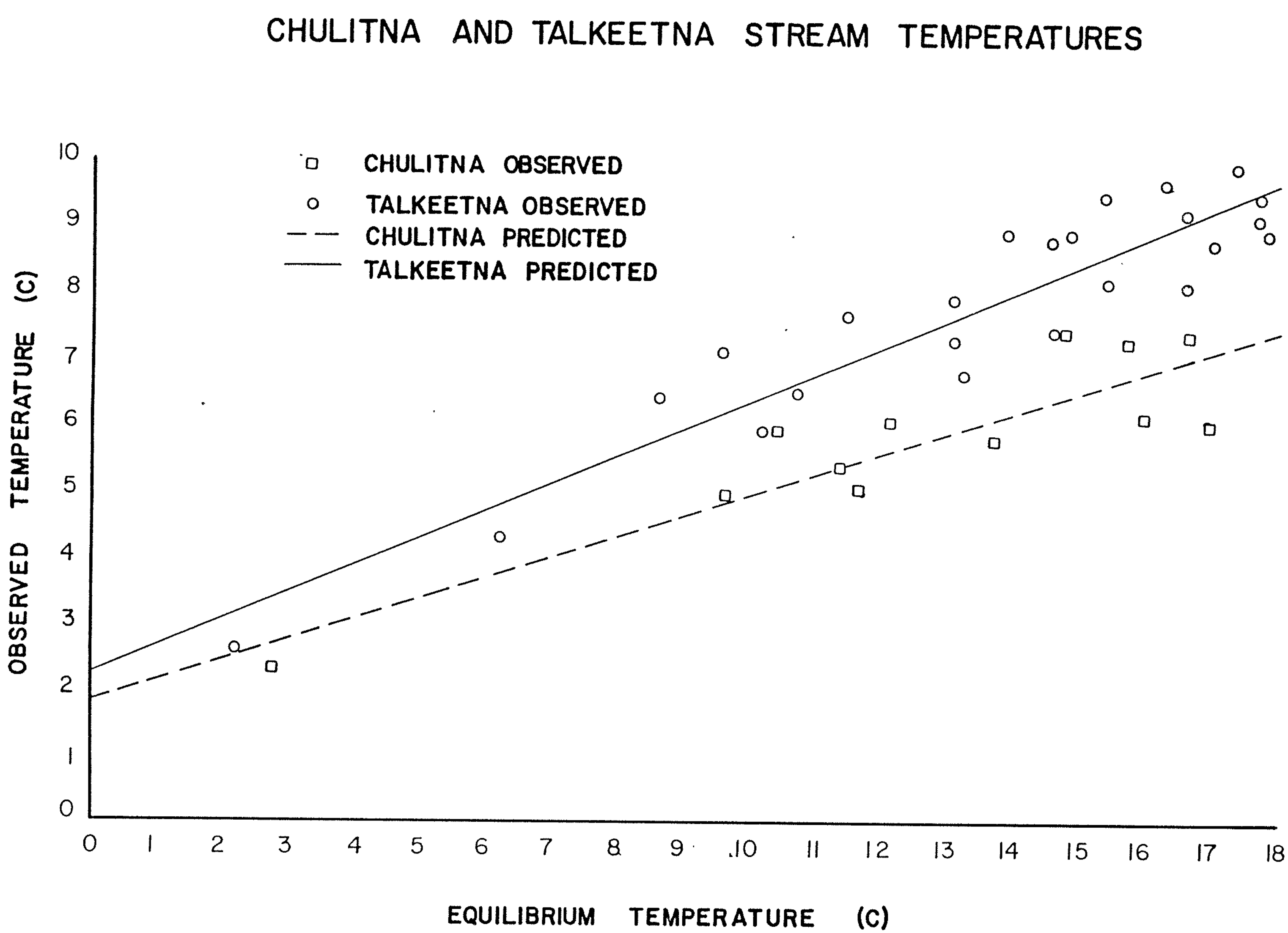
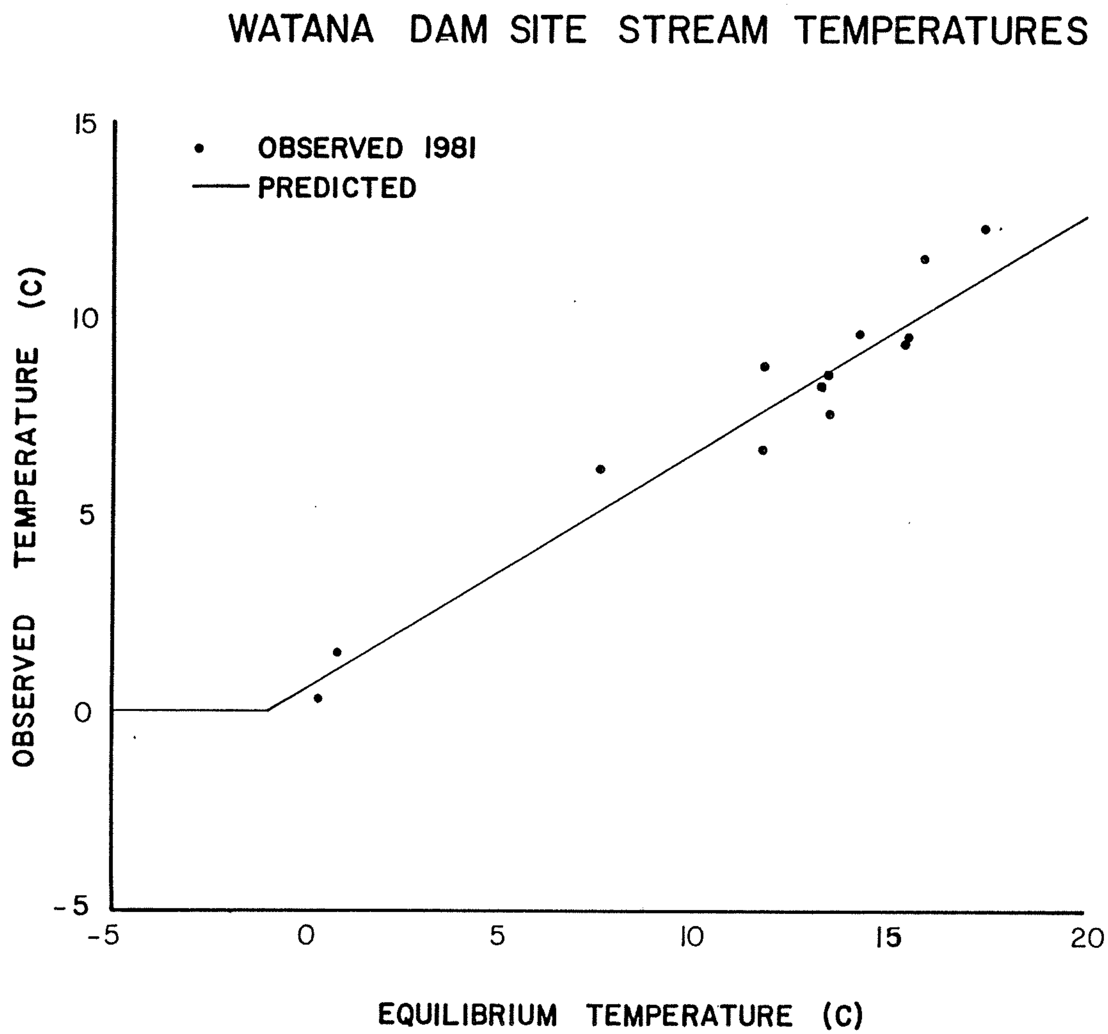


Figure 8. Watana dam site water temperature regression function.



cover data for the period covered in this report, 1971 to 1982. This period of record allows stream temperature simulations under extreme and normal meteorologic conditions once these data are adjusted to represent conditions throughout the Susitna basin, ~~conditions~~.

Previously defined monthly values of the dust and reflectivity coefficients (Alaska, Univ., AEIDC, 1983b) were distributed on a weekly basis (Table 3). Air temperature and moisture radiosonde data collected above Anchorage and Fairbanks (U.S. National Weather Service 1968, 1969, 1970, 1980; World Meteorological Organization 1981, 1982) were used to determine elevation lapse functions. These lapse functions are used to convert Talkeetna air temperature and humidity data to locations within the Susitna Basin. Weekly values of the lapse rate coefficients are also presented in Table 3.

The air temperatures predicted with these lapse rate functions and Talkeetna air temperatures were compared with observed air temperatures at the Watana and Devil Canyon dam sites and at a meteorological station at Sherman (R&M 1980, 1982c, 1982d, 1982e, 1982f, 1982g). These plots (Appendix D) indicate that the lapse rate functions are more reliable at temperatures above 0 C (i.e., summer conditions); the temperature lapse rate functions tend to overpredict air temperatures when the actual air temperatures are less than 0 C.

Figures contained within Appendix E illustrate the departure from Talkeetna of weekly temperatures measured at stations within the basin. Inspection of these figures will indicate the difficulty of trying to fit a predictive air temperature lapse rate to the measured lapse rate, particularly in winter. During winter, inversions may or may not be present. The inversions may occur aloft or may dissipate and recur from week to week,

Table 3. Weekly values of meteorological constants

WEEK NUMBER	DUST COEFFICIENT	REFLECTIVITY COEFFICIENT	γ_o (C/m)	γ_1 (C/m)	Z_T (m)	β_o (m^{-1})	β_1 (m^{-1})	Z_R (m)
1	0.3363	0.45	-6.56E-3	--	--	-6.40E-5	--	--
2	0.3363	0.45	-6.56E-3	--	--	-6.40E-5	--	--
3	0.3363	0.45	-6.56E-3	--	--	-6.40E-5	--	--
4	0.3363	0.45	-6.56E-3	--	--	-6.40E-5	--	--
5	0.1291	0.67	-6.56E-3	--	--	-4.96E-5	--	--
6	0.1291	0.67	-6.56E-3	--	--	-4.96E-5	--	--
7	0.1291	0.67	-6.56E-3	--	--	-4.96E-5	--	--
8	0.1291	0.67	-6.56E-3	--	--	-4.96E-5	--	--
9	0.1291	0.67	-6.56E-3	--	--	-4.96E-5	--	--
10	0.2343	0.65	-6.56E-3	--	--	-8.79E-5	--	--
11	0.2343	0.65	-6.56E-3	--	--	-8.79E-5	--	--
12	0.2343	0.65	-6.56E-3	--	--	-8.79E-5	--	--
13	0.2343	0.65	-6.56E-3	--	--	-8.79E-5	--	--
14	0.0938	0.62	-6.56E-3	--	--	-7.77E-5	--	--
15	0.0938	0.62	-6.56E-3	--	--	-7.77E-5	--	--
16	0.0938	0.62	-6.56E-3	--	--	-7.77E-5	--	--
17	0.0938	0.62	-6.56E-3	--	--	-7.77E-5	--	--
18	0.0938	0.62	-6.56E-3	--	--	-7.77E-5	--	--
19	0.2912	0.59	-6.56E-3	--	--	-6.21E-5	--	--
20	0.2912	0.59	-6.56E-3	--	--	-6.21E-5	--	--
21	0.2912	0.59	-6.56E-3	--	--	-6.21E-5	--	--
22	0.2912	0.59	-6.56E-3	--	--	-6.21E-5	--	--
23	0.2372	0.58	-6.56E-3	--	--	-2.12E-5	--	--
24	0.2372	0.58	-6.56E-3	--	--	-2.12E-5	--	--
25	0.2372	0.58	-6.56E-3	--	--	-2.12E-5	--	--
26	0.2372	0.58	-6.56E-3	--	--	-2.12E-5	--	--
27	0.2760	0.48	-5.93E-3	--	--	-1.04E-4	1.13E-5	450
28	0.2760	0.48	-5.93E-3	--	--	-1.04E-4	1.13E-5	450
29	0.2760	0.48	-5.93E-3	--	--	-1.04E-4	1.13E-5	450
30	0.2760	0.48	-5.93E-3	--	--	-1.04E-4	1.13E-5	450
31	0.3085	0.30	-5.95E-3	--	--	-1.93E-4	3.18E-5	525
32	0.3085	0.30	-5.95E-3	--	--	-1.93E-4	3.18E-5	525
33	0.3085	0.30	-5.95E-3	--	--	-1.93E-4	3.18E-5	525
34	0.3085	0.30	-5.95E-3	--	--	-1.93E-4	3.18E-5	525
35	0.3085	0.30	-5.95E-3	--	--	-1.93E-4	3.18E-5	525
36	0.3156	0.24	-6.09E-3	--	--	-1.42E-4	3.45E-3	550
37	0.3156	0.24	-6.09E-3	--	--	-1.42E-4	3.45E-3	550
38	0.3156	0.24	-6.09E-3	--	--	-1.42E-4	3.45E-3	550
39	0.3156	0.24	-6.09E-3	--	--	-1.42E-4	3.45E-3	550
40	0.3078	0.22	-5.64E-3	--	--	-1.87E-4	2.92E-5	550
41	0.3078	0.22	-5.64E-3	--	--	-1.87E-4	2.92E-5	550
42	0.3078	0.22	-5.64E-3	--	--	-1.87E-4	2.92E-5	550
43	0.3078	0.22	-5.64E-3	--	--	-1.87E-4	2.92E-5	550
44	0.3296	0.23	-5.63E-3	--	--	-3.29E-4	1.26E-5	500
45	0.3296	0.23	-5.63E-3	--	--	-3.29E-4	1.26E-5	500
46	0.3296	0.23	-5.63E-3	--	--	-3.29E-4	1.26E-5	500
47	0.3296	0.23	-5.63E-3	--	--	-3.29E-4	1.26E-5	500
48	0.3296	0.23	-5.63E-e	--	--	-3.29E-4	1.26E-5	500
49	0.2924	0.24	-5.27E-3	--	--	-3.12E-4	2.90E-6	500
50	0.2924	0.24	-5.27E-3	--	--	-3.12E-4	2.90E-6	500
51	0.2924	0.24	-5.27E-3	--	--	-3.12E-4	2.90E-6	500
52	0.2924	0.24	-5.27E-3	--	--	-3.12E-4	2.90E-6	500

T_{air} (elevation = Z) = $T_{Talkeetna} + \gamma*_o (Z - Z_{Talkeetna}); Z \leq Z_T$

$T_{Talkeetna} + \gamma_o* (Z_T - Z_{Talkeetna}) + \gamma_1* (Z - Z_T); Z > Z_T$

following no set pattern in different years. Three periods have particularly unstable stmospheric condtions: late October, November, and January - all winter climate regimes. The remaining nine predictive profiles fall well within the observed range of temperature change with elevation and generate acceptable air temperature values for input to the stream temperature model.

Weekly averaged wind speed data collected at the R&M sites at Watana, Devil Canyon, and Sherman were compared to the wind speeds observed at Talkeetna (Appendix F). The Talkeetna data appears to represent the average winds occurring in the middle Susitna basin.

MODEL VALIDATION

Mainstem Susitna River temperatures collected between the Watana dam site and the Parks Highway Bridge (ADF&G 1983a) were used to validate the stream temperature simulations. These data were only available for water weeks 37 to 52 for water years 1981 and 1982, and weeks 1 to 4 and 34 to 52 for water year 1983.

The residual errors (predicted temperature minus observed temperature) were plotted as a function of the meteorological variables (air temperature, humidity, possible sunshine and wind speed), distance, and time period (Appendix G). No systematic errors were observed although this analysis helped identify observed stream temperatures which were not representative of mainstem conditions. Some of these data were removed from the validation set after discussions with ADF&G (Quane 1984) suggested that the data could be in error.

The stream temperature model was calibrated by adjusting the water year 1982 and 1983 Watana dam site temperatures to obtain a better fit to downstream temperatures. These adjusted Watana dam site temperatures were used with the water year 1981 observed temperatures to develop a new regression model (Figure 9). This regression plot demonstrates that the adjusted temperatures follow a similar relationship to the observed data (compare with Figure 8). This new regression model provides more representative Watana dam site temperatures useful for pre-project simulations.

The post-calibration statistics are presented in Table 4.

Table 4. Susitna Stream Temperature Simulation Statistics

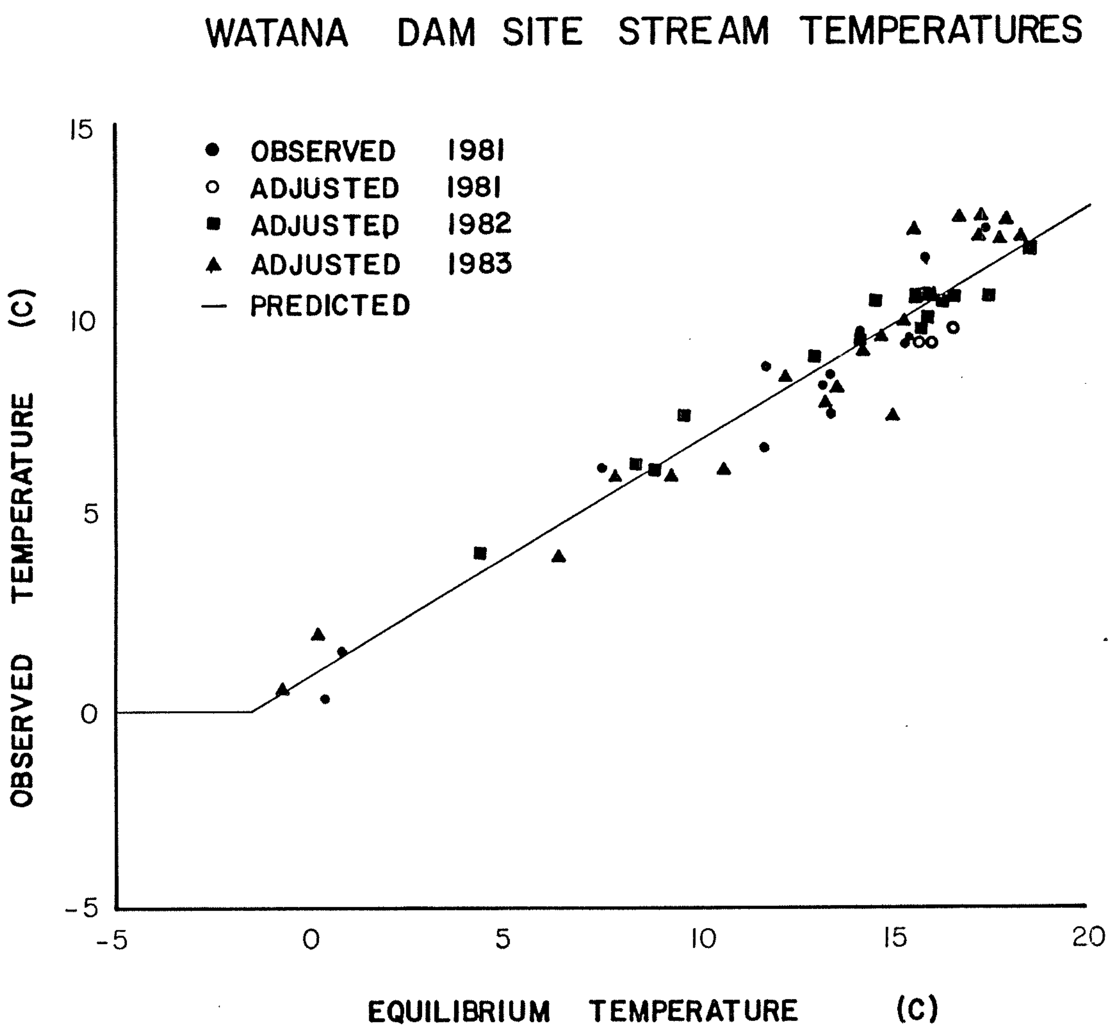
Water year	1981	1982	1983	1981-1983
Number of data points	49	67	124	240
Average error (C)	-0.2	0.0	0.0	-0.1
Standard error (C)	0.8	0.5	0.5	0.5
Maximum over prediction (C)	1.7	1.3	1.9	1.9
Maximum under prediction (C)	2.0	1.1	0.9	2.0

The 90% confidence interval (using the Z statistic) for the water year 1981 to 1983 data is -1.0 C to 0.8 C; 90% of all predicted stream temperatures from the Watana dam site to Parks Highway Bridge will fall within -1.0 C to 0.8 C of the recorded data values.

YEARS SELECTED FOR SIMULATION

Water years 1968 through 1983 were examined for seasonal variations in meteorologic and hydrologic conditions. Hydrologic rankings were determined by the mean summer flow measured at the Gold Creek gage. Winter seasons'

Figure 9. Watana dam site water temperature regression function using adjusted Watana data.



hydrologic rankings are determined from the preceding summer flows, as the summer season controls the amount of water available in the reservoir for winter release. Meteorologic conditions, represented by mean monthly air temperatures at Talkeetna, were ranked by seasonal means. The air temperature and available water rankings for the summer and winter seasons are presented in Tables 5 and 6.

From these sixteen years, four summers and five winters were selected to represent normal and extreme conditions. In this way, the range of available natural conditions could be examined under project operation using a minimum number of simulations. The nine seasons selected for initial simulations are classified with respect to available water and seasonal air temperature in Table 7 below.

Table 7. Classification of Seasons Simulated

Summer	Air Temperature	Available Runoff
1971	Cold	Wet
1974	Warm	Dry
1981	Average	Wet
1982	Average	Average
Winter	**Air Temperature**	**Available Runoff**
1971-1972	Cold	Wet
1974-1975	Average	Dry
1976-1977	Warm	Dry
1981-1982	Average	Wet
1982-1983	Average	Average

Summer seasons are easy to categorize. The cold, wet summer of 1971 was expected to result in the coldest downstream temperature, while the warm, dry summer of 1974 was expected to result in the warmest down river temperatures.

