"SUSITNA AQUATIC STUDY PROGRAM.
INSTREAM TEMPERATURE AND ICE STUDIES
WORKSHO. .

MAY 15, 1984

HANDOUT MATERIALS."

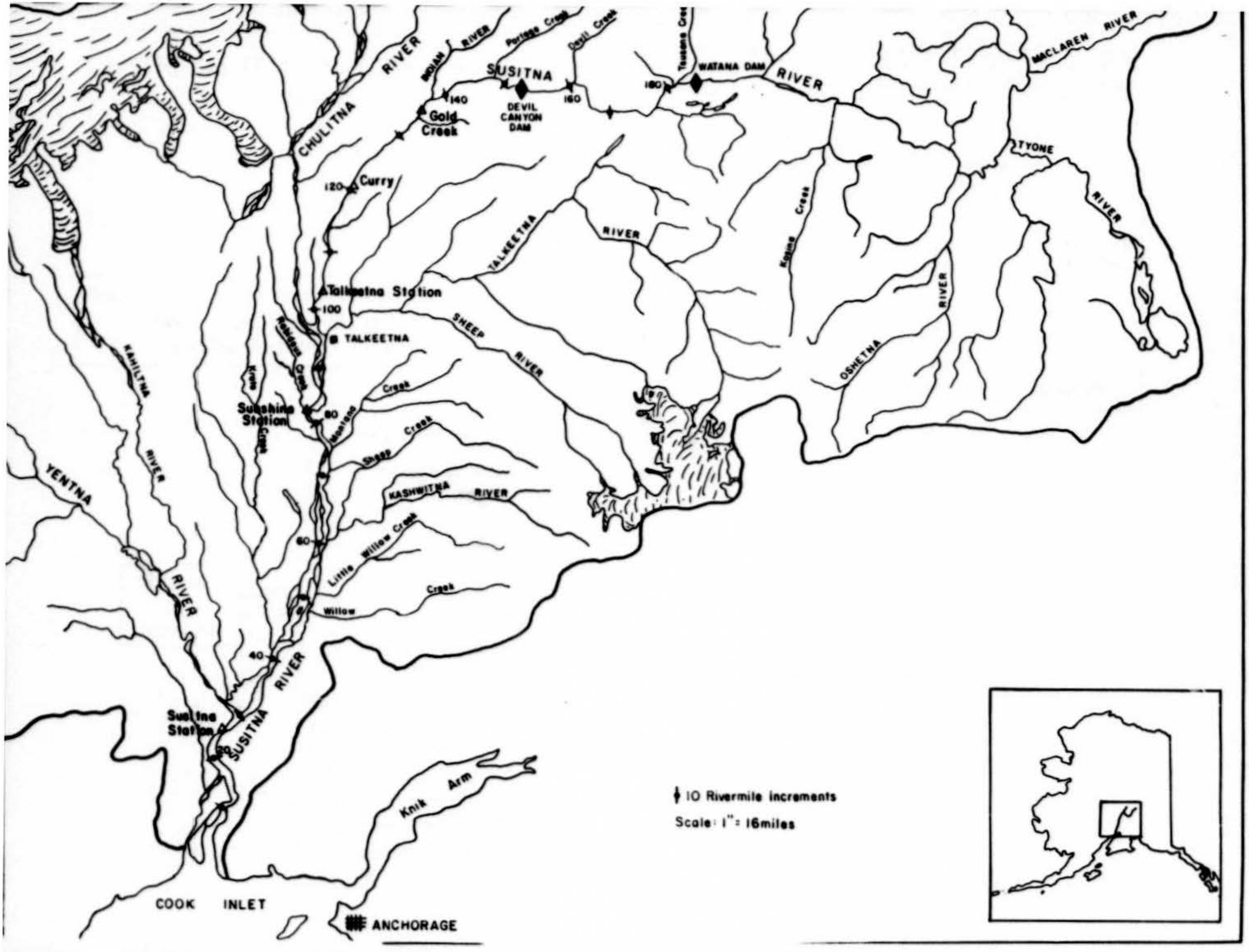
SUS
342

Ice and Temperature Studies Workshop
May 15, 1984

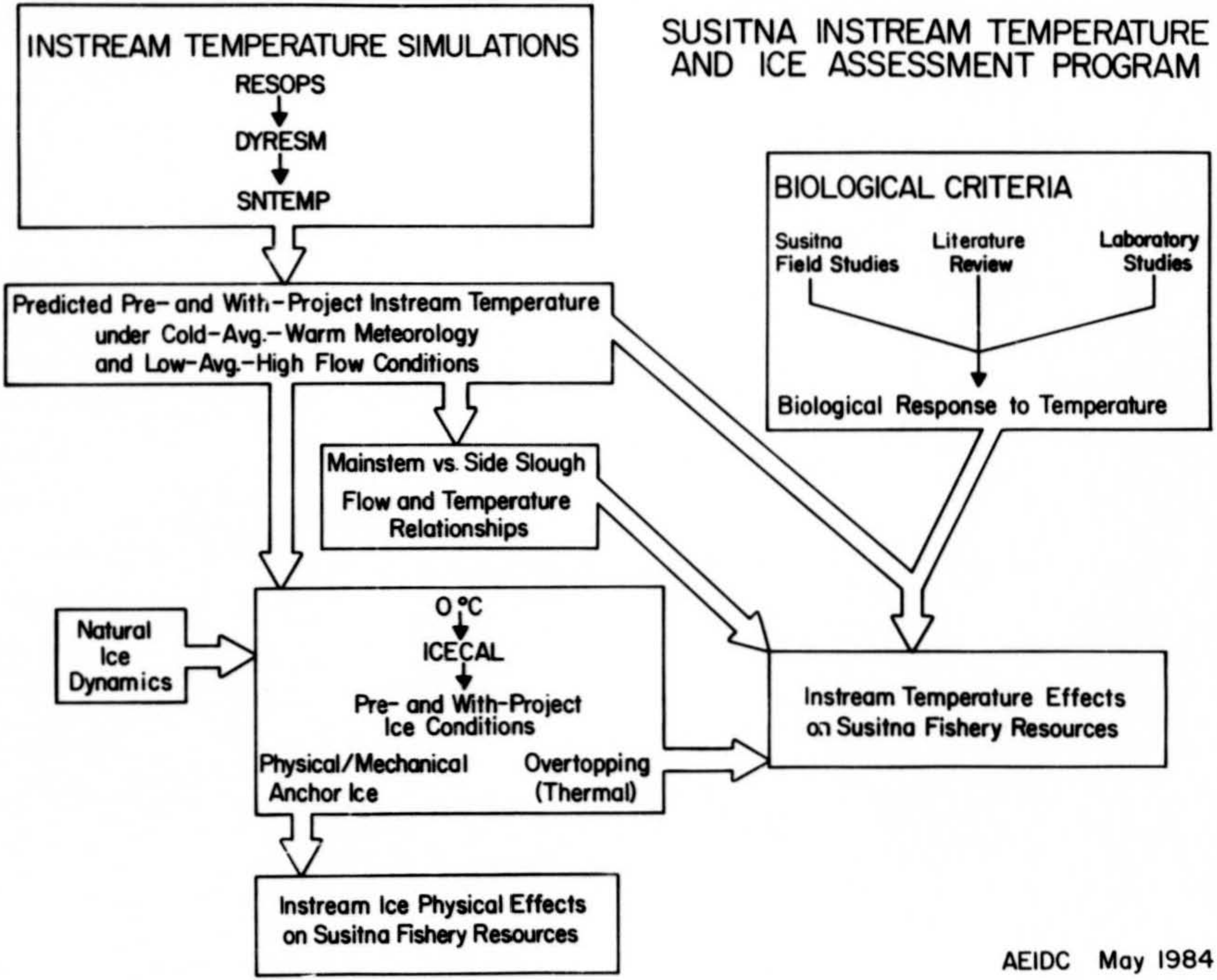
Agenda and Schedule

(8:30)	I.	Introduction
(8:45)	II.	Overview of Ice and Temperature Assessment Program
(9:00)		DISCUSSION
(9:30)	III.	Instream Temperature Predictions A. Reservoir Conditions B. Instream Temperature Conditions C. Side Slough Temperature Conditions
(10:10)		DISCUSSION
(10:50)		BREAK
(11:00)	IV.	Development of Temperature Criteria for Fishery Assessment A. Field Studies of Instream Habitat (Temperature) Relationships B. Literature Review and Laboratory Studies
(11:30)		DISCUSSION
(12:00)		LUNCH
(1:00)	V.	Analysis of Instream Temperature Effects
(1:20)		DISCUSSION
(2:00)	VI.	Instream Ice Predictions and Analysis A. Natural Instream Ice Conditions 1. Physical Processes 2. Fishery Habitat Investigations B. With Project Instream Ice Predictions C. Ice Assessment Approach
(3:00)		DISCUSSION
(3:45)	VII.	Summary & Announcements

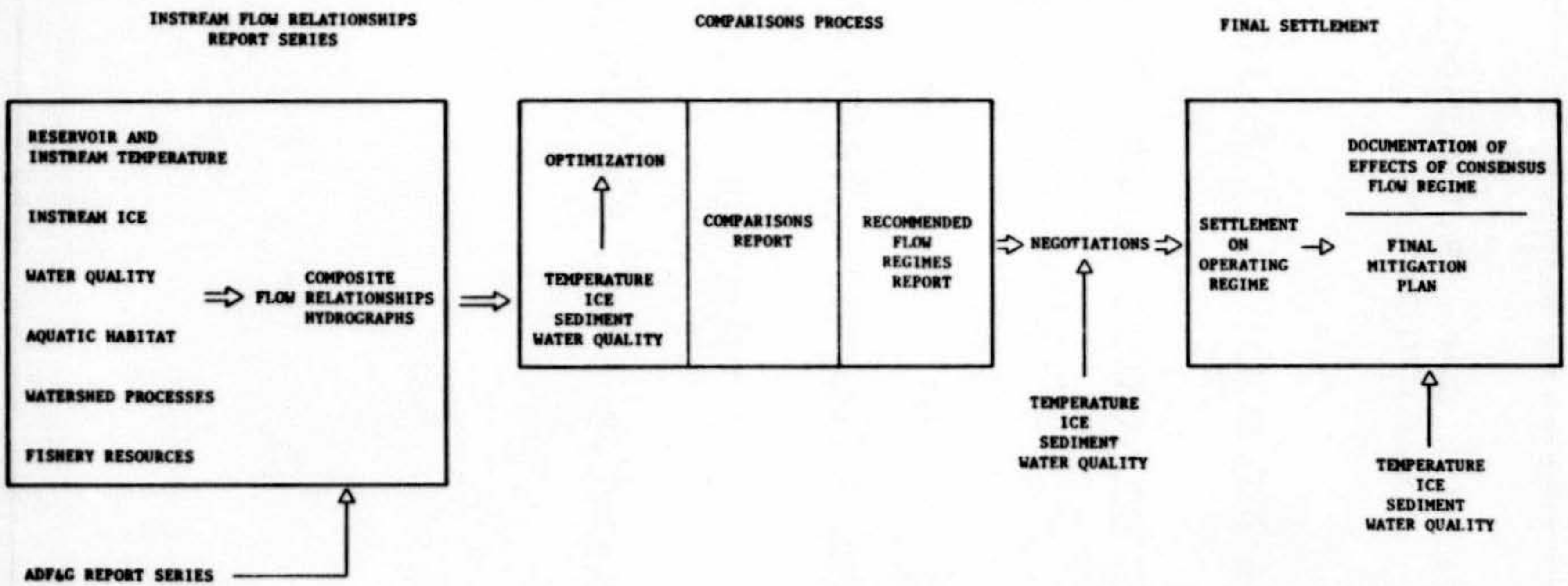
Presentations will be brief; opportunity will be provided for answering questions after each presentation. Longer discussion periods follow each workshop segment.


MACLAREN RIVER
Portage Creek
Devil Creek
Tsusena Creek
WATANA DAM
SUSITNA
RIVER
INDIAN RIVER
CHULITNA RIVER
140
Gold Creek
DEVIL CANYON DAM
160
180
TYONE
RIVER
Curry
120
TALKEETNA
RIVER
Kosina Creek
Talkeetna Station
100
TALKEETNA
SHEEP RIVER
OSHETNA
RIVER
Rabideux Creek
Krota Creek
Sunshine Station
80
Montana Creek
Sheep Creek
KAHILTNA RIVER
YENTNA
KASHWITNA RIVER
60
Little Willow Creek
Willow Creek
RIVER
40
SUSITNA RIVER
Susitna Station
20
Knik Arm
10 Rivermile increments
Scale: 1" = 16miles
COOK INLET
ANCHORAGE

SUSITNA INSTREAM TEMPERATURE AND ICE ASSESSMENT PROGRAM



AEIDC May 1984

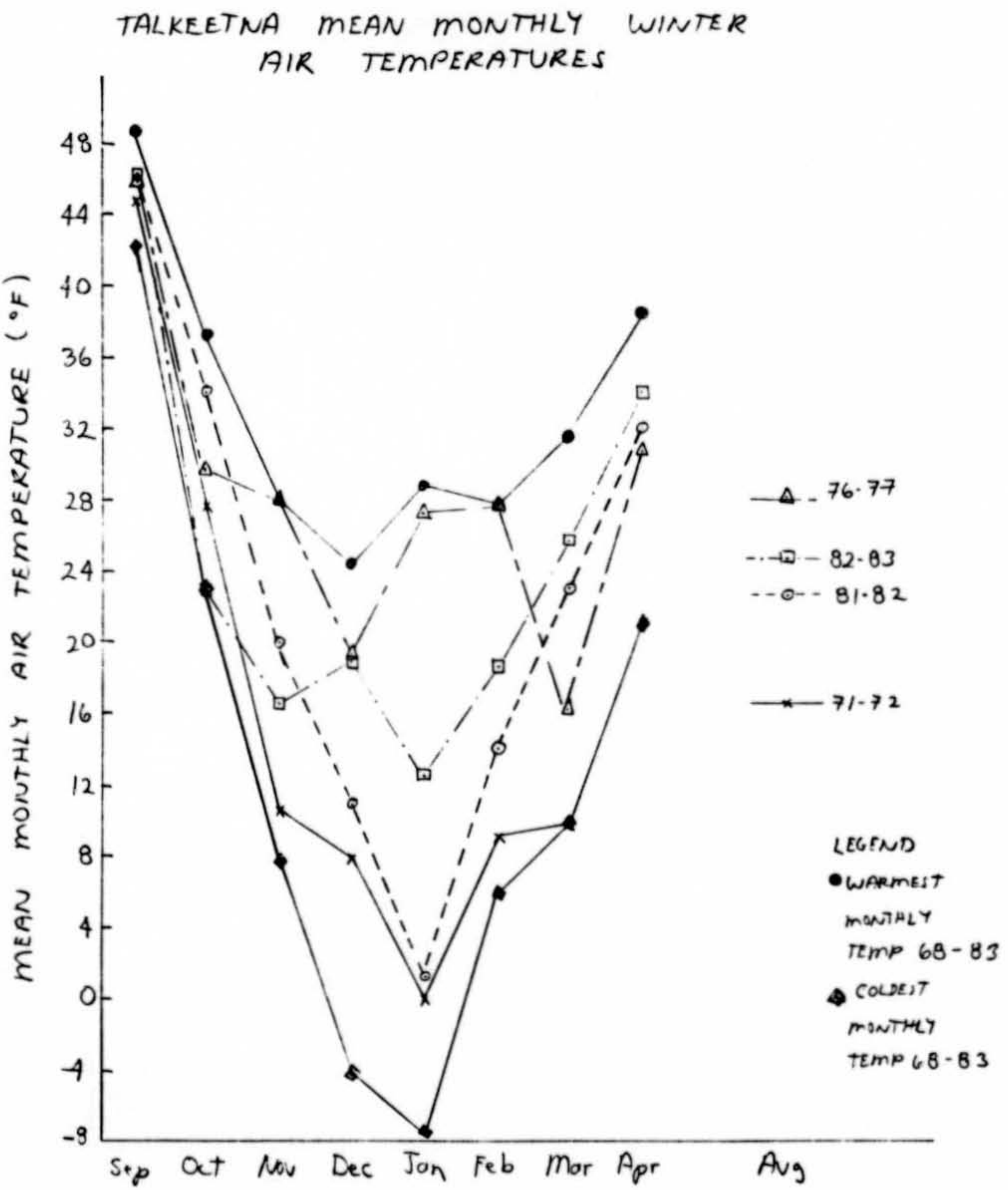

INSTREAM FLOW RELATIONSHIPS REPORT SERIES
COMPARISONS PROCESS
FINAL SETTLEMENT
RESERVOIR AND INSTREAM TEMPERATURE
INSTREAM ICE
WATER QUALITY
AQUATIC HABITAT
WATERSHED PROCESSES
FISHERY RESOURCES
COMPOSITE FLOW RELATIONSHIPS HYDROGRAPHS
ADF&G REPORT SERIES
OPTIMIZATION
TEMPERATURE ICE SEDIMENT WATER QUALITY
COMPARISONS REPORT
RECOMMENDED FLOW REGIMES REPORT
NEGOTIATIONS
TEMPERATURE ICE SEDIMENT WATER QUALITY
SETTLEMENT ON OPERATING REGIME
DOCUMENTATION OF EFFECTS OF CONSENSUS FLOW REGIME
FINAL MITIGATION PLAN
TEMPERATURE ICE SEDIMENT WATER QUALITY

WATER TEMPERATURE AND ICE SIMULATION METHODOLOGY

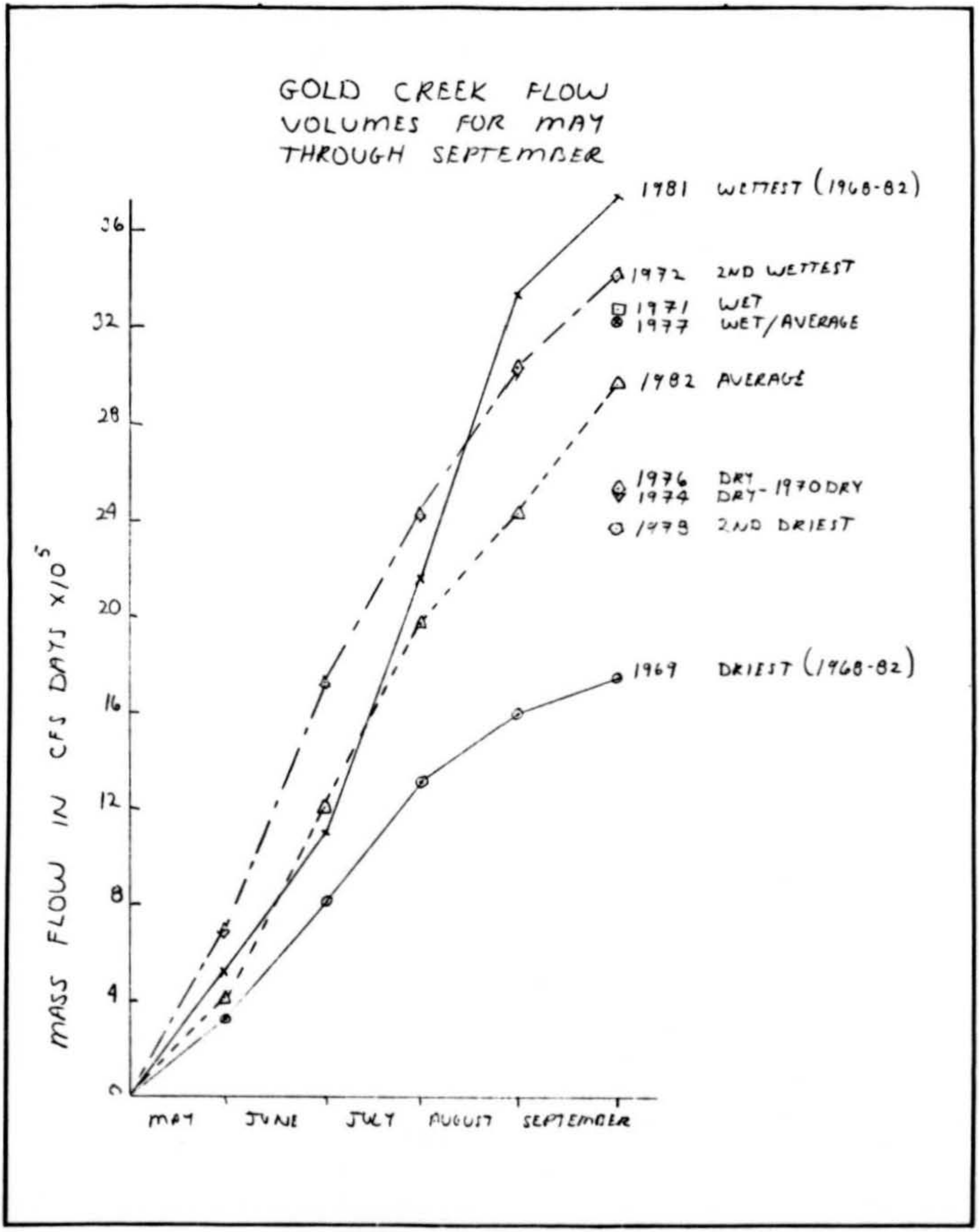
1. RATIONALE - BOUNDING
2. WINTER AND SUMMER SIMULATION PERIODS
3. METEOROLOGIC AND HYDROLOGIC CONDITIONS
4. PROJECT OPERATION
5. SUMMARY OF EXTREME CASES

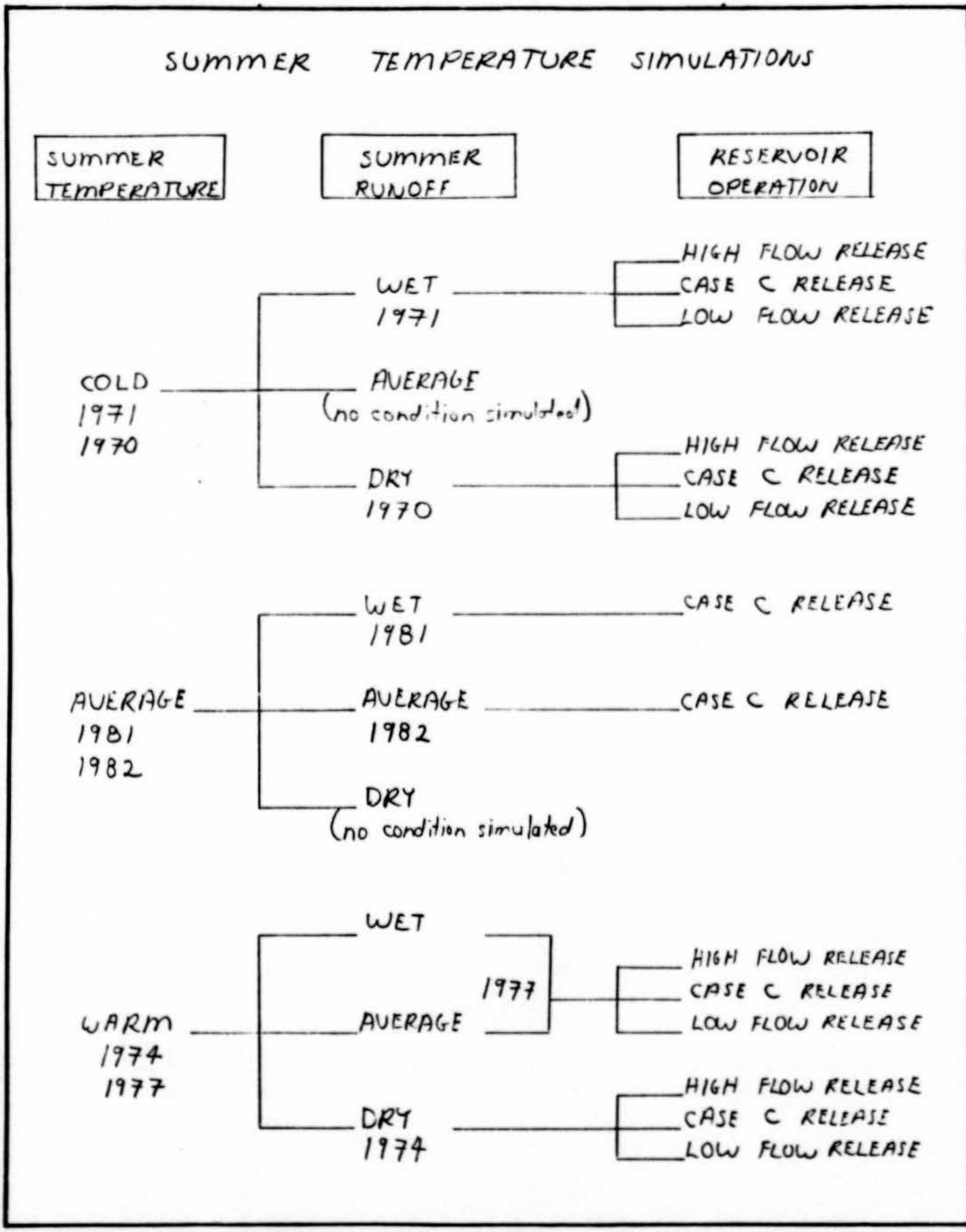
WINTER TEMPERATURE AND ICE SIMULATIONS

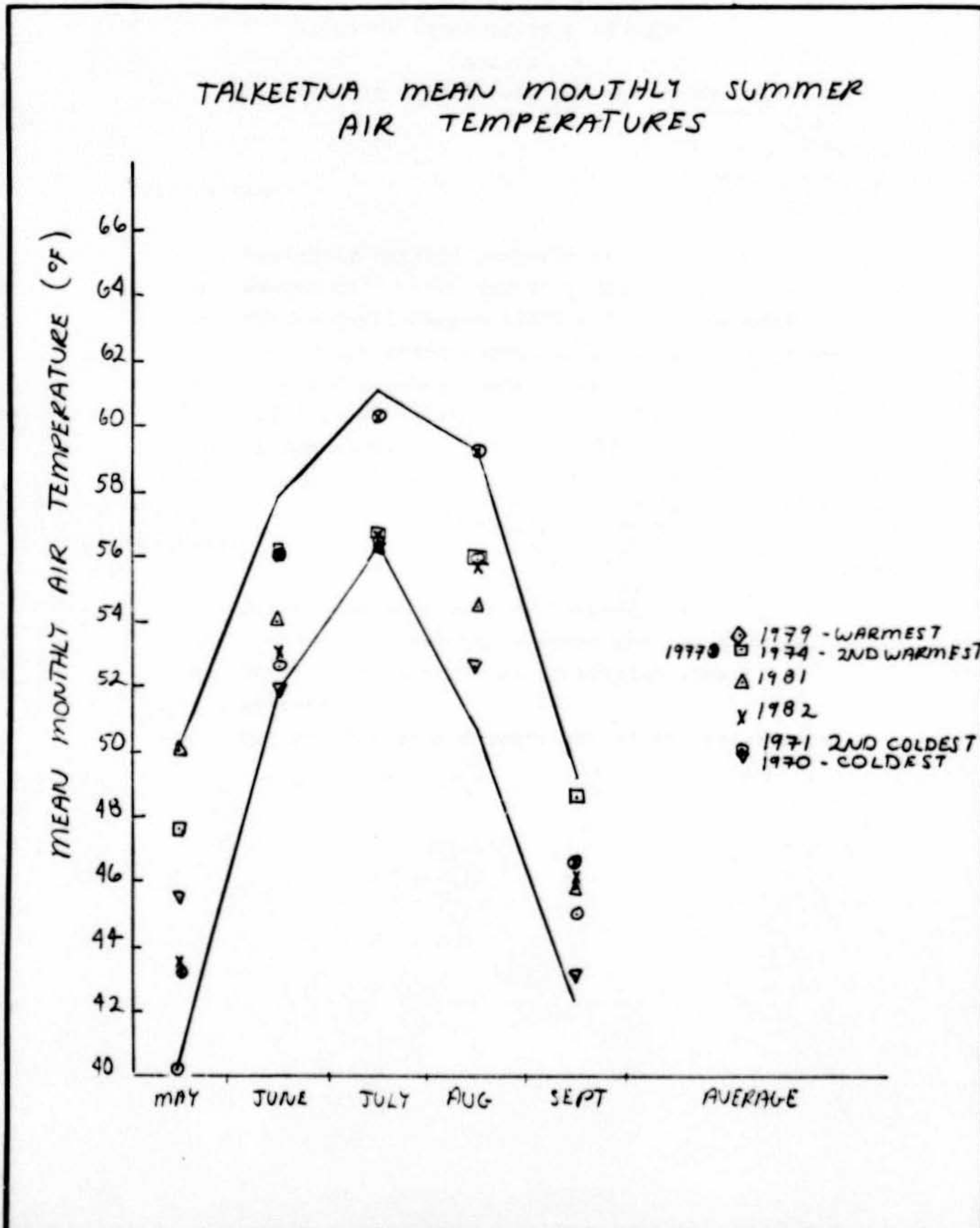
WINTER TEMPERATURE	ANTECEDENT SUMMER RUNOFF	RESERVOIR OPERATION RULE
COLD (71-72)	WET (71-72)	DUPLICATE NATURAL (ie. try for 0°C)
		WARMEST OUTFLOW TEMPERATURE
	AVERAGE (no conditions simulated)	
	DRY (synthetic)	DUPLICATE NATURAL (schedule A)
		WARMEST OUTFLOW TEMPERATURE (sched A)
		DUPLICATE NATURAL SEVERE DROUGHT (constant 5000cfs)
AVERAGE (81-82 82-83 74-75)	WET (81-82)	DUPLICATE NATURAL
	AVERAGE (82-83)	DUPLICATE NATURAL
	DRY (74-75)	DUPLICATE NATURAL
WARM (76-77)	WET (synthetic)	DUPLICATE NATURAL (schedule B)
		WARMEST OUTFLOW TEMPERATURE (sched B)
	AVERAGE (no conditions simulated)	
	DRY (76-77)	DUPLICATE NATURAL
		WARMEST OUTFLOW TEMPERATURE



TALKEETNA MEAN MONTHLY WINTER AIR TEMPERATURES
MEAN MONTHLY AIR TEMPERATURE (°F)
48
44
40
36
32
28
24
20
16
12
8
4
0
-4
-8
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Aug
MONTH
76-77
82-83
81-82
71-72
LEGEND
WARMEST MONTHLY TEMP 68-83
COLDEST MONTHLY TEMP 68-83


GOLD CREEK FLOW VOLUMES FOR MAY THROUGH SEPTEMBER
1981 WETTEST (1968-82)
1972 2ND WETTEST
1971 WET
1977 WET/AVERAGE
1982 AVERAGE
1976 DRY - 1970 DRY
1974 DRY
1978 2ND DRIEST
1969 DRIEST (1968-82)
MASS FLOW IN CFS DAYS X10^5
36
32
28
24
20
16
12
8
4
0
MAY
JUNE
JULY
AUGUST
SEPTEMBER


SUMMER TEMPERATURE SIMULATIONS
SUMMER TEMPERATURE
SUMMER RUNOFF
RESERVOIR OPERATION
COLD 1971 1970
WET 1971
HIGH FLOW RELEASE
CASE C RELEASE
LOW FLOW RELEASE
AVERAGE (no condition simulated)
DRY 1970
HIGH FLOW RELEASE
CASE C RELEASE
LOW FLOW RELEASE
AVERAGE 1981 1982
WET 1981
CASE C RELEASE
AVERAGE 1982
CASE C RELEASE
DRY (no condition simulated)
WARM 1974 1977
WET
AVERAGE
1977
HIGH FLOW RELEASE
CASE C RELEASE
LOW FLOW RELEASE
DRY 1974
HIGH FLOW RELEASE
CASE C RELEASE
LOW FLOW RELEASE



TALKEETNA MEAN MONTHLY SUMMER AIR TEMPERATURES
MEAN MONTHLY AIR TEMPERATURE (°F)
66
64
62
60
58
56
54
52
50
48
46
44
42
40
MAY
JUNE
JULY
AUG
SEPT
AVERAGE
1979 - WARMEST
1977 1974 - 2ND WARMEST
1981
1982
1971 2ND COLDEST
1970 - COLDEST

SUSITNA HYDROELECTRIC PROJECT

TASK 42

RESERVOIR TEMPERATURE AND ICE STUDY

Introduction:

- o Reservoir outflow temperatures.
- o Watana only (1996 and 2001 demands).
- o Watana/Devil Canyon (2002 and 2020 demands).
- o Case C operating condition (Aug. min Q = 12,000 cfs).
- o Flow and weather conditions.
- o Multi-level intakes.
- o DYRESM model.
- o Eklutna Lake Study.