Table 5. Summer (May through September) air temperature and flow rankings

Summer	Air Temp. at Talkeetna (C)	Ranking	Flow at Gold Creek (cfs)	Ranking
1968	11.2	7	20030	7
1969	11.1	8	11320	15
1970	9.9	15	16350	12
1971	10.0	14	21400	5
1972	10.4	12	22160	2
1973	10.1	13	16730	10
1974	11.7	3	16260	13
1975	10.7	10	21960	3
1976	11.2	5	16520	11
1977	11.7	2	21080	6
1978	11.4	4	15400	14
1979	12.0	1	19730	8
1980	10.8	9	21610	4
1981	11.2	6	24290	1
1982	10.6	11	19330	9

Table 6. Winter (September through April) air temperature and flow rankings

Winter	Air Temperature at Talkeetna (c)	Ranking	Preceding Summer Flow at Gold Creek (cfs)	Ranking
1968-69	-6.2	6	20030	7
1969-70	-2.3	14	11320	15
1970-71	-8.1	2	16350	12
1971-72	-8.7	1	21400	5
1972-73	-6.6	5	22160	2
1973-74	-6.6	4	16730	10
1974-75	-6.0	7	16260	13
1975-76	-6.6	3	21960	3
1976-77	-2.2	15	16520	11
1977-78	-4.1	10	21080	6
1978-79	-3.9	11	15400	14
1979-80	-3.3	12	19730	8
1980-81	-2.8	13	21610	4
1981-82	-5.2	8	24290	1
1982-83	-4.2	9	19330	9

Winters are less straightforward. A cold winter with low reservoir storage (due to a preceding dry summer) would be expected to result in downstream temperatures most similar to natural conditions, presumably not a problem. A warm, wet winter would be expected to give the warmest downriver temperatures, delaying formation of an ice cover. Neither of these two cases have been simulated thus far. Other concerns, such as the extent of ice formation, were important in year selection thus far. A cold winter with high reservoir storage (1971-72) would be expected to result in the greatest ice impact.

INSTREAM FISHERY RESOURCE ANALYSIS

THERMAL RELATIONS AND TERMINOLOGY

An approach to the determination of water temperatures which harm or enhance aquatic life involves the development of thermal criteria for the species or communities involved. Criteria permit judgement of the nature of effects by examining the amount of departure from either preferred or tolerated environmental conditions. AEIDC conducted a review of the literature dealing with the development and use of thermal criteria for fish. Some basic thermal responses of aquatic organisms are defined and briefly reviewed here.

The naturally occurring temperatures of surface waters of the earth's temperate zone vary from 0 to over 40 C as a function of latitude, altitude, season, time of day, flow, depth, and other variables (Brungs and Jones 1977). The rate of metabolism in poikilotherms depends on environmental temperature. Natural environmental variations create conditions that are optimum at times, but can also be above or below optimum for particular physiological and behavioral functions of the species present. Temperatures which are preferentially selected by fish generally represent temperatures at which they are physiologically most efficient. The actual temperatures selected by fish vary widely.

Aquatic organisms have upper and lower thermal tolerance limits, optimum temperatures for growth, preferred temperatures in thermal gradients, and temperature limitations for migration, spawning, and egg incubation. The term "selected" or "preferred" temperature is defined as the range of temperatures in which animals congregate or spend the most time in a free choice situation and is sometimes considered synonymous with "optimum" (Reynolds 1977; Alabaster and Lloyd 1982). Preferred temperatures may change under certain conditions. During a lab experiment with unlimited food supply, juvenile sockeye salmon sustained optimum growth at 15 C, but when food was limited optimum growth occurred at progressively lower temperatures (Brett 1971).

Each life stage of every fish species has a characteristic tolerance range of temperature as a consequence of acclimation, a physical adaptation to environmental conditions. The tolerance range can be adjusted upward by acclimation to warmer water and downward to cooler water. Much of the thermal acclimation process in fish occurs over a period of hours or days, and 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 acclimated.

Temperatures beyond the tolerance range are referred to as incipient lethal temperatures, upper and lower thresholds where temperature begins to have a lethal effect. At temperatures above or below the incipient lethal temperatures, survival depends on the duration of exposure with mortality occurring more rapidly with greater temperature deviation from the threshold. The upper boundary of the resistance zone above which survival is virtually zero is referred to as the critical thermal maximum (CTM). No critical thermal minimum has been established primarily because most research has concentrated on the environmental effects on aquatic life from heated effluent and most cold-adapted fish can tolerate temperatures approaching 0 C for varying periods of time. It is also likely that fish are behaviorally more flexible to temperature changes at colder temperatures (Cherry and Cairns 1982).

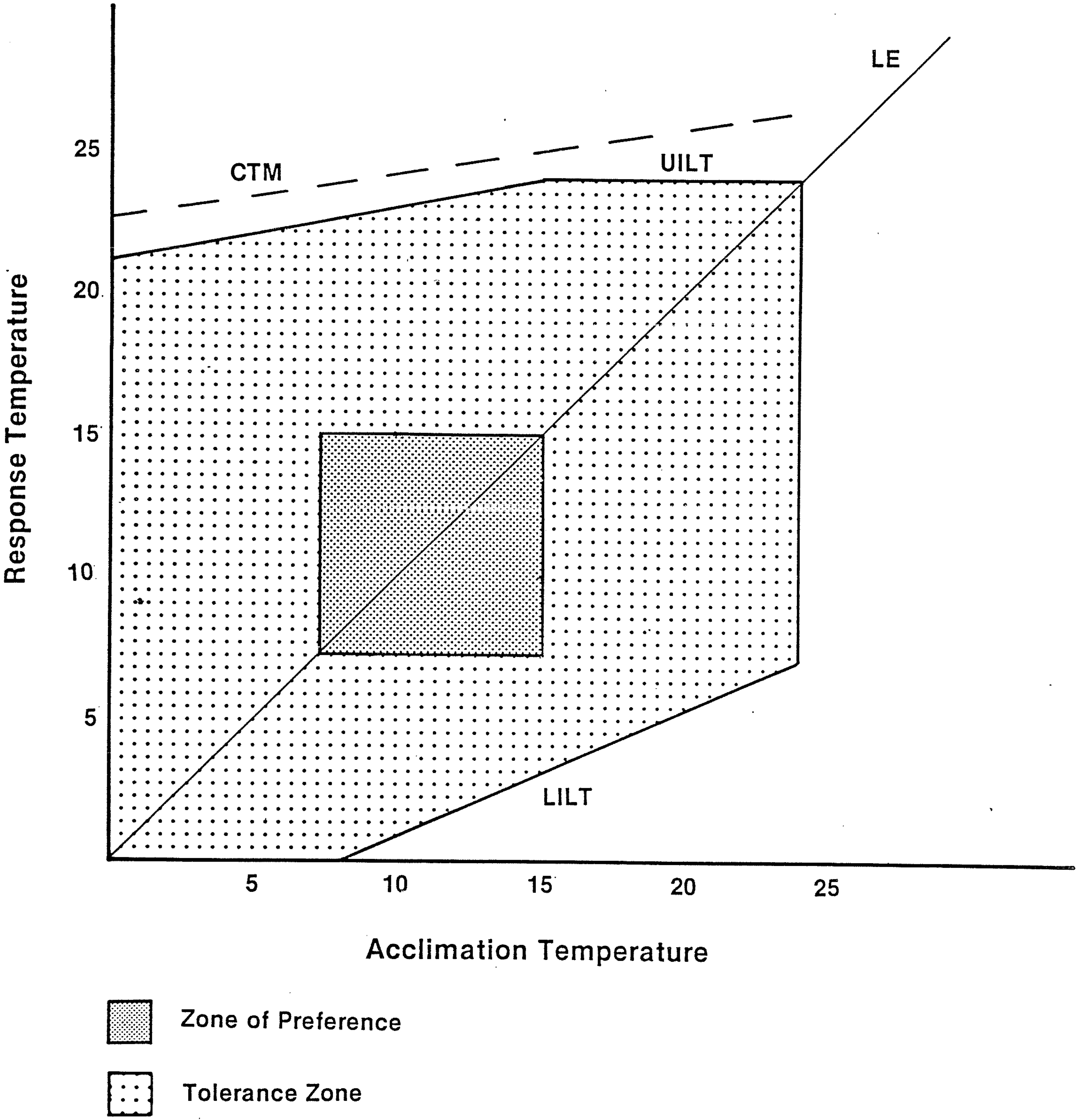
Jobling (1981) developed a diagram showing the relationship between acclimation temperature and fish response based on a literature review. This diagram has been modified to show temperature responses in salmon (Figure 10). Optimum temperatures are not necessary at all times to maintain populations and moderate temperature fluctuations can generally be tolerated as long as a the upper limit is not exceeded for long periods.

SUSITNA RIVER FISHERY RESOURCE

Any applied temperature criteria should be closely related to the water body in question and to its particular community of organisms. At least nineteen species of fish are known to inhabit the Susitna drainage, fifteen of which have been captured in the Susitna River between Devil Canyon and Talkeetna (Table 8). Five of these are anadromous and 10 are resident species.

Salmon Resource

Anadromous species form the basis of commercial and sport fishing in



CTM — Critical Thermal Maximum
UILT — Upper Incipient Lethal Temperature
LILT — Lower Incipient Lethal Temperature
LE — Line of Equality

Fig. 10. Diagram showing temperature relations of salmon. (Adapted from Jobling 1981)

Table 8. List of Common and scientific names of fish found to date in the Susitna River Between Talkeetna and Devil Canyon

Arctic lamprey	*Lampetra japonica* (martens)
Arctic grayling	*Thymallus arcticus* (Pallas)
Round whitefish	*Prosopium cylindraceum* (Pallas)
Humpback whitefish	*Coregonus pidschian* (Gmelin)
Rainbow trout	*Salmo gairdneri* (Richardson)
Dolly varden	*Salvelinus malma* (Walbaum)
Pink (humpback) salmon	*Oncorhynchus gorbuscha* (Walbaum)
Sockeye (red) salmon	*Onchorhynchus nerka* (Walbaum)
Chinook (king) salmon	*Oncorhynchus tshawytscha* (Walbaum)
Coho (silver) salmon	*Oncorhynchus kisutch* (Walbaum)
Chum (dog) salmon	*Oncorhynchus keta* (Walbaum)
Longnose sucker	*Catostomus catostomus* (Forster)
Threespine stickleback	*Gasterosteus aculeatus* (Linnaeus)
Burbot	*Lota lota* (Linnaeus)
Slimy sculpin	*Cottus cognatus* (Richardson)

Upper Cook Inlet. Five species of salmon (chinook, coho, chum, sockeye, and pink) are harvested as they migrate to their stream of origin. The Susitna River drainage is the largest watershed in Upper Cook Inlet and is considered to be the inlet's largest salmon-producing system.

The Alaska Department of Fish and Game has attempted to determine the escapement of Pacific salmon into the Susitna River using side scan sonar and tag/recapture population estimates (Table 9). These estimates should be considered conservative as they do not account for escapements into systems downstream of RM 80.

Fishwheel and stream survey data have been used to determine the timing patterns of salmon into and through the mainstem as well as into the various sloughs and tributaries. This timing varies among species, but in general the peak inmigration and spawning time for salmon above Talkeetna is between late June and September (Table 10). Peak juvenile outmigration occurs between June and August.

Between the Chulitna River confluence (RM 98.5) and Chinook Creek (RM 156.8) in Devil Canyon are at least 18 tributaries and 34 sloughs that provide potential spawning habitat (Figure 11). The largest number of salmon use the tributaries for spawning. Next in importance are the sloughs with only a small fraction using mainstem habitat for spawning.

Escapement survey counts in the tributary streams do not reflect the total number of spawning salmon, only the relative population density by species within the surveyed index areas. These index areas range in length from 0.25 to 15 miles. Of the Susitna tributaries between Talkeetna and Devil Canyon, Indian River (RM 138.6), Portage Creek (RM 148.9), Whiskers Creek (RM 101.4), Lane Creek (RM 113.6), and Fourth of July Creek (RM 131.0)

Table 9. Susitna River escapements by species and sampling location, 1981 - 1983

SAMPLING LOCATION	RIVER MILE	CHINOOK[2]			SOCKEYE			PINKS			CHUM			COHO			TOTAL		
		1981	1982	1983	1981	1982	1983	1981	1982	1983	1981	1982	1983	1981	1982	1983	1981	1982	1983
Yentna Station	04	—	—	—	139,400	113,800	104,400	36,100	447,300	60,700	19,800	27,800	10,800	17,000	34,100	8,900	212,300	623,000	184,800
Sunshine Station	80	—	52,900	91,200	133,500	151,500	71,700	49,500	443,200	40,600	262,900	430,400	266,000	19,800	45,700	15,200	465,700	1,123,700	480,800
Talkeetna Station	103	—	10,900	14,500	4,800	3,100	4,200	2,300	73,000	9,500	20,800	49,100	50,400	3,300	5,100	2,400	31,200	141,200	78,300
Curry Station	120	—	11,300	10,000	2,800	1,300	1,900	1,000	58,800	5,500	13,100	29,400	21,100	1,100	2,400	800	18,000	103,200	38,800
Total[4]	—	—	—	—	272,500	265,200	176,200	85,600	890,500	101,300	282,700	458,200	276,800	36,800	79,800	24,100	677,600	1,693,700	578,400

1. Escapement numbers were derived from tag/recapture population estimates with the exception of the Yentna Station escapements which are represented by sonar counts.

2. Stations were not operating during entire chinook migration and total escapements are not available.

3. Total escapement minus chinook counts.

4. Susitna River drainage escapement (Yentna Station and Sunshine Station) minus chinook counts and escapement into other tributaries downstream of RM 77.

Source: ADF&G 1983

Table 10. Susitna River Salmon Periodicity

	HABITAT	DATE RANGE	DATE PEAK
CHINOOK (KING) SALMON			
Adult inmigration	Cook Inlet-Talk.	May 25-Jul 9	Jun 18-Jun 30
	Talkeetna-D.C.	Jun 9-Aug 20	Jun 24-Jul 24
	Upper river tribs	Jul 1-Aug 6	
Outmigration	Upper river	May 18-Oct 3[1]	Jun 19-Aug 30
Spawning	Upper river tribs	Jul 1-Aug 10	Jul 20-Jul 27
COHO (SILVER) SALMON			
Adult inmigration	Cook Inlet-Talk.	Jul 19-Aug 24	Jul 21-Aug 2
	Talkeetna-D.C.	Aug 1-Sep 19	Aug 12-Sep 5
	Upper river tribs	Aug 8-Sep 27	
Outmigration	Upper river	May 18-Oct 12[1]	May 28-Aug 21
Spawning	Upper river tribs	Sep 1-Oct 8	Sep 5-Sep 24
CHUM SALMON			
Adult inmigration	Cook Inlet-Talk.	Jul 10-Aug 25	Jul 26-Aug 2
	Talkeetna-D.C.	Jul 22-Sep 15	Aug 3-Aug 27
	Upper river tribs	Jul 27-Sep 6	
	Upper river sloughs	Aug 6-Sep 5	
Outmigration	Upper river	May 18-Aug 20	May 28-Jul 17
Spawning	Upper river tribs	Jul 27-Oct 1	Aug 5-Sep 10
	Upper river sloughs	Aug 5-Oct 11	Aug 20-Sep 25
	Upper river mainstem	Sep 2-Sep 19	
SOCKEYE (RED) SALMON			
Adult inmigration	Cook Inlet-Talk.	Jul 4-Aug 8	Jul 18-Jul 25
	Talkeetna-D.C.	Jul 16-Sep 18	Jul 20-Aug 14
Outmigration	Upper river	May 18-Oct 11[1]	Jun 22-Jul 17
Spawning	Upper river sloughs	Aug 5-Oct 11	Aug 25-Sep 25

[1] All migration includes migration to and between habitat, not just outmigration

SOURCE: ADF&G 1981q, 1981b, 1983a, 1983b, 1983c

Table 10. (Continued) Susitna River Salmon Periodicity

	HABITAT	DATE RANGE	DATE PEAK
PINK SALMON			
Adult inmigration	Cook Inlet-Talk.	Jul 20-Aug 24	Jul 28-Jul 30
	Talkeetna-D.C.	Jul 20-Aug 29	Aug 1-Aug 21
	Upper river tribs	Jul 27-Aug 23	
	Upper river sloughs	Aug 4-Aug 17	
Outmigration	Upper river	May 19-Jul 17	May 29-Jun 8
Spawning	Upper river tribs	Jul 27-Aug 30	Aug 10-Aug 25
	Upper river sloughs	Aug 4-Aug 30	Aug 15-Aug 30

[1]All migration includes migration to and between habitat, not just outmigration
SOURCE: ADF&G 1981q, 1981b, 1983a, 1983b, 1983c

Figure 11. Susitna River map showing important habitats and geographic features between RM 100 and 153.

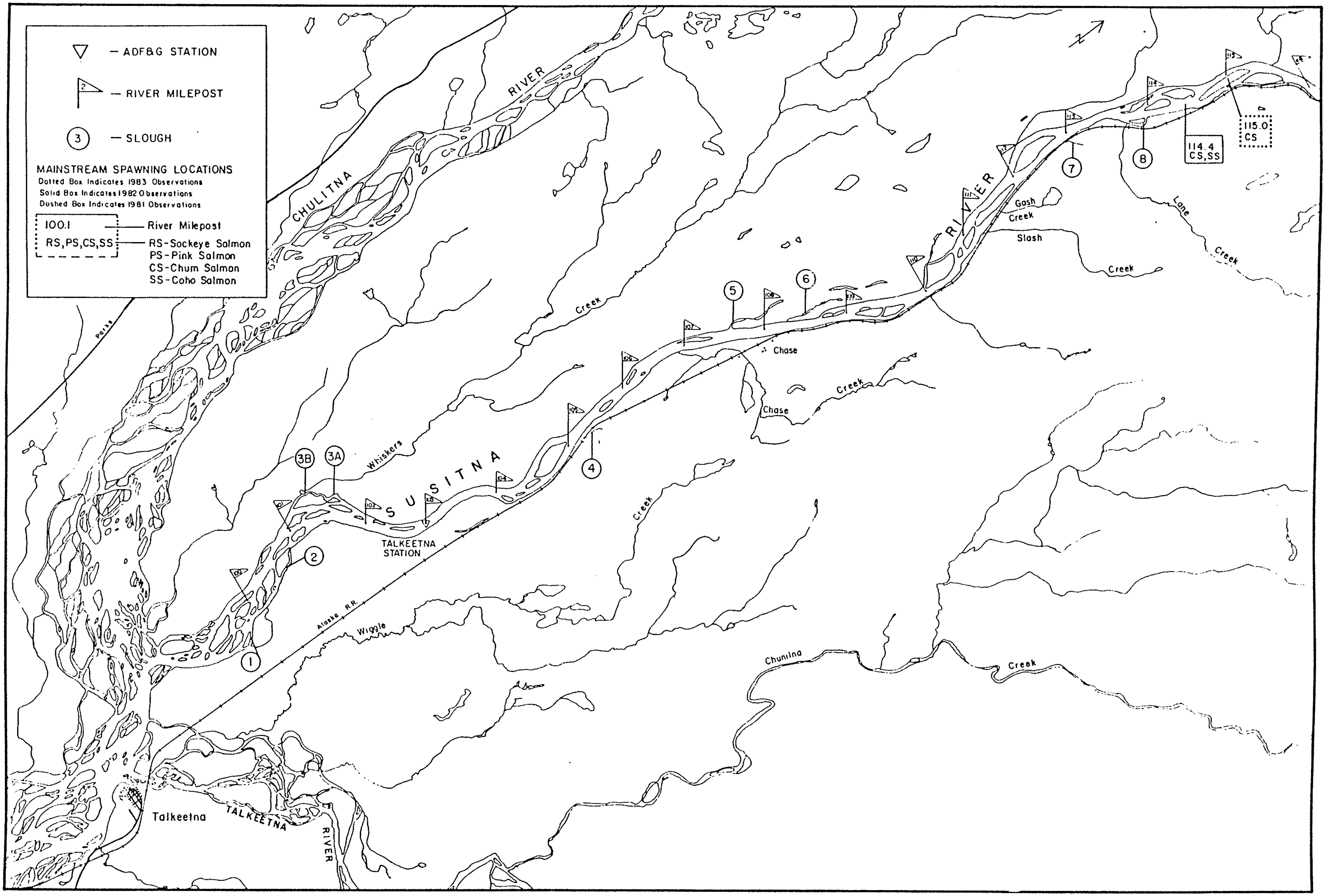


Figure 11. Susitna River map showing important habitat and geographic features between RM 100 and 153.