Purposes:

- o Daily reservoir outflow temperatures.
- o Downstream river temperature and ice studies.
- o Environmental study and potential impact assessment.
- o Optimal design and operation of the reservoirs.

CYW H/E May 13, 1984

The Reservoirs:

a. Physical Characteristics:

a.1. Watana Reservoir:

(1) Dam height = 885 ft

(2) At El. 2185 ft. norm. max. operating level:

Surface area = 38,000 acres

Total volume = 9,470,000 acre-ft

Reservoir length = 48 miles

Max. depth = 725 ft

Shoreline length = 183 miles

a.2. Devil Canyon Reservoir:

(1) Dam height = 646 ft

(2) At El. 1455 ft. norm. max. operating level:

Surface area = 7,800 acres

Total volume = 1,090,000 acre-ft

Reservoir length = 26 miles

Max. depth = 580 ft

Shoreline length = 76 miles

Watana Operation:

(a) Multi-level intake:

Four-level ports (6 units).

(b) Mid-level outlet work:

Cone valve max. Q = 24,000 cfs.

(c) Spillway (gated):

Allows surcharge to El. 2193.0.

Devil Canyon Operation:

(a) Multi-level intake:

Two-level ports (4 units).

(b) Mid-level intake:

Passes flow up to 38,500 cfs through cone valves.

(c) Spillway (gated):

No surcharge considered.

Reservoir Operation:

1. Multi-level intake structures:
   - (1) Watana = 4-level ports.
   - (2) Devil Canyon = 2-level ports.
   - (3) Single level operation.
   - (4) Port level selection:
     Outflow temperature follows inflow temperature.
   - (5) Submergence requirement.

2. Watana Reservoir Filling:
   - (1) Filling criteria:
     - (a) Downstream flow requirements.
     - (b) Safe flood storage (250-yr flood).
     - (c) Low level outlet max. Q = 30,000 cfs.
   - (2) Simulation:
     - (a) Second year filling.
     - (b) 1974 flow and weather conditions.
   - (3) First year filling:
     - (a) 400 ft in 5 months (May-Sept.).
     - (b) expected outflow temperatures:
       Summer: ave. inflow temp. (1°-15°C).
       Winter: 4°C.
   - (4) Second year filling:
     - (a) additional 200 ft.
     - (b) expected outflow temperatures:
       Summer-Fall: 4°C.
       Winter: 1°-3°C (with intakes opeating).

The DYRESM Model:

- o Predicts the ave. reservoir thermal structure.
- o Simulates the principal physical processes through parameterizations.
- o Major constants determined from experimental or field data.
- o Reservoir is divided into horizontal slabs which move vertically.
- o The basic time step is one day but can be reduced to as small as one quarter hour.
- o Frazil ice input incorporated.
- o Snow-Ice model: tested and verified.
- o Daily flow and meteorological data required.
- o Past applications:
  - (1) Wellington Reservoir (Australia).
  - (2) Kootenay Lake (B.C., Canada).
  - (3) Babine Lake (B.C., Canada).
  - (4) Char Lake (NW Territory, Canada).

Calibration and Verification of the DYRESM Model:

Eklutna Lake Study:

(1) Eklutna Lake:
- o 30 miles NE of Anchorage.
- o 6.5 miles long.
- o 180 feet deep.

(2) Field data (since May 1982).
- o Flow and weather data (daily).
- o Outflow (powerhouse): daily Q and temp.
- o Reservoir temperature profiles:
  Summer-Fall: twice a month.
  Winter-Spring: once a month.

(3) Study period: June 1982 to May 1983.

(4) DYRESM Model enhanced.

(5) The outflow temperatures are simulated within ± 1°C.

(6) Satisfactorily duplicated the general reservoir hydrothermal behaviors.

(7) The study will be continued.

(8) No further model enhancements expected.

(9) Applicable to the South Central Alaskan reservoirs.

The DYRESM model enhancements:

(1) Long wave atmospheric radiation formulas.

(2) Outflow dynamics:
- o Intake structure - geometry and intake levels.
- o Bathymetic and approach conditions near the intake structure.

(3) Vapor pressure data development.

(4) Wind forcing effect (treated as an equivalent deepening of epilimnion).

The DYRESM model enhancements:

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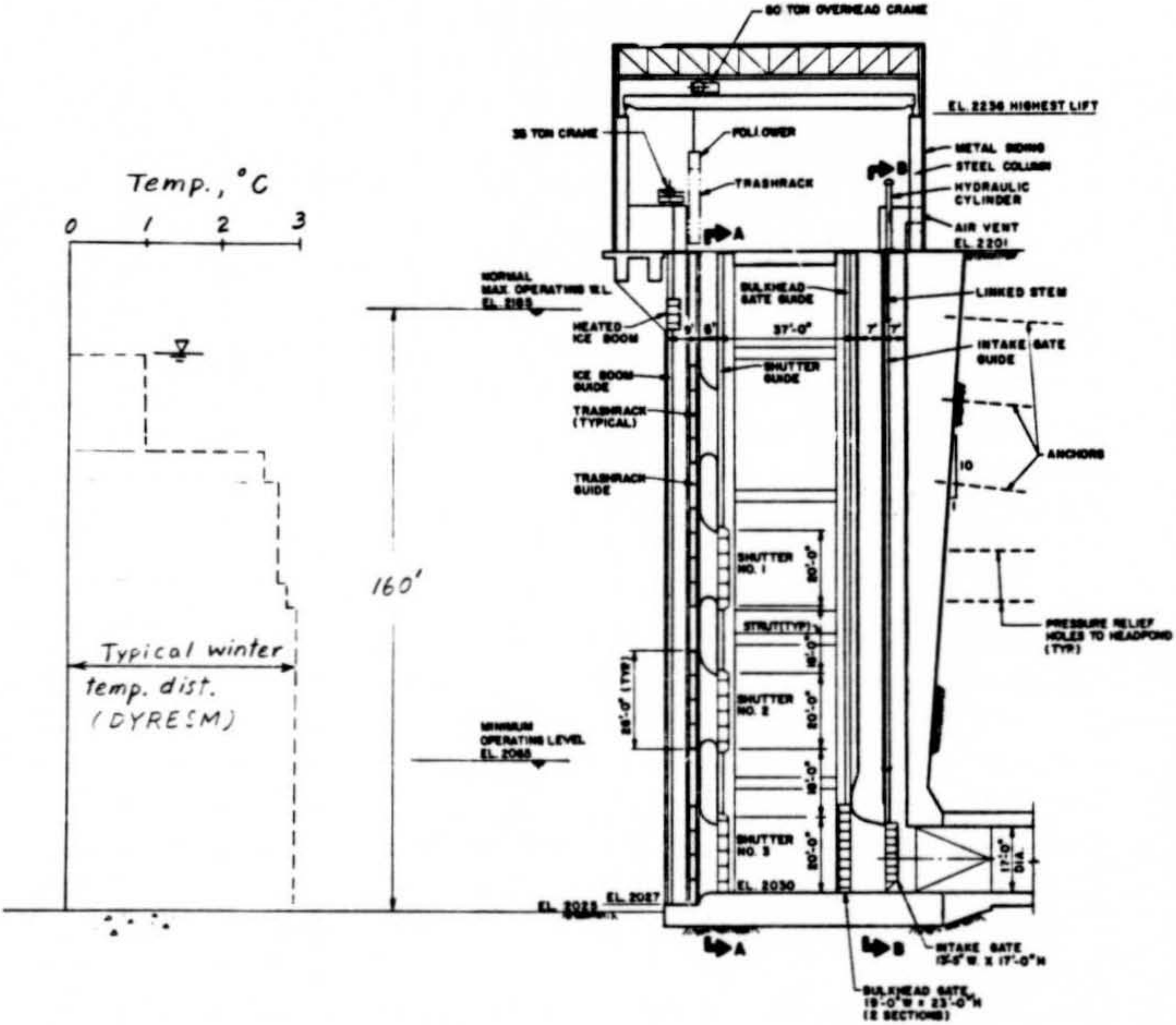
Status of Production runs:

Flow Condition \ Demand	Watana only		Watana/D.C.		2nd yr Filling (Watana)	Pool Following (Watana)	Level 4 only (Watana)
	1996	2001	2002	2020			
May 1981-May 1982	✓✓	✓✓	✓x	✓x	(1996) ✓x	(1996) ✓✓	(1996) ✓x
May 1982-May 1983	✓✓	✓✓	✓	✓	(1996) ✓x		
May 1971-May 1972	✓✓	✓✓	✓	✓			
May 1974-May 1975	✓✓	✓✓	✓	✓	(1996) ✓		
May 1976-May 1977	✓✓		✓	✓			

✓ Cases to be studied.

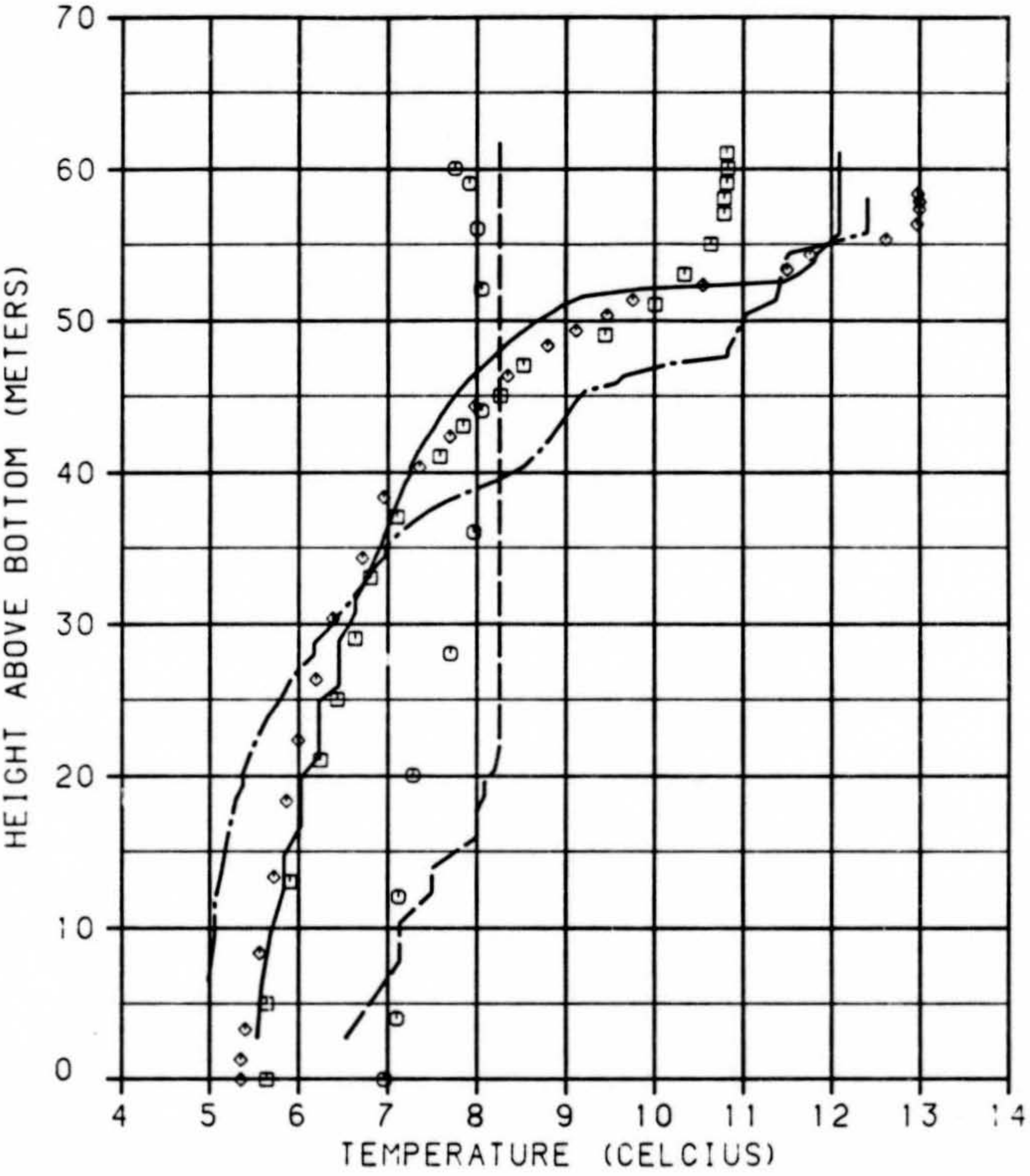
✓✓ Cases studied.

✓x Cases being studied.



SECTION THRU
INTAKE GATE CONTROL STRUCTURE

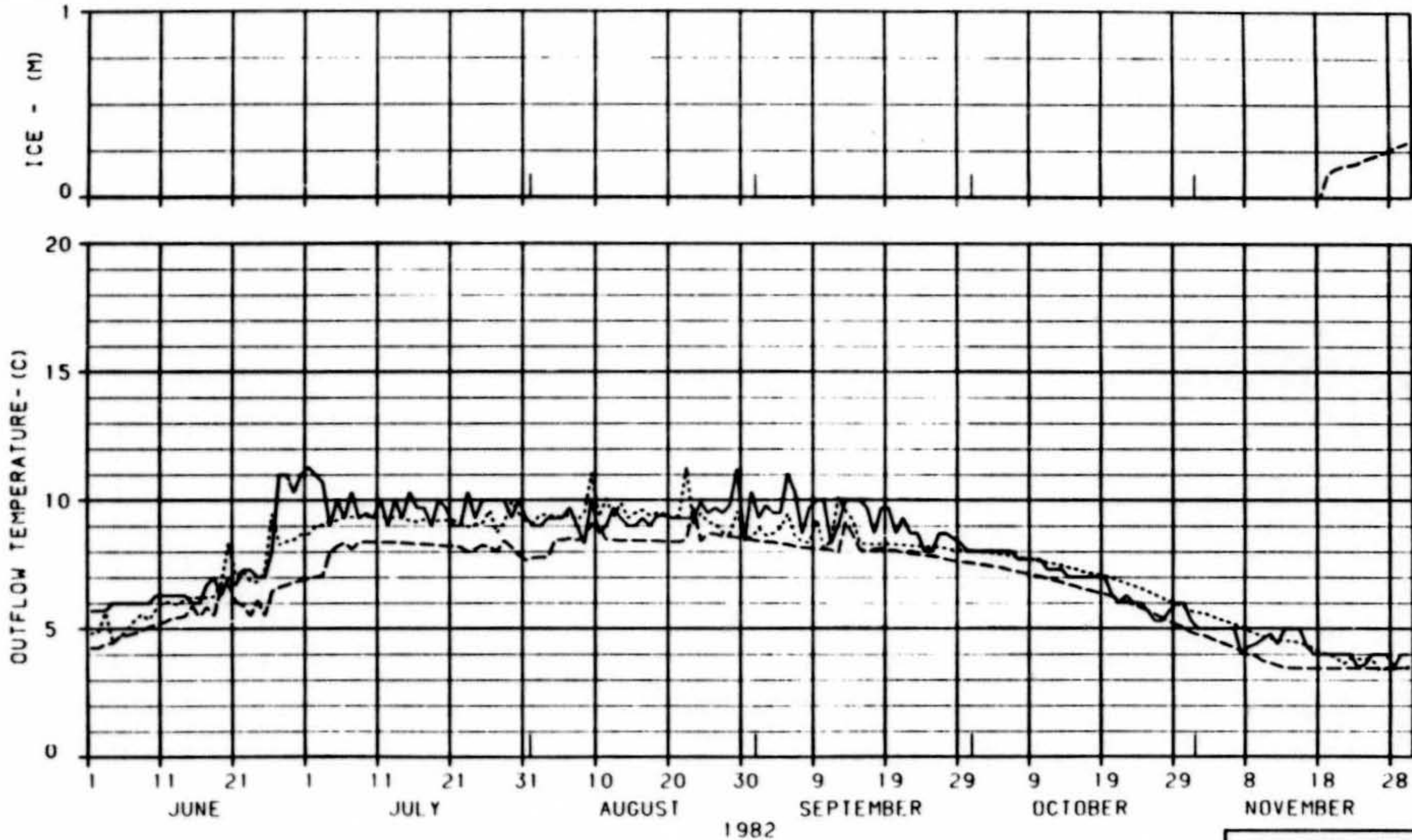
WATANA
POWER INTAKE



LEGEND:

- ◆ AUGUST 11, 1982 - MEASURED
- —·— AUGUST 11, 1982 - PREDICTED
- ▣ SEPTEMBER 9, 1982 - MEASURED
- —— SEPTEMBER 9, 1982 - PREDICTED
- ⊙ SEPTEMBER 21, 1982 - MEASURED
- — — SEPTEMBER 21, 1982 - PREDICTED

ALASKA POWER AUTHORITY		
SUSITNA PROJECT	DYRESM MODEL	
EKLUTNA LAKE OBSERVED AND PREDICTED TEMPERATURE PROFILES		
HARZA-EBASCO JOINT VENTURE		
CHICAGO, ILLINOIS	30 DEC 83	1563.142 HYD14



LEGEND:

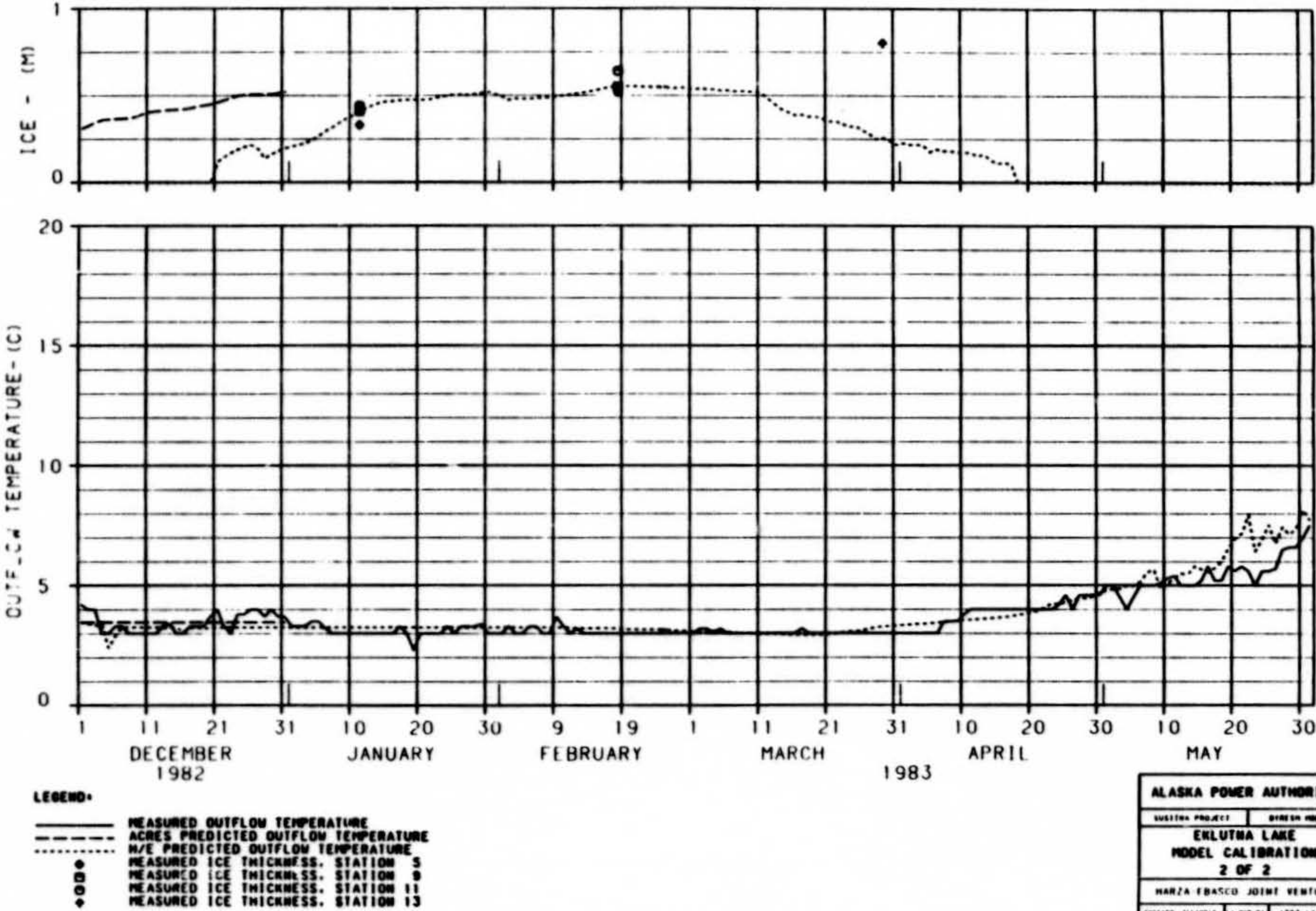
- ———— MEASURED OUTFLOW TEMPERATURE
- – – – – ACRES PREDICTED OUTFLOW TEMPERATURE
- ·········· H/E PREDICTED OUTFLOW TEMPERATURE

ALASKA POWER AUTHORITY

SUSITNA PROJECT | DYRESM MODEL

EKLUTNA LAKE
MODEL CALIBRATION
1 OF 2

HARZA-EBASCO JOINT VENTURE

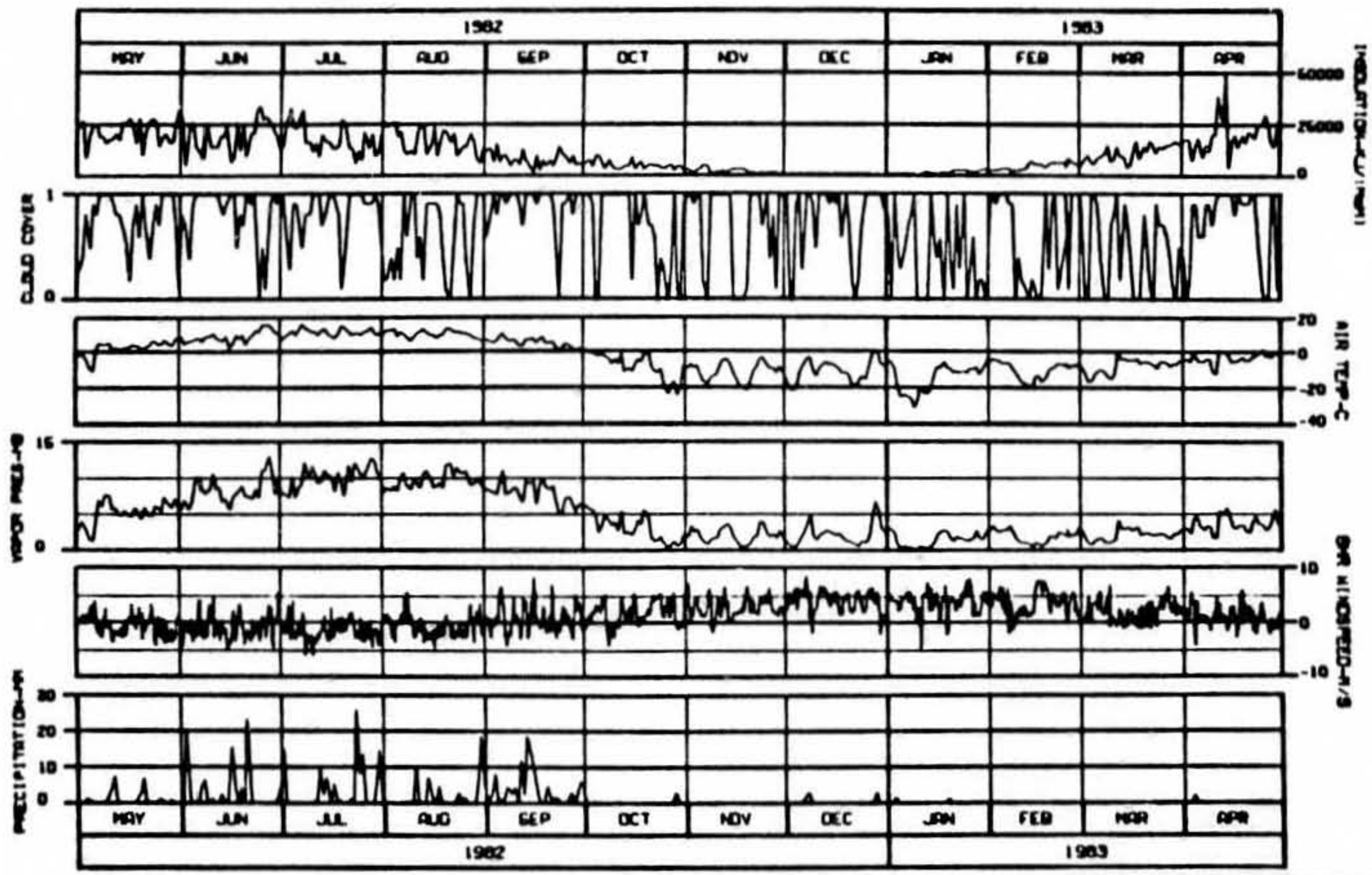


ALASKA POWER AUTHORITY

SUSITNA PROJECT | DYRESM MODEL

EKLUTNA LAKE
MODEL CALIBRATION
2 OF 2

HARZA-EBASCO JOINT VENTURE

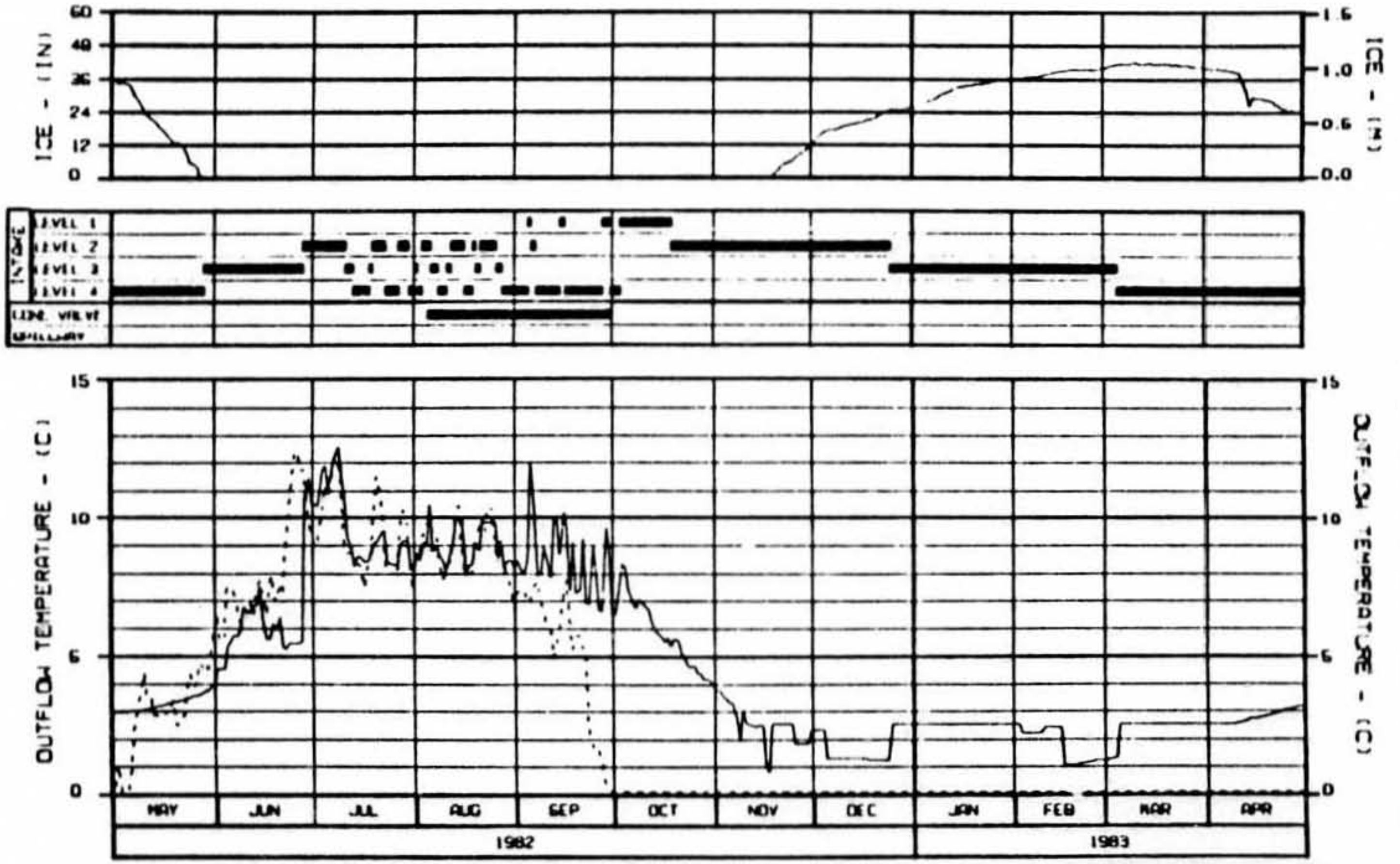


ALASKA POWER AUTHORITY

SUSITNA PROJECT | DYRESM MODEL

WATANA RESERVOIR
WEATHER DATA

HARZA-EBASCO JOINT VENTURE



LEGEND: CASE: ** WA81182196E - WATANA OPERATION ALONE IN 1996 **

——— PREDICTED OUTFLOW TEMPERATURE
- - - - - INFLOW TEMPERATURE

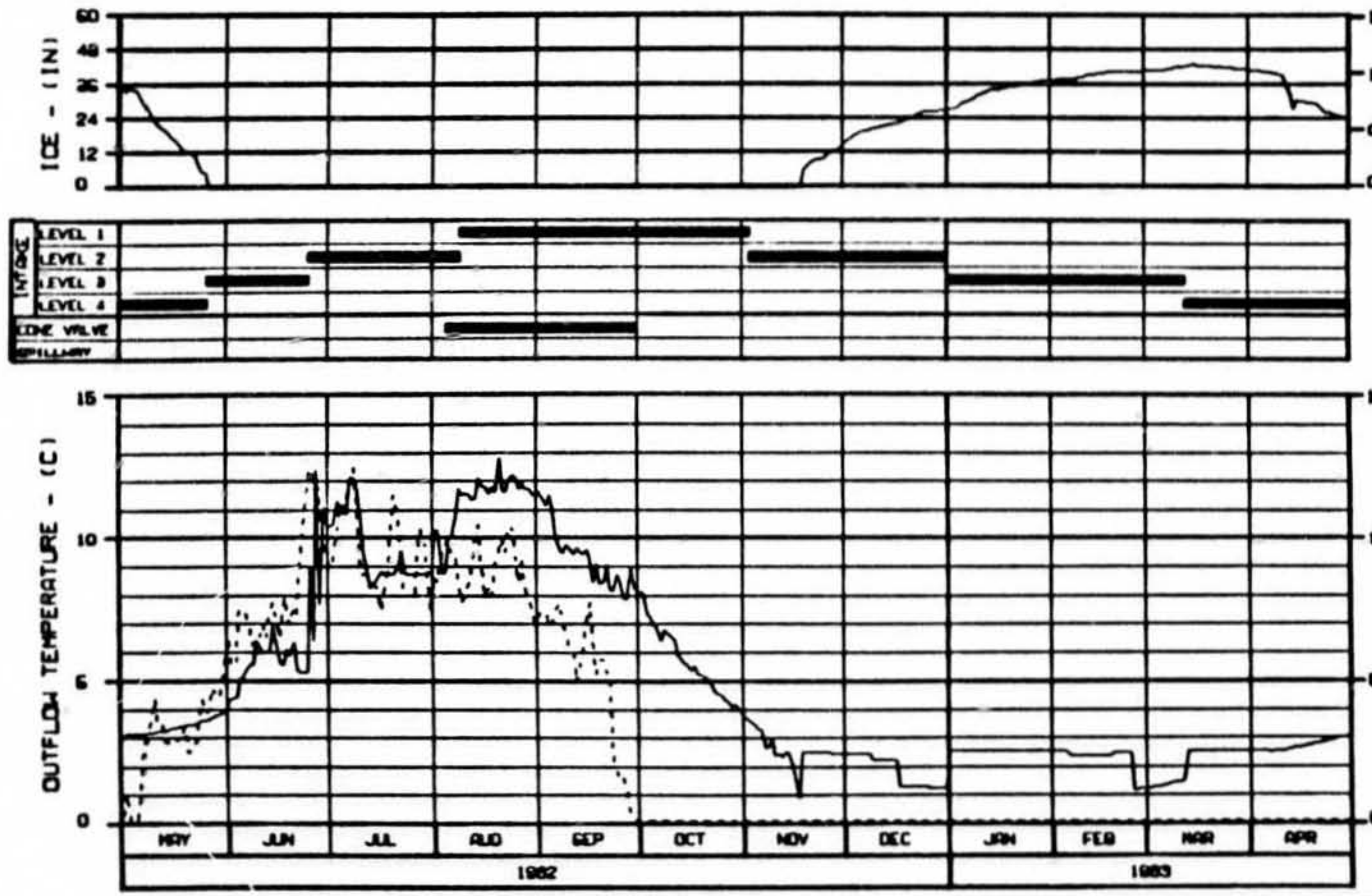
NOTES:
1. INTAKE PORT LEVEL 1 AT ELEVATION 2161 FT (656.6 M)
2. INTAKE PORT LEVEL 2 AT ELEVATION 2114 FT (644.3 M)
3. INTAKE PORT LEVEL 3 AT ELEVATION 2077 FT (633.1 M)
4. INTAKE PORT LEVEL 4 AT ELEVATION 2040 FT (621.8 M)
5. CONE VALVE AT ELEVATION 2040 FT (621.8 M)
6. SPILLWAY CREST AT ELEVATION 2148 FT (654.7 M)

ALASKA POWER AUTHORITY

SUSITNA PROJECT | DYRESM MODEL

WATANA RESERVOIR
OUTFLOW TEMPERATURE
AND ICE GROWTH

HARZA-EBASCO JOINT VENTURE



LEGEND: CASE: ** WA81(82)9SH - WATANA OPERATION ALONE IN 1995 **
** (POOL FOLLOWING) **

——————— PREDICTED OUTFLOW TEMPERATURE
- - - - - - - INFLOW TEMPERATURE

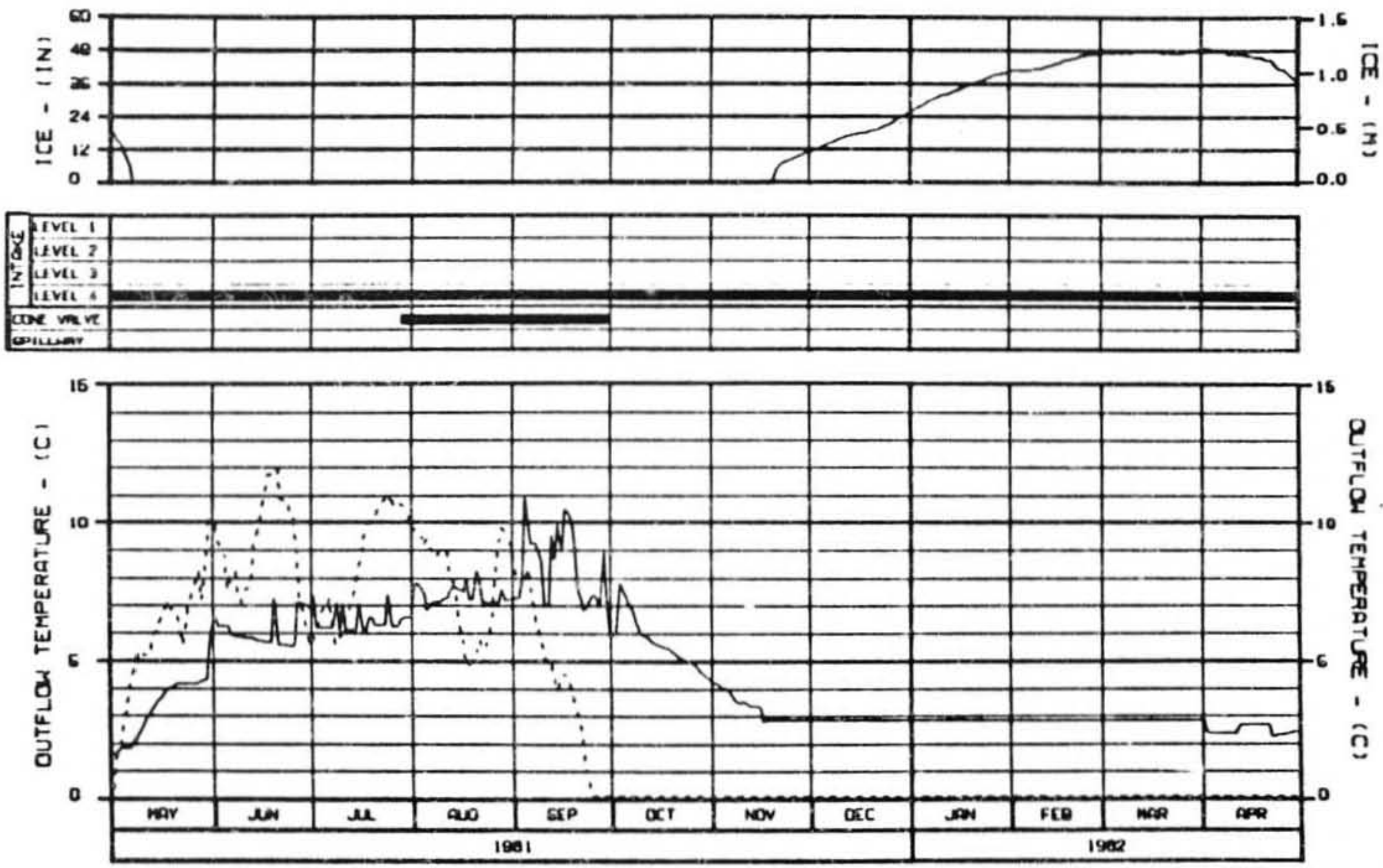
NOTES:
1. INTAKE PORT LEVEL 1 AT ELEVATION 2151 FT (655.6 M)
2. INTAKE PORT LEVEL 2 AT ELEVATION 2114 FT (644.3 M)
3. INTAKE PORT LEVEL 3 AT ELEVATION 2077 FT (633.1 M)
4. INTAKE PORT LEVEL 4 AT ELEVATION 2040 FT (621.8 M)
5. CONE VALVE AT ELEVATION 2040 FT (621.8 M)
6. SPILLWAY CREST AT ELEVATION 2148 FT (654.7 M)

ALASKA POWER AUTHORITY

SUSITNA PROJECT | DYRESM MODEL

WATANA RESERVOIR
OUTFLOW TEMPERATURE
AND ICE GROWTH

HARZA-EBASCO JOINT VENTURE



LEGEND: CASE: **** WA81(82)96) ..... LEVEL 4 ONLY *****

——— PREDICTED OUTFLOW TEMPERATURE
- - - - INFLOW TEMPERATURE

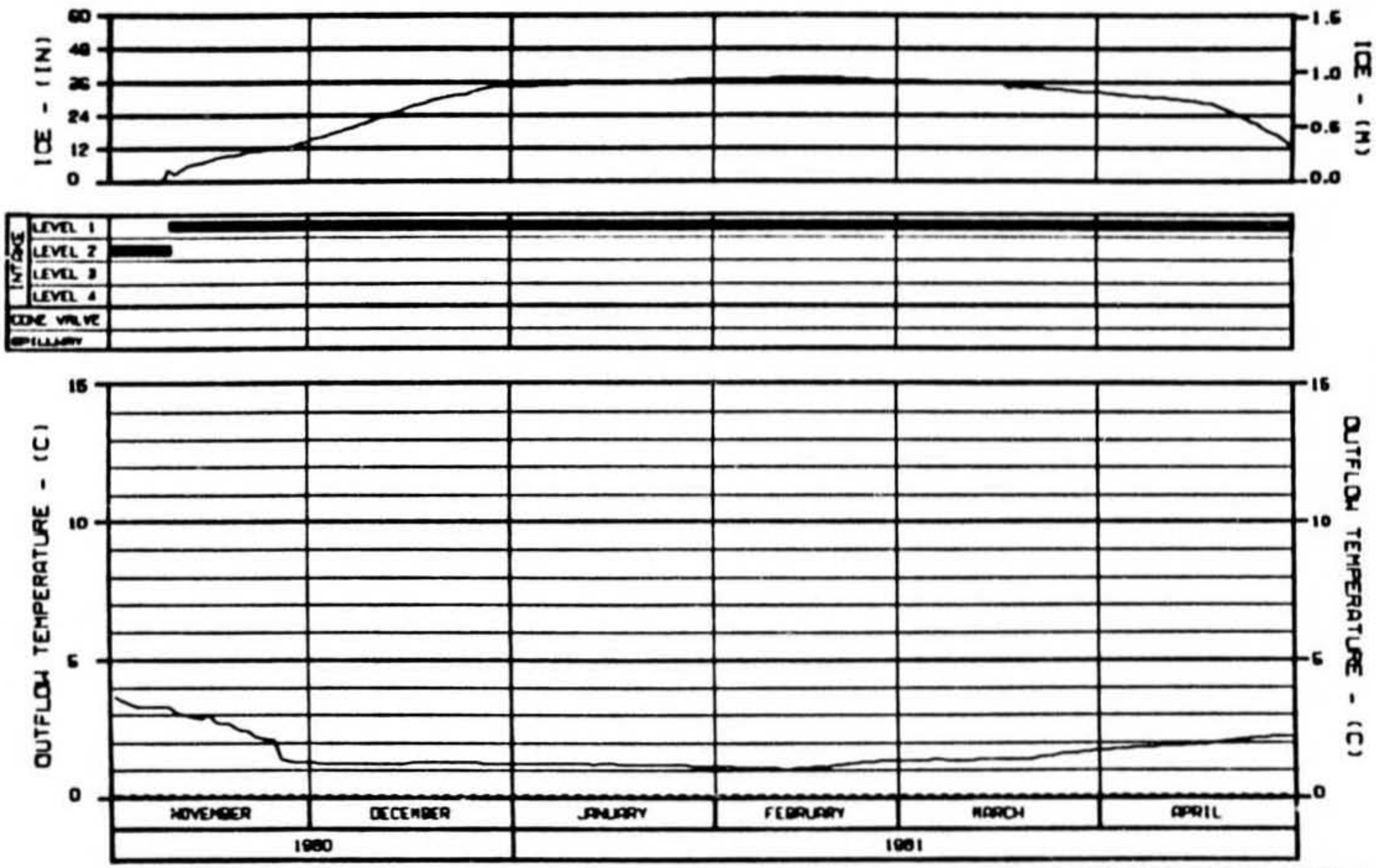
NOTES:
1. INTAKE PORT LEVEL 1 AT ELEVATION 2161 FT (656.6 M)
2. INTAKE PORT LEVEL 2 AT ELEVATION 2114 FT (644.3 M)
3. INTAKE PORT LEVEL 3 AT ELEVATION 2077 FT (633.1 M)
4. INTAKE PORT LEVEL 4 AT ELEVATION 2040 FT (621.8 M)
5. CONE VALVE AT ELEVATION 2040 FT (621.8 M)
6. SPILLWAY CREST AT ELEVATION 2148 FT (654.7 M)

ALASKA POWER AUTHORITY

SUSITNA PROJECT | DYRESM MODEL

WATANA RESERVOIR
OUTFLOW TEMPERATURE
AND ICE GROWTH

HARZA-EBASCO JOINT VENTURE

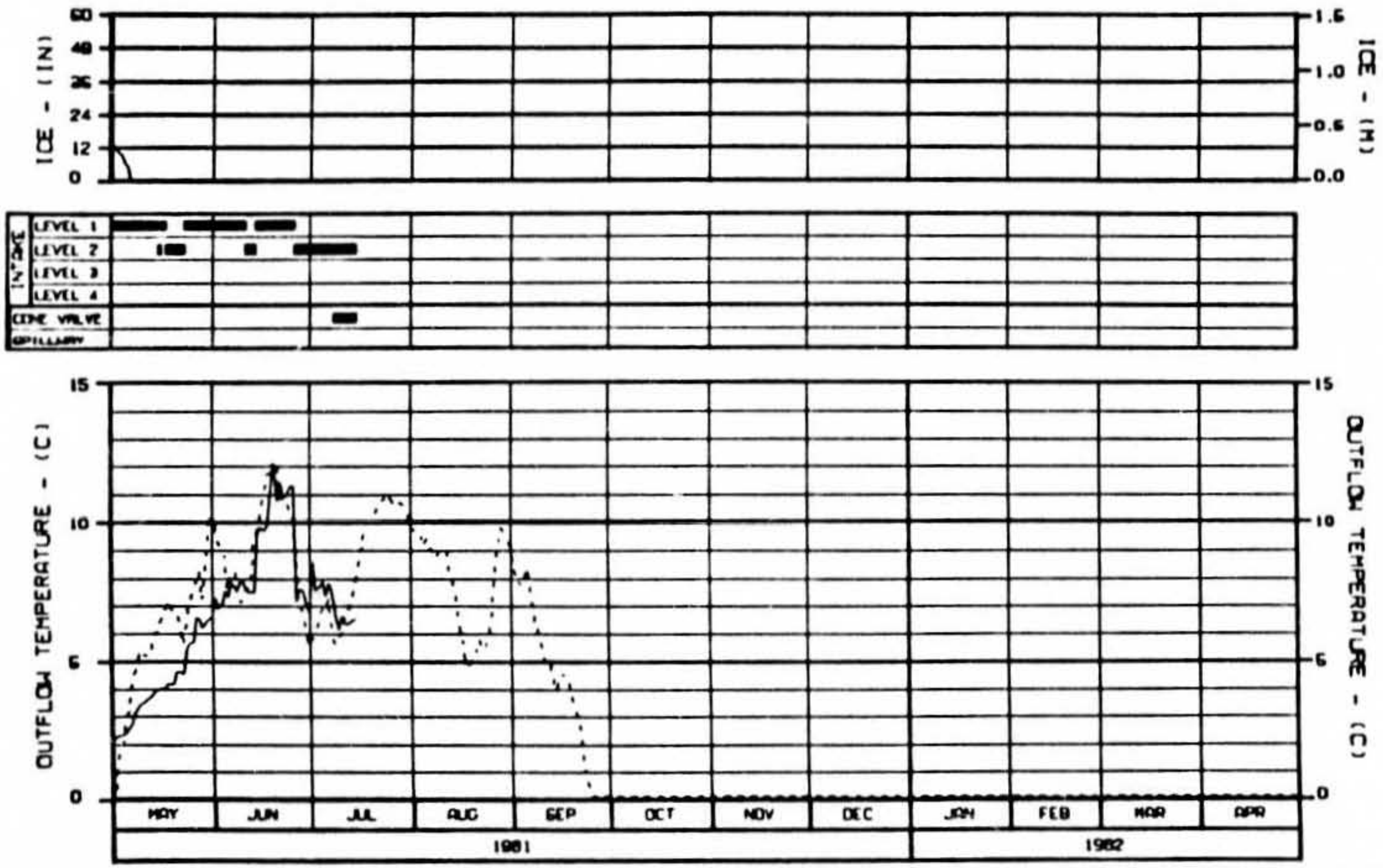


LEGEND: CASE: ■■ DC811021O2A - DEVIL CANYON OPERATION WITH WATANA IN 2002 ■■

——— PREDICTED OUTFLOW TEMPERATURE
- - - - - - - INFLOW TEMPERATURE

NOTES:
1. INTAKE PORT LEVEL 1 AT ELEVATION 1426 FT (434.34 M)
2. INTAKE PORT LEVEL 2 AT ELEVATION 1376 FT (419.10 M)
5. CONE VALVE AT ELEVATION 990 FT (301.76 M)
6. SPILLWAY CREST AT ELEVATION 1404 FT (427.94 M)

ALASKA POWER AUTHORITY	
SUSITNA PROJECT	DYRESM MODEL
DEVIL CANYON RESERVOIR OUTFLOW TEMPERATURE AND ICE GROWTH	
HARZA-EBASCO JOINT VENTURE	



LEGEND: CASE: ** DC811821 02A - DEVIL CANYON OPERATION WITH WATANA IN 2002 **

——— PREDICTED OUTFLOW TEMPERATURE
- - - - - - - INFLOW TEMPERATURE

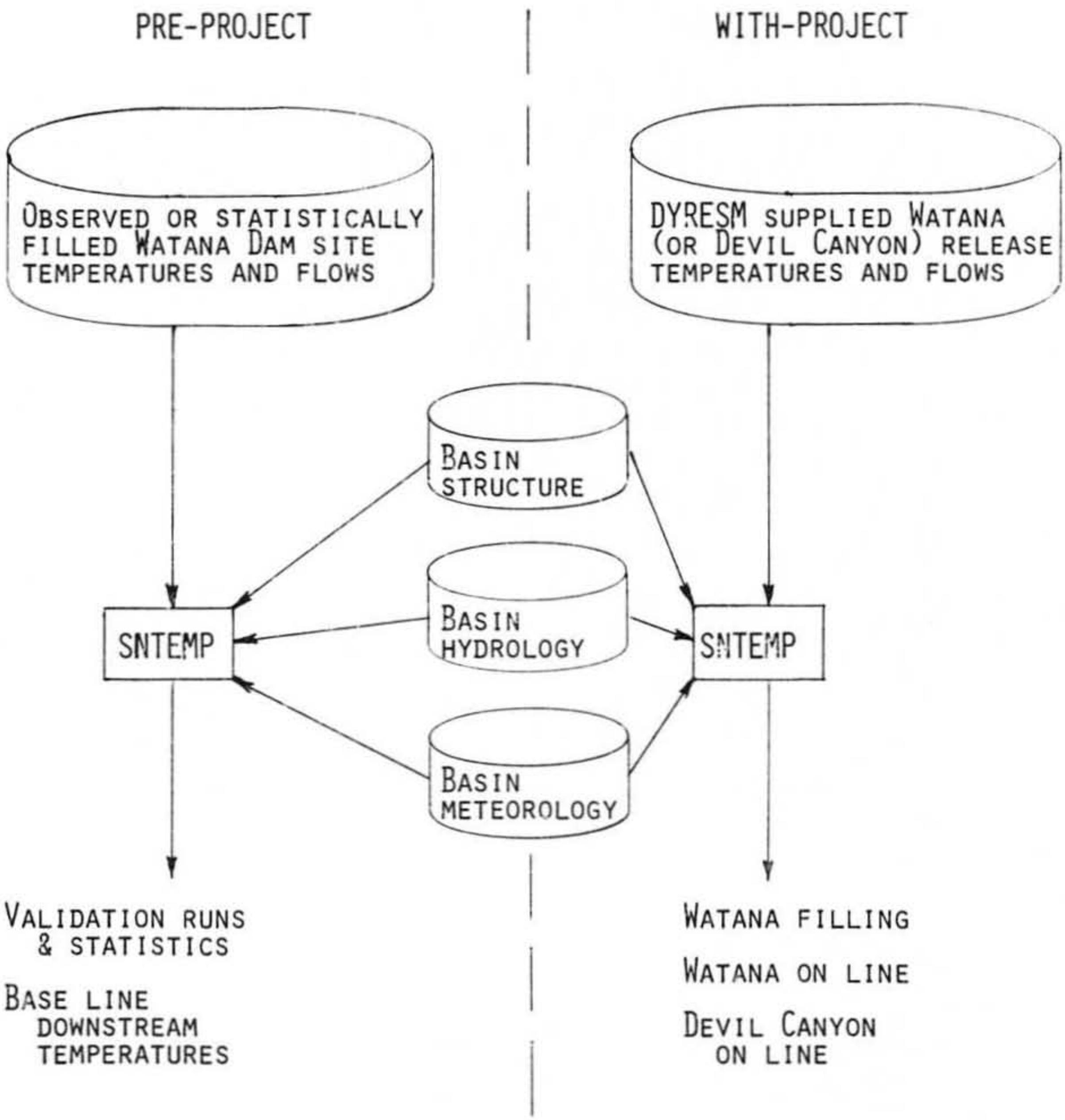
NOTES: 1. INTAKE PORT LEVEL 1 AT ELEVATION 1425 FT (434.34 M)
2. INTAKE PORT LEVEL 2 AT ELEVATION 1375 FT (419.10 M)
5. CONE VALVE AT ELEVATION 990 FT (301.75 M)
6. SPILLWAY CREST AT ELEVATION 1404 FT (427.94 M)

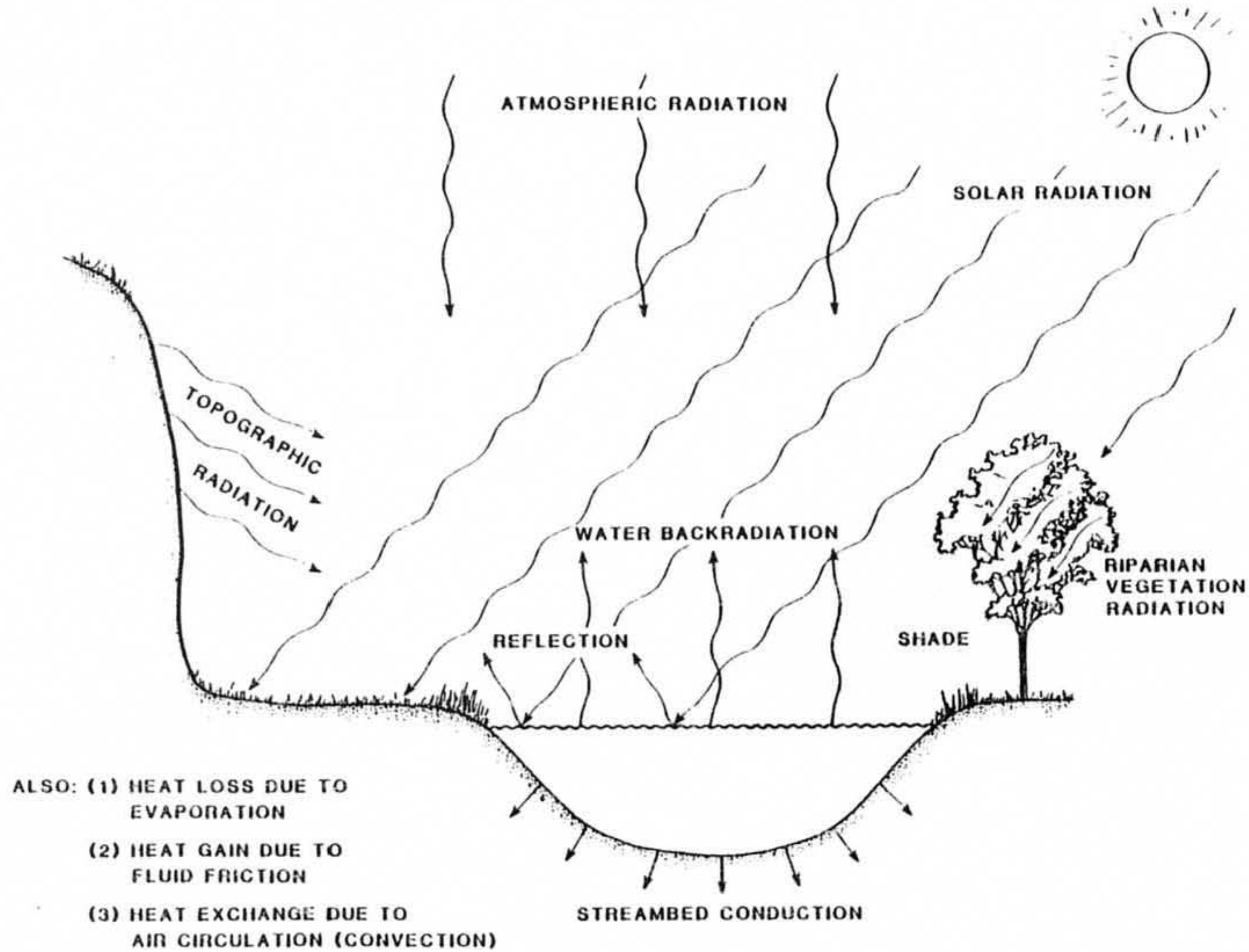
ALASKA POWER AUTHORITY

SUSITNA PROJECT | DYRESM MODEL

DEVIL CANYON RESERVOIR
OUTFLOW TEMPERATURE
AND ICE GROWTH

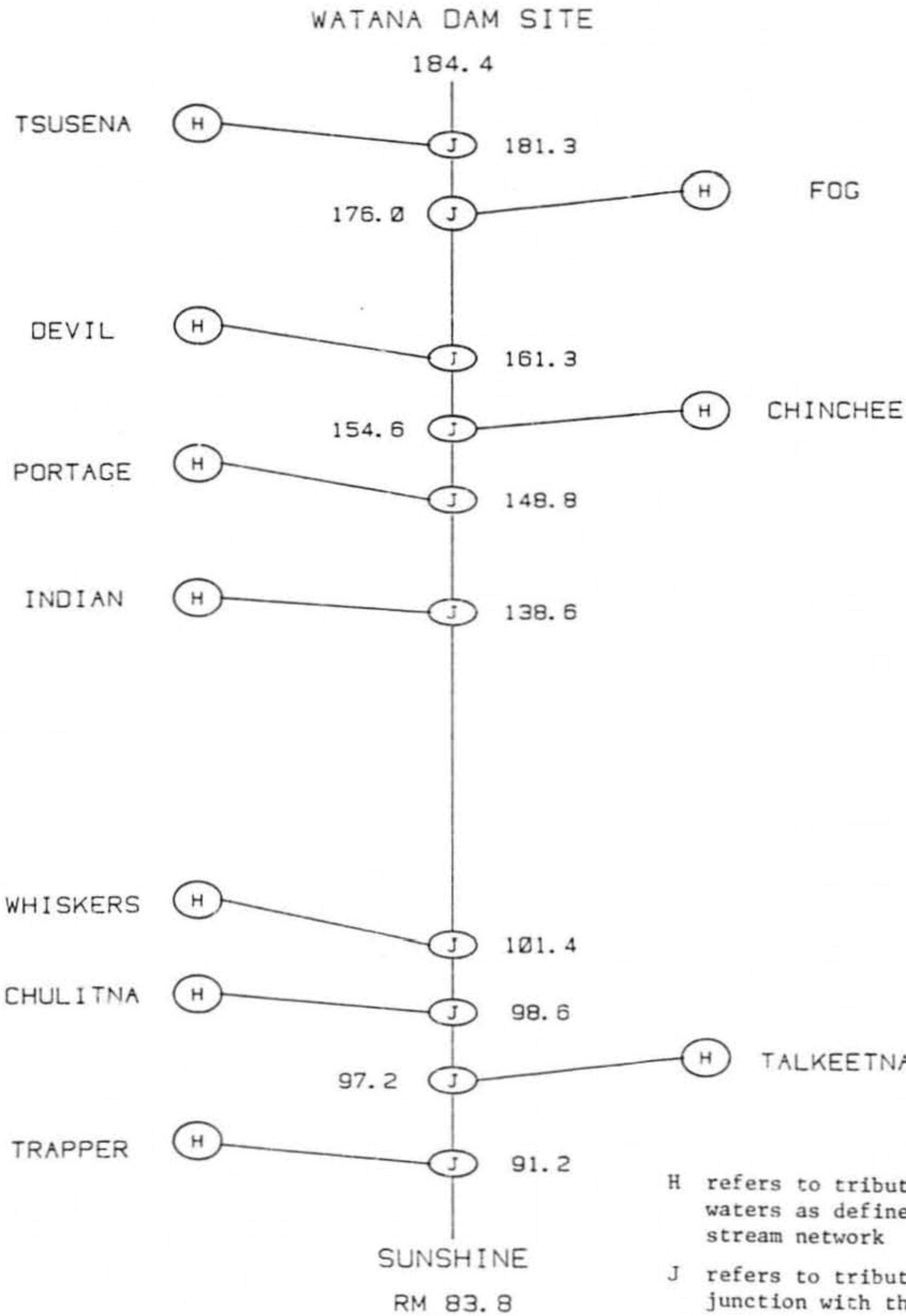
HARZA-EBASCO JOINT VENTURE


PRE-PROJECT
WITH-PROJECT
OBSERVED OR STATISTICALLY FILLED WATANA DAM SITE TEMPERATURES AND FLOWS
DYRESM SUPPLIED WATANA (OR DEVIL CANYON) RELEASE TEMPERATURES AND FLOWS
BASIN STRUCTURE
BASIN HYDROLOGY
BASIN METEOROLOGY
SNTEMP
SNTEMP
VALIDATION RUNS & STATISTICS
BASE LINE DOWNSTREAM TEMPERATURES
WATANA FILLING
WATANA ON LINE
DEVIL CANYON ON LINE



Heat flux sources.