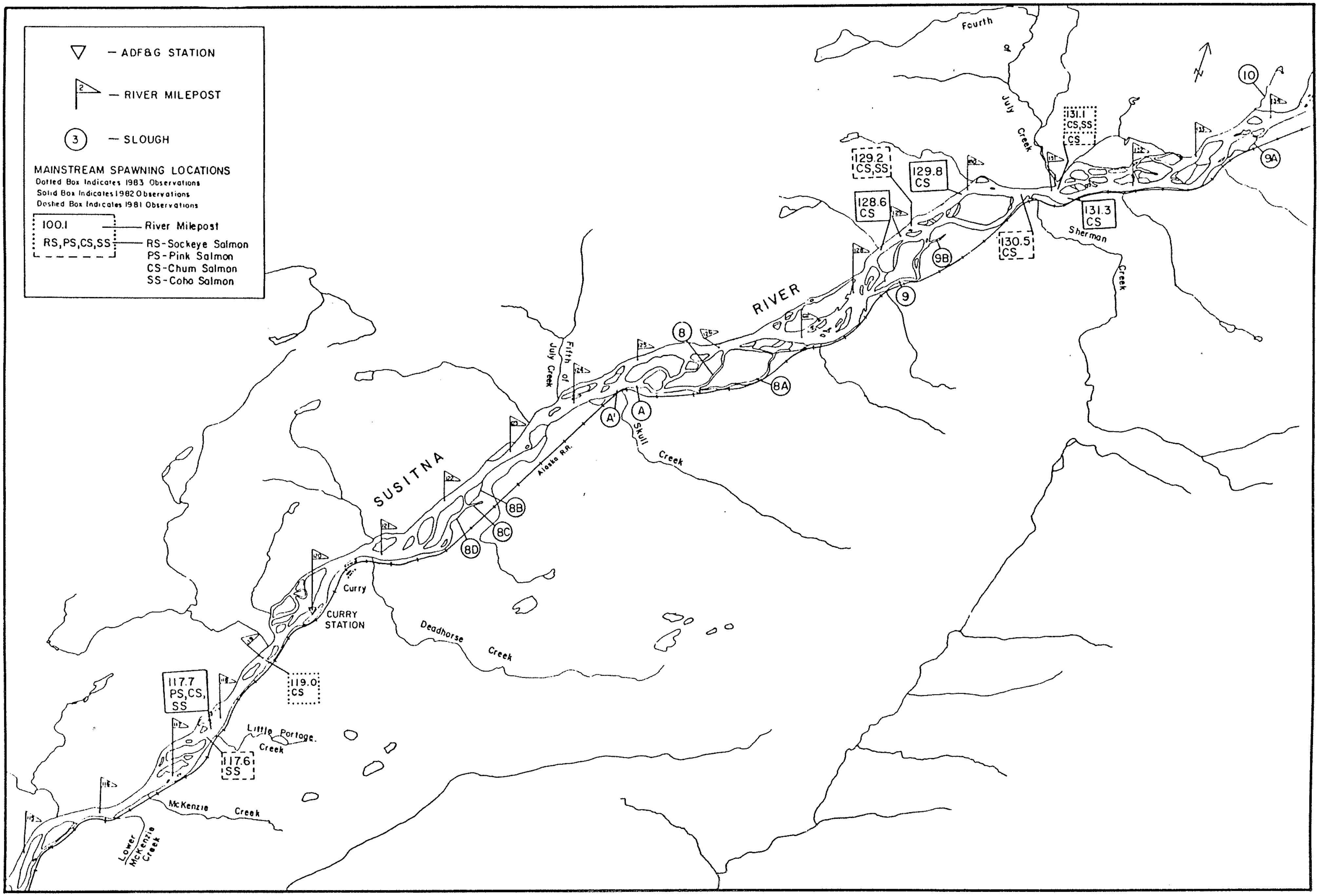
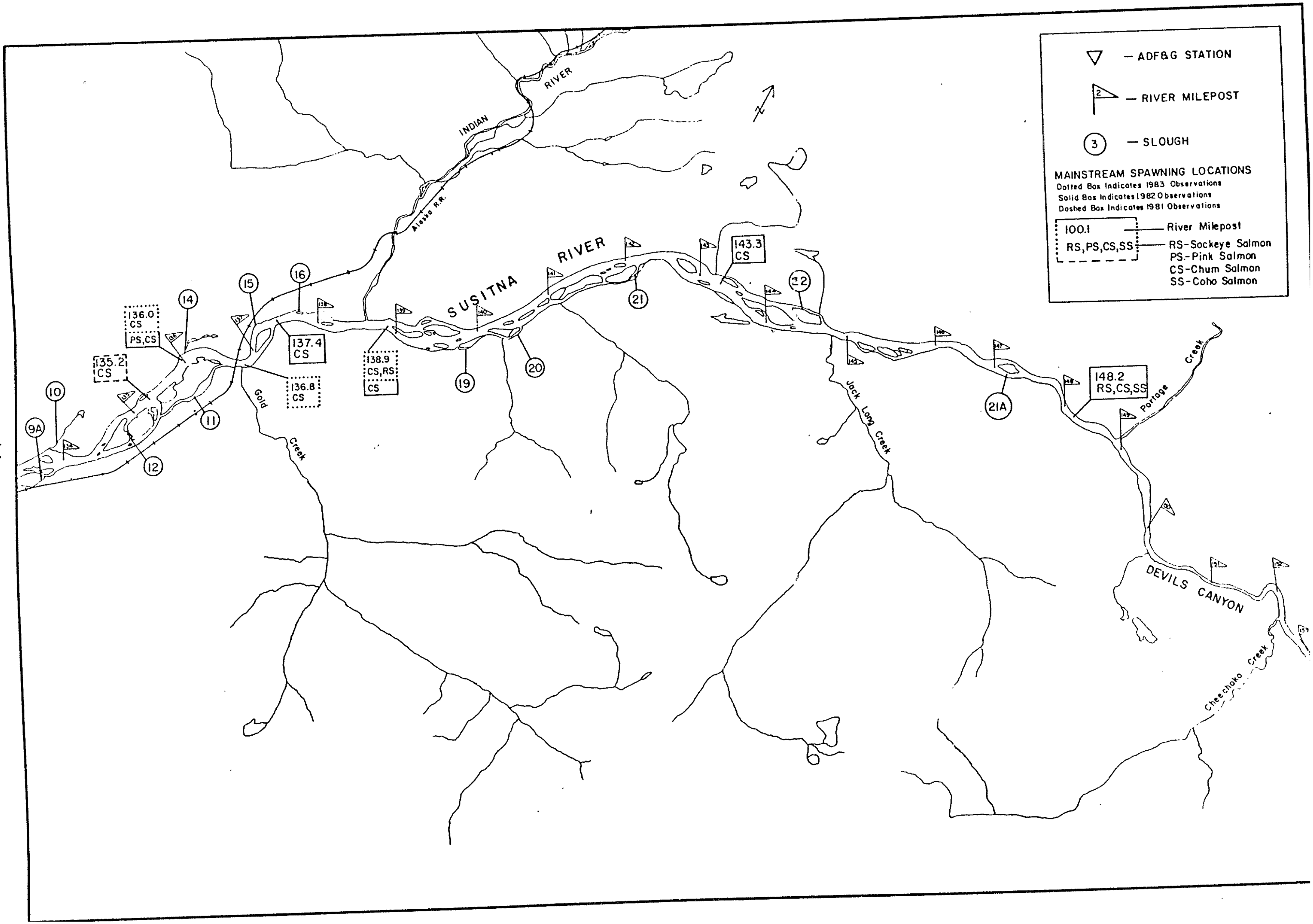


Figure 11. Susitna River map showing important habitat and geographic features between RM 100 and 153.



contain the bulk of the tributary escapement for chinook, coho, pink, and chum salmon (Table 11).

Chum and sockeye salmon are the principal species utilizing slough habitats for spawning, and over seventy-three percent of the peak slough escapement counts for chum and sockeye during 1981-1983 occurred in just four of these 34 sloughs: 8A, 9, 11, and 21 (Table 12). Ninety-two percent of the sockeye and sixty-six percent of the slough-spawning chum salmon were counted in these four sloughs (ADF&G 1981; 1983b; Barrett et al. 1984). Almost all sockeye spawning above Talkeetna takes place in sloughs. A small number of pink salmon use the sloughs for spawning (Table 12). Coho and chinook salmon spawn almost entirely in tributaries.

The ADF&G conducted mainstem spawning surveys in 1981 and 1982 using portable and boat-mounted electroshockers, examining 317 and 1,211 sites, respectively (ADF&G 1983b). In 1983 no inclusive mainstem spawning surveys were conducted. However, six spawning areas were found during stream and slough surveys (Barrett et al. 1983). In 1981, 12 mainstem spawning sites were observed between RM 68.3 and 135.2, of which six were above the Chulitna River confluence. Fourteen chum salmon were observed at four sites and seven coho at two sites. In 1982, 10 mainstem spawning sites were observed between RM 114 and 148.2. Five hundred and fifty chum salmon were observed at nine sites, one sockeye at one site, 20 pinks at one site, and six coho at three sites. In 1983, six mainstem spawning sites were documented between RM 115.0 and 138.9. Two hundred and eighty-six chum salmon were observed at these sites, 11 sockeye at RM 138.6, and two coho salmon at RM 131.1.

With the exception of pink salmon, substantial freshwater rearing occurs in the reach of the Susitna River between the Chulitna confluence and Devil

Table 11. Peak salmon survey counts above Talkeetna for Susitna River tributary streams.

STREAM	SURVEY DISTANCE	Coho					Chinook							
YEAR		74	76	81	82	83	75	76	77	78	79	81	82	83
Whiskers Creek (RM 101.4)	0.25	27		70	176	115	22	8						3
Chase Creek (RM 106.9)	0.25	40		80	36	12							15	
Slash Creek (RM 111.2)	0.75				6	2								
Gash Creek (RM 111.6)	1.0			141	74	19								
Lane Creek (RM 113.6)	0.5			3	5	2						40	47	12
Lower McKenzie (RM 116.2)	1.5			56	133	18								
McKenzie Creek (RM 116.7)	0.25													
Little Portage (RM 117.7)	0.25				8									
Fifth of July (RM 123.7)	0.25												3	
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	1	14					56	6
Gold Creek (RM 136.7)	0.25				1								21	23
Indian River (RM 138.6)	15.0	64	30	85	101	53	10	537	393	114	285	422	1053	1193
Jack Long (RM 144.5)	0.25				1	1							2	6
Portage Creek (RM 148.9)	15.0	150	100	22	88	15	29	702	374	140	140	659	1253	3140
Cheechako Creek (RM 152.5)	3.0												16	25
Chinook Creek (RM 156.8)	2.0												4	8
TOTAL		307	147	458	633	260	62	1261	767	254	425	1121	2473	4416

Table 11 (continued). Peak salmon survey counts above Talkeetna for Susitna River tributary streams.

STREAM	SURVEY DISTANCE	Chum							Sockeye						
YEAR		74	75	76	77	81	82	83	74	75	76	77	81	82	83
Whiskers Creek (RM 101.4)	0.25					1									
Chase Creek (RM 106.9)	0.25					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								
Lower McKenzie (RM 116.2)	1.5					14		1					1		
McKenzie Creek (RM 116.7)	0.25									46					
Little Portage (RM 117.7)	0.25						31								
Fifth of July (RM 123.7)	0.25							6							
Skull Creek (RM 124.7)	0.25					10	1								
Sherman Creek (RM 130.8)	0.25					9									
Fourth of July (RM 131.0)	0.25	594		78	11	90	191	148		1					
Gold Creek (RM136.7)	0.25														
Indian River (RM 138.6)	15.0	531	70	134	776	40	1346	811		1	2	1			1
Jack Long (RM 144.5)	0.25						3	2							
Portage Creek (RM 148.9)	15.0	276		300			153	526							
Cheechako Creek (RM 152.5)	3.0														
Chinook Creek (RM 156.8)	2.0														
TOTAL		1401	73	512	789	241	1736	1494	1	48	2	1	1		1

Table 11 (continued). Peak salmon survey counts above Talkeetna for Susitna River tributary streams.

STREAM	SURVEY DISTANCE	Pink						
YEAR		74	75	76	77	81	82	83
Whisker's Creek (RM 101.4)	0.25			75		1	138	
Chase Creek (RM 106.9)	0.25			50		38	107	6
Slash Creek (RM 111.2)	0.75							
Gash Creek (RM 111.6)	1.0							
Lane Creek (RM 113.6)	0.5	82	106		1103	291	640	28
Lower McKenzie (RM 116.2)	1.5						23	17
McKenzie Creek (RM 116.7)	0.25						17	
Little Portage (RM 117.7)	0.25						140	7
Fifth of July (RM 123.7)	0.25					2	113	9
Skull Creek (RM 124.7)	0.25					8	12	1
Sherman Creek (RM 130.8)	0.25					6	24	
Fourth of July (RM 131.0)	0.25	159	148	4000	612	29	702	78
Gold Creek (RM 136.7)	0.25			32			11	7
Indian River (RM 138.6)	15.0	577	321	5000	1611	2	738	886
Jack Long (RM 144.5)	0.25					1		5
Portage Creek (RM 148.9)	15.0	218		3000			169	285
Cheechako Creek (RM 152.5)	3.0						21	
Chinook Creek (RM 156.8)	2.0							
TOTAL		1036	575	12157	3326	378	2855	1329

Source: Barrett 1974, Riis 1977
ADF&G 1976, 1978, 1981b, 1983b

Table 12. Peak slough escapment counts above Talkeetna

		CHUM							SOCKEYE							PINK					COHO	
SLOUGH NO.	RIVER MILE	1974	1975	1976	1977	1981	1982	1983	1974	1975	1976	1977	1981	1982	1983	1976	1977	1981	1982	1983	1982	1983
1	99.6					6																
2	100.4					27		49														
3B	101.4		50					3		15			7		5			1				
3A	101.9												1									
Talkeetna St.	103.0																					
4	105.2																					
5	107.2						2	1														
6	108.2	1																				
6A	112.3					11	2						1						35		35	
7	113.2																					
8	113.7					302												25				
Curry St.	120.0																					
8D	121.8						23															
8C	121.9						48	4						2								
8B	122.2					1	80	104				2		5								
Moose	123.5					167	23	68						8	22				8			
A1	124.6					140		77														
A	124.7					34		2										2			1	
8A	125.1				51	620	336	37				70	177	68	66				28		4	
B	126.3						58	7						8	2				32			
9	128.3	511	181		36	260	300	169	8			6	10	5	2				12			
9B	129.2					90	5						81	1								
9A	133.3					182	118	105					2	1	1							
10	133.8				2		2	1							1							
11	135.3	33		66	116	411	459	238	79	84	78	214	893	456	248	1			131			
12	135.4																					
13	135.7		1			4		4														
14	135.9	2																				
15	137.2		1			1	1				1								132	1	14	14
16	137.3	2	12		4	3											13					
17	138.9	24				38	21	90					6		6							5
18	139.1																					
19	139.7	4				3		3	3		32	8	23		5				1	1		
20	140.0	107		2	28	14	30	63		20			2						64	7		
21	141.1	668	250	30	304	274	736	319	13	75	23		38	53	197				64			
21A	145.5																					
22	144.5					8		114														
Total		1352	495	98	451	2596	2244	1458	103	194	134	300	1241	607	555	1	13	28	507	10	53	19

Source: Barrett 1974, Riis, 1977. ADF & G 1976, 78, 81b, 83b, 83c, Sus 244.

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Canyon. Juvenile salmon are unequally distributed among four macrohabitat types: tributary, upland slough, side slough, and side channel.

Juvenile chinook salmon are distributed mostly in tributaries and side channels throughout the entire May to October rearing season. Coho are mostly rearing in tributaries and upland sloughs during this time. Sockeye are found evenly distributed between upland and side sloughs from May through early September. Chum are mainly distributed between side sloughs and tributaries from May through July (Dugan et al. 1984).

Resident Species

Of the ten resident fish species found between Talkeetna and Devil Canyon, only rainbow trout, Arctic grayling, burbot, round whitefish, and slimy sculpins are abundant in the area. Longnose suckers, Dolly Varden, humpback whitefish, threespine stickleback, and Arctic lamprey occur throughout the river below Devil Canyon but appear to be more abundant below the Chulitna River confluence (Sundet and Wenger 1984). Rainbow trout and Arctic grayling provide significant sport fishing, especially near tributary mouths.

Rainbow trout and Arctic grayling spend most of the open water season in tributaries and sloughs, using the mainstem more as a migration and overwintering area. Burbot generally occupy the turbid mainstem waters year round while whitefish and longnose suckers can be found in both mainstem and tributaries during the open water season.

Rainbow trout and Arctic grayling move into tributaries to spawn in the spring after breakup. Whiskers, Lane, and Fourth of July Creeks are the primary tributaries used for rainbow spawning (Sundet and Wenger 1984). Round whitefish are believed to spawn in October at either mainstem or tributary mouth locations (Sundet and Wenger 1984). Burbot spawning generally occurs between January and March under the ice in mainstem-influenced areas.

TEMPERATURE TOLERANCE/PREFERENCE CRITERIA DEVELOPMENT

Significant changes in water temperature may affect the composition of the aquatic community. Altered thermal characteristics of an ecosystem can be either detrimental or beneficial. An assessment of the effects of water temperature change on fish is enhanced by establishing temperature criteria. Criteria are ranges of water temperature determined to be biologically acceptable to fish for satisfactory physiological and behavioral activity. However, application of temperature criteria in an environmental assessment of a specific water body must be as closely related to the specific water body and to its particular community of organisms as possible. This is accomplished by modifying general regional criteria to make them applicable to that specific water body.

Limits of temperature tolerance or allowable temperature variations change throughout development, and, particularly at the most sensitive life stages, differ among species. The sequence of events relating to gonad maturation, spawning migration, release of gametes, development of the egg and embryo, and commencement of feeding represents one of the more complex phenomena in nature. These events are generally the most thermally sensitive of all life stages (Brungs and Jones 1977).

Anadromous salmonids are a highly mobile species that depend on temperature synchrony among different environments for various phases of their life cycle. There is the danger of dissynchrony if one area's temperature is altered and not another's (Brungs and Jones 1977). Successful early fry production and emigration can be followed by unsuccessful, premature feeding activity in a cold and still unproductive environment.

Examination of the literature shows that variations in spawning dates and temperatures are common. These variations suggest that fish demonstrate a biological plasticity and that their tolerance range can vary by species, lifestage, and geographic setting. Overall tolerance and preference ranges for Pacific salmon vary between 0 and 24 C and 7 and 14 C respectively. Temperature tolerance data exist over a wide area and many years of natural history observation. Since those published data (Table 13) are not all specific to the Susitna drainage, they must be used only as an aid in developing preliminary temperature tolerance ranges. Life phases potentially affected by temperature changes are adult inmigration, spawning, embryo incubation, juvenile rearing, and fry/smolt outmigration.

Adult Inmigration

Adult Pacific salmon have been reported to migrate into freshwater systems in water temperatures which range from 1.5 to over 19 C. Adult fish can usually tolerate a wider range of temperature than embryos (Alabaster and Lloyd 1982). 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 at temperatures as low as 4 C or colder (Bell 1983).

Table 13. Observed temperature ranges for various life stages of Pacific Salmon

SPECIES OF FISH	LIFE STAGE	SOURCE	LOCATION	TEMPERATURE RANGE C MIGRATION	SPAWNING	INCUBATION	REARING
Chum	Adult	Bell 1973		8.3-21.0	7.2-12.8		
		Bell 1983		1.5			
		ADF&G 1980	Kuskokwim Tributaries	5.0-12.8			
		Mattson & Hobart 1962	Southeast AK	4.4-19.4			
		McNeil & Bailey 1975	Southeast AK		7.0-13.0		
		Wilson 1981	Kodiak Island		6.5-12.5		
		Neave 1966	B.C.		4.0-16.0		
		Rukhlov 1969	Sakhalin, USSR		1.8-8.2		
		Merritt & Raymond 1983	Noatak R, AK		2.5		
		ADF&G 1984	Susitna R, AK	5.6-15.5	4.5-12.3		
	Juvenile	Trasky 1974	Salcha R, AK	5.0-7.0			
		Sano 1966	Bolshaia R, USSR	6.0-10.0			
		Bell 1973		6.7-13.5			11.2-15.7
		McNeil & Bailey 1975	Southeast, AK				4.4-15.7
		Wilson 1979	Kodiak Island	5.0-7.0			
		Raymond 1981	Delta R, AK	3.0-5.5			
		Merritt & Raymond 1983	Noatak R, AK	5.0-12.0			
		ADF&G 1984	Susitna R, AK	4.2-14.5			1.3-16.2
	Egg/ Alevin	Bell 1973			4.4-13.3		
		McNeil 1969	Southeast AK			0-15.0	
		Merritt & Raymond 1983	Noatak R, AK			0.2-9.0	
		Sano 1966	Japan			4	
		McNeil & Bailey 1975	Southeast AK			4.4	
		Kogl 1965	Chena R, AK			0.5-4.5	
		Francisco 1977	Delta R, AK			0.4-6.7	
		Raymond 1981	Clear, AK			2.0-4.5	
		ADF&G 1983	Susitna R, AK			0-7.4	
		Waangard & Burger 1983	Lab.			0.5-8.0	
		ADF&G 1984	Susitna R, AK			2.0-4.3[5]	

Table [illegible] (Continued) Observed temperature ranges for various life stages of Pacific Salmon

SPECIES OF FISH	LIFE STAGE	SOURCE	LOCATION	TEMPERATURE RANGE C MIGRATION	SPAWNING	INCUBATION	REARING
Coho	Adult	Bell 1973		7.2-15.6	4.4-9.5		
		Bell 1983		4			
		McNeil & Bailey 1975	Southeast AK		7.0-13.0		
		McMahon 1983		5-19,5-11[3]	2-17,5-13[3]		
		Wallis 1983	Anchor R, AK	2-15,7-14[4]			
		ADF&G 1984	Susitna R, AK	5.8-15.5			
	Juvenile	Cederholm & Scarlet 1982	Washington St.	6			
		Bustard & Narver 1975	Vancouver Is., BC	7			
		Bell 1973		7.0-16.5			11.8-14.6
		McNeil & Bailey 1975	Southeast AK				4.4-15.7
		McMahon 1983		4-16,6-12[3]			4-21,7-15[3]
		Wallis 1983	Anchor R, AK	2-15,7-14[4]			
		Whitmore 1979	Caribou L, AK	11-15.5			
			Seldovia L, AK	3.0-5.7			
		ADF&G 1984	Susitna R, AK	4.2-14.5			
	Egg/ Alevin	Bell 1973				4.4-13.3	
		McMahon 1983				4-14,4-10[3]	
		Dong 1981	Washington St.			1.3-12.4,4-6.5[3]	
Pink	Adult	Bell 1973		7.2-15.6	7.2-12.8		
		Bell 1983	USSR	5			
		McNeil & Bailey 1975	Southeast AK		7.0-13		
		Sheridan 1962	Southeast AK		7.2-18.4		
		McNeil et al. 1964	Southeast AK		10.0-13.0		
		ADF&G 1984	Susitna R, AK	7.8-15.5	8.0-11.0		
	Juvenile	Bell 1973					5.6-14.6
		McNeil & Bailey 1975	Southeast AK				4.4-15.7
		Wilson 1979	Kodiak Island	5.0-7.0			
		Wickett 1958	British Columbia	4.0-5.0			
		ADF&G 1984	Susitna R, AK	4.2-14.5			
	Egg/ Alevin	Bell 1973				4.4-13.3	
		Bailey & Evans 1971	Southeast AK			4.5	
		Combs & Burrows 1957	Lab.			0.5-5.5	
		McNeil et al. 1964	Southeast AK			1.0-8.0	

Table 13. (Continued) Observed temperature ranges for various life stages of Pacific Salmon

SPECIES OF FISH	LIFE STAGE	SOURCE	LOCATION	TEMPERATURE RANGE C: MIGRATION	SPAWNING	INCUBATION	REARING
Sockeye	Adult	Bell 1973		7.2-15.6	10.6-12.2		
		Bell 1983		2.5			
		McNeil & Bailey 1975	Southeast AK		7.0-13.0		
		Nelson 1983	Southeast AK	8.3-14.3			
		ADF&G 1984	Susitna R, AK	5.8-15.5	4.9-10.5		
	Juvenile	McCart 1967	British Columbia	5.0-17.0			
		Raleigh 1971	Lab.	4.5			
		Bell 1973					11.2-14.6
		McNeil & Bailey 1975	Southeast AK				4.4-15.7
		Fried & Laner 1981	Bristol Bay, AK	4.0-7.0			
		Bucher 1981	Bristol Bay, AK	4.4-17.8			
		Hartman et al. 1967	Alaska-wide	4.5-10.0			
		Flagg 1983	Kasilof R, AK	6.7-14.4			
		ADF&G 1984	Susitna R, AK	4.2-14.0			
	Egg/ Alevin	Bell 1973				4.4-13.3	
		Combs 1965	Lab.			4.5-14.3,1.5[2]	
		ADF & G 1983	Susitna R, AK			2.9-7.4	
		Waangard & Burger 1983	Lab.			2.0-6.5	
		ADF & G 1984	Susitna R, AK			2.0-4.3[5]	
Chinook	Adult	Bell 1973		3.3-13.9	5.6-13.9		
		Bell 1983		4			
		McNeil & Bailey 1975	Southeast AK		7.0-13.0		
		Wallis 1983	Anchor R, AK	2-14,5-10[4]			
		ADF&G 1984	Susitna R, AK	6.6-15.6	7.8-13.6		
	Juvenile	Raymond 1979	Columbia R	7			
		Bell 1973					7.3-14.6
		McNeil & Bailey 1975	Southeast AK				4.4-15.7
		AEIDC 1982	Southcent. AK	4.5			
		Wallis 1983	Anchor R, AK	6-16,8-16[4]			
		ADF&G 1984	Susitna R, AK	4.2-14.5			
	Egg/ Alevin	Bell 1973				5.0-14.4	
		Combs 1965	Lab.			1.5[2]	
		Alderdice & Velsen 1978				2.5-16.0	

Reiser and Bjornn (1979) report that deviations from natural stream temperatures can also lead to other factors, such as disease outbreaks in migrating fish, which can alter migration timing. Disease infection rates in anadromous salmonids increase markedly above 13 C (Fryer and Pilcher 1974; Groberg et al. 1978). Temperatures above the upper tolerance range have been reported to stop fish migration (Bell 1980). Low temperatures have been reported by ADF&G biologists to stop pink salmon inmigration and increase milling activity near the Main Bay hatchery site in Prince William Sound (Krasnowski 1984). While the holding pond raceway water varied between 6 and 6.5 C, the pink salmon would not enter and continued to mill in the seawater which was at a temperature between 10 and 12 C. When the raceway water temperature was raised to 8.5 C the salmon then entered the holding pond.