Stream network from Watana to Sunshine.



H refers to tributary headwaters as defined in the stream network

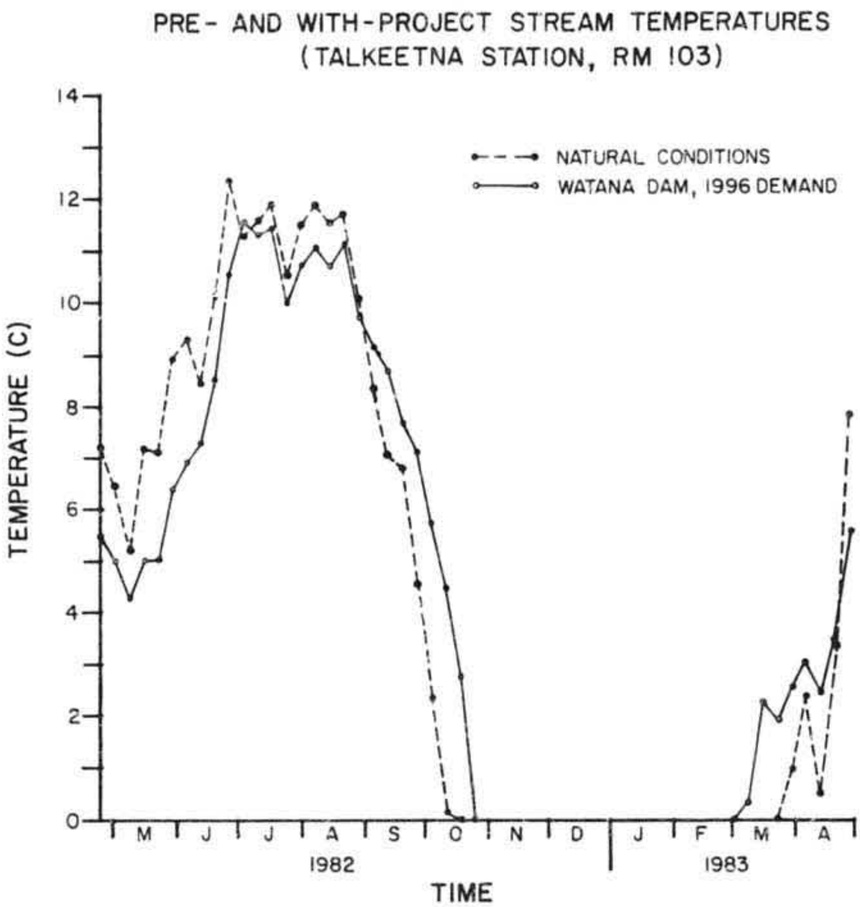
J refers to tributary junction with the mainstem

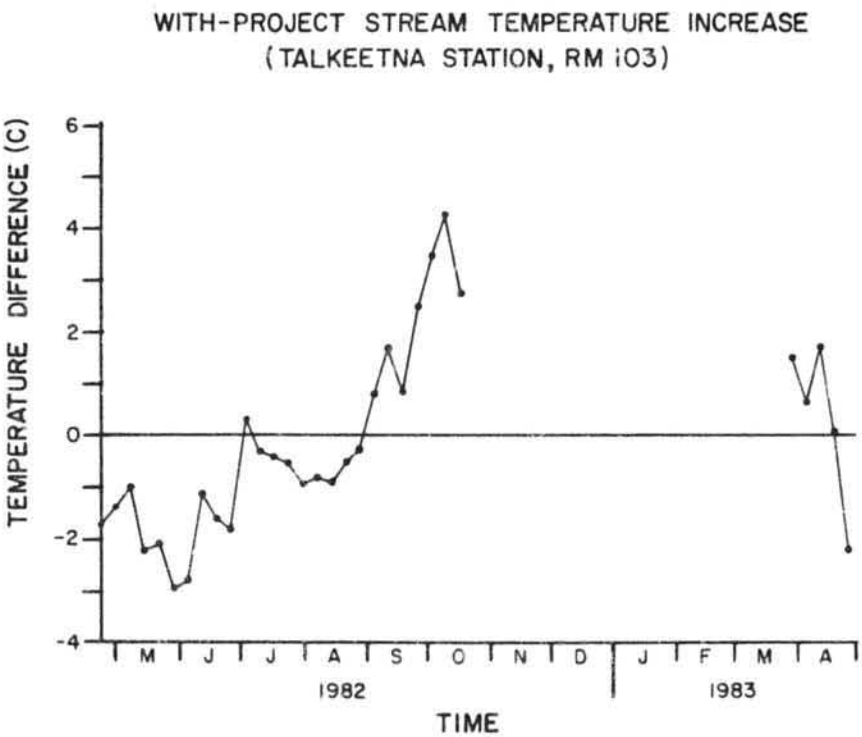
Numbers refer to River Mile as interpolated from R&M River Mile Index (1981).

STREAM TEMPERATURE SIMULATION STATISTICS

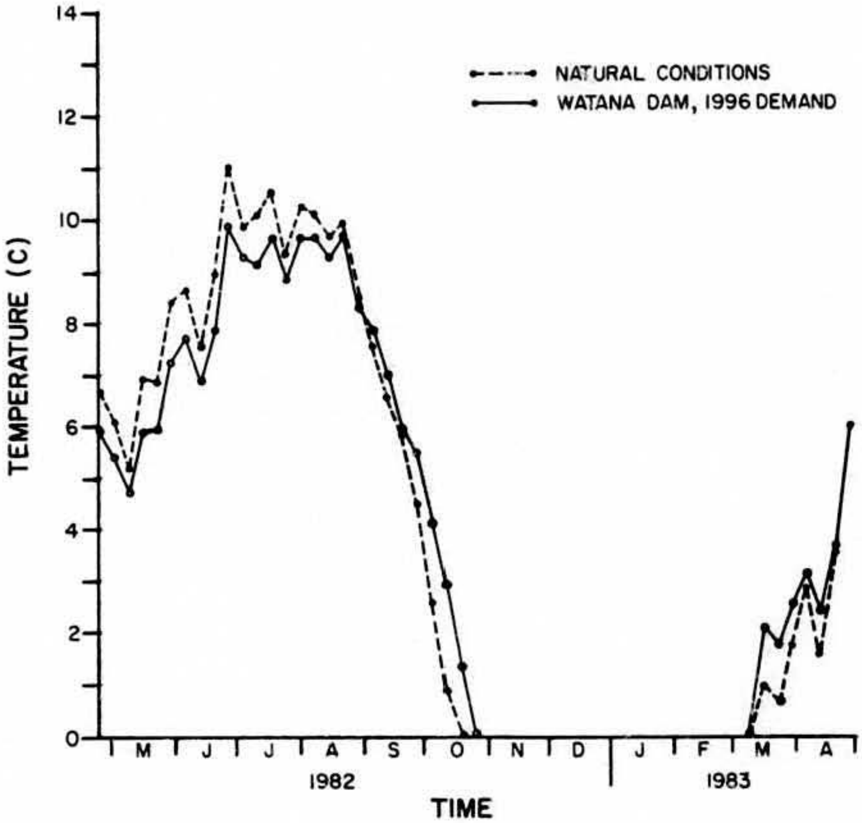
	1981	1982	1983	81-83
DATA VALUES	49	67	124	240
AVERAGE BIAS (c)	- 0.2	0.0	0.0	- 0.1
STANDARD ERROR (c)	0.8	0.5	0.5	0.5
MAX OVERPREDICTION (c)	1.7	1.3	1.9	1.9
MAX UNDERPREDICTION (c)	2.0	1.1	0.9	2.0

90% OF PREDICTIONS WILL BE WITHIN - 1.0 C TO 0.8 C OF ACTUAL VALUES

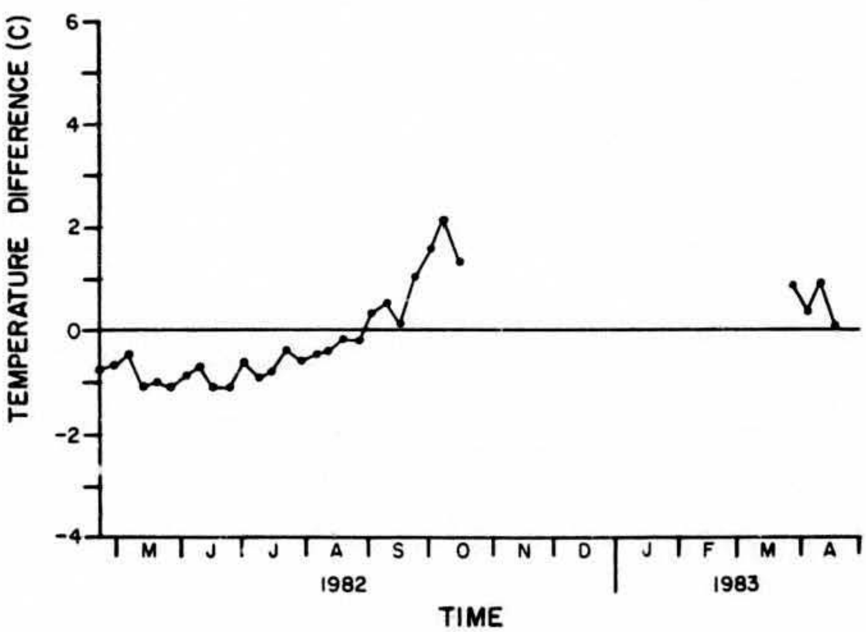

PRE- AND WITH-PROJECT STREAM TEMPERATURES
(TALKEETNA STATION, RM 103)
NATURAL CONDITIONS
WATANA DAM, 1996 DEMAND
TEMPERATURE (C)
14
12
10
8
6
4
2
0
M
J
J
A
S
O
N
D
J
F
M
A
1982
1983
TIME


WITH-PROJECT STREAM TEMPERATURE INCREASE
(TALKEETNA STATION, RM 103)
TEMPERATURE DIFFERENCE (C)
6
4
2
0
-2
-4
M
J
J
A
S
O
N
D
J
F
M
A
1982
1983
TIME

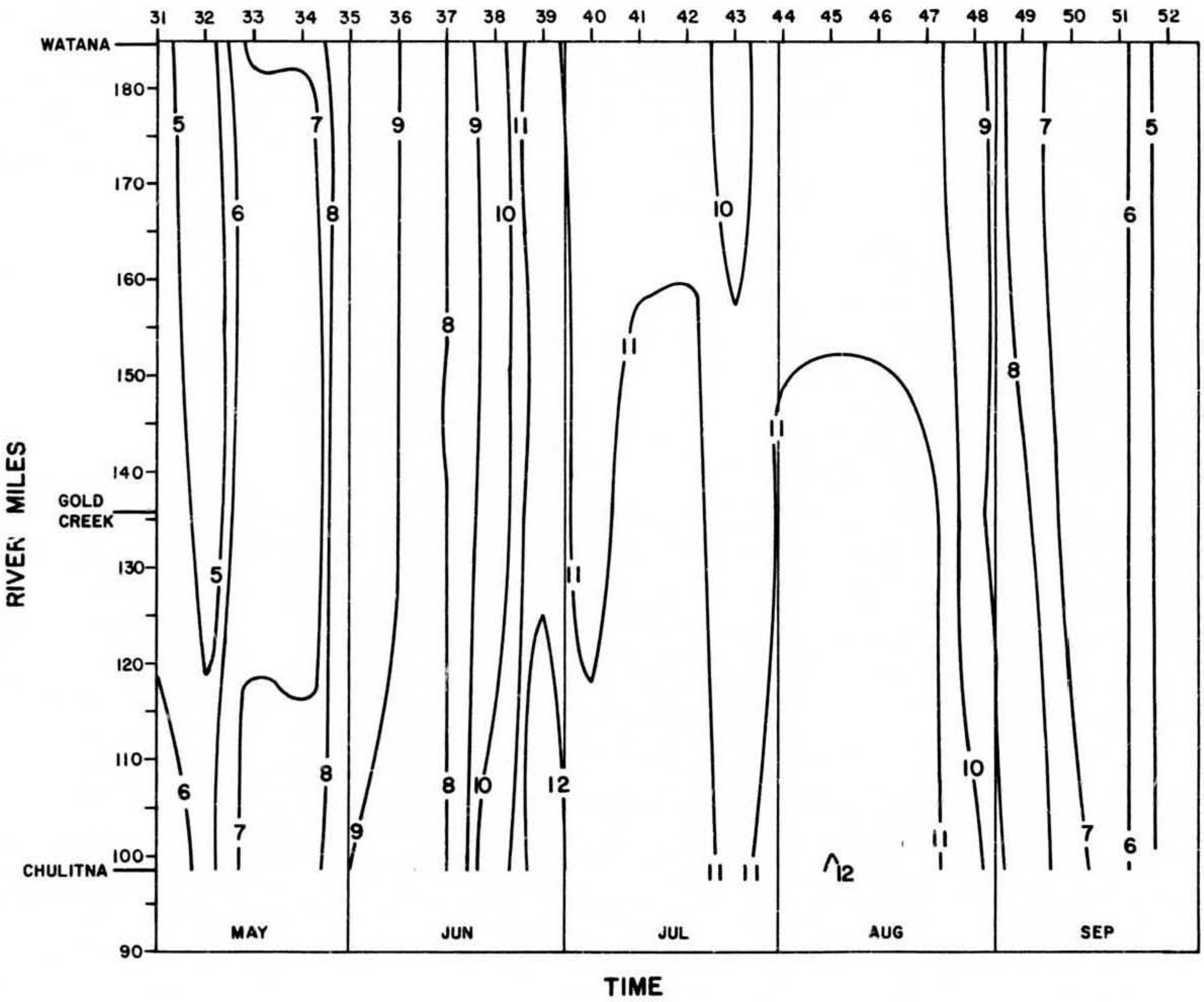
PRE- AND WITH-PROJECT STREAM TEMPERATURES
(SUNSHINE STATION, RM 84)



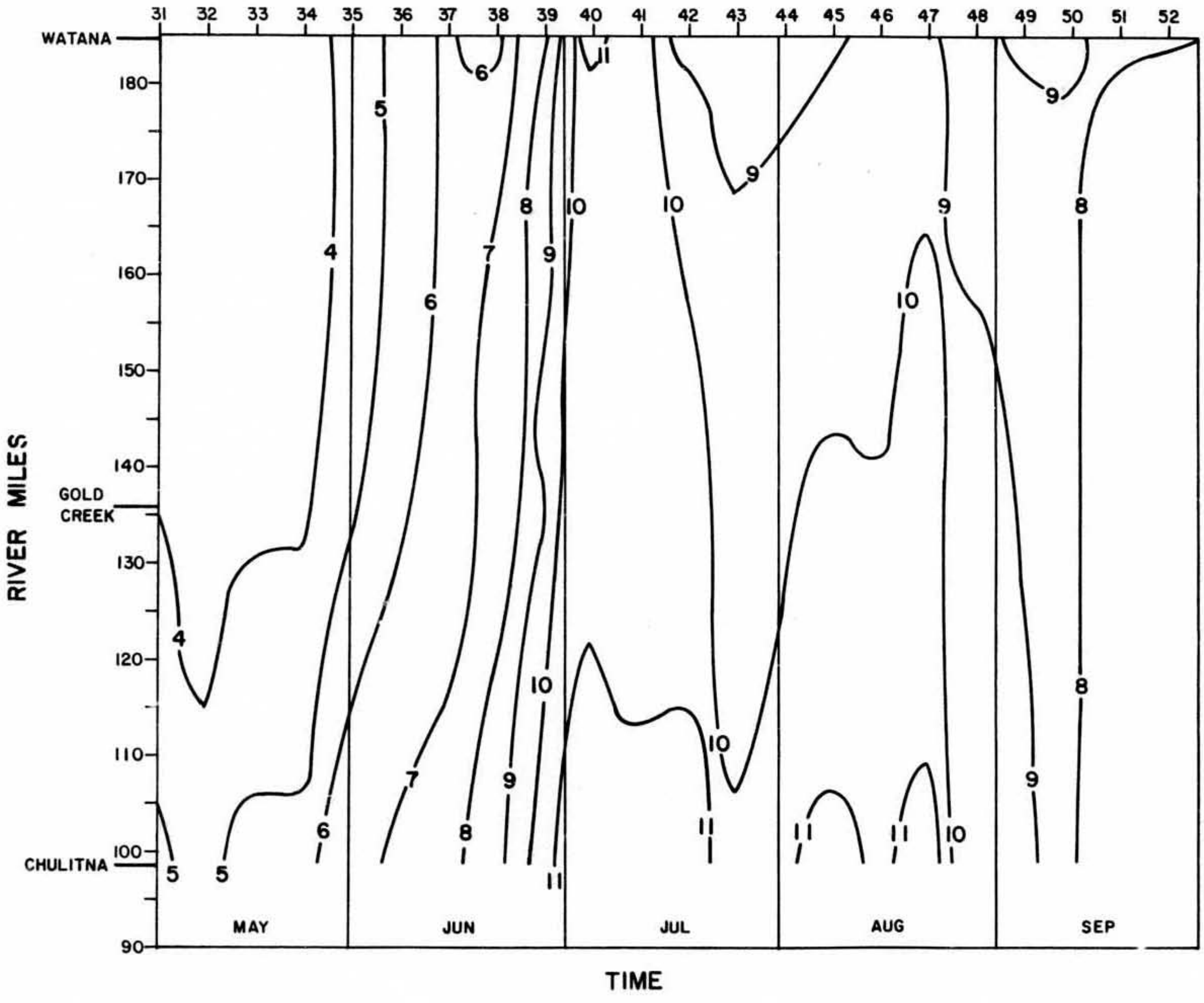
WITH-PROJECT STREAM TEMPERATURE INCREASE
(SUNSHINE STATION, RM 84)



MIDDLE SUSITNA RIVER - ISOTHERMS
WY 1982 (NATURAL CONDITION)

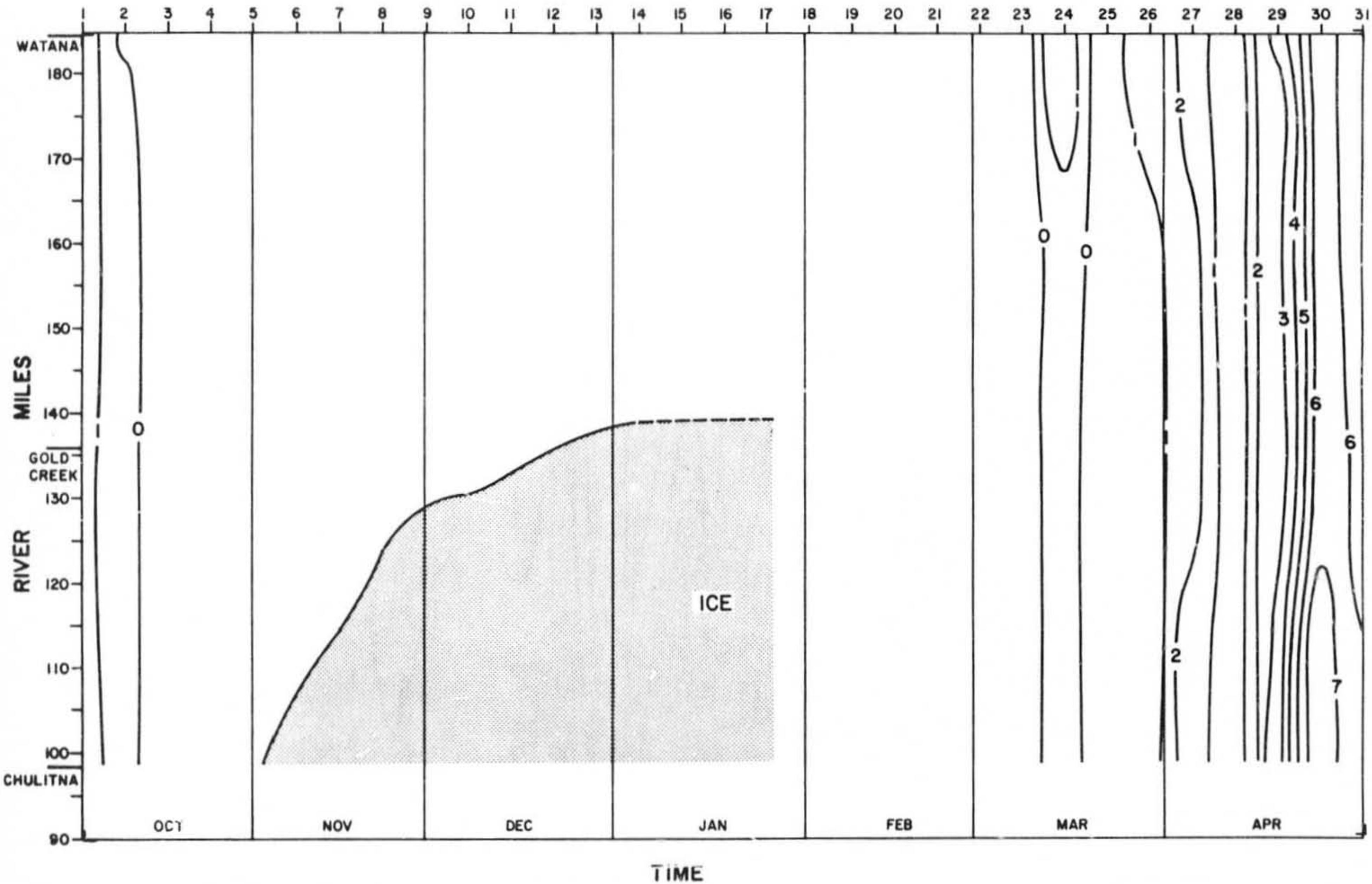


MIDDLE SUSITNA RIVER – ISOTHERMS
WY 1982 (1996 DEMAND)



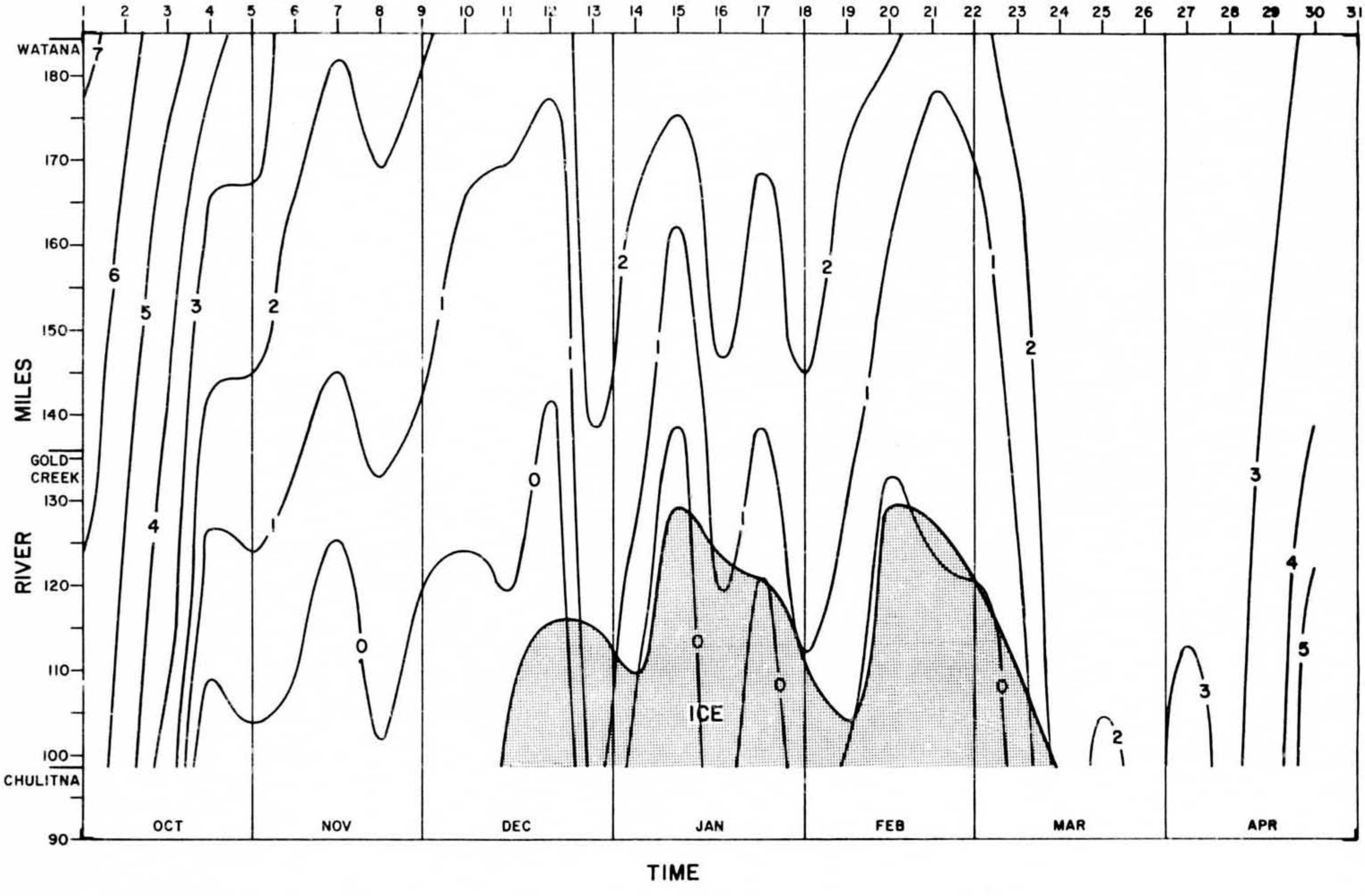
MIDDLE SUSITNA RIVER - ISOTHERMS

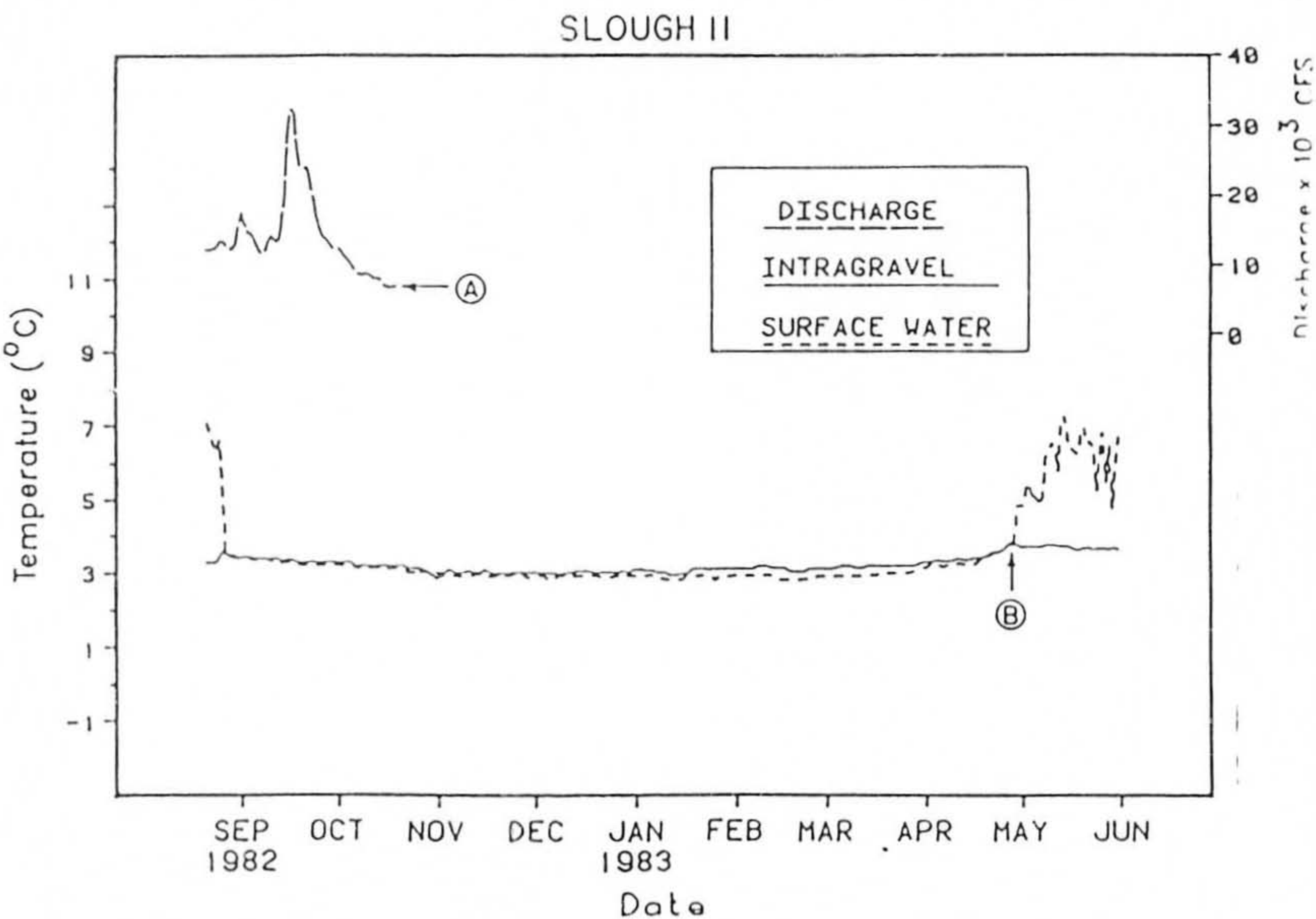
WY 1983 (NATURAL CONDITION)



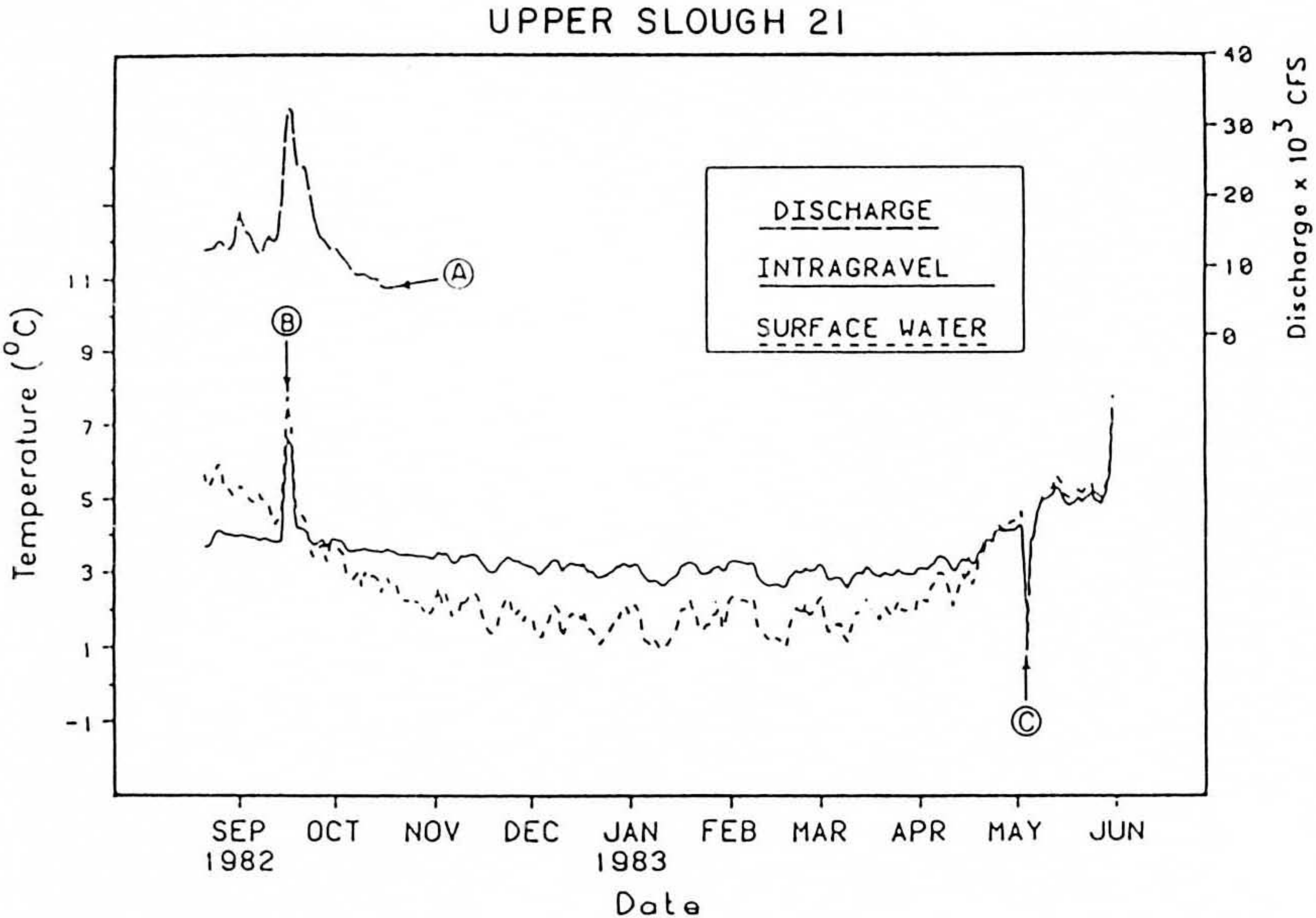
MIDDLE SUSITNA RIVER – ISOTHERMS

WY 1983 (1996 DEMAND)





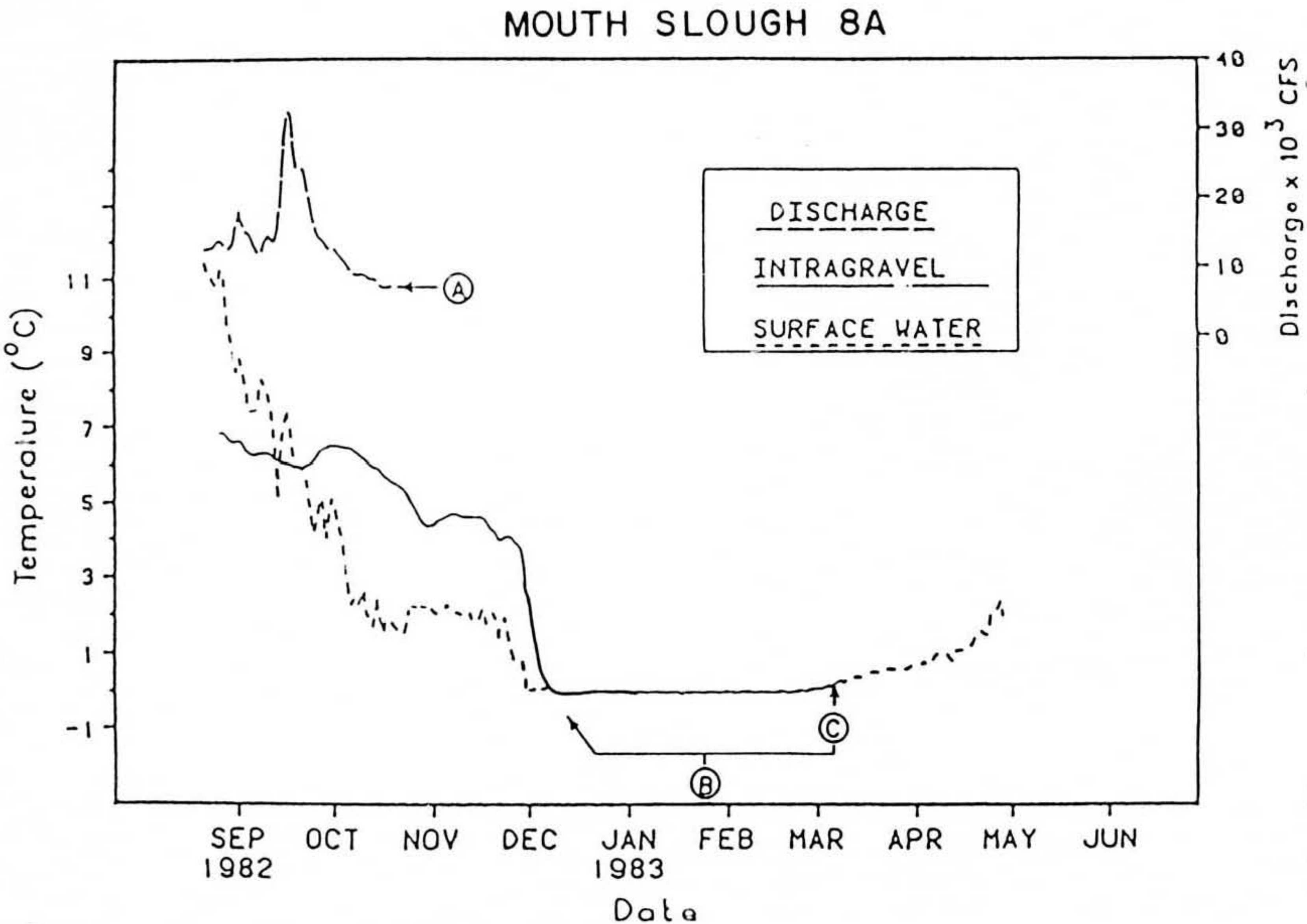
SLOUGH II
DISCHARGE
INTRAGRAVEL
SURFACE WATER
Temperature (°C)
Date
SEP 1982
OCT
NOV
DEC
JAN 1983
FEB
MAR
APR
MAY
JUN
A
B



Ⓐ Discharge data not available after October 19.

Ⓑ Slough breached in September 1982.

Ⓒ Slough breached during breakup.



(A) Discharge data not available after October 19.

(B) Surface and intragravel temperature are the same.

(C) Intragravel probe severed by ice movement along bank.

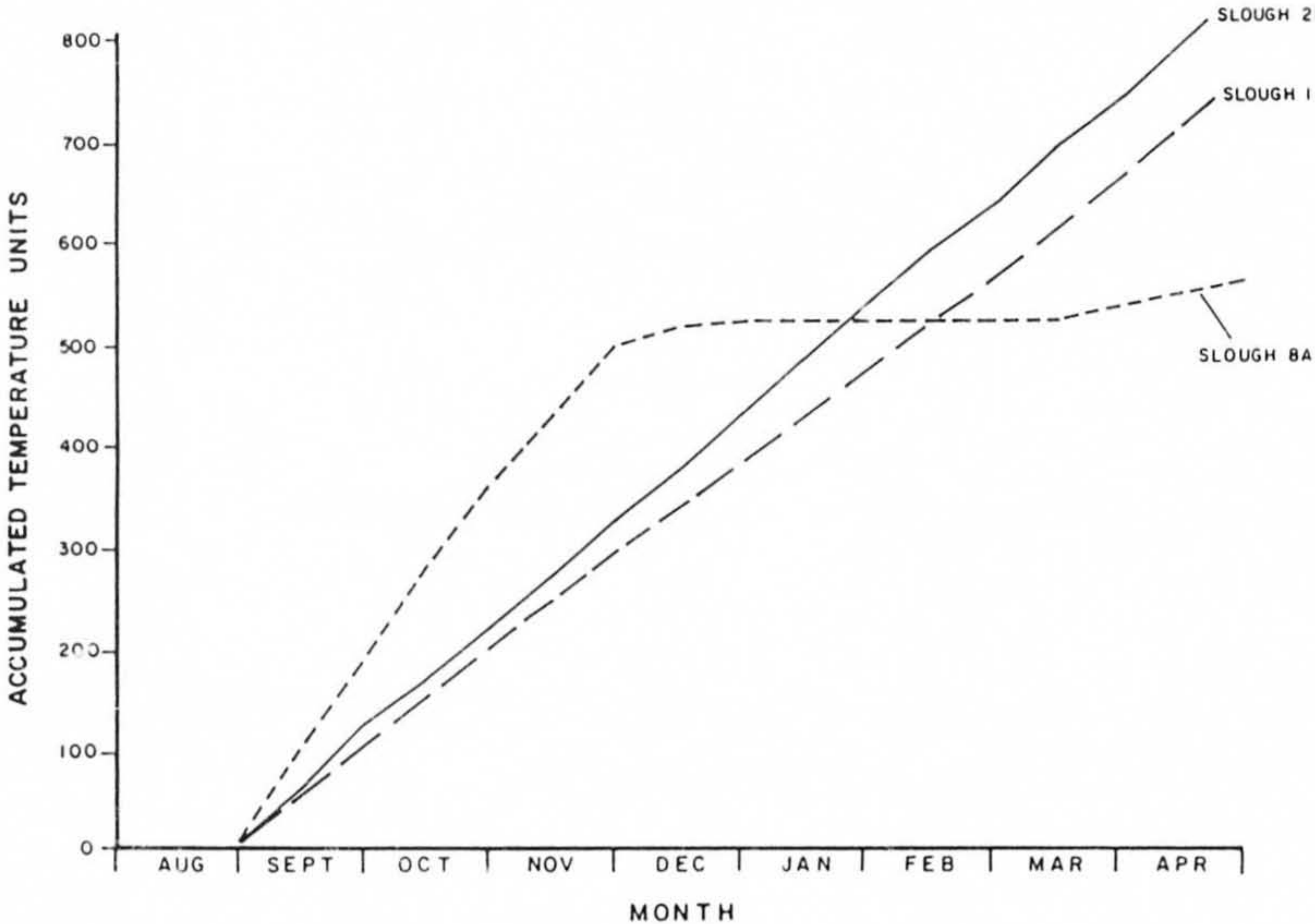


Figure 3-18. Accumulated temperature units for intragravel water at three sloughs, winter 1982-1983. For both Slough 8A and Slough 21, the values were interpolated using data from two different Datapod recorders in these sloughs. Because of equipment loss or malfunction, a continuous record for any one of these recorders was not obtained.

Figure _. 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 Is.		6.5-12.5		
		Neave 1966	Brit. Col.		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	4.5-13.2		
	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 Is.	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 1966	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	
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			

Figure _. (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 (cont)	Juvenile	Cederholm & Scarlet 1982	Washington St.	6			
		Bustard & Narver 1975	Vancouver Is., Brit. Col.	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]	
Pink	Adult	Bell 1973		7.2-15.6	7.2-12.8		
		Bell 1983	USSR	5			
		McNeil & Bailey 1975	Southeast Alaska		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 Is.	5.0-7.0			
		Wickett 1962	Brit. Col.	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	
		Godin 1980	Lab.			3.4-15.0	
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- 7.6		

Figure _. (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 (cont)	Juvenile	McCart 1967	Brit. Col.	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	Bris.Bay, AK	4.0- 7.0			
		Bucher 1981	Bris.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	
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	7.8-10.9		
	Juvenile	Raymond 1979	Columbia R	7			7.3-14.6
		Bell 1973					
		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	

Note: [1] Single temperature values are lower observed thresholds.
[2] After eggs had developed to the 128-cell or early blastula stage at 5.5 °C
[3] Optimum range
[4] Peak migration range

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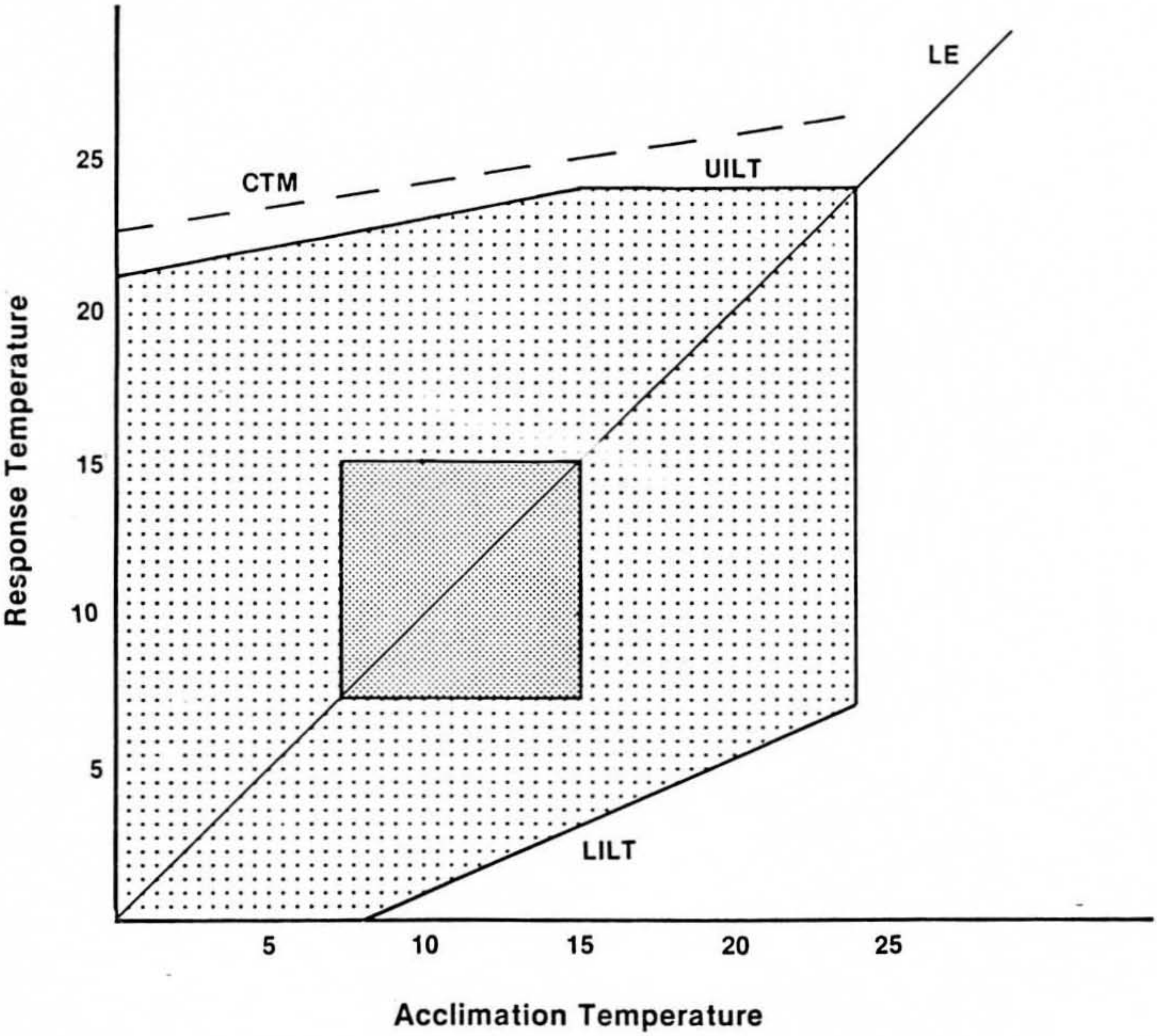
Terminology

Acclimation - a physiological adaptation to natural or applied environmental conditions.

Incipient lethal level or temperature - upper and lower temperature level where temperature is beginning to have a lethal effect.

Preferred or selected temperature - 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.

Zone tolerance - thermal zone in which fish can live free from the lethal effects of temperature.

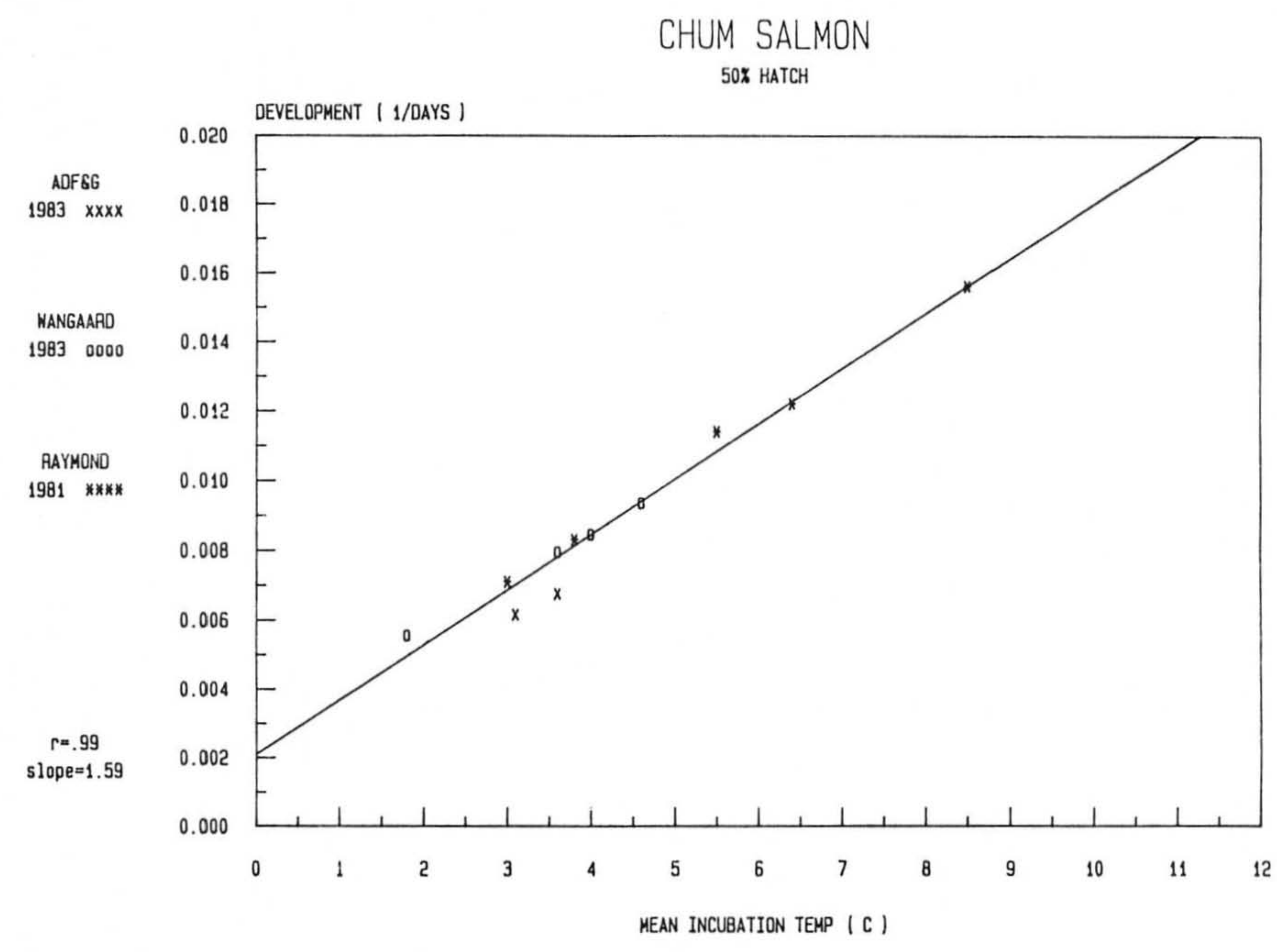


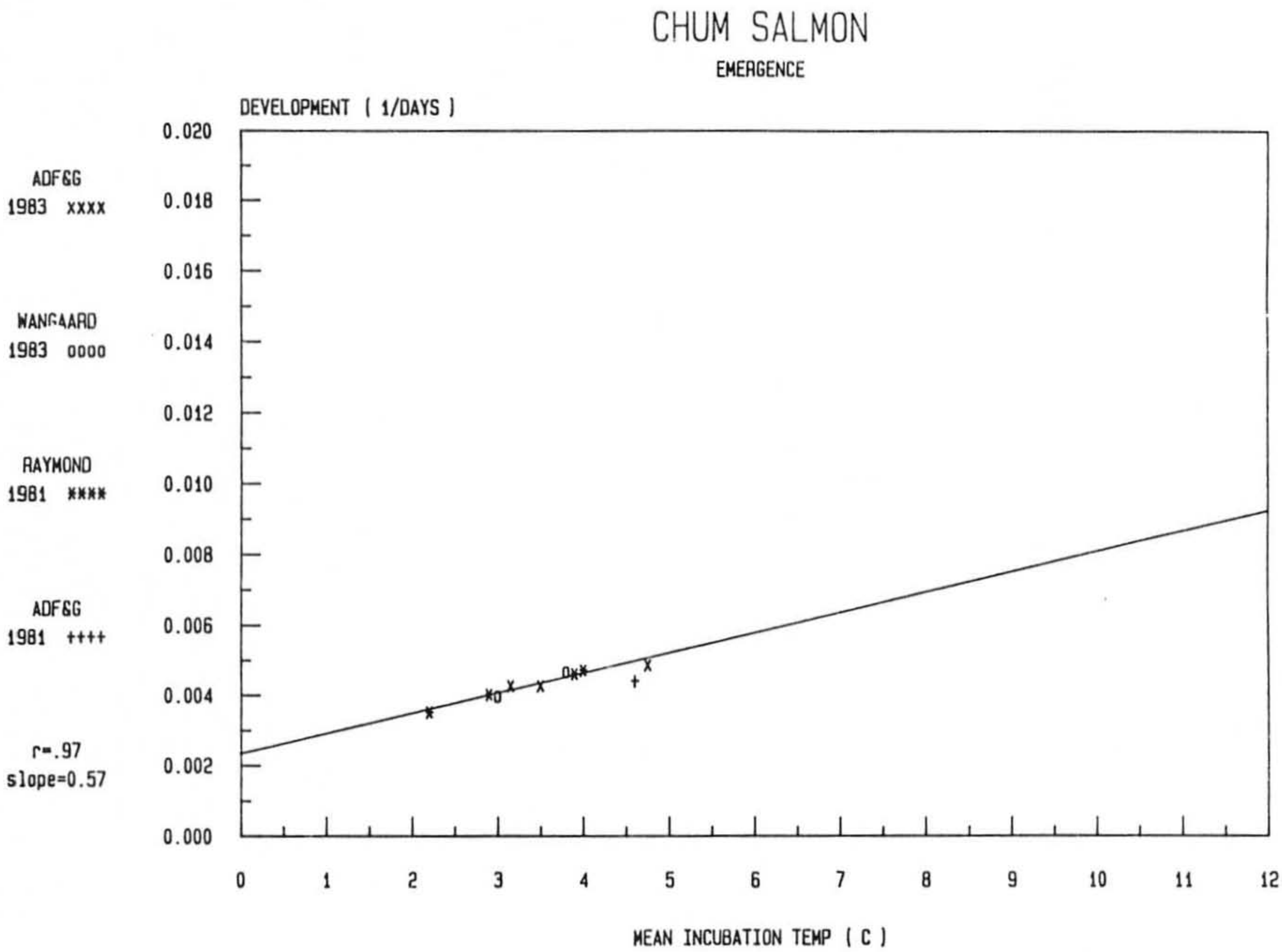
Zone of Preference

Tolerance Zone

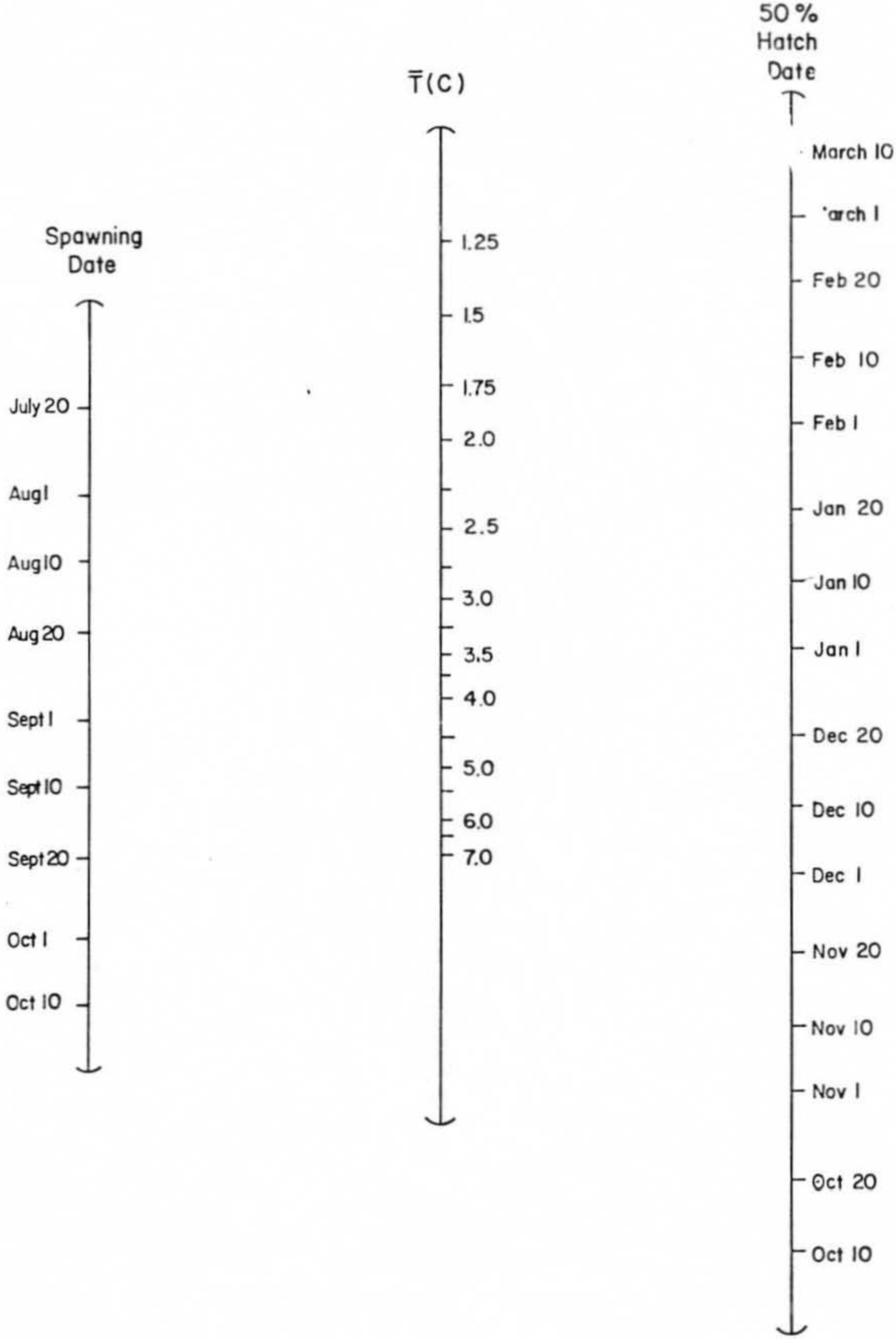
CTM — Critical Thermal Maximum
UILT — Upper Incipient Lethal Temperature
LILT — Lower Incipient Lethal Temperature
LE — Line of Equality