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.

Adult Spawning

Thermal requirements for eggs, larvae, and/or juvenile emergence may differ from those of adults. The genetic contributions to successive generations are of more importance than the longevity of the individual organism, making the thermal preference of the adults subordinate during spawning to that of the eggs and larvae (Reynolds 1977).

Spawning of adult Pacific salmon has been reported to occur in water temperatures which range from approximately 4 to 18 C, although the preferred temperature range for all five species is reported by McNeil and Bailey

(1975) as 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 freshwater fish that spawns in winter. The spawning activity usually takes place in water 0.5 to 1.5 C (Scott and Crossman 1973; Alabaster and Lloyd 1982). Temperatures between 0 and 0.7 C were observed in 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; and Bryan and Kato 1975). They are believed to spawn in the Susitna during October while water temperatures are dropping rapidly. An increase in water temperatures in winter at the time of reproduction could severely affect spawning of whitefish and burbot (Alabaster and Lloyd 1982).

Embryo Incubation

Compared with the other life phases, embryo development is perhaps most directly influenced by water temperature. Temperature ranges that cause no increased mortality of embryos 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 eggs 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 eggs are reportedly 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), 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 egg 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. They determined that eggs exposed to cooler spawning temperature experienced greater incubation mortality than eggs 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 mortality for pink salmon when initial incubation water temperatures were held below 2 C during this initial incubation period.

Mean intragravel water temperatures for the four primary spawning Susitna sloughs range from 2.0 to 4.3 C (ADF&G 1983c ~~sus 243~~). Slough 8A was overtopped by cold mainstem water from an ice jam occurring in late November 1982. This cold mainstem water (near 0 C) depressed the intragravel water temperature and delayed salmon development and emergence in this slough. Large numbers of dead embryos at this site suggests that increased mortality may have occurred (ADF&G 1983c). Slight increases in embryo mortalities and alevin abnormalities were shown to occur when average temperatures were maintained at a level less than 3.4 C during experimental lab tests of developing Susitna chum and sockeye salmon embryos (Wangaard and Burger 1983). It appears that a complete loss of all incubating salmon eggs will not occur if the reduced water temperatures occur after closure of the embryonic blastopore.

The most sensitive eggs to temperature 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 which are exposed to diurnal fluctuations of temperature (Alabaster and Lloyd 1982).

Juvenile Rearing

Water temperature effects on 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).

According to literature reviewed to date, juvenile salmon activity slows at water temperatures lower than 4 C. At these lower water 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 above 7 C, fish quit feeding and moved into deeper water or closer to objects providing cover. In Grant Creek near Seward, Alaska, juvenile salmonids were inactive and inhabiting the cover afforded by streambed cobble and large gravel substrates at 1.0 to 4.5 C water temperatures (Alaska, Univ., AEIDC, 1982).

Generally, the tolerable temperature range for rearing 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 were between 2.4 and 15.5 C (ADF&G 1983d), a slightly wider range. Juvenile coho and chinook salmon have also been successfully reared in Alaska hatcheries at temperatures between 2 and 4 C (Pratt 1984). In an experiment at Auke Bay lab, coho salmon grew at 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 around 4 C and higher, the coho's metabolism is sufficiently active to require food whereas below these temperatures the fish can remain inactive enough to not require feeding.

Fry/Smolt Outmigration

Water temperature change may serve as a stimulus for smolt outmigration (Sano 1966). Juvenile chinook salmon outmigrations from the Salmon River, Idaho have been shown to be related to sudden rises in water temperature (Raymond 1979). The critical temperature triggering this movement appeared to be 7 C and outmigrations were slowed when water temperatures dropped below 7 C. Low temperatures seemed to slow the rate of outmigrations for coho salmon in the Clearwater River, Washington, and only minor movement was noted below 6 C (Cederholm and Scarlet 1982). Juvenile chinook and coho salmon have been observed to stop outmigrating when water temperature falls below 7 C (Raymond 1979; Cederholm and Scarlet 1982; Bustard and Narver 1975). Outmigration for sockeye salmon begins as temperature rises during the spring to 4.4 to 5.0 C (Foerster 1968). To insure optimum conditions for smoltification, timing of migration, and survival of salmon smolts, Wedemeyer et al. (1980) stated that water temperature should follow the natural seasonal cycle as closely as possible.

In the Susitna River, salmon smolt outmigration generally occurs from mid-May through August (Dugan et al. 1984). River ice breakup generally precedes a large part of the initial chum and pink salmon fry outmigration period. Outmigration of pink salmon occurs between mid-May and mid-July, 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 smolts outmigrate from mid-May to early October, with peaks occurring in June, July, and August, respectively.

In addition to salmon smolt outmigration, there is also a migration between habitats as fish redistribute themselves into slough, side channel and mainstem habitats for overwintering. These emigrations generally peak in August for chinook and coho salmon (Dugan 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) (~~ADF&G 1984~~).

During May, Susitna river temperatures generally range from just above freezing to 7 C. June River temperatures normally range from 2.5 to 9.0 C. July water temperatures range from 5.0 to 16 C, while during August mainstem water temperatures are warmest, ranging from 8 to 15 C. In September 4.0 to 10.0 C is the normal range for mainstem water temperatures from Devil Canyon to Talkeetna.

EFFECTS ANALYSIS

Temperature regimes in the Devil Canyon to Talkeetna reach are evaluated with respect to the various life stage temperature tolerances. In order to facilitate this evaluation, temperature tolerances are graphically represented over a one-year time frame by fish life stage for the five species of Pacific salmon. These figures (Appendix H) are then overlayed with the temperature profiles from river miles 100, 130, and 150 for the years 1971-72, 1974-75, 1981-82, and 1982-83. Three scenarios are examined: (1) natural versus Watana dam operation; (2) natural versus combined operation of the Watana and Devil Canyon dams; and (3) natural versus Watana reservoir filling.

Only in cases where the simulated temperature regimes fall outside the life phase temperature tolerances, is an obvious adverse impact established. In cases where project conditions do not exceed tolerances but are substantially different from natural, a discussion follows.

RESULTS AND DISCUSSION

PROJECT EFFECTS ON INSTREAM TEMPERATURE

Instream temperatures were simulated under two Watana-only and two Watana/Devil Canyon load demands as well as under natural conditions for five winter and four summer seasons. Resultant temperatures are available for each week at over 80 mainstem locations from the Watana dam face downstream to Sunshine. These results are condensed in this section, and discussed in terms of change to the downstream temperature regime resulting from project operation. These temperature changes are discussed more fully in a later section with specific reference to the effect on fisheries.

The downstream temperatures predicted from simulations are presented in three forms.

1. Weekly temperatures are presented in Appendix A for locations at river miles 83.8, 98.6, 130.1 and 150.2 for all scenarios, and at river mile

184.4 (Watana dam face) for natural and Watana-only scenarios. These tables provide comparisons between natural and with-project results for specific weeks.

2. Isotherm plots for the river reach between the downstream-most dam face and Sunshine are presented in Appendix B for each scenario. These figures synopsize an entire simulation on one graph, showing lines of equal temperatures plotted as functions of river location and time. A horizontal line drawn across the plot at any river mile will show a temperature time series at that location, while a vertical drawn at any week provides a time-constant temperature profile.

3. Seasonal temperature history plots for three river locations (approximately river miles 100, 130 and 150) comparing natural and with-project scenarios are provided with corresponding fish preference criteria in Appendix H. These graphics are useful for comparing the seasonal variations between the with-project and natural temperature regimes.

A number of points should be kept in mind when considering the temperature simulation results.

1. Reduced to simplest terms, operation of the proposed reservoirs will effect downstream temperature in two ways.

   a. The temperature of dam release water will usually differ from temperatures which would naturally occur at that time in that reach of river. Reservoirs tend to dampen the variation that naturally occurs in a river system, with cooler-than-normal water released during the summer, and warmer-than-normal water released during the winter.

b. By altering the amount of water normally in the mainstem, dam operations alter the rate of cooling or warming of the downstream river. Basically, larger flows take longer to approach ambient temperature.

2. Tributaries entering the mainstem river below the dam will buffer the effect of the project, larger tributaries having a greater effect. The Chulitna and Talkeetna Rivers, which join the Susitna within two miles of each other, add a combined flow that is approximately 130% of the Susitna River flow (on an annual basis). Thus these two rivers have a considerable buffering effect on the Susitna water temperature.

3. The stream temperature model assumes instantaneous flow mixing at tributary confluences. In reality, tributary flows tend to hug the bank on the side of the mainstem river after converging, maintaining a plume distinct from the mainstem water for a considerable distance downstream.

4. The temperature model does not simulate an ice cover, but rather assumes an open water surface throughout the year. Consequently, simulated temperatures rise quickly in spring in response to increased solar input and warmer air temperatures, whereas the actual presence of either a full ice cover or residual channel ice serves to temper these rises. Thus predicted temperatures during this period should be regarded cautiously.

NATURAL CONDITION SIMULATIONS

The study reach of river normally cools from the upstream end down, approaching 0 C sometime during October. The river remains at 0 C until after breakup, which occurs in early-to-mid May. There is usually a January thaw in the basin that would raise the water temperature if not for the insulating ice and snow cover.

After breakup, temperatures rise rapidly, reaching 11 to 13 C. During the four summers simulated, peak temperatures all occurred within water weeks 30 through 41 (June 17 - July 14). These summer peaks ranged from 10.9 to 13.0 C at river mile 150, 10.9 to 12.9 C at river mile 130, and 11.8 to 13.1 C at river mile 100.

Cooling begins sometime between mid-August and early September, once again reaching 0 C sometime in October.

WATANA ONLY, 1966 AND 2001 DEMANDS

Two power load demands were used in the single-dam simulations, that of the first year of Watana operation, 1996, and that of the year before Devil Canyon becomes operational, 2001. There were strikingly slight differences between downriver temperatures simulated under these two demands. Mean summer temperatures (Table 14) show no differences greater than 0.05 C at any of the three locations examined (RM 150, 130 and 100) for the summers simulated. On a weekly basis, temperatures are generally within a few tenths of a degree between the 1996 and 2001 simulations.

Mean summer temperatures are approximately 1.0 C cooler than natural at both river miles 150 and 130 under both load demands. By river mile 100, 84 miles downstream of Watana dam, this difference in summer means is reduced to less than 0.6 C.

Operation of the project has the effect of delaying summer temperature rises as well as reducing temperatures. With-project temperatures are consistently cooler than natural prior to water week 40 (August 26 - September 1). After this period, with-project temperatures are warmer than natural.

Table 14. Mean summer (water weeks 31-52) water temperatures (C) under various load demands for three mainstem locations

River Mile 150

Demand Year	1971	1974	1981	1982	Mean
Natural	7.27	8.64	8.88	8.74	8.38
1996	6.65	7.29	7.87	7.71	7.38
2001	6.65	7.34	7.92	7.66	7.39
2002	5.82	6.67	6.38	6.54	6.35
2020	5.81	6.90	6.97	6.78	6.62

River Mile 130

Demand Year	1971	1974	1981	1982	Mean
Natural	7.77	8.70	8.56	8.75	8.45
1996	6.77	7.51	7.88	7.76	7.48
2001	6.79	7.54	7.92	7.72	7.49
2002	6.20	7.17	6.82	6.95	6.79
2020	6.19	7.39	7.32	7.17	7.02

River Mile 100

Demand Year	1971	1974	1981	1982	Mean
Natural	8.26	9.35	9.09	9.35	9.01
1996	7.58	8.65	8.81	8.74	8.46
2001	7.58	8.66	8.81	8.71	8.44
2002	7.14	8.40	7.85	8.00	7.85
2020	7.19	8.65	8.41	8.39	8.16

Table 15. Simulated summer peak temperature ranges (C) at selected locations

River mile 150

Demand Year	Temperature Range (C)	Water weeks when peaks occurred
Natural	10.9 - 13.0	38 - 41
1996	9.4 - 11.1	40 - 46
2001	9.4 - 11.1	38 - 46
2002	8.3 - 10.2	41 - 51
2020	8.5 - 11.2	44 - 48

River mile 130

Demand Year	Temperature Range (C)	Water weeks when peaks occurred
Natural	10.9 - 12.9	38 - 41
1996	9.7 - 10.7	40 - 46
2001	9.7 - 10.7	41 - 46
2002	8.6 - 10.2	41 - 48
2020	8.6 - 10.8	

River mile 100

Demand Year	Temperature Range (C)	Water weeks when peaks occurred
Natural	11.8 - 13.1	38 - 41
1996	11.2 - 12.1	38 - 46
2001	11.2 - 12.3	38 - 46
2002	10.6 - 11.5	38 - 41
2020	10.9 - 11.6	41 - 44

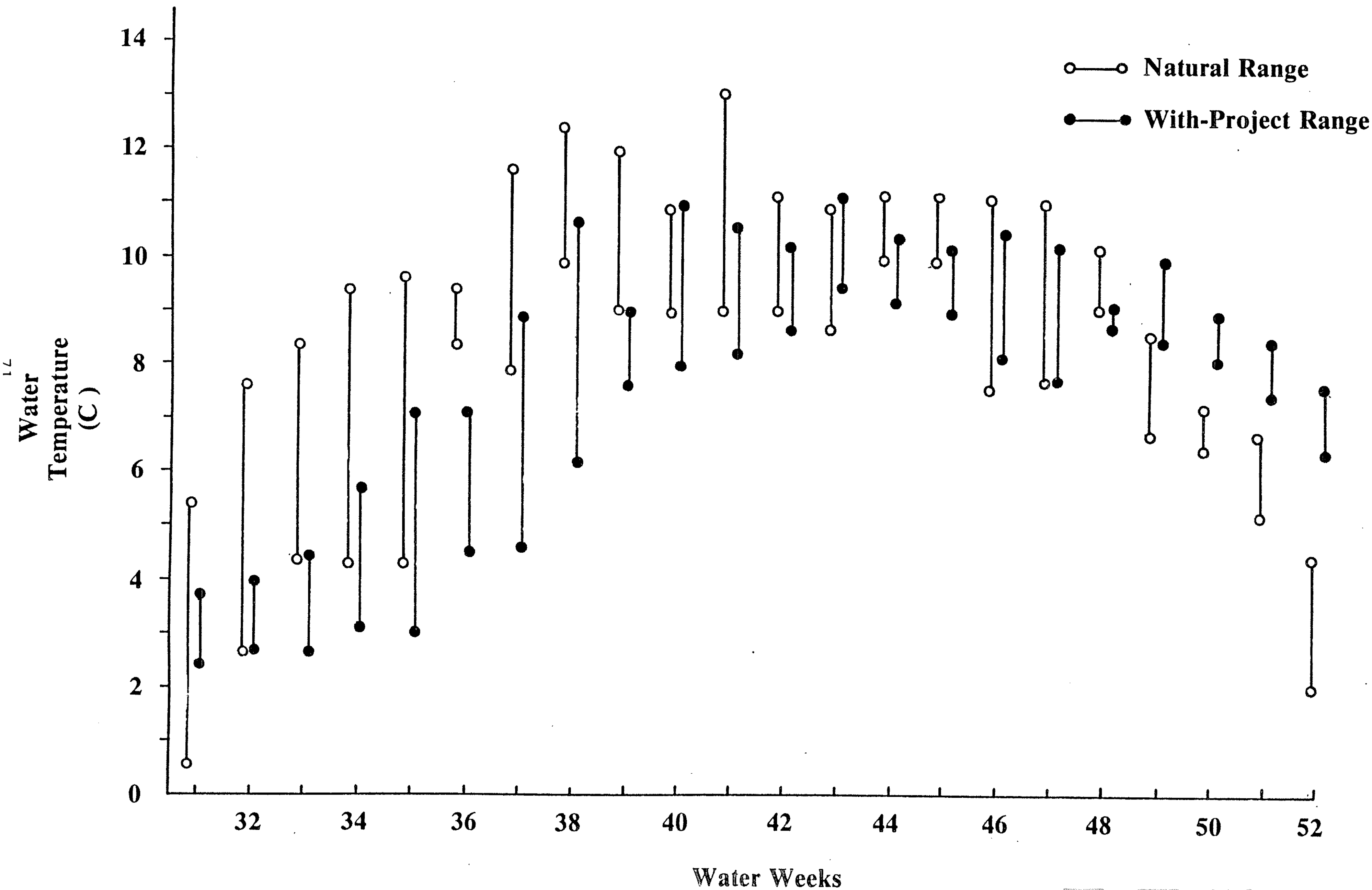
Summer peak temperatures are also reduced up to 2 C; and generally occur later in the summer than under natural conditions (Table 15).

Figure 12 provides a comparison of weekly summer temperature ranges at river mile 150 for natural and 1996 demand simulations, graphically synopsizing the observations discussed above. The average variation within each week is noticably lower under with-project conditions, 2.1 C as compared with 2.7 C under natural conditions. Graphically, these values correspond to the average length of the vertical temperature range lines. This suggests that the reservoir has a stabilizing effect on summer instream temperature variation.

Simulated natural river temperatures are 0 C at the Watana dam site from mid-to-late October at least through the end of March (weeks 4 through 26). Simulated Watana reservoir releases during this period range from 0.6 to 4.7 C. Consequently, river temperatures immediately downstream from the dam face will be warmer than under natural conditions.

The location of the 0 C point and consequent ice front location downstream from the dam varies as a function of flow, reservoir release temperature and meteorology. For the four winters simulated by Harza's ICECAL model, ice front movement into the middle river was delayed from two to seven weeks. In most cases, the ice front under with-project conditions never reached the same upstream location as under natural conditions, but remained 5 to 25 miles further downstream. However, in the coldest winter, 1971-72, the ice front reached the same location as under natural conditions by February 1. The location of these ice fronts are shown on the isotherm plots in Appendix B.

Figure 12. Comparison of weekly river temperature ranges (C) at river mile 150 for four summer simulations, natural and Watana 1996 demand results.



WATANA/DEVIL CANYON 2002 and 2020 DEMANDS

The two-dam configuration was simulated under two load demands, 2002, the first year Devil Canyon comes on line, and 2020, a typical year at full operational capacity. Addition of the second dam moves the release facility further downstream, eliminating a 33-mile reach where, under a single-dam scheme, water temperatures begin equilibration to ambient temperatures. The thermal consequences of this second dam are more severe deviations from natural conditions than under the single-dam case. Summer temperatures are cooler and winter temperatures warmer than both natural and the Watana-only scheme.

Just as in the case of the single dam, temperatures increase slowly throughout the summer, remaining cooler than natural temperatures until early September (water week 49, September 2-8), and then staying warmer than natural through the fall and winter (natural winter temperatures being 0 C). Summer peak temperatures are reduced by as much as 3.0 C (Table 15), which generally occur later in the season than under the natural regime.

Surprisingly, summer simulations under the 2002 demand result in colder water temperatures than those simulated under the 2020 demand. Mean seasonal temperatures, averaged for the four 2002 summers simulated, are approximately 2.0, 1.7 and 1.2 C colder than natural at river miles 150, 130 and 100 respectively (see Table 14). By comparison, mean summer temperature differences from natural conditions for river miles 150, 130 and 100 under the 2020 demand are 1.8, 1.4 and 0.9 C respectively. It should be noted that these means are lower than natural, in part because of the season definition, April 30 through September 30. With-project temperatures are considerably warmer than natural through the fall; thus these differences in summer means would decrease if the season were defined to run into October.

Figure 13 provides the weekly temperature ranges at river mile 150 for the four summer simulations under natural and the 2002 load demand conditions.

WATANA FILLING

Filling the Watana reservoir is scheduled to begin in May, 1991. Filling will continue through three summers, and will be completed sometime in late summer, 1993 (Acres American 1983). Winter discharges will be released at natural flow levels during these years.