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

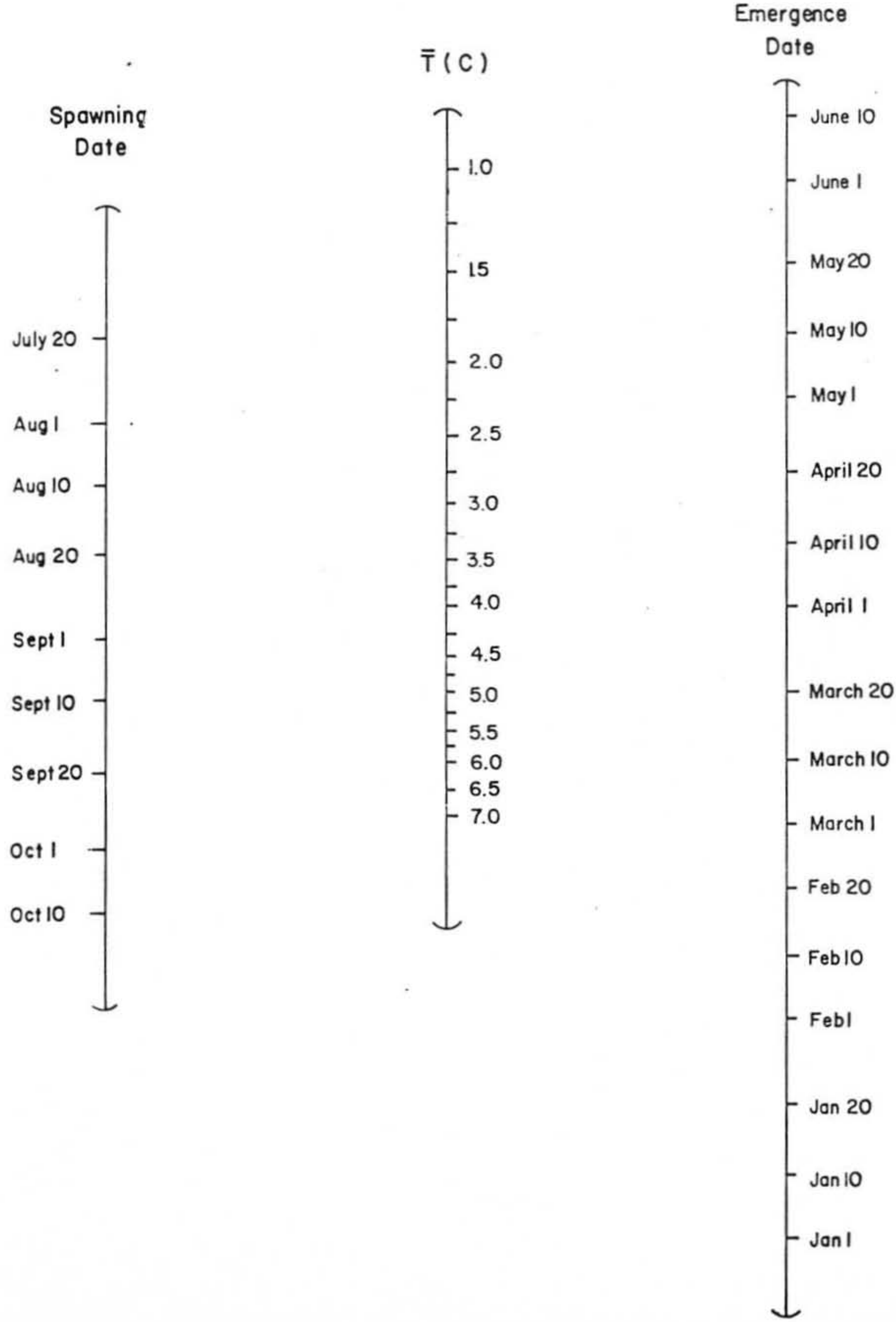

CHUM SALMON
50% HATCH
DEVELOPMENT (1/DAYS)
ADF&G
1983 XXXX
WANGAARD
1983 0000
RAYMOND
1981 ****
r=.99
slope=1.59
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
1
2
3
4
5
6
7
8
9
10
11
12
MEAN INCUBATION TEMP (C)


CHUM SALMON
EMERGENCE
DEVELOPMENT (1/DAYS)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
1
2
3
4
5
6
7
8
9
10
11
12
MEAN INCUBATION TEMP (C)
ADF&G
1983 xxxx
WANGAARD
1983 oooo
RAYMOND
1981 ****
ADF&G
1981 ++++
r=.97
slope=0.57

CHUM SALMON NOMAGRAPH



CHUM SALMON NOMAGRAPH

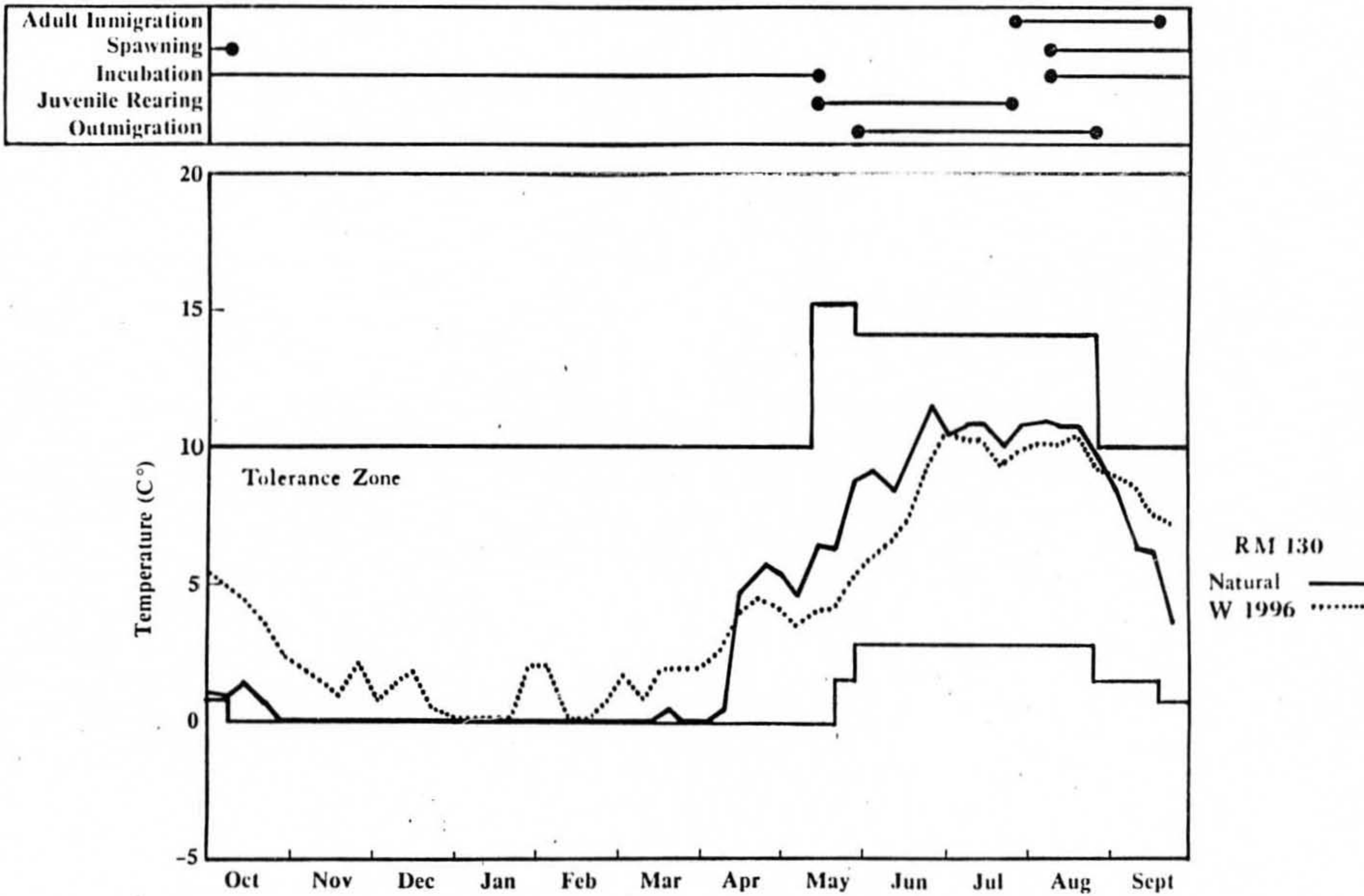


PRELIMINARY SALMON TOLERANCE CRITERIA FOR SUSITNA RIVER DRAINAGE

SPECIES	LIFE PHASE	TEMPERATURE °C TOLERANCE	TEMPERATURE °C PREFERRED
Chum	Adult Migration	1.5-21.0	6.0-13.0
	Spawning	1.0-16.0	6.0-13.0
	Incubation[1]	0-10.0	2.0- 8.0
	Rearing	1.5-16.0	5.0-15.0
	Smolt Migration	3.0-13.0	5.0-10.0
Sockeye	Adult Migration	2.5-16.0	6.0-12.0
	Spawning	4.0-14.0	6.0-12.0
	Incubation[1]	2.0-14.0	4.5- 8.0
	Rearing	4.0-16.0	7.0-14.0
	Smolt Migration	4.0-18.0	5.0-10.0
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	5.0-10.0
Chinook	Adult Migration	2.0-16.0	7.0-13.0
	Spawning	5.0-14.0	7.0-12.0
	Incubation[1]	1.5-16.0	4.0-12.0
	Rearing	4.0-16.0	7.0-14.0
	Smolt Migration	4.0-16.0	7.0-14.0
Coho	Adult Migration	2.0-19.0	6.0-11.0
	Spawning	2.0-17.0	6.0-13.0
	Incubation[1]	0-14.0	4.0-10.0
	Rearing	4.0-21.0	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 as criteria for incubation.

Chum Salmon

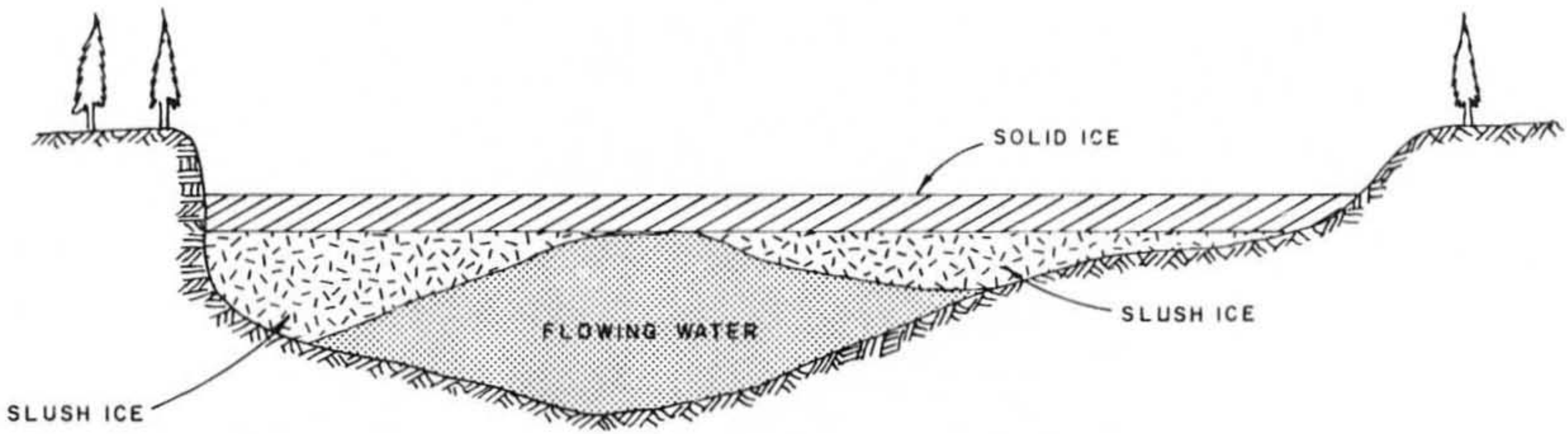


Adult Inmigration
Spawning
Incubation
Juvenile Rearing
Outmigration
20
15
10
5
0
-5
Temperature (C°)
Tolerance Zone
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
RM 130
Natural
W 1996

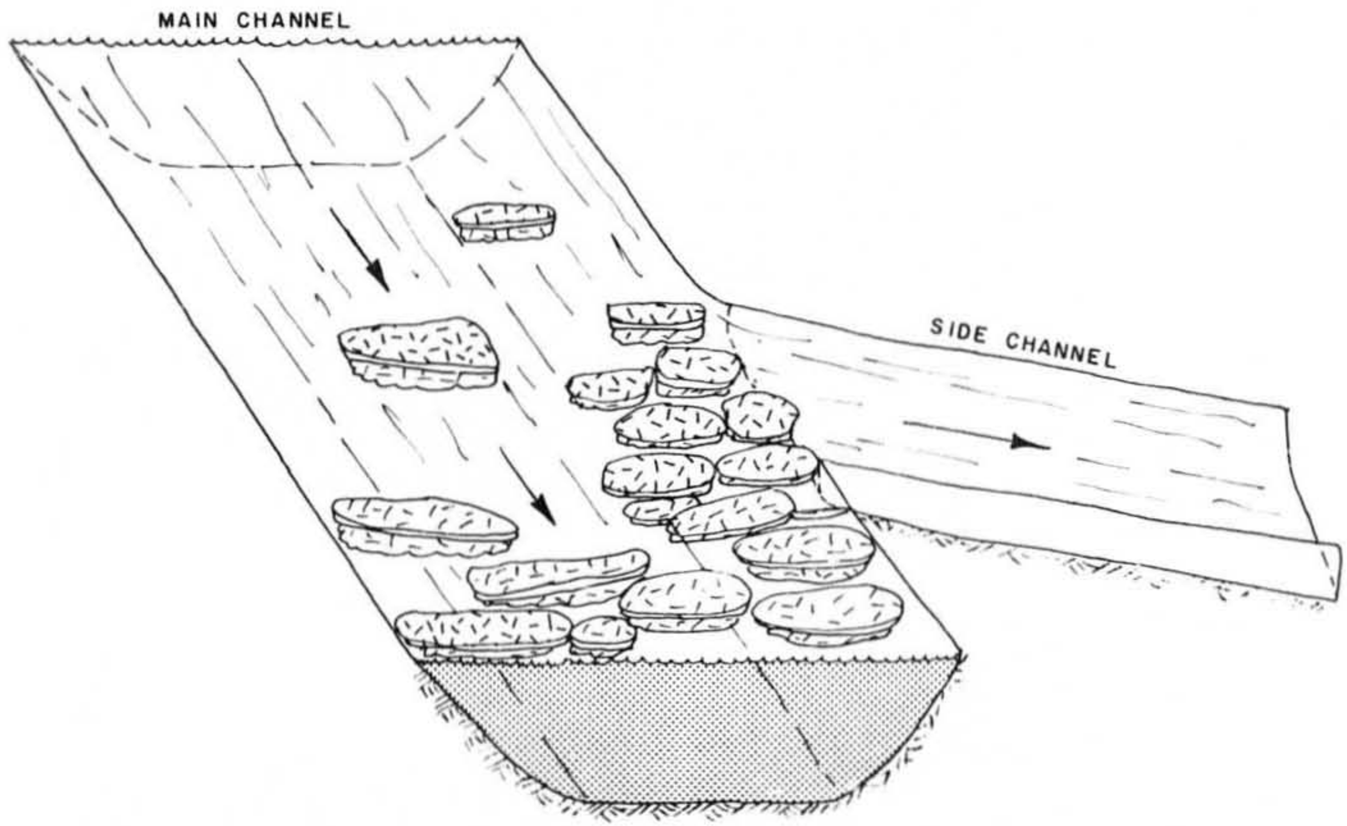
Figure Mean temperature °C September 1 through April 30.

	1974-1975			1982-1983		
RM	NATURAL	WATANA 1996	WATANA 2001	NATURAL	WATANA 1996	WATANA 2001
150	0.9	2.1	2.4	1.1	2.8	3.1
130	1.0	1.8	2.0	1.2	2.4	2.5
100	1.1	1.6	1.7	1.3	2.0	2.2

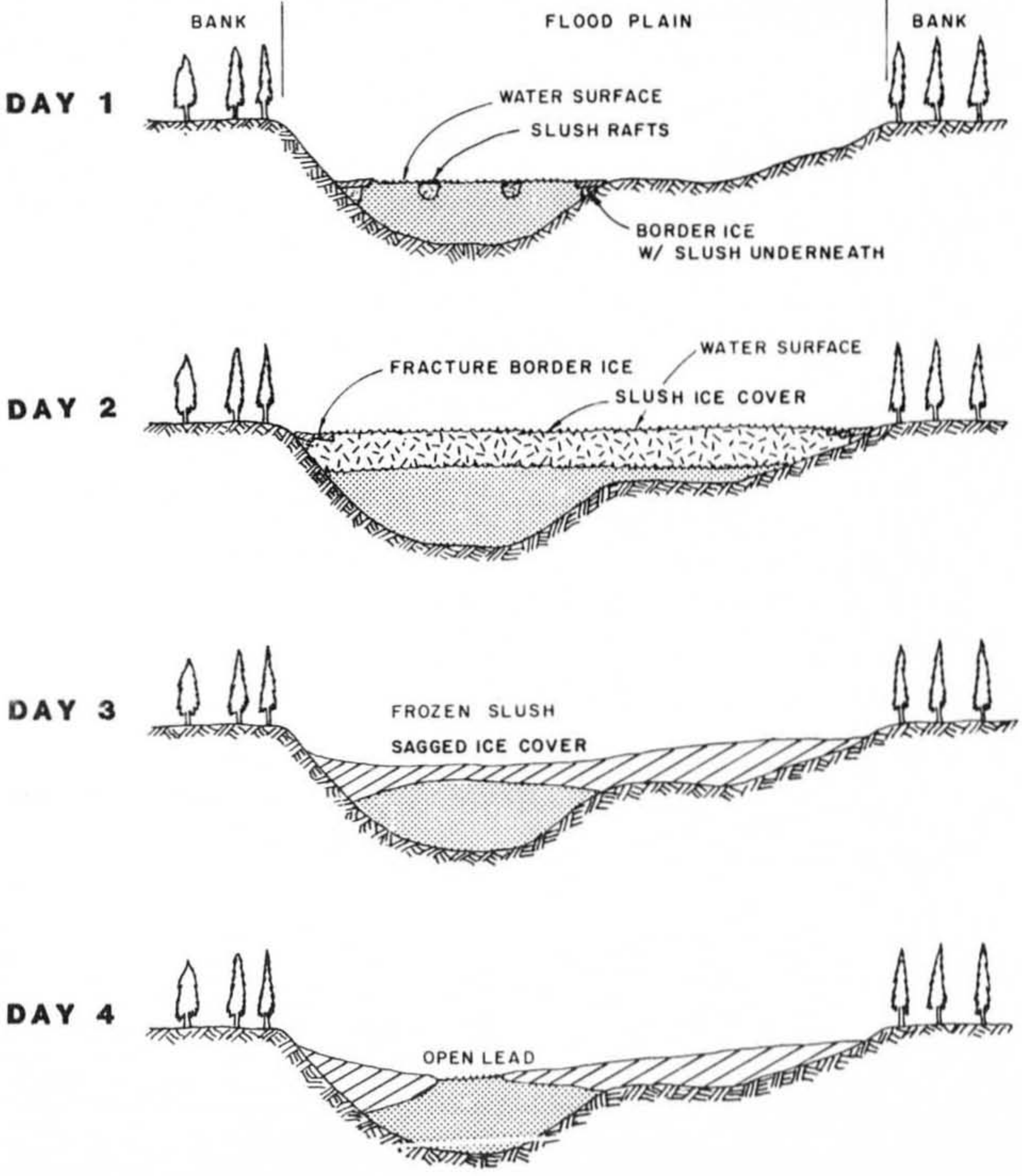
TYPICAL MAIN CHANNEL CROSS SECTION



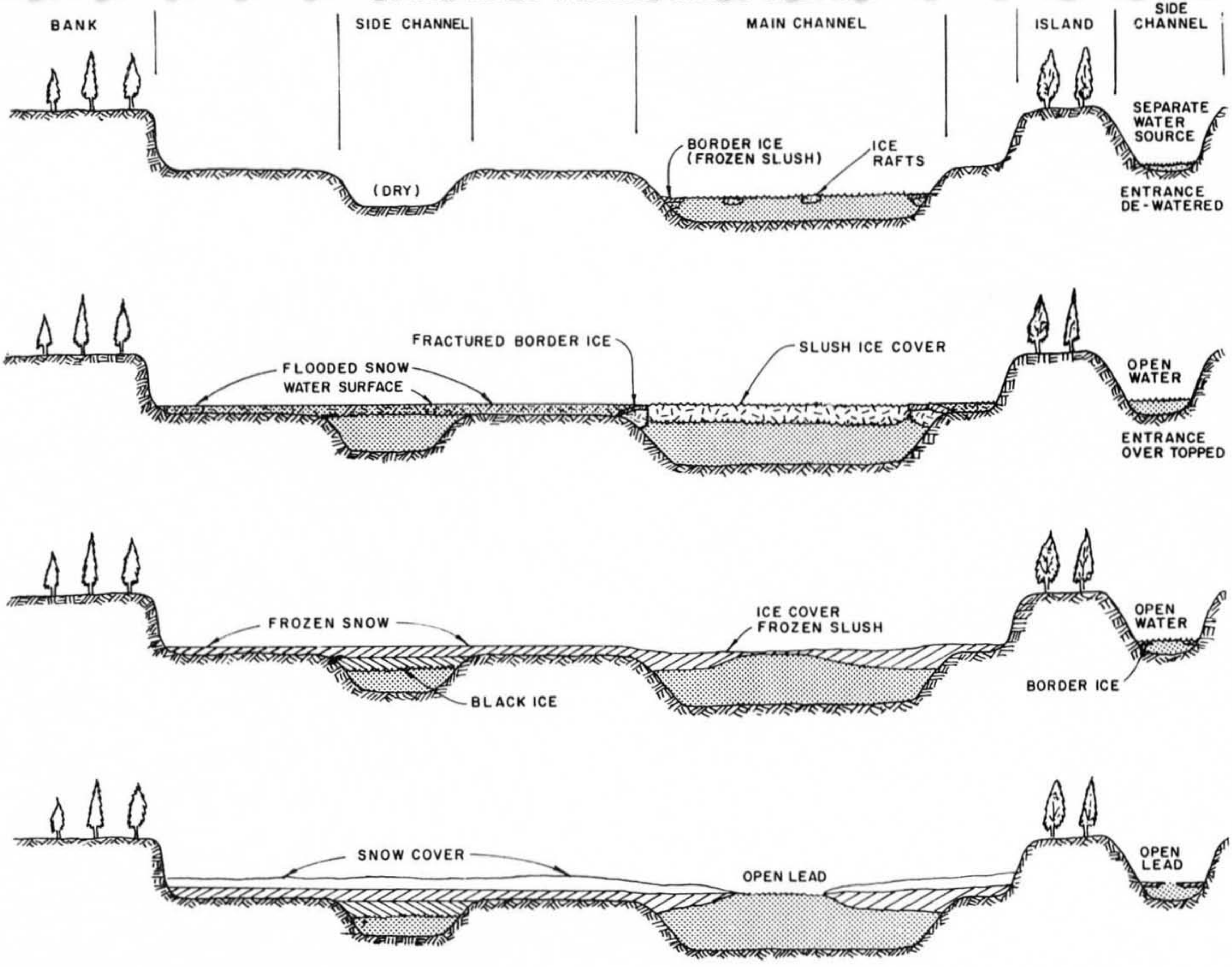
SIDE CHANNEL FLOODING



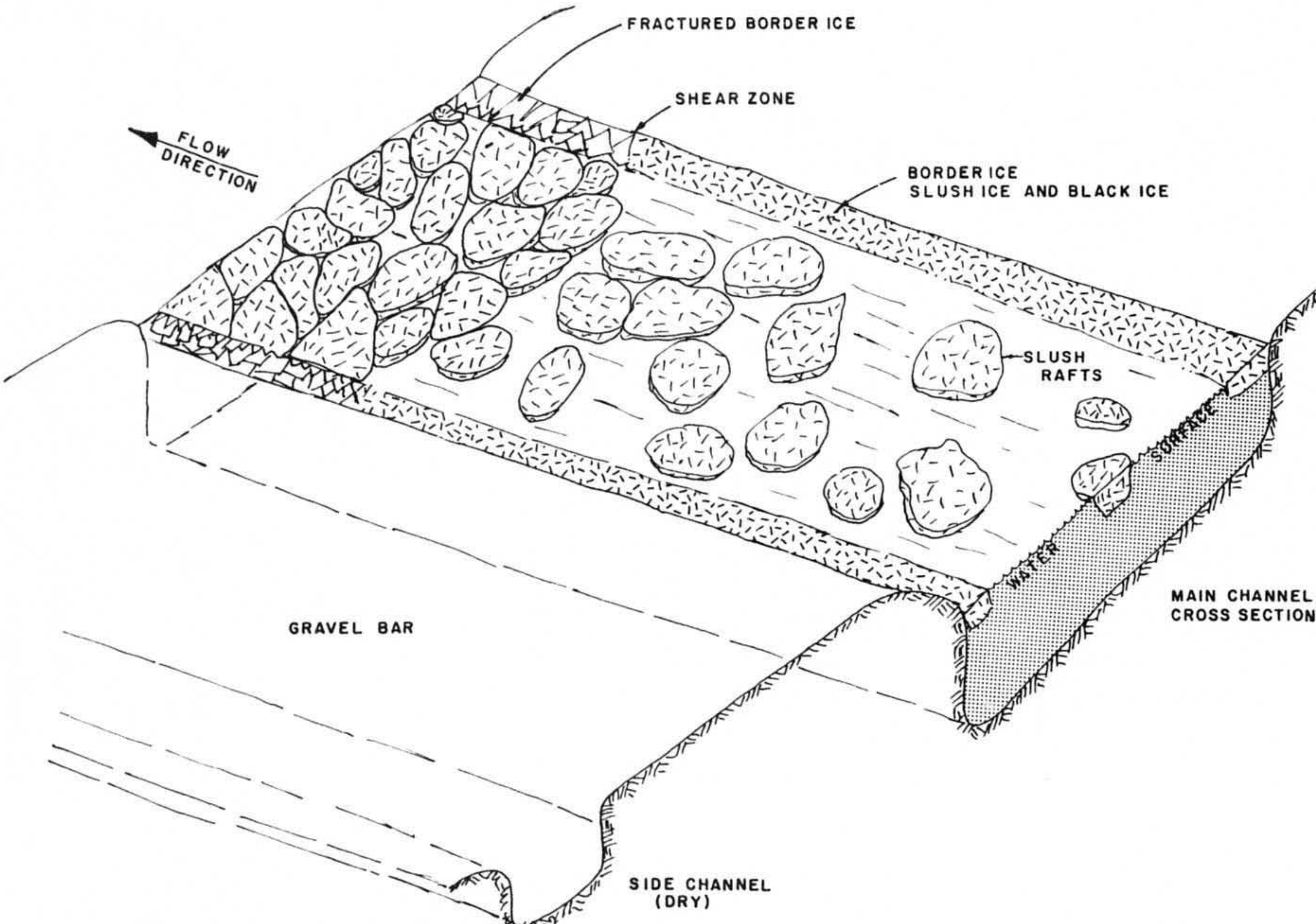
MIDDLE RIVER TYPICAL CROSS SECTION

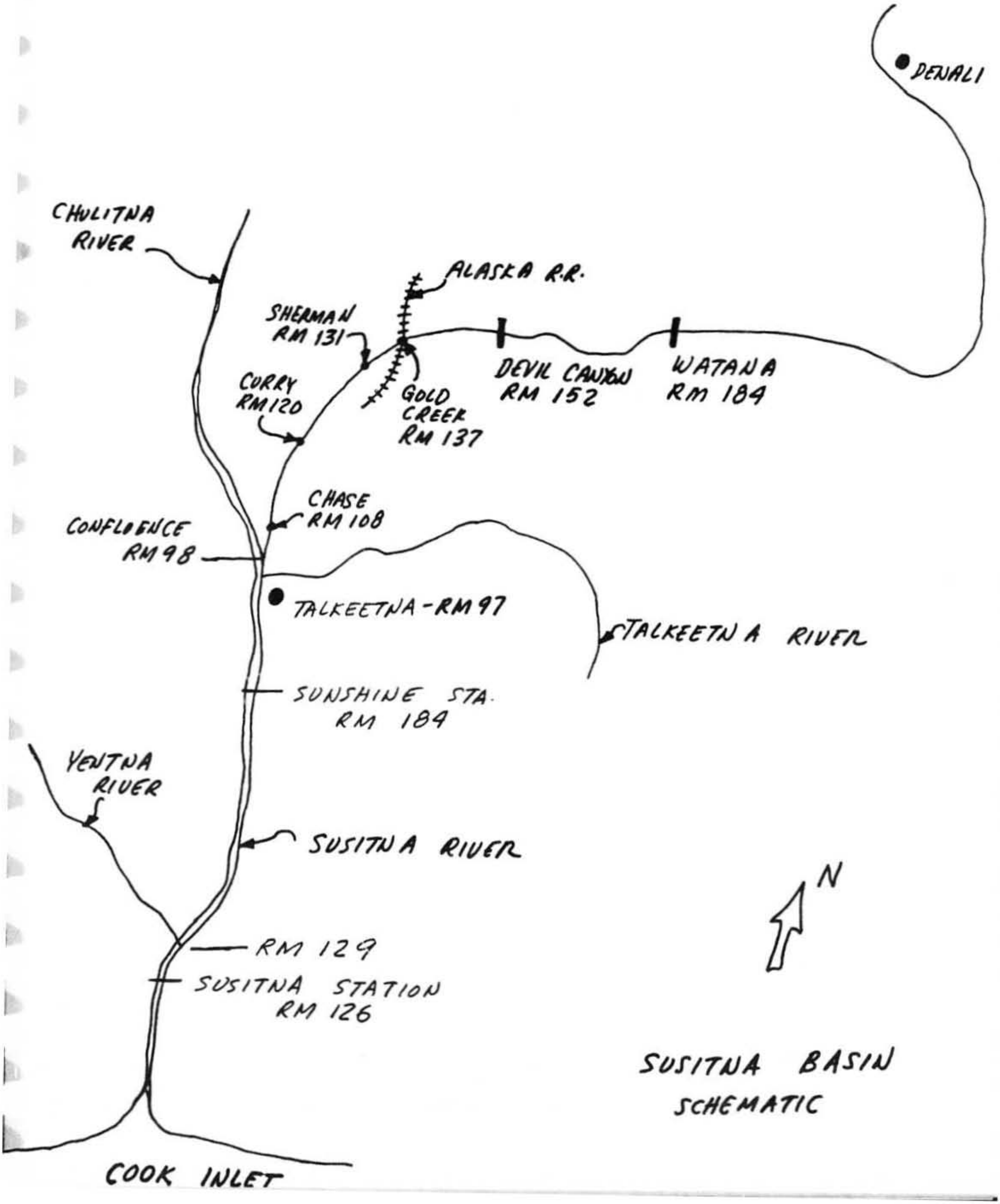


LOWER RIVER TYPICAL CROSS SECTION

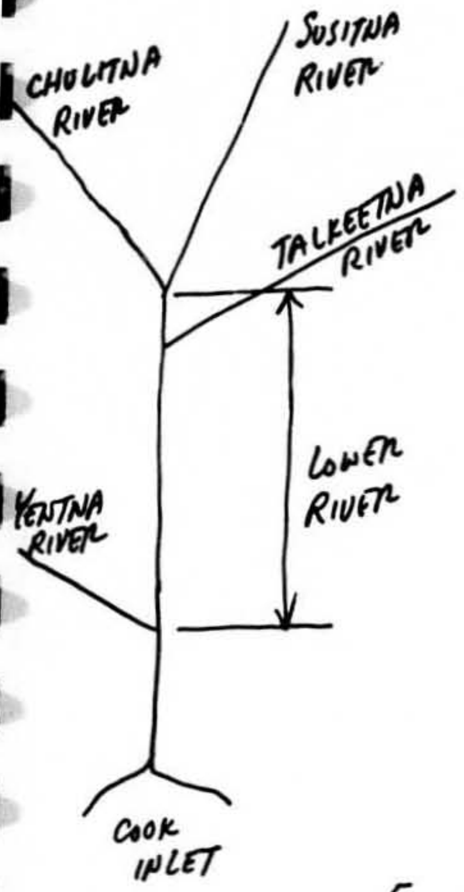


JUXTAPOSITIONING





SUSITNA BASIN SCHEMATIC



PROCEDURE USED TO FILL LOWER RIVER
(YENTNA TO CONFLUENCE)

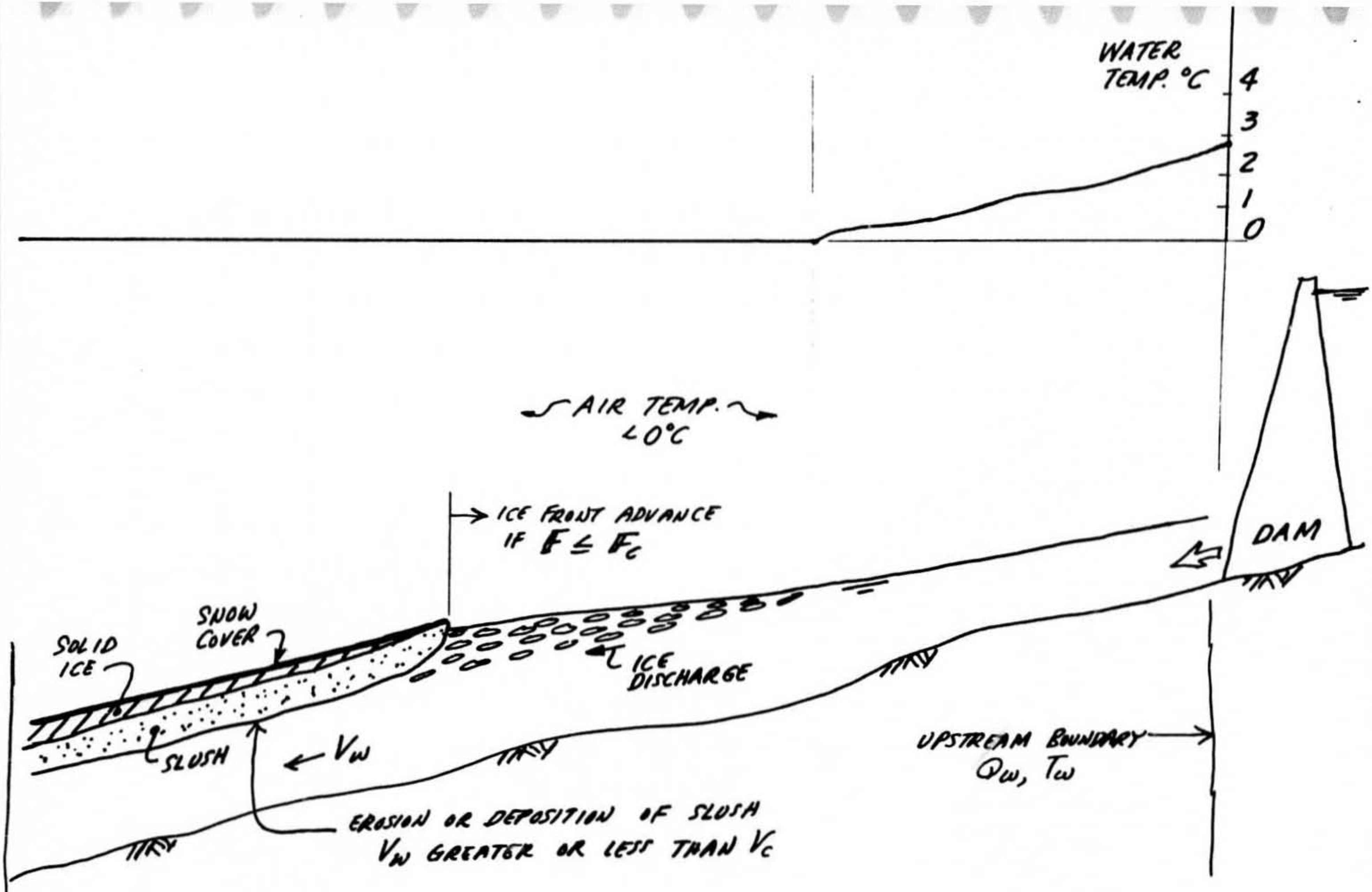
PRE-PROJECT (1982 AND 1983)

1. Model Ice Output from Middle Reach.
2. Add 25% for Chulitna and Talkeetna.
3. Estimate ice production in Lower River. Assumes heat transfer coefficient, river width, based on observed progression rate.
4. Based on average of total ice delivered to Lower River for the two years, and an additional allowance of 25% for with-project, establish ice volume to be stored in Lower River with-project.

5. Correlate Chulitna + Talkeetna Rivers ice production with freezing degree days at Talkeetna. Correlate Lower River ice production with freezing degree days at Talkeetna and location of ice front.

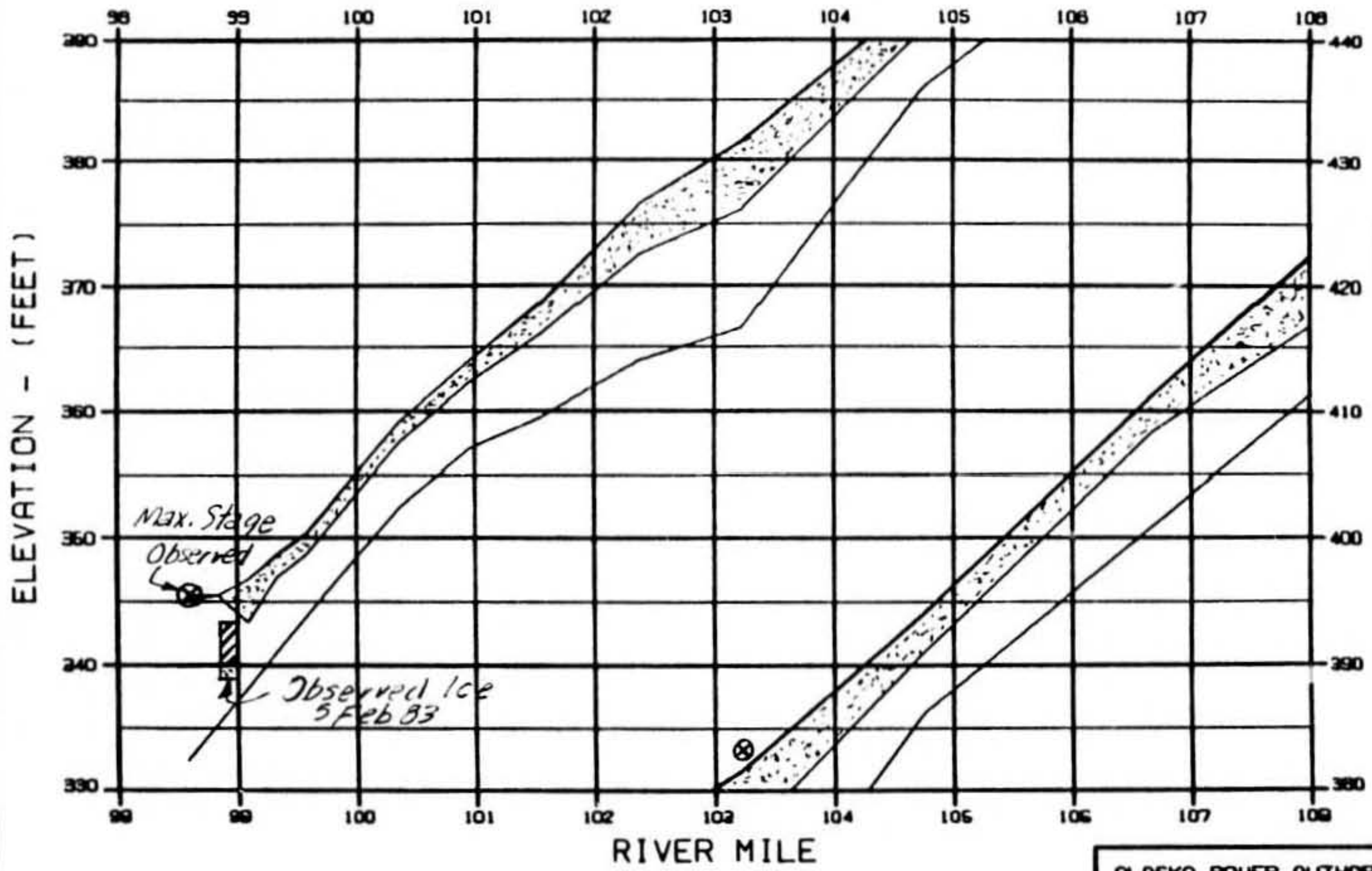
WITH PROJECT

1. Start Ice model in Middle Reach on November 1, with ice front assumed at Yentna.
2. Compute ice production in Middle Reach.
3. Estimate ice production from Chulitna + Talkeetna.
4. " " " in Lower River.
5. Cumulate volume until required volume is attained.
6. Start ice front up Middle Reach.



SUSITNA PROJECT
INSTREAM ICE MODEL
RIVER FREEZE-UP

c



LEGEND:

- TOP OF SOLID ICE
- SLUSH/SOLID ICE INTERFACE
- BOTTOM OF SLUSH ICE
- RIVER BED

WEATHER PERIOD : 1 NOV 82 - 20 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE028

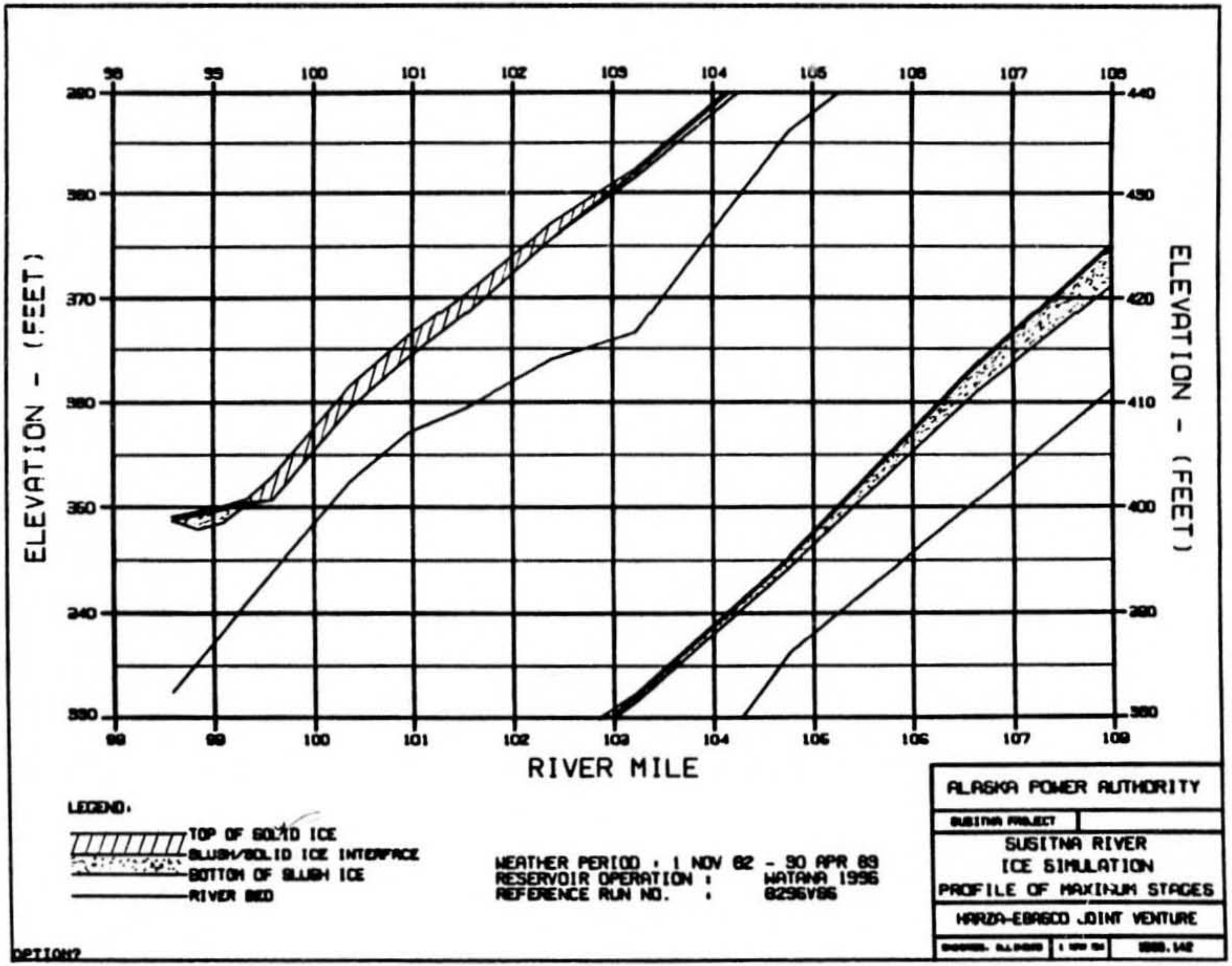
ALASKA POWER AUTHORITY

SUSITNA PROJECT

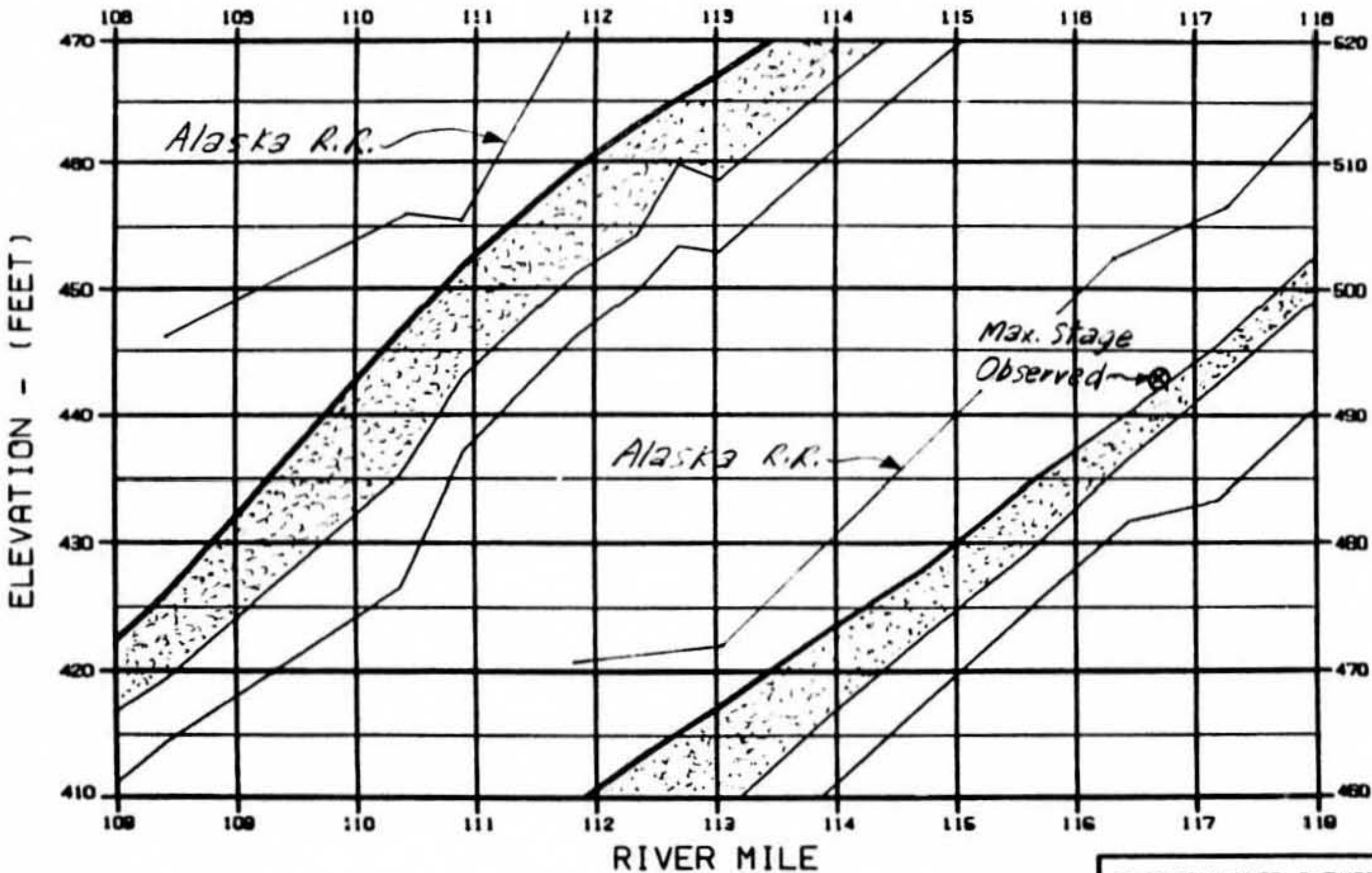
SUSITNA RIVER
ICE SIMULATION
PROFILE OF MAXIMUM STAGES

HARZA-EBASCO JOINT VENTURE

OPTION?


ELEVATION - (FEET)
ELEVATION - (FEET)
RIVER MILE
98
99
100
101
102
103
104
105
106
107
108
LEGEND:
TOP OF SOLID ICE
SLUSH/SOLID ICE INTERFACE
BOTTOM OF SLUSH ICE
RIVER BED
WEATHER PERIOD : 1 NOV 82 - 30 APR 83
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : 8296V86
ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
ICE SIMULATION
PROFILE OF MAXIMUM STAGES
HARZA-EBASCO JOINT VENTURE
OPTION2

C



LEGEND:

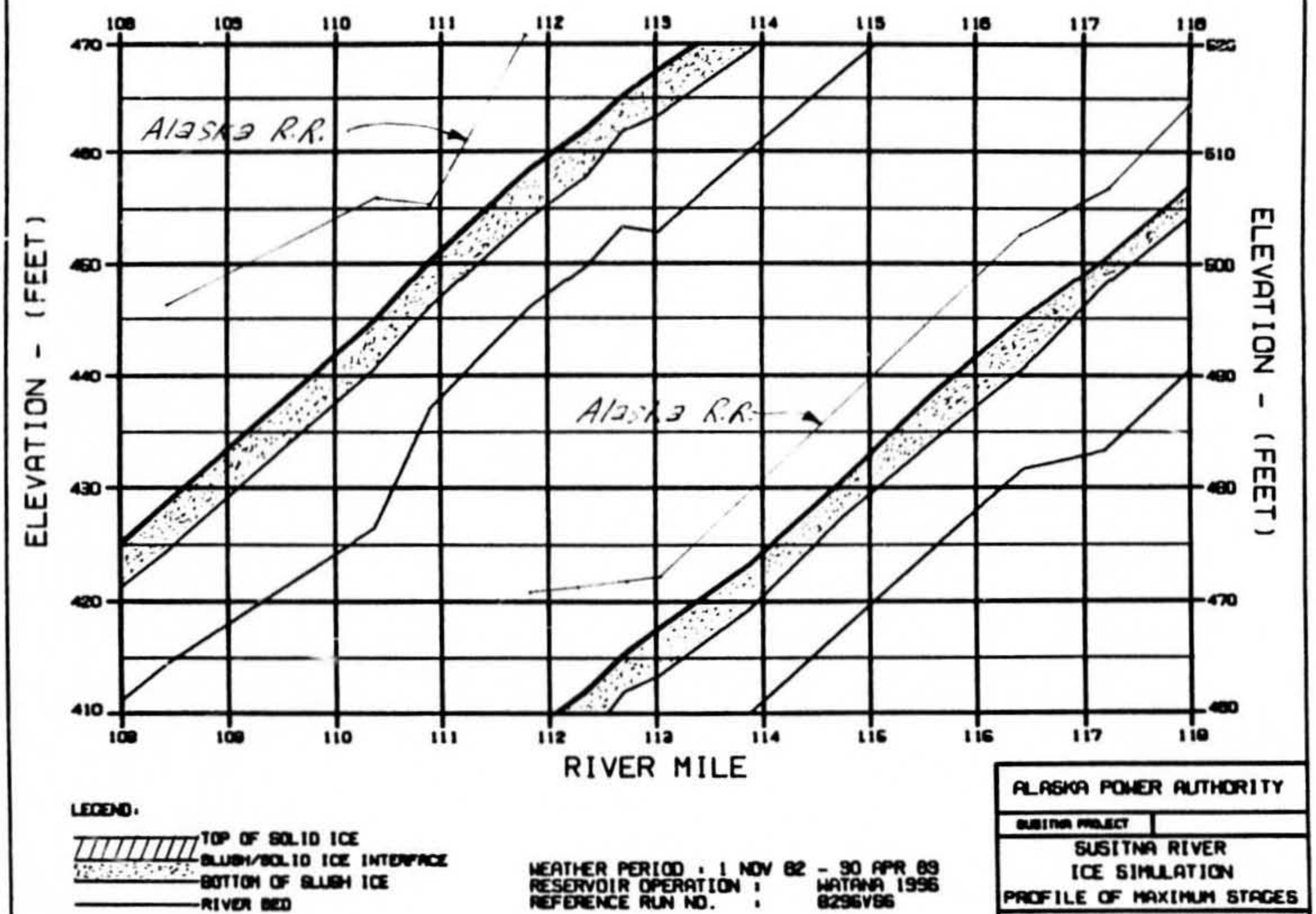
- TOP OF SOLID ICE
- SLUSH/SOLID ICE INTERFACE
- BOTTOM OF SLUSH ICE
- RIVER BED

WEATHER PERIOD : 1 NOV 82 - 20 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE82B

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
ICE SIMULATION
PROFILE OF MAXIMUM STAGES
HARZA-EBASCO JOINT VENTURE
1888.142

OPTION?