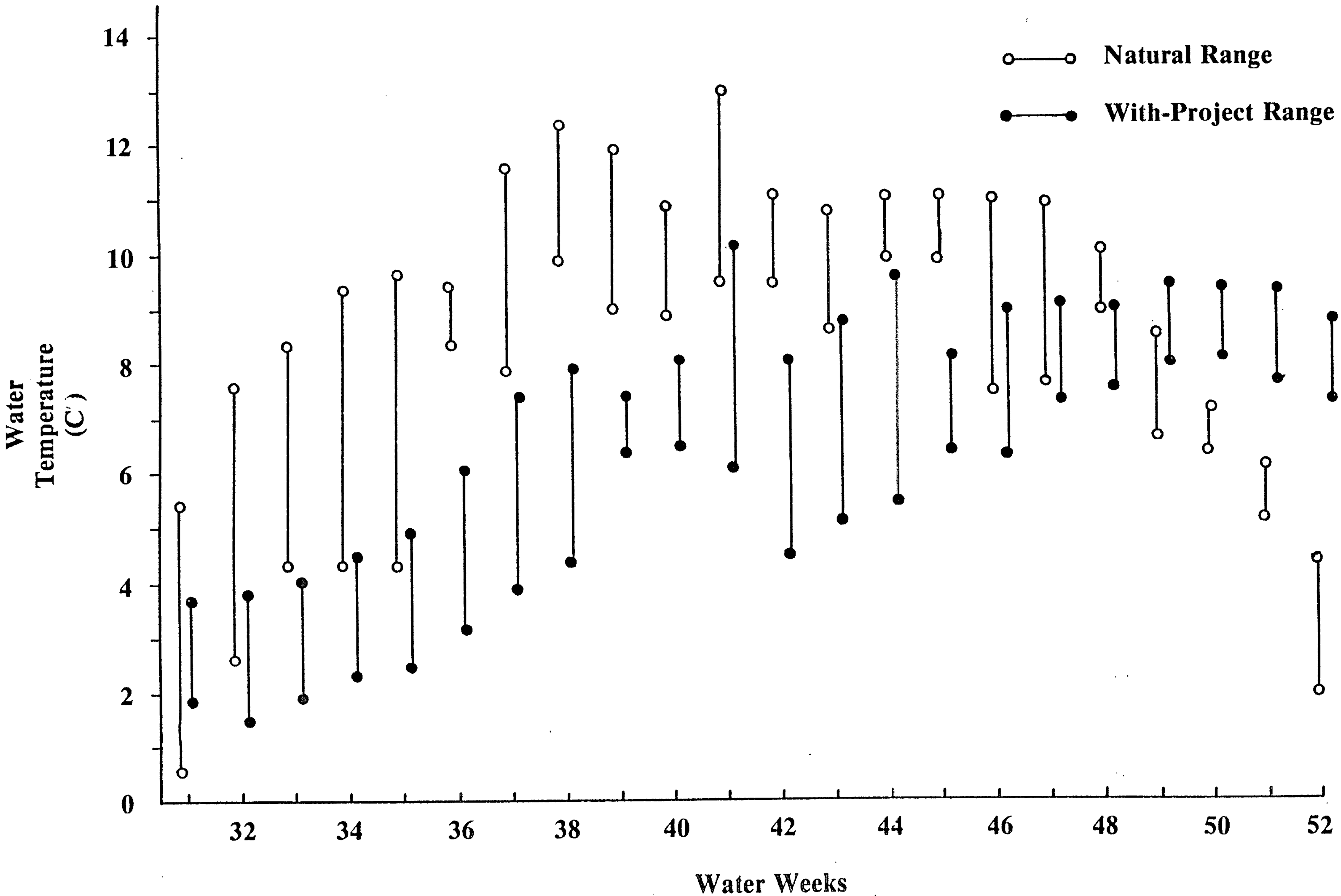
Reservoir operations/temperature simulations and subsequent downriver temperature simulations were done covering the winter 1991-92 through summer 1993 period. The historic hydrology/meteorology used for these simulations are listed in Table 16.

Season/ Demand	Winter 1991-92	Summer 1992	Winter 1992-93	Summer 1993
Historic Hydrology/ Meteorology	1982-83	1981 1971	1981-82 1971-72	1982

Table 16. Historic hydrologic/meteorologic conditions used for Watana filling simulations.

Summer release temperatures were slightly colder under 1992 demand than under the 1991 demand. The two historic summer periods used for simulating the 1992 conditions differed greatly, the 1971 summer being the coldest of those years considered. For both summer 1992 demand simulations, release temperatures were no greater than 4.2 C through the first part of the summer (week 44 - July 29 to August 4 for 1981; week 46 - August 12 to 18 for 1971), followed by warmer than natural releases. Even with the warm releases late in the summer, mean seasonal temperatures at river mile 150

Figure 13. Comparison of weekly river temperature ranges (C) at river mile 150 for four summer simulations, natural and Watana/Devil Canyon 2002 demand results.



were 1.3 and 2.5 C colder than natural for the 1971 and 1981 simulations respectively. For the early-to-mid part of the summer (water weeks 31-46), this difference is greater, 2.9 and 2.8 C for 1971 and 1981 simulations. These results are synopsized for river miles 150, 130 and 100 in Table 17. Figures 14 and 15 compare temperature time series at river mile 150 for these two summer simulations with corresponding natural condition simulations.

The preceding year of filling, 1991, was simulated with historic hydrology/meteorology from 1982. The mean temperature figures (Table 18) are very similar to those of the 1992-demand/1981-condition simulation discussed previously. The major difference is that release temperatures in the 1991 demand case warmed earlier in the summer, reaching 5 C by week 30 (June 17-23). Late summer release temperatures were not as high as in the 1992 simulations, keeping the season mean temperature low. Temperature time series at river mile 150, comparing this case with natural 1982 summer simulations, appear in Figure 16.

TOLERANCE AND PREFERENCE CRITERIA FOR FISH

Preliminary tolerance and preference ranges for thermal impact assessment have been established for the five Pacific salmon species found in the Susitna drainage. These limits are based on literature, lab studies, field studies and observed Susitna drainage temperatures (Table 19). The tolerance zones have been established for each life phase activity excluding incubation. Within this range fish can expect to live and function free from the lethal effects of temperature. Susitna river fish are acclimated to a temperature range between 0 and approximately 18 C. Within this range, the preferred temperature range for most salmonid life phases is between 6 and 12 C. The upper and lower incipient lethal temperatures for the salmon life

Table 17. Mean summer temperatures (C) for Watana filling, 1992 demand, at selected locations.

River Mile 150

Demand Year	Water weeks 31-52 1971	1981	Water weeks 31-46 1971	1981
Natural	7.27	8.88	8.12	9.13
1992	5.94	7.12	5.26	6.34

River Mile 130

Demand Year	Water weeks 31-52 1971	1981	Water weeks 31-46 1971	1981
Natural	7.77	8.56	8.14	9.14
1992	6.22	7.39	5.71	6.82

River Mile 100

Demand Year	Water weeks 31-52 1971	1981	Water weeks 31-46 1971	1981
Natural	8.26	9.09	8.67	9.74
1992	7.11	8.41	6.84	8.19

Figure 14. Simulated weekly river temperatures (C) at river mile 150 for summer 1971, natural and Watana 1992 demand filling results.

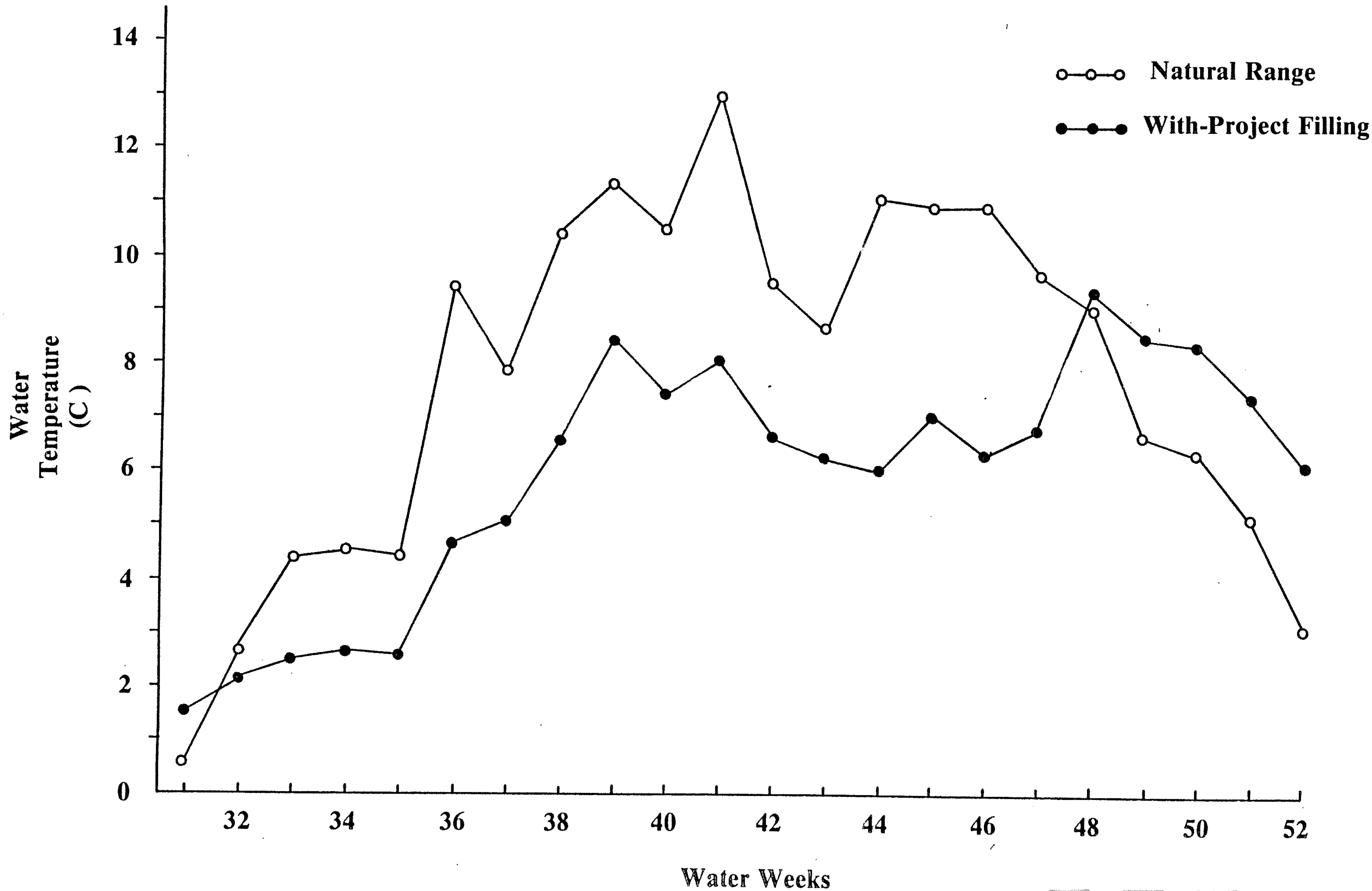


Figure 15. Simulated weekly river temperatures (C) at river mile 150 for summer 1981, natural and Watana 1992 demand filling results.

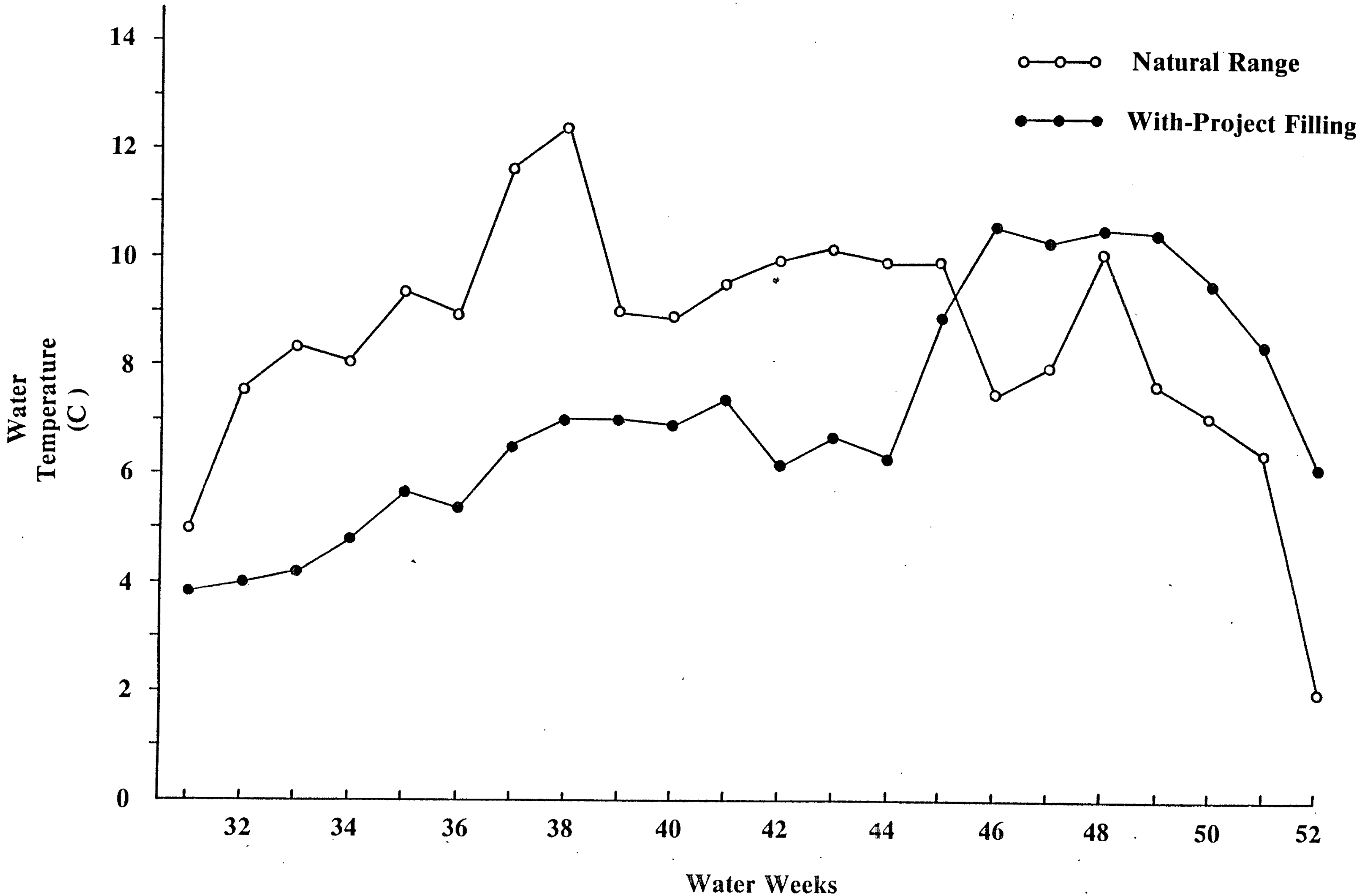


Table 18. Mean summer temperatures (C) for Watana filling, 1991 demand, at selected locations.

River Mile 150

Demand Year	Water weeks 31-52 1982	Water weeks 31-46 1982
Natural	8.74	9.16
1991	6.95	6.49

River Mile 130

Demand Year	Water weeks 31-52 1982	Water weeks 31-46 1982
Natural	8.75	9.14
1991	7.17	6.84

River Mile 100

Demand Year	Water weeks 31-52 1982	Water weeks 31-46 1982
Natural	9.35	9.81
1991	8.10	7.99

Figure 16. Simulated weekly river temperatures (C) at river mile 150 for summer 1982, natural and Watana 1991 demand filling results.

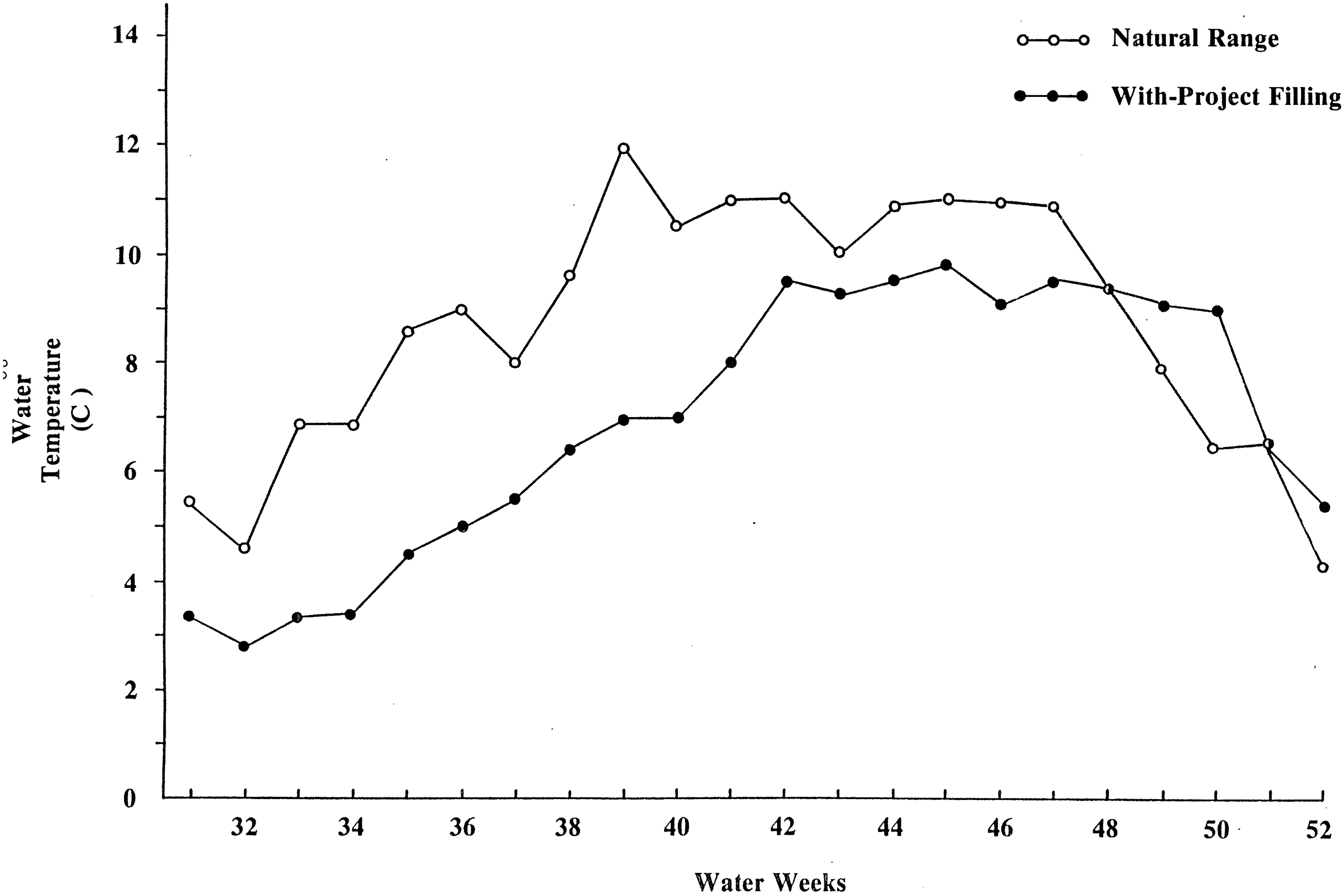


Table 19. Preliminary salmon tolerance criteria for Susitna River drainage.

		TEMPERATURE RANGE °C	
SPECIES	LIFE PHASE	TOLERANCE	PREFERRED
Chum	Adult Migration	1.5-18.0	6.0-13.0
	Spawning	1.0-14.0	6.0-13.0
	Incubation[1]	0-12.0	2.0- 8.0
	Rearing	1.5-16.0	5.0-15.0
	Smolt Migration	3.0-13.0	5.0-12.0
Sockeye	Adult Migration	2.5-16.0	6.0-12.0
	Spawning	4.0-14.0	6.0-12.0
	Incubation[1]	0-14.0	4.5- 8.0
	Rearing	2.0-16.0	7.0-14.0
	Smolt Migration	4.0-18.0	5.0-12.0
Pink	Adult Migration	5.0-18.0	7.0-13.0
	Spawning	7.0-18.0	8.0-13.0
	Incubation[1]	0-13.0	4.0-10.0
	Smolt Migration	4.0-13.0	5.0-12.0
Chinook	Adult Migration	2.0-16.0	7.0-13.0
	Spawning	5.0-14.0	7.0-12.0
	Incubation[1]	0-16.0	4.0-12.0
	Rearing	2.0-16.0	7.0-14.0
	Smolt Migration	4.0-16.0	7.0-14.0
Coho	Adult Migration	2.0-18.0	6.0-11.0
	Spawnig	2.0-17.0	6.0-13.0
	Incubation[1]	0-14.0	4.0-10.0
	Rearing	2.0-18.0	7.0-15.0
	Smolt Migration	2.0-16.0	6.0-12.0

[1]Embryo incubation rate increases as temperature rises. Accumulated temperature units or days to emergence should be determined for each species for incubation.

phases excluding incubation would range between 13 and 18 C and 1 to 7 C, respectively.

Embryo incubation rates increase with temperature. Accumulated temperature units, or days to hatching and emergence, should be determined as criteria for incubation. Wangaard and 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 fifty percent emergence for chum and sockeye salmon under natural conditions. Development times were computed and plotted for data from these studies and from data available in the literature. The resulting regression gave a linear relationship between mean incubation temperature and development rate (the inverse of the time to emergence) for chum and sockeye between approximately 2 and 10 C (Figures 17-20). Variation in incubation time of at least 10% of the mean can occur within a species and further variation may be caused by fluctuating temperatures during incubation (Crisp 1981). The calculated regression can give only an approximate estimate of development time.

A simplified way of estimating emergence time is to develop a nomagraph (Figure 21) from the incubation temperature versus development rate figures By rearranging the regression equation, a formula can be developed to predict the time to emergence given the average incubation temperature:

$$\text{Days} = \frac{1000}{0.574\ T + 2.342}$$

This formual is used to develop a nomagraph capable of predicting the date of emergence given the date of spawning and the average temperature. The left axis of the nomagraph becomes the known range of spawning dates (July 20 - October 10) and the right axis are the emergence dates. By

Figure 17. Development time to emergence versus mean incubation temperature for chum salmon.

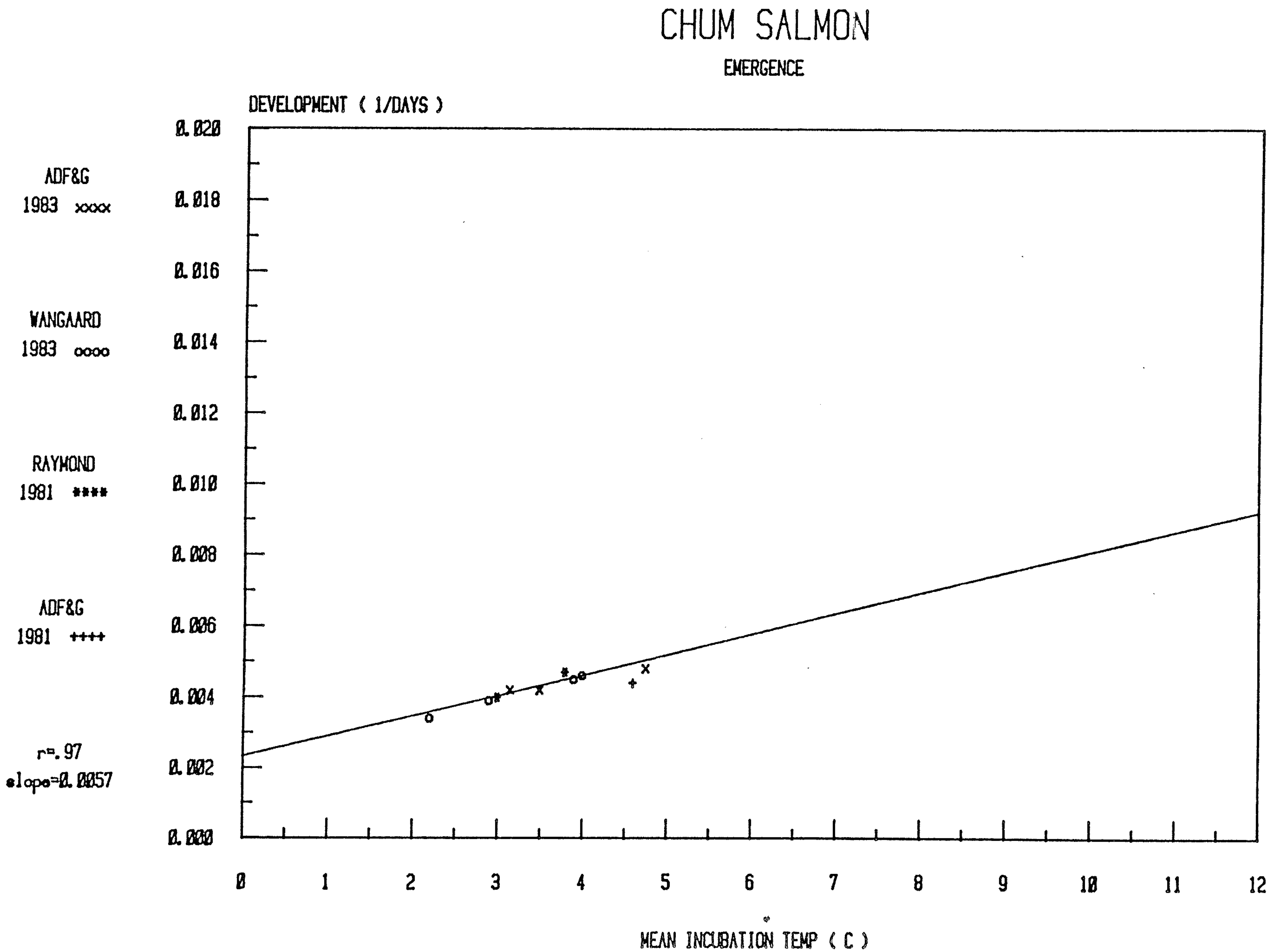


Figure 18. Development time to 50% hatch versus mean incubation temperature for chum salmon.

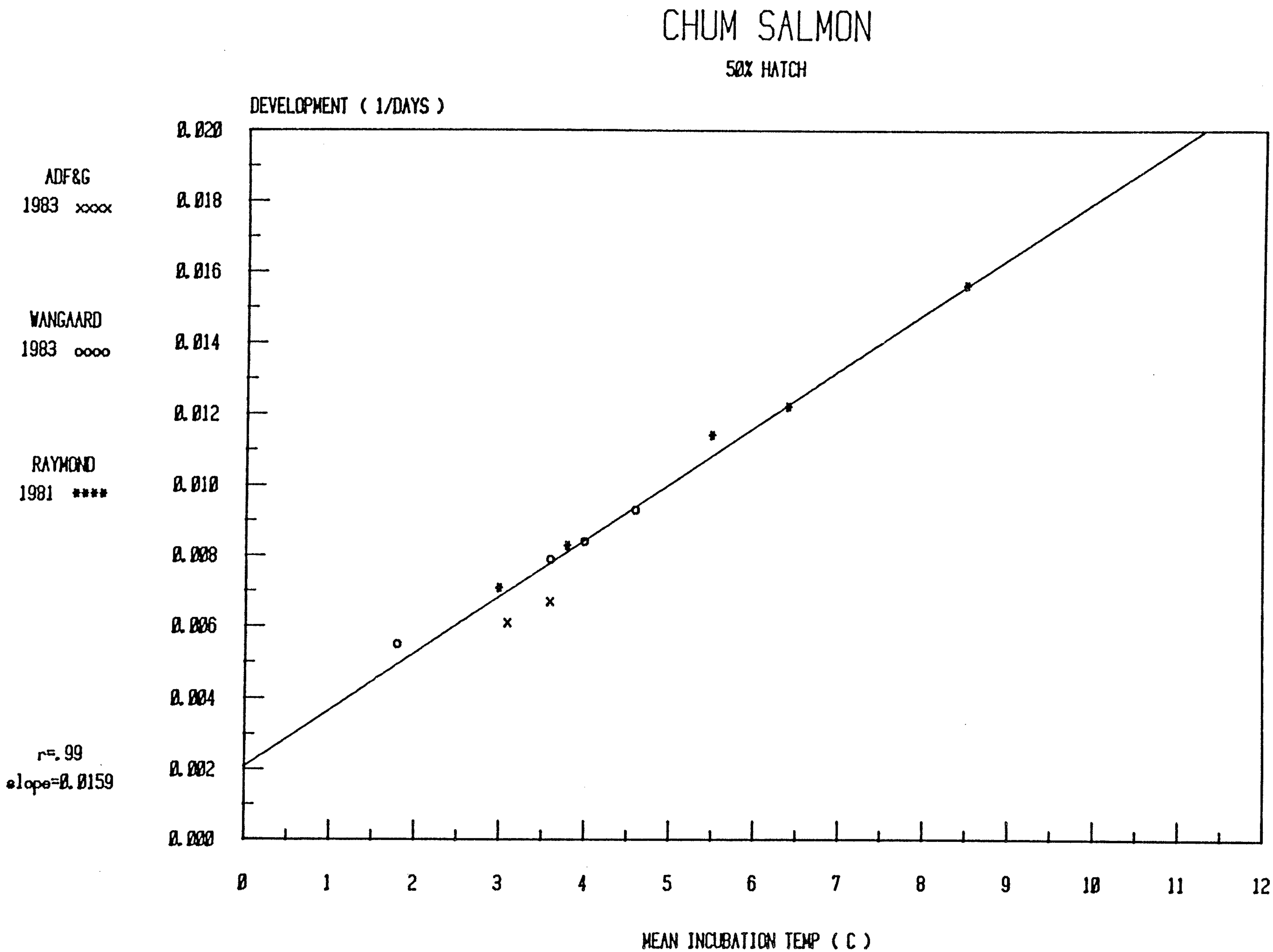


Figure 19. Development time to emergence versus mean incubation temperature for sockeye salmon.

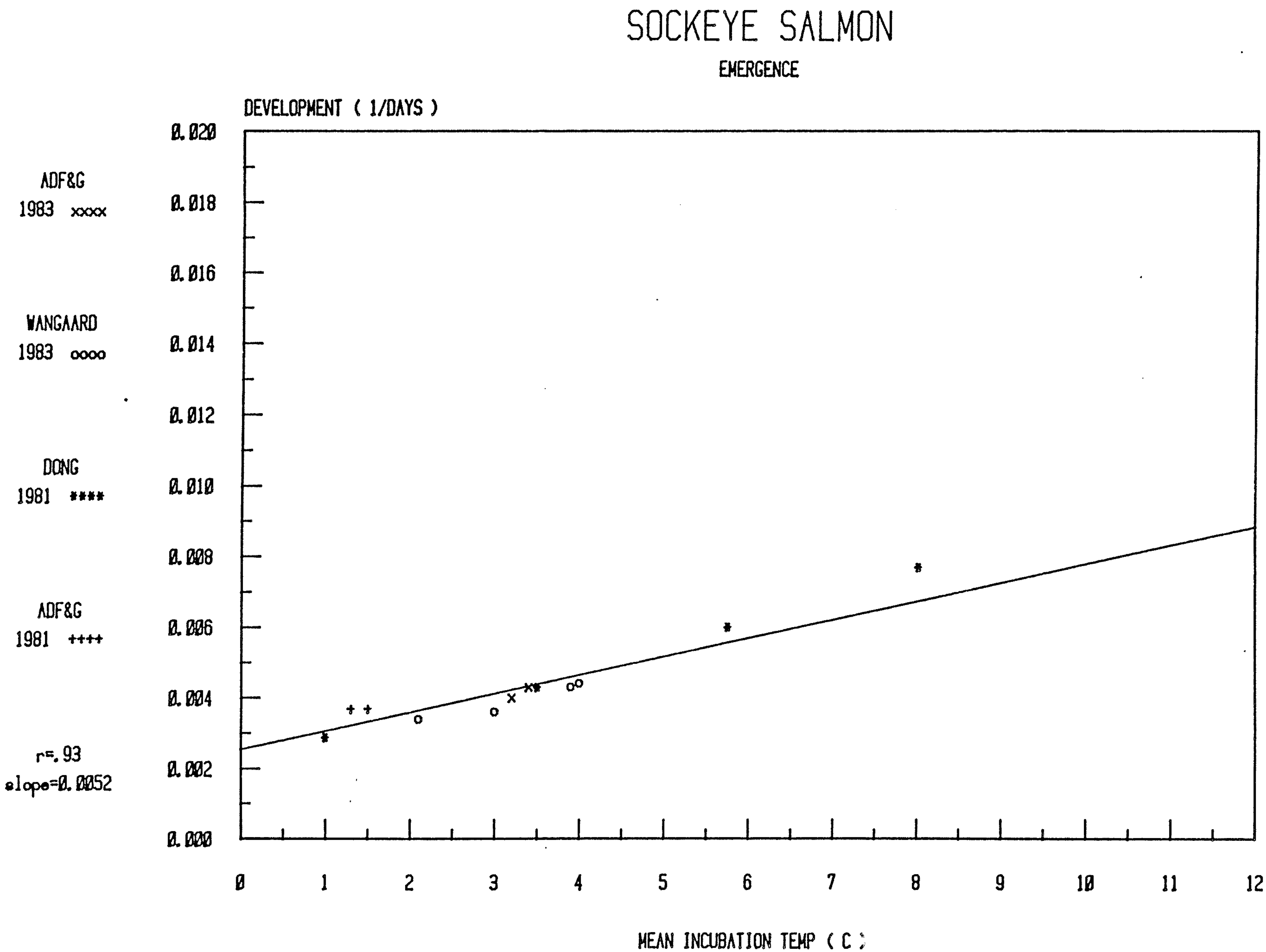


Figure 20. Development time to 50% hatch versus mean incubation temperature for sockeye salmon.

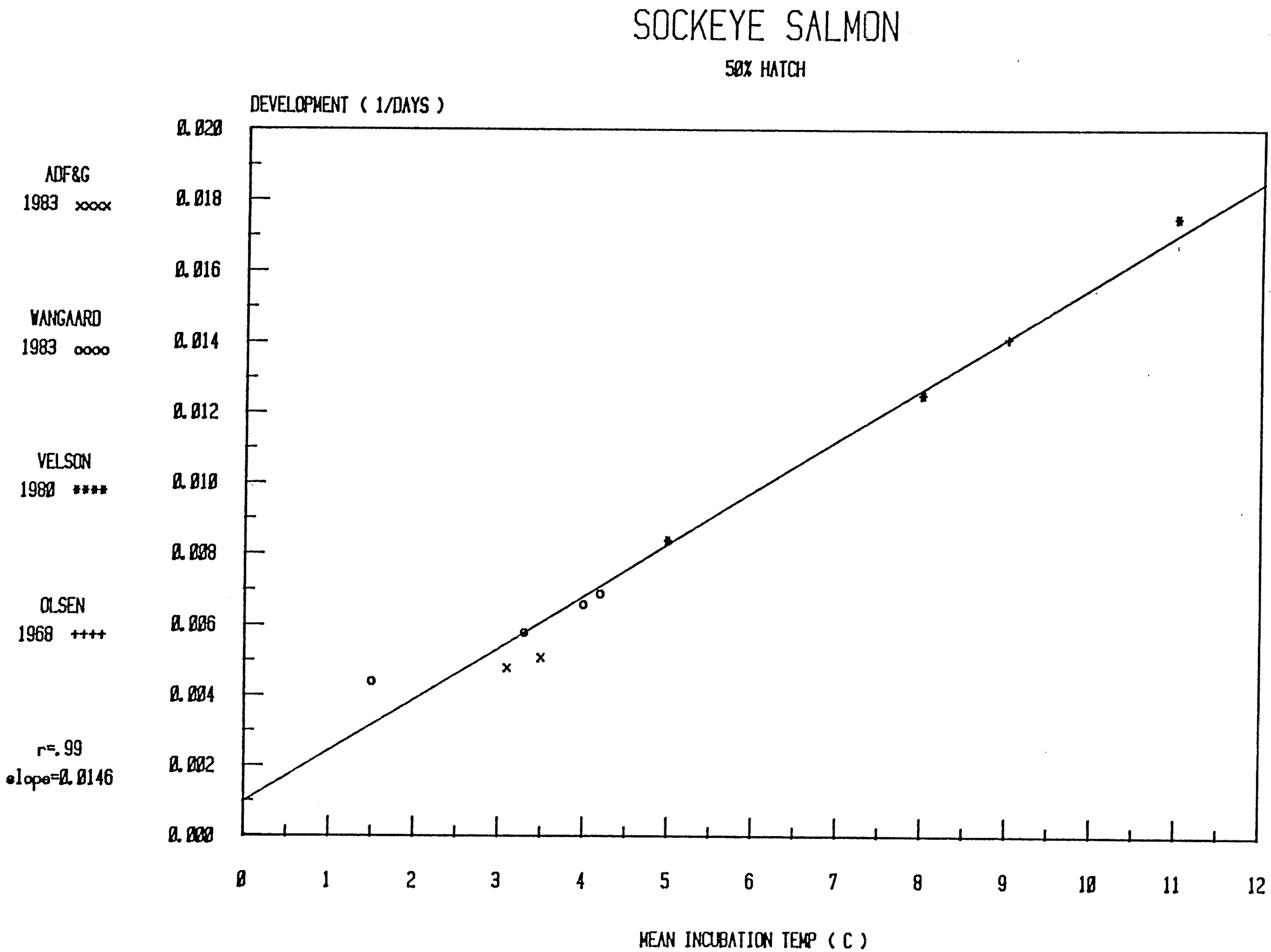
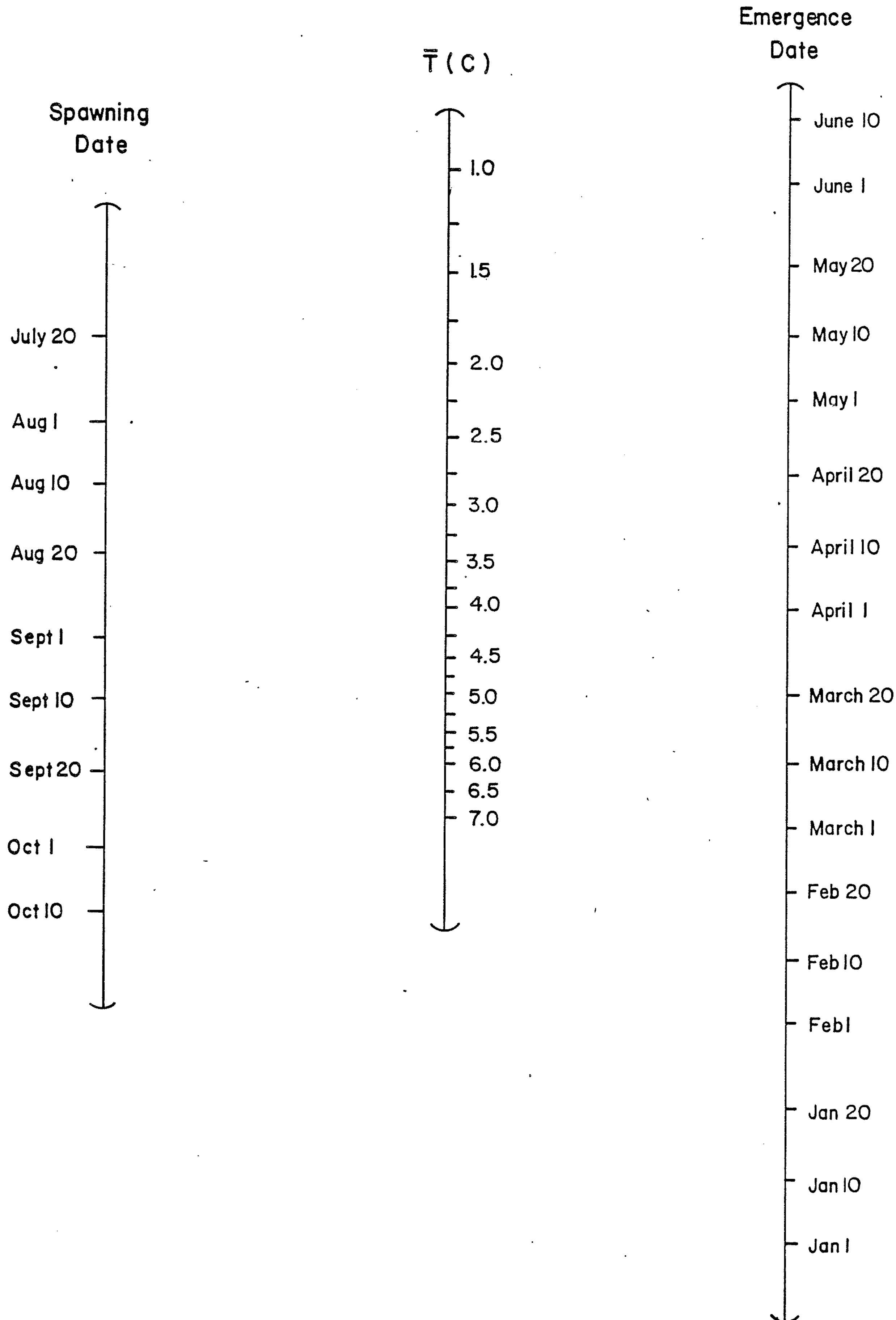


Figure 21. Chum salmon spawning time versus mean incubation temperature nomagraph.



solving the equation for any temperature of interest, the number of Julian days for that average incubating temperature to emergence can be determined.

EFFECTS OF PROJECT-RELATED TEMPERATURES ON FISHERY RESOURCES

In this section, pre- and with-project temperature regimes in the Devil Canyon to Talkeetna reach are evaluated with respect to the various life stage temperature tolerances established for the five species of Pacific salmon. Appendix H contains temperature history plots profiles for river miles 150, 130, and 100 in relation to the five Pacific salmon life phase activities for three scenarios: (1) natural versus Watana dam operation; (2) natural versus combined operation of the Watana and Devil Canyon dams; and (3) natural versus Watana reservoir filling.

The life phase activities of migration, spawning, and rearing generally take place in the open water season of May through October. Table 20 shows the weekly temperature ranges for May through October at representative locations between Devil Canyon and Sunshine for natural conditions and with-project related scenarios.

Embryo incubation generally takes place over the long winter time period of September through April. The expected differences between natural and with-project water temperatures are shown in Table 21.

The most apparent project-related change in Susitna River water temperature above Talkeetna will occur in the mainstem and side channels since these habitats will be directly affected by change in river discharge. These habitats are primarily used by adult salmon and juveniles as migration corridors; however, chinook salmon juvenile have been found to be extensively using side channels for rearing. Resident species are also primarily using

Table 20. Weekly temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine, for natural conditions and project related scenarios; May 1982[1].

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	4.7-8.6	6.5	2.8-4.5	3.5	3.3-4.7	3.8	3.4-4.7	3.9	3.7-4.5	4.1	3.6-4.6	4.1
Sherman (130.8)	4.7-8.4	6.4	3.2-4.9	3.9	3.5-5.0	4.1	3.6-5.0	4.2	4.2-5.2	4.6	4.1-5.3	4.6
Whiskers Creek (101.4)	5.3-9.0	7.1	4.1-6.5	5.3	4.4-6.6	5.3	4.4-6.6	5.4	4.9-6.7	5.7	4.9-7.0	5.8
Sunshine (83.8)	5.2-8.4	6.7	4.6-7.3	5.9	4.7-7.3	5.8	4.7-7.3	5.8	4.9-7.3	6.0	4.9-7.4	6.0

[1] Simulations using 1982 hydrologic and meteorologic conditions and results of DYRESM reservoir temperature model for some period.

(Cont'd)

Table 20. Weekly temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine, for natural conditions and project related scenarios; June 1982

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION 1996		WATANA OPERATION 2001		DEVIL CANYON OPERATION 2002		DEVIL CANYON OPERATION 2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	8.1-11.9	9.7	5.0-7.0	6.0	5.7-8.9	7.1	5.7-8.2	6.9	4.7-6.9	5.8	4.7-6.8	5.6
Sherman (130.8)	8.0-11.8	9.6	5.3-7.6	6.4	5.8-9.0	7.1	5.8-8.5	7.0	5.3-7.8	6.4	5.3-7.8	6.3
Whiskers Creek (101.4)	8.5-12.5	10.1	6.5-9.0	7.5	7.1-10.8	8.5	7.1-10.4	8.4	6.7-9.9	8.0	6.8-10.1	8.1
Sunshine (83.8)	7.6-11.0	9.1	6.7-9.6	7.9	6.9-9.9	8.1	6.9-9.8	8.1	6.8-9.7	8.0	6.7-9.7	8.0

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; July 1982.

Simulated Weekly Temperatures (C)

LOCATION	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
(River Mile)	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	10.1-11.1	10.7	7.0-9.6	8.5	9.4-10.9	10.2	9.3-10.7	10.1	5.1-10.2	7.3	7.3-8.9	8.2
Sherman (130.8)	10.0-11.2	10.7	7.3-.9.9	8.8	9.3-10.5	10.1	9.2-10.3	10.0	5.6-10.2	7.8	8.2-9.4	8.7
Whiskers Creek 10 (101.4)	10.6-12.0	11.4	8.8-10.9	9.8	10.1-11.7	11.2	10.1-11.6	11.2	6.7-11.5	9.2	10.1-11.3	10.5
Sunshine (83.8)	9.3-10.5	9.9	8.8-9.9	9.2	8.8-9.7	9.3	8.9-9.7	9.3	8.0-9.1	8.8	8.6-9.5	9.0

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; August 1982.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION 1996		WATANA OPERATION 2001		DEVIL CANYON OPERATION 2002		DEVIL CANYON OPERATION 2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	9.4-11.1	10.7	9.2-9.8	9.5	9.0-10.2	9.7	8.9-10.3	9.6	5.5-8.5	7.4	7.3-10.2	8.1
Sherman (130.8)	9.5-11.2	10.7	9.5-10.1	9.7	9.1-10.4	9.9	9.0-10.5	9.8	6.2-9.0	7.9	7.8-10.3	8.5
Whiskers Creek (101.4)	10.1-12.0	11.4	10.1-11.1	10.6	9.8-11.3	10.8	9.8-11.4	10.8	7.4-10.0	9.0	8.7-11.1	9.7
Sunshine (83.8)	8.5-10.2	9.7	8.4-9.8	9.4	8.3-9.7	9.3	8.3-9.7	9.3	8.2-9.3	8.8	7.9-9.4	9.0

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; September 1982.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	4.3-7.9	6.3	5.4-9.2	7.5	7.5-9.0	8.3	7.6-9.0	8.3	8.4-8.6	8.5	7.2-9.1	8.4
Sherman (130.8)	4.4-8.0	6.4	5.0-9.0	7.2	7.2-8.9	8.0	7.2-8.9	8.1	8.0-8.6	8.4	6.9-9.0	8.1
Whiskers Creek (101.4)	4.6-8.4	6.7	5.0-9.3	7.4	7.1-9.2	8.2	7.1-9.2	8.2	7.7-8.9	8.4	6.7-9.3	8.2
Sunshine (83.8)	4.5-7.6	6.1	4.5-7.9	6.2	5.5-7.8	6.6	5.5-7.8	6.6	5.6-7.8	6.7	5.1-7.8	6.4

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; October 1982.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	0-2.2	0.6	0.2.2	0.8	2.2-6.5	4.6	2.3-6.7	4.8	6.3-8.3	7.5	4.6-7.7	6.4
Sherman (130.8)	0-2.3	0.7	0-2.4	0.8	1.1-6.0	3.9	1.2-6.2	4.0	4.3-7.6	6.2	3.4-7.2	5.6
Whiskers Creek (101.4)	0-2.3	0.6	0-2.2	0.6	0-5.7	3.1	0-5.8	3.2	1.5-6.9	4.5	1.4-6.6	4.4
Sunshine (83.8)	0-2.6	0.9	0.3-1.8	1.1	0-4.1	2.1	0-3.6	2.1	0.8-3.8	2.6	0.7-3.7	2.6

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; May 1981.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	5.0-9.3	7.7	3.8-5.7	4.5	3.6-7.1	4.9	3.6-7.2	5.0	2.5-4.9	3.8	2.6-5.1	3.9
Sherman (130.8)	5.1-9.4	7.7	4.2-6.3	5.0	3.9-7.2	5.3	3.9-7.3	5.3	3.0-6.0	4.6	3.1-6.2	4.8
Whiskers Creek (101.4)	5.7-10.1	8.3	5.0-8.4	6.6	4.7-9.2	6.8	4.7-9.2	6.8	4.0-8.1	6.2	4.0-8.5	6.5
Sunshine (83.8)	5.2-9.4	7.7	4.9-8.4	6.8	4.8-8.5	6.9	4.8-8.5	6.9	4.5-8.3	6.7	4.5-8.4	6.8

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; June 1981.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION 1996		WATANA OPERATION 2001		DEVIL CANYON OPERATION 2002		DEVIL CANYON OPERATION 2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	8.9-12.4	10.5	5.4-7.0	6.5	7.1-10.6	8.8	7.4-11.1	9.1	6.1-7.9	7.2	6.1-8.8	7.5
Sherman (130.8)	8.8-12.3	10.4	5.8-7.9	7.1	6.9-10.3	8.7	7.1-10.7	8.9	6.5-8.7	7.8	6.5-9.4	8.0
Whiskers Creek (101.4)	9.3-13.1	11.1	7.2-10.1	8.9	8.1-12.1	10.2	8.3-12.3	10.3	7.7-10.8	9.4	7.8-11.3	9.7
Sunshine (83.8)	8.0-10.7	9.4	7.1-9.3	8.4	7.2-9.6	8.6	7.2-9.6	8.6	7.2-9.4	8.5	7.2-9.5	8.5

(Cont'd) Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; July 1981.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	8.9-10.2	9.6	6.2-7.4	6.8	8.0-11.1	9.4	8.2-11.0	9.5	4.5-7.0	5.8	6.4-10.7	8.2
Sherman (130.8)	9.0-10.3	9.7	6.9-7.7	7.4	8.2-10.7	9.3	8.2-10.7	9.3	5.1-7.6	6.4	6.9-10.4	8.4
Whiskers Creek (101.4)	9.7-10.9	10.2	7.9-9.0	8.6	9.1-11.5	10.2	9.1-11.4	10.2	6.1-9.0	7.5	8.3-11.4	9.7
Sunshine (83.8)	9.1-9.9	9.4	8.4-8.9	8.6	8.5-9.5	9.0	8.5-9.5	9.0	7.8-8.6	8.3	8.3-9.3	8.8

(Cont'd) Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; August 1981.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	7.5-10.1	9.1	6.3-10.6	9.3	7.7-10.3	8.7	8.0-10.5	8.8	7.1-7.6	7.4	5.1-11.2	7.5
Sherman (130.8)	7.6-10.1	9.2	7.0-10.4	9.3	7.9-10.1	8.8	7.8-10.3	8.8	7.5-7.9	7.7	5.5-10.8	7.7
Whiskers Creek (101.4)	8.0-10.7	9.7	8.1-11.0	9.9	8.4-10.9	9.4	8.3-11.0	9.4	8.0-8.6	8.3	6.0-11.6	8.4
Sunshine (83.8)	7.7-9.8	9.0	8.4-9.4	9.0	7.9-9.6	8.8	7.8-9.6	8.8	7.6-8.9	8.4	6.9-9.5	8.3

(Cont'd) Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; September 1981.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	2.0-7.7	5.8	6.2-10.4	8.6	6.5-9.1	8.0	6.4-9.0	7.9	8.0-8.5	8.2	8.4-8.6	8.5
Sherman (130.8)	2.2-7.9	6.0	5.5-10.2	8.2	6.1-9.1	7.9	6.0-9.0	7.8	7.6-8.2	8.1	7.8-8.5	8.3
Whiskers Creek (101.4)	2.2-8.4	6.3	4.8-10.5	8.2	5.7-9.5	7.9	5.5-9.4	7.8	6.9-8.6	8.1	7.1-9.0	8.3
Sunshine (83.8)	2.3-7.8	5.8	3.2-8.5	6.5	4.0-8.2	6.6	3.9-8.2	6.6	4.5-8.1	6.7	4.6-8.0	6.8

(Cont'd) Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; October 1981.

Simulated Weekly Temperatures (C)

LOCATION	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
(River Mile)	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	0.5-1.3	0.8	0-1.6	0.8	3.9-5.6	4.8	3.8-5.6	4.7	6.3-7.6	7.0	6.3-7.6	7.0
Sherman (130.8)	0.5-1.4	1.0	0.1-1.6	0.9	3.5-5.2	4.4	3.4-5.1	4.3	5.4-6.8	6.2	5.7-7.0	6.5
Whiskers Creek (101.4)	0.5-1.4	1.0	0-1.5	0.8	3.2-4.7	4.1	3.1-4.6	4.0	4.5-5.8	5.3	5.0-6.2	5.8
Sunshine (83.8)	1.1-1.9	1.6	1.3-2.3	1.9	2.5-3.6	3.3	2.4-3.4	2.9	3.0-4.0	3.7	3.5-4.6	4.2

(Cont'd) Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; May 1974.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	5.2-9.6	7.2			2.7-4.6	3.2	2.5-4.7	3.1	1.5-3.4	2.2	1.8-3.3	2.2
Sherman (130.8)	5.6-9.4	7.2			3.2-5.2	3.8	3.1-5.2	3.7	2.4-4.6	3.2	2.7-4.6	3.3
Whiskers Creek (101.4)	6.1-9.9	7.6			4.0-6.5	4.7	4.3-7.1	5.2	3.8-6.7	4.8	4.0-6.9	5.0
Sunshine (83.8)	5.7-9.2	7.2			5-8.3	6.3	4.9-8.3	6.3	4.7-8.2	6.1	4.7-8.3	6.2

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; June 1974.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	8.3-10.9	9.7			5.2-8.9	7	5.3-8.8	7.0	3.9-7.2	5.5	3.8-7.2	5.4
Sherman (130.8)	8.3-10.9	9.7			5.7-9.2	7.5	5.7-9.2	7.5	4.9-8.2	6.5	4.9-8.2	6.5
Whiskers Creek (101.4)	8.7-11.6	10.3			6.7-10.5	8.7	7.2-11.1	9.2	6.5-10.3	8.4	6.7-10.5	8.6
Sunshine (83.8)	8.0-10.1	9.1			7.3-9.3	8.4	7.3-9.3	8.4	7.2-9.1	8.2	7.3-9.1	8.2

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; July 1974.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	10.3-10.8	10.6			8.2-9.5	9.0	8.3-9.5	9.1	7.3-8.8	8.1	7.4-8.9	8.2
Sherman (130.8)	10.3-10.8	10.6			8.5-9.5	9.2	8.5-9.5	9.2	7.8-9.1	8.6	7.9-9.2	8.6
Whiskers Creek (101.4)	10.7-11.4	11.1			9.4-10.5	10.1	9.8-11.0	10.6	9.4-10.5	10.2	9.6-10.7	10.4
Sunshine (83.8)	9.4-9.8	9.6			8.7-9.1	9.0	8.7-9.1	9.0	8.6-9.0	8.9	8.6-9.0	8.9

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; August 1974.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL Range	NATURAL Mean	WATANA FILLING Range	WATANA FILLING Mean	WATANA OPERATION 1996 Range	WATANA OPERATION 1996 Mean	WATANA OPERATION 2001 Range	WATANA OPERATION 2001 Mean	DEVIL CANYON OPERATION 2002 Range	DEVIL CANYON OPERATION 2002 Mean	DEVIL CANYON OPERATION 2020 Range	DEVIL CANYON OPERATION 2020 Mean
Portage Creek (148.9)	7.7-10.6	9.7			8.8-10.4	9.6	9.0-10.5	9.7	8.2-9.6	9.0	9.5-10.2	9.9
Sherman (130.8)	7.9-10.7	9.8			8.8-10.4	9.7	9.0-10.4	9.7	8.6-9.9	9.2	9.5-10.3	10.0
Whiskers Creek (101.4)	8.2-11.2	10.2			9.1-11.0	10.2	9.4-11.2	10.5	9.5-11.1	10.1	10.2-11.2	10.7
Sunshine (83.8)	7.4-9.8	9.0			7.6-9.4	8.9	7.6-9.4	8.9	7.6-9.2	8.7	7.9-9.3	8.9

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; September 1974.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	3.9-8.5	6.2			6.3-9.8	8.1	6.4-9.8	8.3	8.8-9.4	9.2	8.4-10.0	9.3
Sherman (130.8)	4.1-8.6	6.4			5.8-9.6	7.9	5.8-9.6	8.0	8.0-9.4	8.9	7.5-9.9	9.0
Whiskers Creek (101.4)	4.2-8.9	6.7			5.7-9.9	8.0	5.8-10.0	8.2	7.5-9.9	9.0	7.1-10.3	9.0
Sunshine (83.8)	4.4-8.1	6.3			4.7-8.2	6.7	4.7-8.2	6.7	5.3-8.1	7.0	5.0-8.3	6.9

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; October 1974.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	0-0.1	0			3.6-4.5	4.1	3.6-4.6	4.1	4.1-7.3	5.7	3.7-6.8	5.3
Sherman (130.8)	0-0.2	0.1			3.1-3.7	3.4	3.1-3.7	3.4	3.7-6.1	5.0	3.2-5.4	4.4
Whiskers Creek (101.4)	0-0.1	0			2.2-2.9	2.5	2.4-2.9	2.5	3.0-4.5	3.9	2.5-3.8	3.2
Sunshine (83.8)	0.7-1.3	1.0			1.5-2.2	1.9	1.5-2.2	1.9	2.2-2.9	2.5	1.8-2.5	2.1

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; May 1971.

Simulated Weekly Temperatures (C)

LOCATION	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
(River Mile)					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	0.6-4.5	3.3	1.5-2.7	2.3	2.4-3.1	2.9	2.4-3.1	2.9	2.2-2.5	2.3	2.0-2.4	2.2
Sherman (130.8)	0.9-4.6	3.5	1.5-3.1	2.6	2.3-3.5	3.1	2.4-3.5	3.1	2.2-3.0	2.7	2.1-2.9	2.6
Whiskers Creek (101.4)	1.3-5.4	4.1	1.7-4.2	3.3	2.4-4.1	3.5	2.4-4.4	3.7	2.2-4.0	3.3	2.1-3.6	3.3
Sunshine (83.8)	2.0-5.2	4.1	2.1-4.8	3.8	2.4-4.8	4.0	2.4-4.8	4.0	2.3-4.7	3.8	2.3-4.6	3.8

(Cont'd) Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; June 1971.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	7.8-11.3	9.7	4.7-8.4	6.2	4.5-7.6	5.7	4.5-7.6	5.7	3.2-6.3	4.4	3.0-6.5	4.4
Sherman (130.8)	7.7-11.2	9.6	5.1-8.1	6.3	4.9-7.8	6.1	4.9-7.8	6.1	4.2-7.0	5.3	4.2-7.2	5.4
Whiskers Creek (101.4)	8.0-11.7	10.0	6.0-9.9	7.9	5.4-8.9	7.1	5.7-9.5	7.6	5.4-9.0	6.9	5.4-9.3	7.1
Sunshine (83.8)	7.7-10.6	9.3	7.1-9.6	8.4	7.0-9.6	8.4	7.0-9.6	8.4	7.0-9.5	8.3	7.0-9.6	8.3

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; July 1971.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	8.7-13.0	10.6	6.3-8.1	7.1	7.9-9.4	8.7	7.9-9.5	8.6	6.5-8.1	7.6	6.6-8.1	7.6
Sherman (130.8)	8.8-13.0	10.6	6.9-8.8	7.6	8.0-9.7	8.7	8.1-9.7	8.6	7.1-8.5	8.0	7.2-8.5	8.0
Whiskers Creek (101.4)	9.2-13.6	11.1	7.9-11.1	9.1	8.9-11.0	9.6	9.2-11.7	9.9	8.6-10.6	9.4	8.9-10.9	9.5
Sunshine (83.8)	8.1-11.5	9.7	7.5-10.3	8.7	7.7-10.4	8.9	7.7-10.4	8.8	7.6-10.3	8.8	7.6-10.3	8.7

(Cont'd) Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; August 1971.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	9.0-10.9	10.1	6.0-9.3	7.1	8.7-8.9	8.8	8.7-9.2	8.9	6.3-8.4	7.4	6.4-8.5	7.4
Sherman (130.8)	9.0-10.9	10.1	6.8-9.2	7.6	8.9	8.9	8.9-9.3	9.0	6.8-8.6	7.7	7.0-8.6	7.8
Whiskers Creek (101.4)	9.5-11.3	10.6	8.1-9.7	8.6	9.2-9.5	9.3	9.4-10.6	9.7	7.9-9.1	8.6	8.0-9.6	8.8
Sunshine (83.8)	8.5-10.4	9.6	8.2-9.5	8.8	8.5-9.7	9.1	8.5-9.2	9.1	8.3-9.4	8.8	8.2-9.4	8.8

(Cont'd) Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; September 1971.

Simulated Weekly Temperatures (C)

LOCATION (River Mile)	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	3.1-6.7	5.3	6.1-8.5	7.6	6.5-8.4	7.6	6.5-8.4	7.6	7.3-8.4	7.9	7.3-8.4	7.9
Sherman (130.8)	3.3-6.9	5.5	5.6-8.2	7.3	6.2-8.3	7.4	6.2-8.3	7.4	7.0-8.4	7.8	7.0-8.3	7.8
Whiskers Creek (101.4)	3.5-7.1	5.8	5.3-8.3	7.3	6.1-8.4	7.5	6.0-8.5	7.5	6.7-8.5	7.8	6.7-8.5	7.8
Sunshine (83.8)	3.6-6.6	5.5	4.3-6.8	5.9	4.8-7.2	6.2	4.8-7.2	6.2	5.2-7.2	6.4	5.2-7.2	6.4

(Cont'd)

Table 20. Weekly Temperature ranges for mainstem Susitna River, Devil Canyon to Sunshine for natural conditions and project related scenarios; October 1971.

Simulated Weekly Temperatures (C)

LOCATION	NATURAL		WATANA FILLING		WATANA OPERATION				DEVIL CANYON OPERATION			
(River Mile)					1996		2001		2002		2020	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Portage Creek (148.9)	0-1.5	0.5	0-2.5	1.1	2.3-5.1	3.9	2.2-5.1	3.9	3.1-6.4	4.9	3.1-6.4	4.9
Sherman (130.8)	0-1.7	0.6	0-2.4	1.0	1.5-4.8	3.4	1.4-4.8	3.4	2.0-5.9	4.2	2.4-6.0	4.4
Whiskers Creek (101.4)	0-1.8	0.6	0-2.2	0.8	0-4.5	2.7	0-4.5	2.7	0.3-5.4	3.2	1.1-5.6	3.7
Sunshine (83.8)	0-2.4	1.2	0-2.7	1.5	0-3.7	2.1	0-3.7	2.1	0-3.9	2.2	0.2-4.2	2.5

Table 21: Susitna River temperature Ranges (C) under four climatological scenarios for the period September through April.

1971 - 72										
			Watana Operational				Devil Canyon Operational			
	Natural		1996		2001		2002		2020	
RM	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
150	0-6.8	0.7	0-8.4	1.9	0-8.4	1.7	0.7-8.4	2.3	0.6-8.4	2.6
130	0-6.9	0.8	0-8.3	1.5	0-8.3	1.5	0-8.4	1.6	0-8.3	2.0
100	0-7.1	0.8	0-8.5	1.4	0-8.5	1.3	0-8.5	1.4	0-8.5	1.6

1974 - 75										
			Watana Operational				Devil Canyon Operational			
	Natural		1996		2001		2002		2020	
RM	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
150	0-8.5	0.9	0-9.8	2.0	0-9.8	2.2	1.2-9.4	3.0	0.5-10.0	3.0
130	0-8.6	1.0	0-9.6	1.7	0-9.6	1.8	0-9.4	2.3	0-9.9	2.3
100	0-9.1	1.1	0-10.0	1.5	0-10.0	1.6	0-9.9	1.9	0-10.3	1.9

1981 - 82										
			Watana Operational				Devil Canyon Operational			
	Natural		1996		2001		2002		2020	
RM	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
150	0-7.7	1.1	0-9.1	2.8	0.4-9.0	3.0	1.8-8.3	4.0	0.8-8.6	3.9
130	0-7.9	1.1	0-9.1	2.4	0-9.0	2.5	0.7-8.2	3.2	0-8.5	3.4
100	0-8.4	1.3	0-9.5	2.1	0-9.4	2.1	0-8.6	2.4	0-9.0	2.7

1982 - 83										
			Watana Operational				Devil Canyon Operational			
	Natural		1996		2001		2002		2020	
RM	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
150	0-7.9	1.1	0.1-9.0	2.7	0-9.0	2.9	0.9-8.6	3.5	0.6-9.1	3.2
130	0-8.0	1.2	0-8.9	2.3	0-8.8	2.4	0-8.6	2.8	0-9.0	2.7
100	0-8.4	1.3	0-9.2	2.0	0-9.1	2.1	0-8.9	2.2	0-9.3	2.1

the mainstem and side channel habitat for migration with the exception of burbot which use the mainstem year-round.

SALMON

Adult Immigration

The Upper Susitna salmon peak immigration period is from late June through early September (see Table 10). Natural June temperatures range from approximately 8.0 to 13.1 C above the Chulitna confluence and 7.8 to 12.4 C near Portage Creek. During Watana filling, water temperatures would be approximately 2.2 C cooler above the confluence and 3.7 C cooler at Portage Creek. Watana-only operational water temperatures would range from 1.6 to 2.9 C cooler above the confluence and 0.9 to 4.0 C cooler at Portage Creek. Devil Canyon operational temperatures would range from 1.7 to 3.1 C cooler above the confluence and 3.3 to 5.2 C cooler at Portage Creek. The only salmon entering the Upper Susitna during June are chinook, the majority of which pass Talkeetna during the last week in June and first three weeks in July.

Natural July Susitna River temperatures range from approximately 9 to 13.5 C above the Chulitna confluence and 8.5 to 13 C near Portage Creek. During Watana filling, water temperatures would be approximately 1.6 to 2.0 C cooler above the confluence and 2.5 - 3.5 C cooler near Portage Creek. Watana-only operational water temperatures would range from 0 to 1.5 C cooler above the confluence and 0.2 to 2.0 C cooler at Portage Creek. Devil Canyon operational temperatures would range from 0.9 to 2.7 C cooler above the confluence and 2.0 to 3.8 C cooler near Portage Creek.

Natural August Susitna River temperatures range from approximately 8 to 12 C just above the Chulitna confluence to 7.5 to 11 C near Portage Creek.

During Watana filling, water temperatures would be approximately 0 to 2.0 C cooler above the confluence and 0 to 3.0 C cooler at Portage Creek. Watana-only operational temperatures would range from 0 to 1.3 cooler above the confluence and 0 to 1.3 C cooler near Portage Creek. Devil Canyon operational temperatures would range from 0.1 to 2.4 C cooler above the confluence and 0.7 to 3.3 C cooler at Portage Creek. Chinook Salmon will have nearly completed their spawning immigration by August, but the other four salmon species will be at their peak abundance in the mainstem while moving toward spawning grounds.

Natural September Susitna River temperatures range from approximately 2.2 to 8.5 C near Portage Creek. During Watana filling, water temperatures would be approximately 0.7 to 1.9 C warmer above the confluence and 1.2 to 2.8 C warmer at Portage Creek. Watana-only operational temperatures would be approximately 1.6 C warmer above the confluence and 2.2 C warmer near Portage Creek. Devil Canyon operational temperatures would range from 1.7 to 2.3 C warmer above the confluence and 2.2 to 3.1 C warmer at Portage Creek. Except for coho salmon, mainstem adult migration is almost completed by September.

The simulated temperature regimes from Devil Canyon to the Chulitna confluence for filling and the one- and two-dam operational scenarios are cooler than natural for June, July, and August and warmer than natural for September. For the adult inmigrating salmon during June through September comparing the four meteorological data sets for reservoir outlet temperature simulations, there will then be reduced water temperatures from Devil Canyon to the Chulitna confluence during June through August and increased water temperatures in this reach during September for filling and both one- and two dam scenarios.

These cooler conditions are the most extreme during the two-dam scenario where water temperatures can be as much as 3 C cooler just above the Chulitna confluence and 5 C cooler near Portage Creek during June. July and August two-dam water temperatures could be as much as 2.7 and 2.4 C cooler above the confluence and 3.8 and 3.3 C cooler near Portage Creek respectively. Even though these temperatures are cooler than natural they are still well within the established temperature tolerances for Susitna adult salmon migrating to spawning habitats (Table 19 and Appendix H). These cooler June through August with-project temperatures are also comparable to the currently existing natural temperatures found in the Chulitna River where salmon naturally migrate to spawning habitats (D. Schmidt 1984). The warmer with-project September temperatures are also well within the temperature tolerances for migrating adult coho salmon (Table 19 and Appendix H). From the temperature simulation runs to date, there is no evidence of any with-project temperatures falling outside of the adult migration tolerance zones for salmon entering the Upper Susitna River (Appendix H).

Adult Spawning

Salmon spawn in the Susitna drainage above the Chulitna confluence from July through September (Table 10). In three years of observation, only 18 mainstem sites above the confluence have been identified as spawning locations. Chum salmon are the only species to have utilized mainstem spawning habitat to any extent and this limited spawning is believed to take place only in areas influenced by ground water upwelling.

The few chum salmon observed spawning in the mainstem do so during the first two weeks of September (Table 10). Chum salmon spawning in the mainstem during September would experience the same slightly warmer temperatures identified for adult inmigration and shown in Table 20. These simulated with-project temperatures for September are well within the spawning tolerances for chum salmon (Table 19). From the temperature simulation runs to date, there is no evidence of any with-project temperatures falling outside of the spawning tolerance zones for adult salmon (Appendix H). There is a possibility of improved spawning habitat from a temperature standpoint that is discussed under incubation.

Embryo Incubation

As described in the methods section and previously noted in the adult spawning section, only a small number of salmon spawn in areas influenced by the mainstem Susitna River. The most fish observed in three years of observation by ADF&G has been 550 chum salmon at nine different mainstem sites. These sites, however, were all believed to be influenced by temperatures from groundwater inflow. Chum salmon spawn in mainstem areas in September and the eggs incubate in the gravel through April.

With-project water temperatures are expected to be warmer during the incubation period of September through April. Simulated natural mainstem average water temperatures for the September to April period range from 0.8 to 1.3 C just above the Chulitna confluence and 0.7 to 1.1 C near Portage Creek (Table 21). During Watana filling, winter water temperatures will essentially mimic natural conditions (Appendix B). Watana-only operational average water temperatures would range from 0.4 to 0.8 C warmer just above the Chulitna confluence and 1.2 to 1.9 C warmer near Portage Creek. Devil Canyon operational temperatures would range from 0.8 to 1.4 C warmer just above the confluence and 1.9 to 2.9 C warmer at Portage Creek.

Referring to the chum salmon nomagraph (Figure 21) and using a spawning date of September 1 with an incubation temperature of 1 C, (an average incubation temperature for the mainstem), indicates fry emerging after June 10. This is much later than what occurs naturally and indicates additional influences on the incubation rate. As noted earlier, chum salmon have been observed to be spawning in mainstem areas influenced by groundwater. This groundwater upwelling is most likely emerces the incubating embryo in warmer water which speeds up development rate, enabling the fry to emerge at a time to ensure a viable population. The late emergence dates that would occur under the natural incubation temperature range of 0.7 to 1.3 C also indicates that temperature could be one limiting factor for successful reproduction in the mainstem in areas not influenced by groundwater upwelling.

Average mainstem temperatures under the Watana-only scenario range from 1.3 to 2.1 C just above the Chulitna confluence and 1.7 to 3.0 C near Portage Creek (Table 21). These temperatures are approaching the range which has been observed in successful slough incubation areas (2.9 to 7.4 with an average of 3.3 C; ADF&G 1983c). Fish spawned in September 1 at an average incubation temperature greater than 2.0 C should emerge in time to produce viable fry (Figure 17).

Average mainstem temperatures below the Devil Canyon dam will range from 1.4 to 2.7 just above the confluence and 2.3 to 4.0 C near Portage Creek (Table 21). Mainstem temperatures above RM 130 in all but the coldest year average above 2.0 C for the incubation period and any eggs deposited under these temperatures should produce viable fry. A better mainstem incubating habitat would exist under project scenarios due to the warmer incubating water temperatures.

Juvenile Rearing

Rearing takes place during the open water period of May through October. Rearing fish would experience the same thermal changes previously described for adult inmigration, i.e., with-project water temperatures would be cooler June through August and warmer in September for filling and operational scenarios (Table 20). In addition to the June through September scenarios, rearing fish will be subjected to cooler water temperatures in May and warmer temperatures in October.

Natural May temperatures range from 1.3 to 10.1 C just above the Chulitna confluence and 0.6 to 9.6 C near Portage Creek. For Watana filling, May temperatures would be 0.8 to 1.8 C cooler just above the Chulitna confluence and 1.0 to 3.2 C cooler at Portage Creek. Watana-only operational temperatures would be 0.6 to 2.9 C cooler above the confluence and 0.4 to 4.1 C cooler near Portage Creek. Devil Canyon operational temperatures would range from 0.8 to. 2.8 C cooler above the confluence and 1.1 to 5.0 cooler near Portage Creek.

Natural October temperatures range from 0 to 2.3 C just above the confluence and 0 to 2.2 C at Portage Creek. During Watana filling, October water water temperatures will be essentially the same as natural. Watana-only operational temperatures would be 2.1 to 3.1 C warmer just above the confluence and 3.4 to 4.2 C warmer near Portage Creek. Devil Canyon operational temperatures would range from 3.1 to 4.8 C warmer just above the confluence and 4.4 to 6.9 C warmer near Portage Creek.

In the Susitna River, only a small proportion of juvenile salmon (chinook 22.6%, coho 3.4%, chum 4.1% and sockeye 8.6%) were found to rear in mainstem or side channel habitats during this open water season (ADF&G 1983). The majority of the juvenile salmon rear in sloughs or tributary habitats where the potential for temperature impacts on growth would be small.

All of the May through October with-project water temperatures fall within the temperature tolerances established for juvenile rearing Table 19 and Appendix H). According to this criteria, there would be no lethal effects from temperature on juvenile salmon rearing. However, since fish growth is temperature dependent, the May through August cooler-than-natural conditions may retard juvenile salmon growth rates.

Estimates of seasonal fish growth were determined with a function of predicted water temperature and current body weight of the fish (Table 22). This growth function was determined by Brett (1974) from observations on sockeye salmon. In order to use this analysis, several assumptions have to be made: (1) growth starts at a body weight of 0.3g, (2) increase in weight occurs at temperatures from 3 to 18 C, (3) all salmon species would exhibit a similar growth pattern as that of sockeye salmon, and (4) fish feed to satiation.

Simulated temperatures near river mile 130 were used in predicting cumulative weight gains during the growing season (Table 22). River mile 130 was chosen as a representative site because it is near the center of the Upper Susitna and is close to many salmon natal areas. Natural growth in this area of the river would range between 5.5 and 8.5 g depending on which temperature simulation is used. Growth would range between 5.0 and 7.3 g for the Watana-only scenario and 3.9 to 6.4 g during Devil Canyon operation. Estimated reduction in fish growth near RM 130 ranges from 8 to 19% for Watana operational and 24 to 29% for Devil Canyon operations. Potential growth reductions would be more evident upstream of RM 130 where temperature differences between with-project and natural conditions are

Table 22. Temperature and cumulative growth for juvenile salmon under pre and post-project conditions at RM 130, 1974 simulations[1]

Month	Week	NATURAL Temp (C)	NATURAL Cum. Wt.(g)	WATANA 1996 Demand Temp (C)	WATANA 1996 Demand Cum. Wt.(g)	DEVIL CANYON 2000 Demand Temp (C)	DEVIL CANYON 2000 Demand Cum. Wt.(g)
May	31	5.6	.35	3.4	.33	2.6	.30
	32	5.7	.42	3.2	.36	2.4	.30
	33	6.1	.48	3.2	.40	2.8	.30
	34	9.1	.62	3.9	.44	3.5	.33
June	35	9.4	.78	5.2	.49	4.6	.37
	36	8.3	.92	5.7	.56	4.9	.42
	37	9.7	1.15	7.1	.65	6.0	.49
	38	9.8	1.44	7.8	.79	6.9	.58
	39	10.9	1.82	9.2	.96	8.2	.71
July	40	10.8	2.26	9.8	1.20	8.7	.87
	41	10.3	2.72	8.1	1.41	7.8	1.02
	42	10.8	3.29	9.3	1.69	8.7	1.23
	43	10.5	3.89	9.5	2.09	9.1	1.47
August	44	10.7	4.52	10.0	2.52	9.9	1.83
	45	10.6	5.21	10.2	3.04	8.6	2.16
	46	10.4	5.90	10.4	3.54	9.3	2.52
	47	7.9	6.43	8.8	4.01	9.0	2.93
	48	9.4	7.09	8.9	4.48	9.1	3.35
September	49	8.6	7.76	9.6	5.14	9.4	3.80
	50	7.0	8.20	8.7	5.70	9.2	4.27
	51	5.8	8.55	7.4	6.09	9.0	4.77
	52	4.1	8.76	5.8	6.39	8.0	5.24
October	1	0.1	8.76	3.6	6.57	6.1	5.52
	2	0.0	8.76	3.7	6.75	5.6	5.83
	3	0.2	8.76	3.1	6.93	4.5	6.05
	4	0.1	8.76	3.1	7.12	3.7	6.22
Cumulative weight gain			8.56		6.82		5.92
Reduction from pre-project growth(%)					19		29

[1]Growth calculations based on specific growth rate data from Brett (1974).

Table 22. (Cont'd) Temperature and cumulative growth for juvenile salmon under pre and post-project conditions at RM 130, 1981 simulations[1]

		NATURAL		WATANA 1996 Demand		DEVIL CANYON 2002 Demand	
Month	Week	Temp (C)	Cum. Wt.(g)	Temp (C)	Cum. Wt.(g)	Temp (C)	Cum. Wt.(g)
May	31	5.1	.34	3.9	.33	3.0	.33
	32	7.5	.44	4.4	.36	4.0	.36
	33	8.2	.55	4.8	.41	4.7	.41
	34	8.1	.67	6.0	.48	5.4	.46
June	35	9.4	.84	7.2	.57	6.0	.53
	36	8.8	1.02	6.9	.66	6.5	.62
	37	11.5	1.32	8.9	.82	8.0	.75
	38	12.3	1.72	10.3	1.04	8.7	.92
	39	9.1	2.05	8.5	1.24	7.8	1.08
July	40	9.0	2.39	8.3	1.46	7.6	1.27
	41	9.4	2.78	8.2	1.71	6.7	1.43
	42	9.9	3.29	9.8	2.11	5.1	1.53
	43	10.3	3.83	10.7	2.60	6.0	1.69
August	44	10.0	4.42	10.1	3.11	7.6	1.98
	45	10.0	5.08	9.1	3.53	7.8	2.27
	46	7.6	5.56	8.1	3.94	7.6	2.59
	47	8.1	6.08	7.9	4.36	7.5	2.95
	48	10.1	6.84	8.9	4.87	7.9	3.31
September	49	7.9	7.40	9.1	5.41	8.2	3.70
	50	7.3	7.83	8.0	5.92	8.2	4.12
	51	6.5	8.27	8.2	6.45	8.2	4.54
	52	2.2	8.27	6.1	6.76	7.6	5.00
October	1	1.0	8.27	5.2	7.00	6.8	5.35
	2	0.9	8.27	4.7	7.24	6.8	5.72
	3	1.4	8.27	4.2	7.43	6.1	6.03
	4	0.5	8.27	3.5	7.63	5.4	6.25
Cumulative weight gain			7.97		7.33		5.95
Reduction from pre-project growth(%)					8		24

[1]Growth calculations based on specific growth rate data from Brett (1974).

Table 22. (Cont'd) Temperature and cumulative growth for juvenile salmon under pre and post-project conditions at RM 130, 1982 simulations[1]

		NATURAL		WATANA 1996 Demand		DEVIL CANYON 2000 Demand	
Month	Week	Temp (C)	Cum. Wt.(g)	Temp (C)	Cum. Wt.(g)	Temp (C)	Cum. Wt.(g)
May	31	5.5	.35	4.1	.33	4.6	.34
	32	4.7	.40	3.5	.36	4.4	.37
	33	6.7	.48	3.9	.40	5.0	.42
	34	6.6	.57	4.0	.44	5.2	.47
June	35	8.4	.70	5.0	.49	5.8	.54
	36	8.9	.86	5.8	.56	5.8	.62
	37	8.0	1.02	6.4	.63	6.1	.69
	38	9.6	1.27	7.3	.74	7.4	.80
	39	11.8	1.65	9.0	.91	8.6	.98
July	40	10.6	2.07	10.5	1.15	9.1	1.17
	41	11.1	2.55	10.2	1.43	10.6	1.48
	42	11.2	3.12	10.2	1.79	7.4	1.67
	43	10.0	3.63	9.3	2.12	6.0	1.84
August	44	11.0	4.26	9.8	2.56	6.6	2.06
	45	11.2	4.93	10.1	3.07	7.4	2.29
	46	11.0	5.63	10.0	3.57	8.3	2.61
	47	11.0	6.41	10.4	4.15	9.0	3.04
	48	9.5	7.20	9.1	4.64	8.7	3.44
September	49	8.0	7.77	8.9	5.18	8.6	3.90
	50	6.7	8.21	8.5	5.75	8.5	4.38
	51	6.6	8.67	7.5	6.27	8.3	4.83
	52	4.4	8.88	7.2	6.67	8.0	5.30
October	1	2.3	8.88	6.0	6.99	7.6	5.80
	2	0.3	8.88	5.0	7.23	6.9	6.19
	3	0.0	8.88	3.6	7.43	5.9	6.49
	4	0.0	8.88	1.2	7.43	4.3	6.66
Cumulative weight gain			8.58		7.13		6.36
Reduction from pre-project growth(%)					16		25

[1]Growth calculations based on specific growth rate data from Brett (1974).

Table 22. (Cont'd) Temperature and cumulative growth for juvenile salmon under pre and post-project conditions at RM 130, 1971 simulations[1]

		NATURAL		WATANA 1996 Demand		DEVIL CANYON 2000 Demand	
Month	Week	Temp (C)	Cum. Wt.(g)	Temp (C)	Cum. Wt.(g)	Temp (C)	Cum. Wt.(g)
May	31	0.9	.30	2.3	.30	2.2	.30
	32	2.9	.30	3.0	.33	2.5	.30
	33	4.5	.34	3.4	.36	2.8	.30
	34	4.6	.39	3.5	.40	2.9	.30
June	35	4.4	.42	3.3	.44	3.0	.33
	36	9.2	.55	5.1	.49	4.2	.36
	37	7.7	.67	4.9	.54	4.4	.40
	38	10.3	.87	6.7	.64	5.4	.45
	39	11.2	1.11	7.8	.77	7.0	.54
July	40	10.5	1.40	8.0	.91	7.1	.63
	41	12.5	1.40	9.7	1.14	8.3	.76
	42	9.9	1.74	8.3	1.34	8.0	.91
	43	8.8	2.08	8.4	1.57	8.1	1.07
August	44	11.1	2.56	9.3	1.88	8.5	1.28
	45	10.8	3.13	8.9	2.21	7.0	1.43
	46	10.9	3.69	8.9	2.58	6.8	1.61
	47	9.7	4.28	8.9	3.00	8.5	1.93
	48	9.0	4.78	8.9	3.41	8.6	2.27
September	49	6.9	5.14	8.3	3.81	8.4	2.59
	50	6.4	5.42	7.9	4.24	8.1	2.95
	51	5.4	5.64	7.2	4.57	7.6	3.31
	52	3.3	5.80	6.2	4.84	7.0	3.60
October	1	1.7	5.80	4.8	5.04	5.9	3.84
	2	0.5	5.80	4.2	5.19	4.9	4.03
	3	0.0	5.80	3.2	5.35	4.0	4.16
	4	0.0	5.80	1.5	5.35	2.0	4.16
Cumulative weight gain			5.50		5.04		3.86
Reduction from pre-project growth(%)					8		28

[1]Growth calculations based on specific growth rate data from Brett (1974).

greater (Table 20 and 23). Downstream from RM 130, potential growth reductions would decrease with smaller temperature differences between with-project and natural scenarios (Tables 20 and 23). Moving downstream, more rearing occurs as more fish enter the system from adjacent slough and tributary habitats.

Growth can be limited by food supply in addition to the controlling effects of temperature. In nature, salmon and trout growth rates are food-supply limited (Brett, et al. 1969). Changes in temperature result in smaller changes in growth at reduced rations compared to satiation feeding. Small drops in temperature during July and August from 10 - 11°C to 8 - 9°C would result in smaller changes in growth rates for fish feeding at reduced ration than those at maximum ration. Since the Susitna River fish are likely feeding on a ration less than satiation level, the expected changes in growth due to temperature reductions would likely be smaller than those predicted in Table 22. Growth reductions, however, could be higher than predicted for fish such as chum salmon that are only actively feeding in the area until mid-July and not able to take advantage of the warmer fall temperatures.

Smolt Outmigration

Outmigrating smolts would experience the same thermal changes previously described for adult inmigration and rearing, i.e., with-project water temperatures would be cooler May through August and warmer in September for filling and operational scenarios (Table 20). Peak juvenile out-migration occurs from June through September and varies by species (Table 10).

The majority of the with-project related temperatures during salmon outmigrating periods fall near or within the established temperature tolerances (Table 19 and Appendix H). According to this criteria, there would be no

Table 23. Simulated monthly mean temperatures (C) for the mainstem Susitna River, Devil Canyon to Talkeetna.

Location	Month	Natural	Watana Opr.	Dif.	DC Oper.	Dif.	Watana Filling	Dif.
Portage Creek (148.9)	May	6.2	3.7	-2.5	3.1	-3.1	3.4	-2.8
	June	9.9	7.2	-2.7	5.7	-4.2	6.2	-3.7
	July	10.4	9.3	-1.1	7.6	-2.8	7.5	-2.9
	Aug	9.9	9.2	-0.7	8.0	-1.9	8.6	-1.3
	Sept	5.9	8.0	+2.1	8.5	+2.6	7.9	+2.0
	Oct	0.6	4.4	+3.8	6.1	+5.5	0.9	+0.3
Sherman (130.8)	May	6.2	4.1	-2.1	3.8	-2.4	3.8	-2.4
	June	9.8	7.4	-2.4	6.5	-3.3	6.6	-3.2
	July	10.4	9.3	-1.1	8.1	-2.3	7.9	-2.5
	Aug	10.0	9.3	-0.7	8.3	-1.7	8.9	-1.1
	Sept	6.2	7.8	+1.6	8.3	+2.1	7.6	+1.4
	Oct	0.6	3.8	+3.2	5.3	+4.7	0.9	+0.3
Whiskers Creek (101.4)	May	6.8	5.2	-1.6	5.1	-1.7	5.1	-1.7
	June	10.4	8.8	-1.6	8.3	-2.1	8.1	-2.3
	July	11.0	10.4	-0.6	9.6	-1.4	9.2	-1.8
	Aug	10.5	10.0	-0.5	9.2	-1.3	9.7	-0.8
	Sept	6.4	7.9	+1.5	8.3	+1.9	7.6	+1.2
	Oct	0.6	3.1	+2.5	4.3	+3.7	0.7	+0.1

lethal effects from temperature on juvenile outmigration. However, near Portage Creek, early June temperatures for the Devil Canyon operational scenario using 1971 meteorology, are predicted to fall slightly outside the established tolerances (Table 19, Appendices B and H). Thus outmigrants from tributaries or sloughs near Portage Creek subjected to cold Devil Canyon operational scenario would confront mainstem temperatures cooler than the lower tolerance level for sockeye, pink and chinook salmon (Table 19 and Appendix H). These temperatures, which are below 4 C, are also considerably cooler than the lower migration threshold for chinook and coho described by Raymond (1979), Cederholm and Scarlett (1982), and Bustard and Narver (1975). During cold scenarios, early June out-migrating salmon could avoid the mainstem and delay out-migration until temperatures warm in late June. As this delay would be two weeks or less in duration and occur only during the coldest scenarios, it should not noticably affect out-migration timing. Temperature is also not the only factor affecting migration timing. Photoperiod, water current, magnetic fields, and lunar phases are all believed to influence migration (Groot 1982 and Godin 1980).

Resident Species many?

The majority of the resident species using habitats in the Talkeetna to Devil Canyon reach of the Susitna River are found throughout most of their life history in tributaries and sloughs. Utilization of the habitats influenced by mainstem water is usually limited to migration or overwintering. No temperature tolerances have been established for resident species; however, since these resident fish spend most of their active feeding and reproduction life phases in areas not directly influenced by mainstem water, they should not experience any adverse temperature effects from project operation. The warmer water temperatures above RM 130 during both the one- and two-dam operational scenarios (Table 21 and Appendix B) should provide a good overwintering environment for outmigrating resident species such as rainblow trout and Arctic grayling from Portage Creek and Indian River.

Burbot and whitefish are the only resident species found in sufficient numbers utilizing habitats influenced by mainstem water temperatures that would be affected by project operation. Both burbot and whitefish spawning and incubation could be altered due to warmer fall and winter temperatures.

Burbot spawn in winter under the ice at water temperatures usually less than 3 C. In the Susitna drainage, this normally takes place in January and February. Under the one- and two-dam project operational scenarios, these conditions may not exist. The ice front will be located between RM 120 and 140 (Appendix B) depending on meteorology. In general, the ice front is farther downstream under the two-dam scenario than for Watana-only. The lack of an ice cover and the warmer winter water temperatures would preclude burbot spawning in the area upstream of the ice front. The extent of this preclusion would vary between RM 120 and 140 depending on meteorology and dam operation.

Whitefish spawn in October under conditions of rapidly decreasing water temperatures. Under the one-dam project scenario, October temperatures would be 2.1 to 4.1 C warmer between Whiskey and Portage creeks and 3.1 to 6.2 C warmer under the two-dam scenario (Table 20). These warmer temperatures could result in a change in the incubation timing for whitefish in this section of the river. The warmer water temperatures would accelerate the development rates of the incubating embryos resulting in early emerging fry. The fry would emerge before their normal time in May and would have reduced survival due to their encounter with a colder more hostile environment with inadequate seasonal food development.

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