CC



WEATHER PERIOD : 1 NOV 82 - 30 APR 83
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : 8296V96

ALASKA POWER AUTHORITY

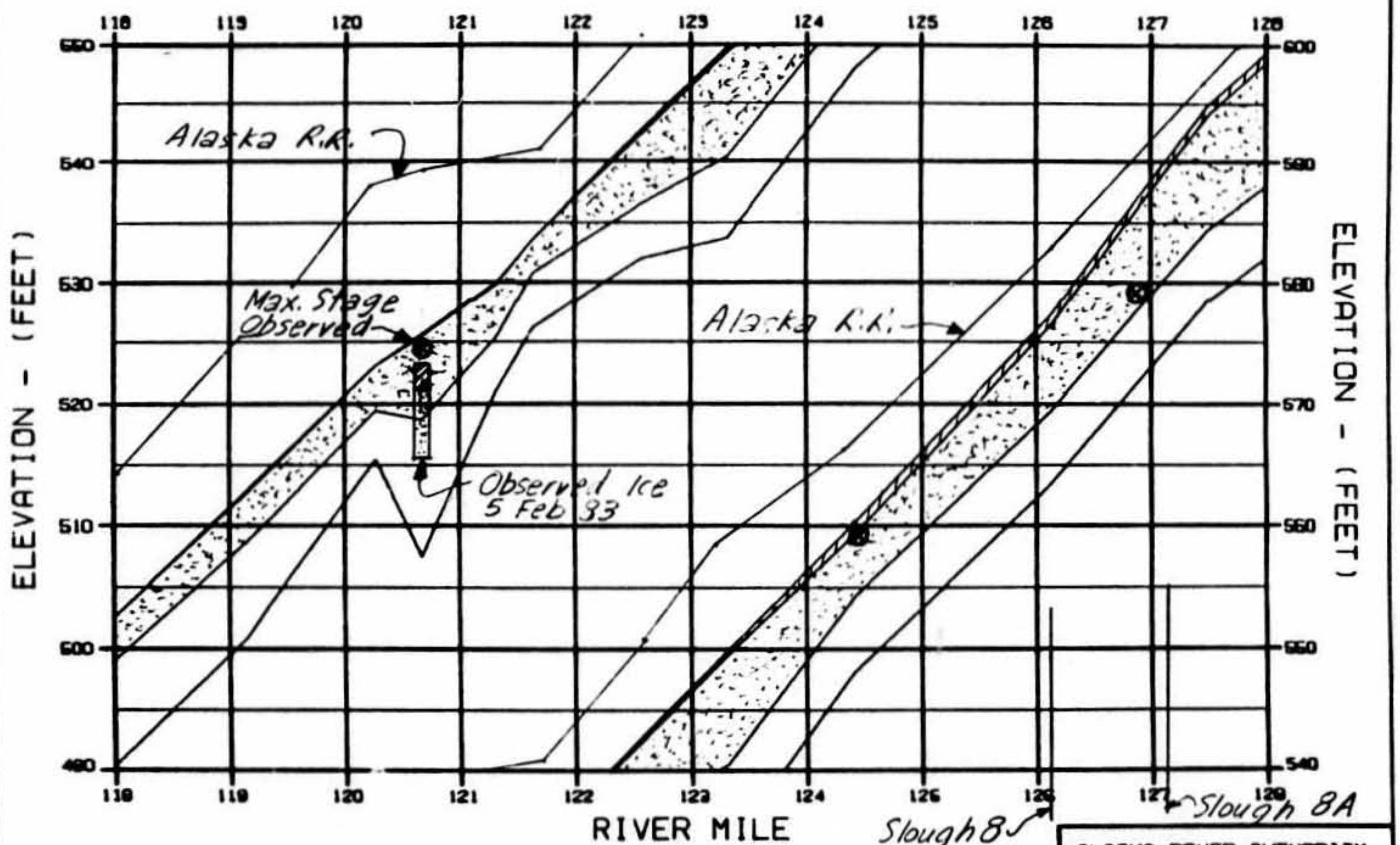
SUSITNA PROJECT

SUSITNA RIVER
ICE SIMULATION
PROFILE OF MAXIMUM STAGES

HARZA-EBASCO JOINT VENTURE

OPTION?

c



LEGEND:

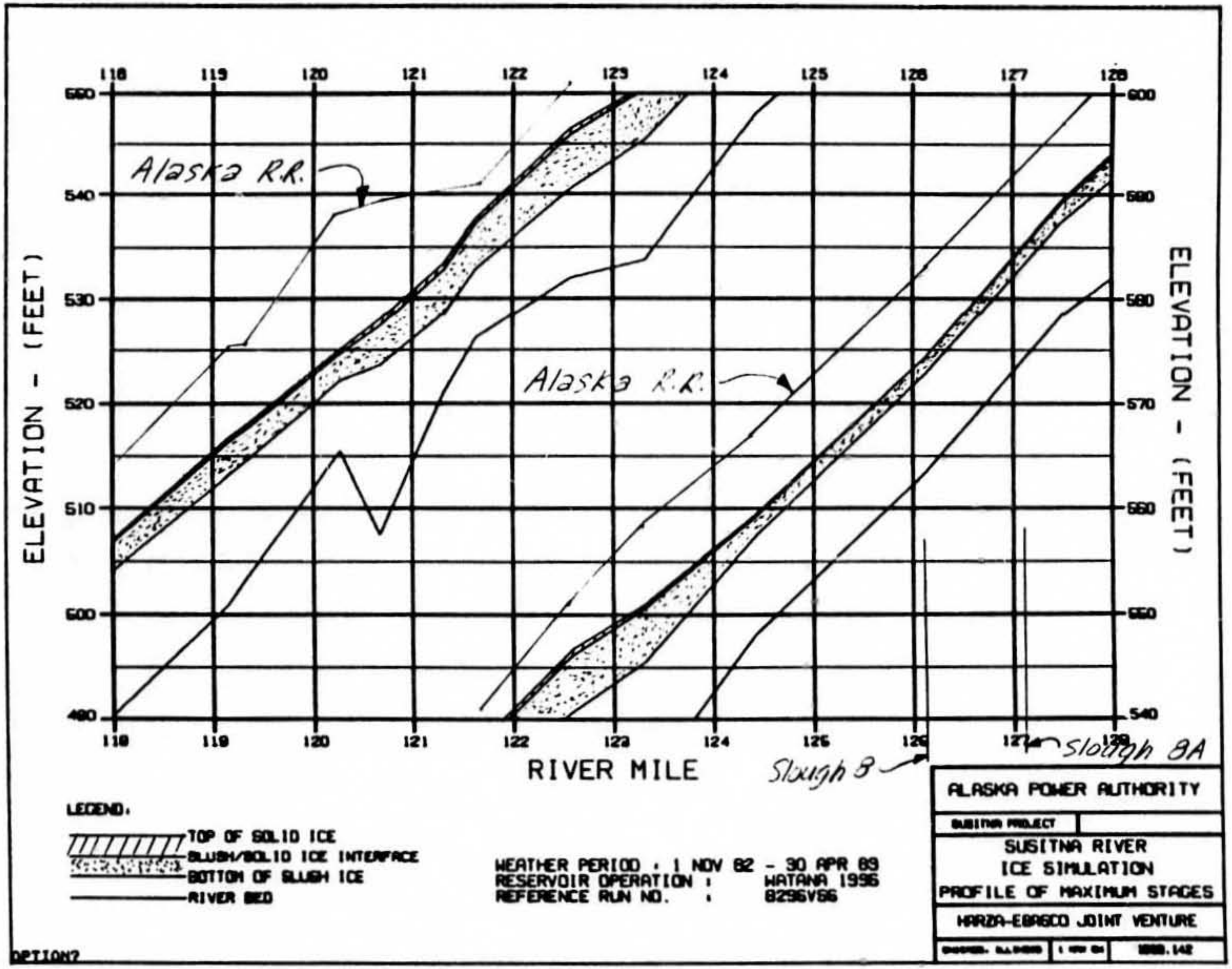
- TOP OF SOLID ICE
- SLUSH/SOLID ICE INTERFACE
- BOTTOM OF SLUSH ICE
- RIVER BED

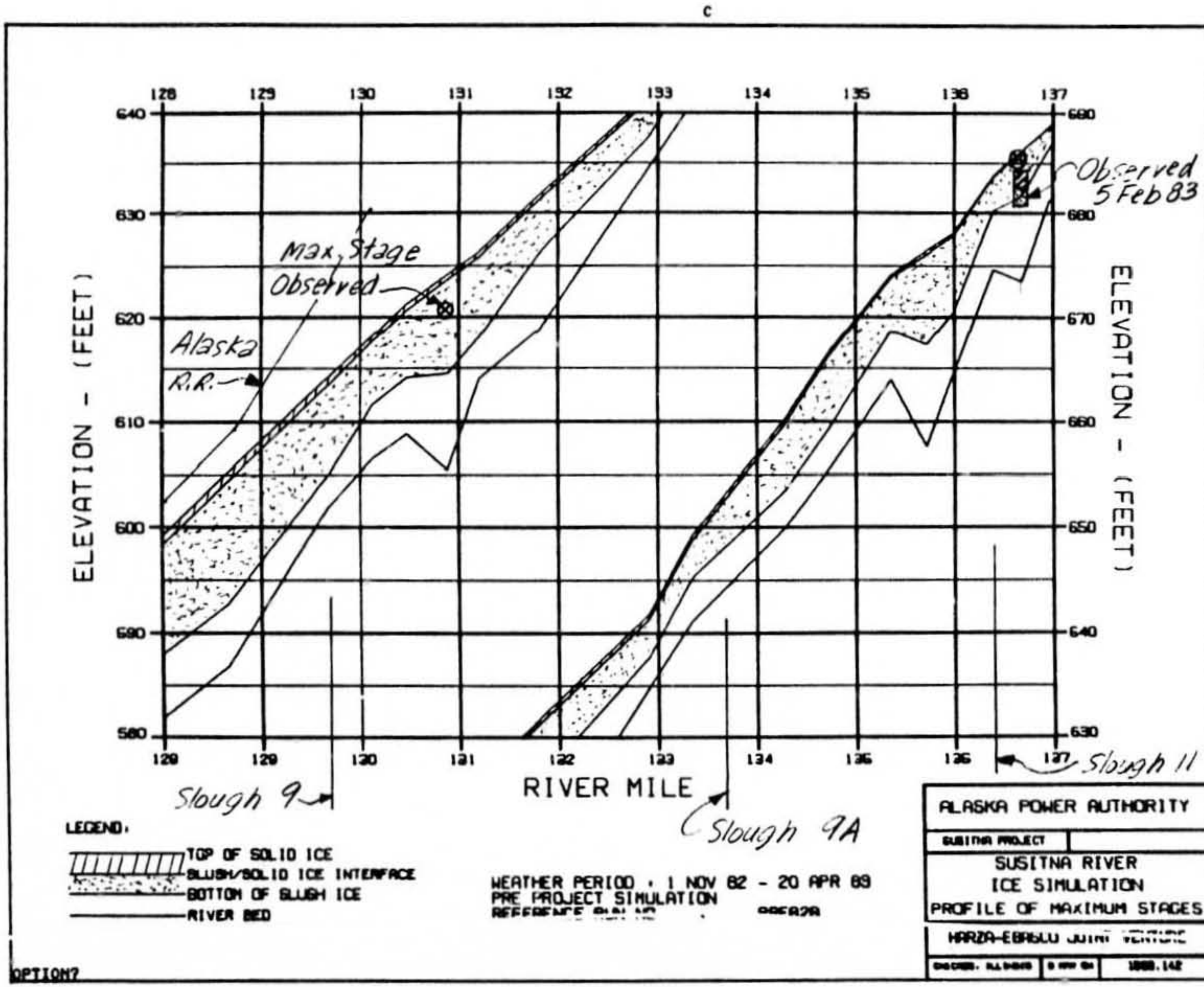
WEATHER PERIOD : 1 NOV 82 - 20 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE82B

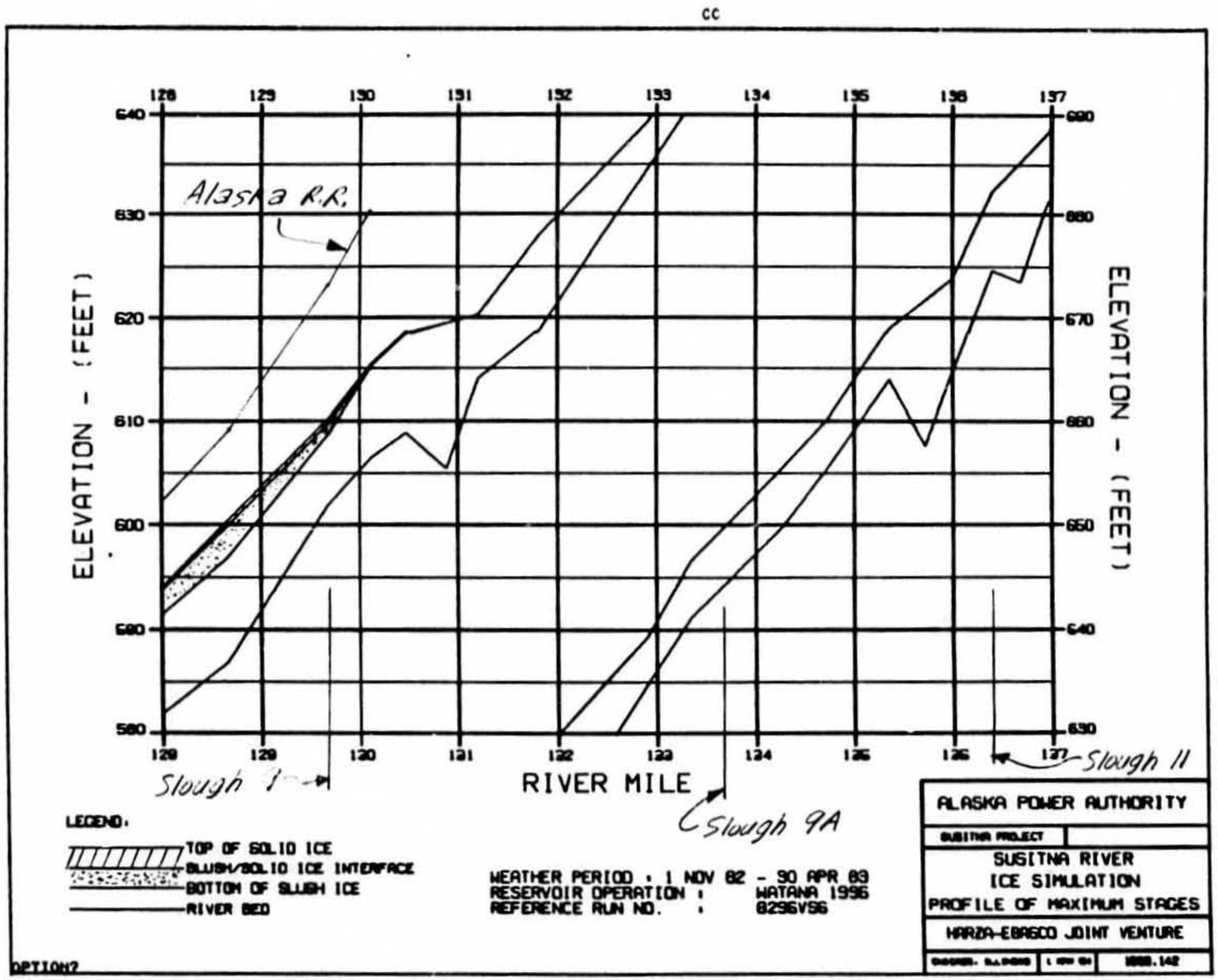
ALASKA POWER AUTHORITY	
SUSITNA PROJECT	
SUSITNA RIVER ICE SIMULATION PROFILE OF MAXIMUM STAGES	
HARZA-EBASCO JOINT VENTURE	
[illegible]	1898.142

OPTION?

CC


ELEVATION - (FEET)
RIVER MILE
118
119
120
121
122
123
124
125
126
127
128
490
500
510
520
530
540
550
540
550
560
570
580
590
600
Alaska R.R.
Alaska R.R.
Slough 8
Slough 8A
LEGEND:
TOP OF SOLID ICE
SLUSH/SOLID ICE INTERFACE
BOTTOM OF SLUSH ICE
RIVER BED
WEATHER PERIOD : 1 NOV 82 - 30 APR 89
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : 8296V66
ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
ICE SIMULATION
PROFILE OF MAXIMUM STAGES
HARZA-EBASCO JOINT VENTURE
OPTION7


c
ELEVATION - (FEET)
640
630
620
610
600
590
580
680
670
660
650
640
630
128
129
130
131
132
133
134
135
136
137
RIVER MILE
Max Stage
Observed
Alaska
R.R.
Observed Ice
5 Feb 83
Slough 9
Slough 9A
Slough 11
LEGEND:
TOP OF SOLID ICE
SLUSH/SOLID ICE INTERFACE
BOTTOM OF SLUSH ICE
RIVER BED
WEATHER PERIOD : 1 NOV 82 - 20 APR 83
PRE PROJECT SIMULATION
ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
ICE SIMULATION
PROFILE OF MAXIMUM STAGES
HARZA-EBASCO JOINT VENTURE
OPTION?


CC
ELEVATION - (FEET)
RIVER MILE
Alaska R.R.
Slough 9
Slough 9A
Slough 11
LEGEND:
TOP OF SOLID ICE
SLUSH/SOLID ICE INTERFACE
BOTTOM OF SLUSH ICE
RIVER BED
WEATHER PERIOD : 1 NOV 82 - 30 APR 83
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : 8296VS6
ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
ICE SIMULATION
PROFILE OF MAXIMUM STAGES
HARZA-EBASCO JOINT VENTURE
OPTION7

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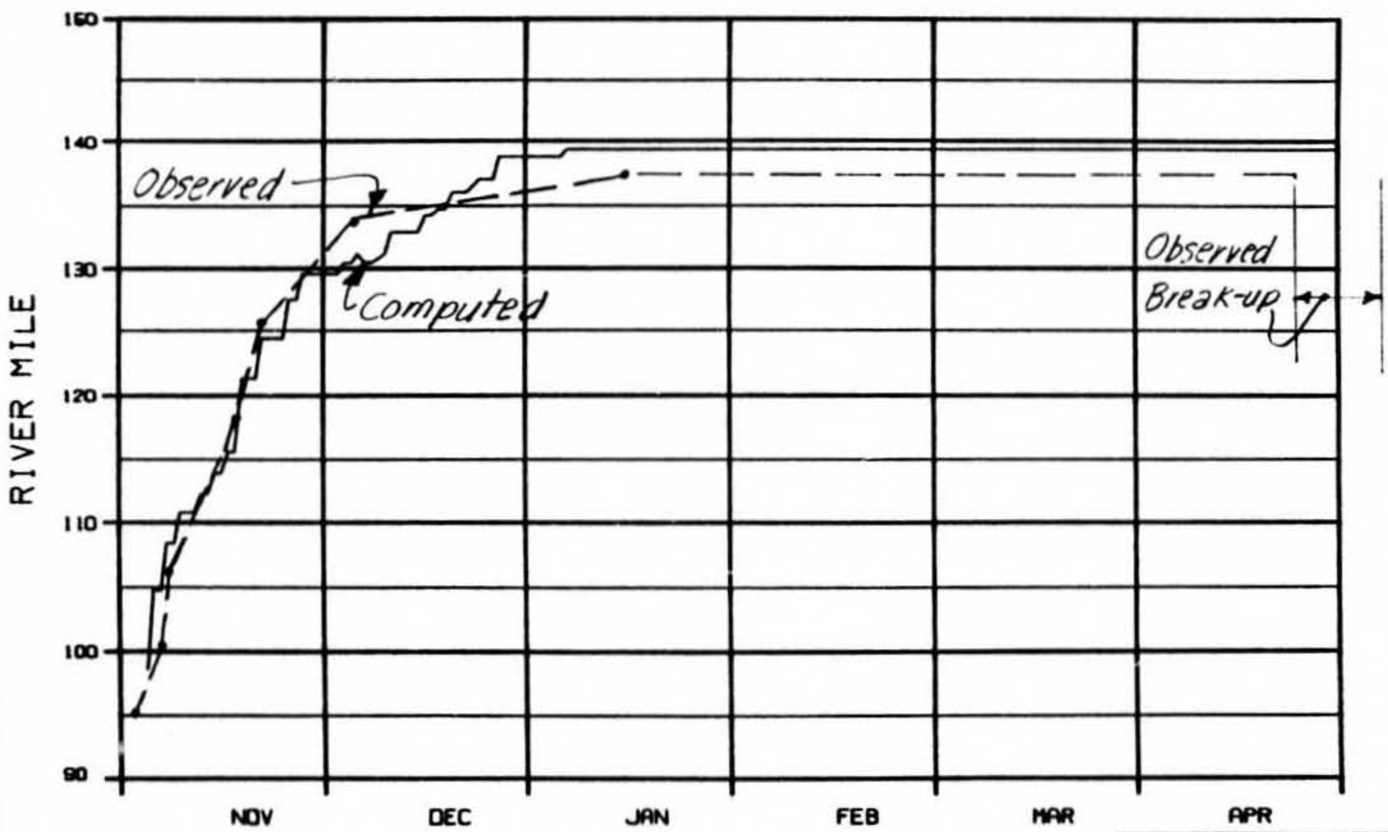


LEGEND:

——— ICE FRONT

– – – ZERO DEGREE ISOTHERM

WEATHER PERIOD : 1 NOV 82 - 30 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE82

ALASKA POWER AUTHORITY

SUSITNA PROJECT

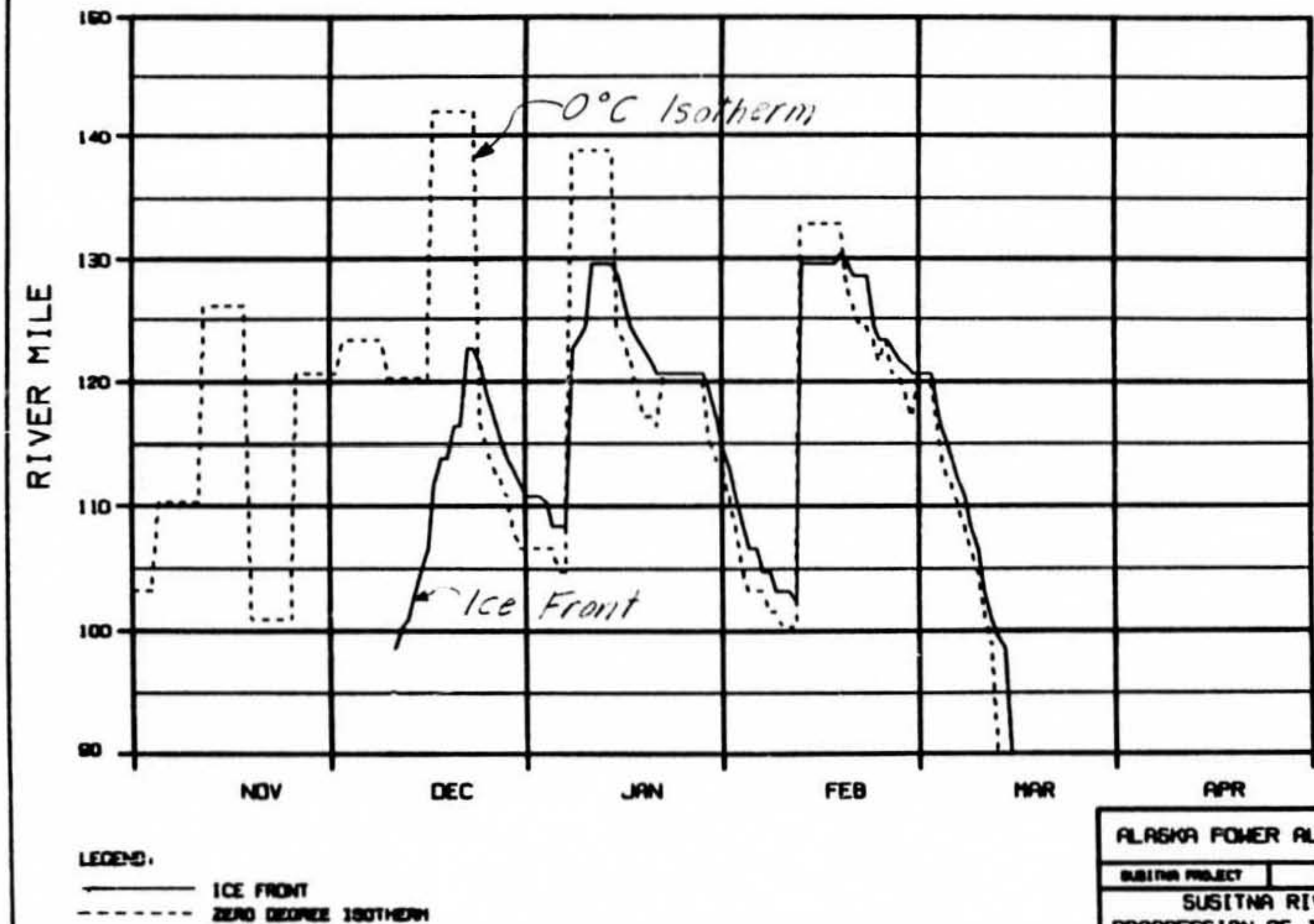
SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM

HARZA-EBASCO JOINT VENTURE

1000.142

OPTION?

CC



WEATHER PERIOD : 1 NOV 82 - 30 APR 83
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : 8296VS6

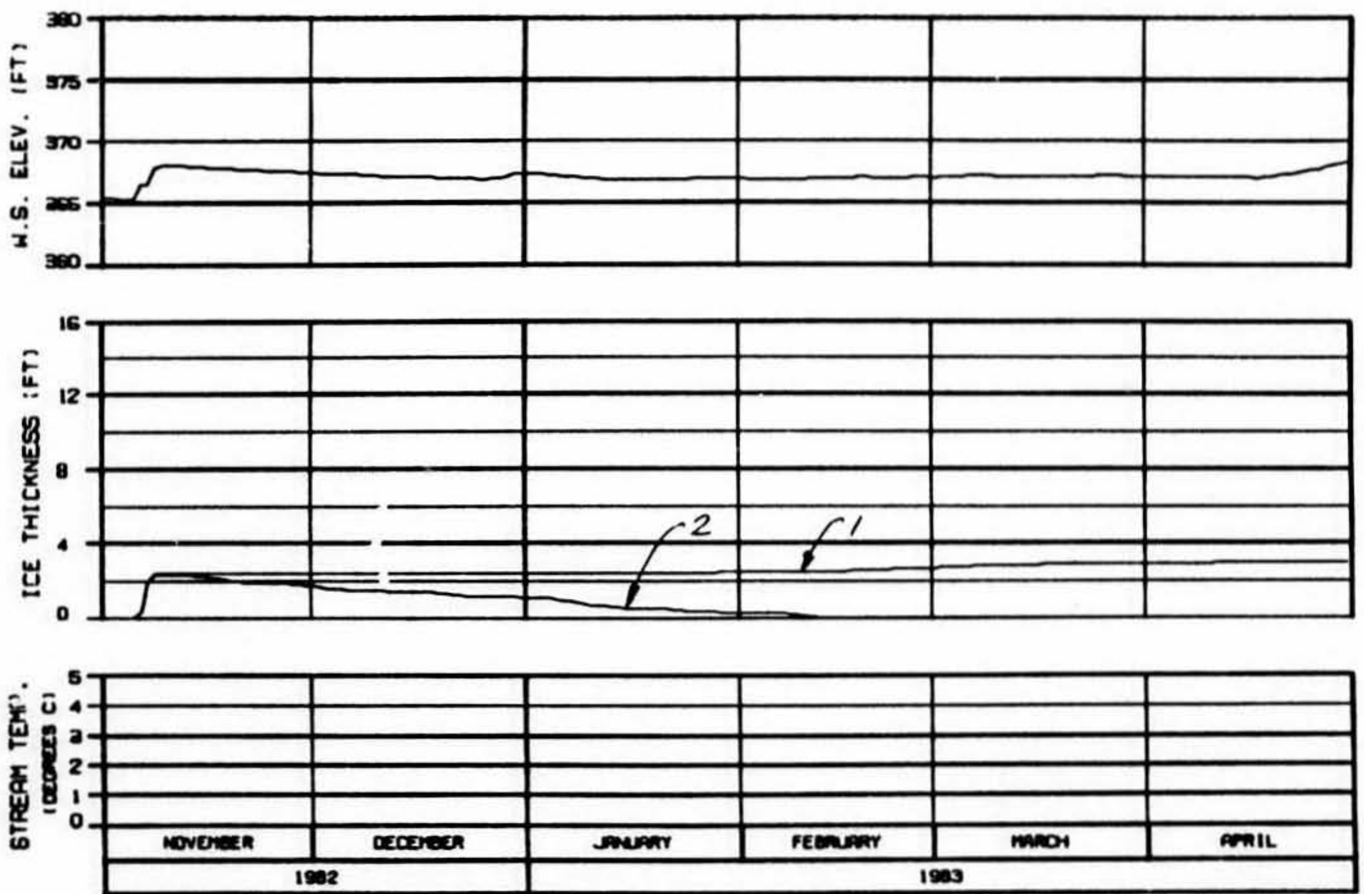
ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM

HARZA-EBASCO JOINT VENTURE

OPTION?



RIVER MILE : 101.50

ICE THICKNESS LEGEND:

1. TOTAL THICKNESS
2. SLUSH COMPONENT

WEATHER PERIOD : 1 NOV 82 TO 30 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE82

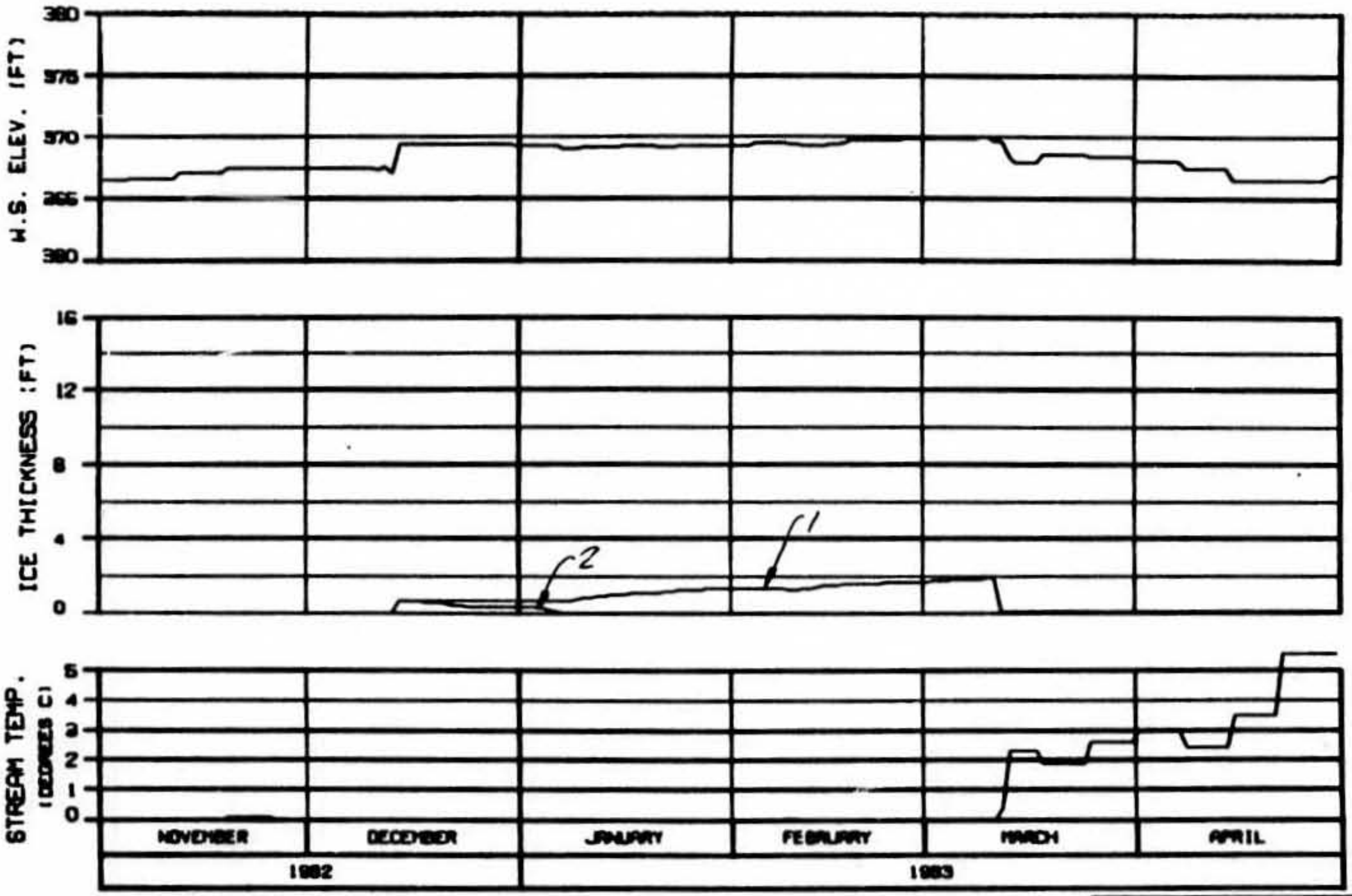
Whiskers Slough

ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
ICE SIMULATION
TIME HISTORY

HARZA-EBASCO JOINT VENTURE



RIVER MILE : 101.50

ICE THICKNESS LEGEND:

1. TOTAL THICKNESS
2. SLUSH COMPONENT

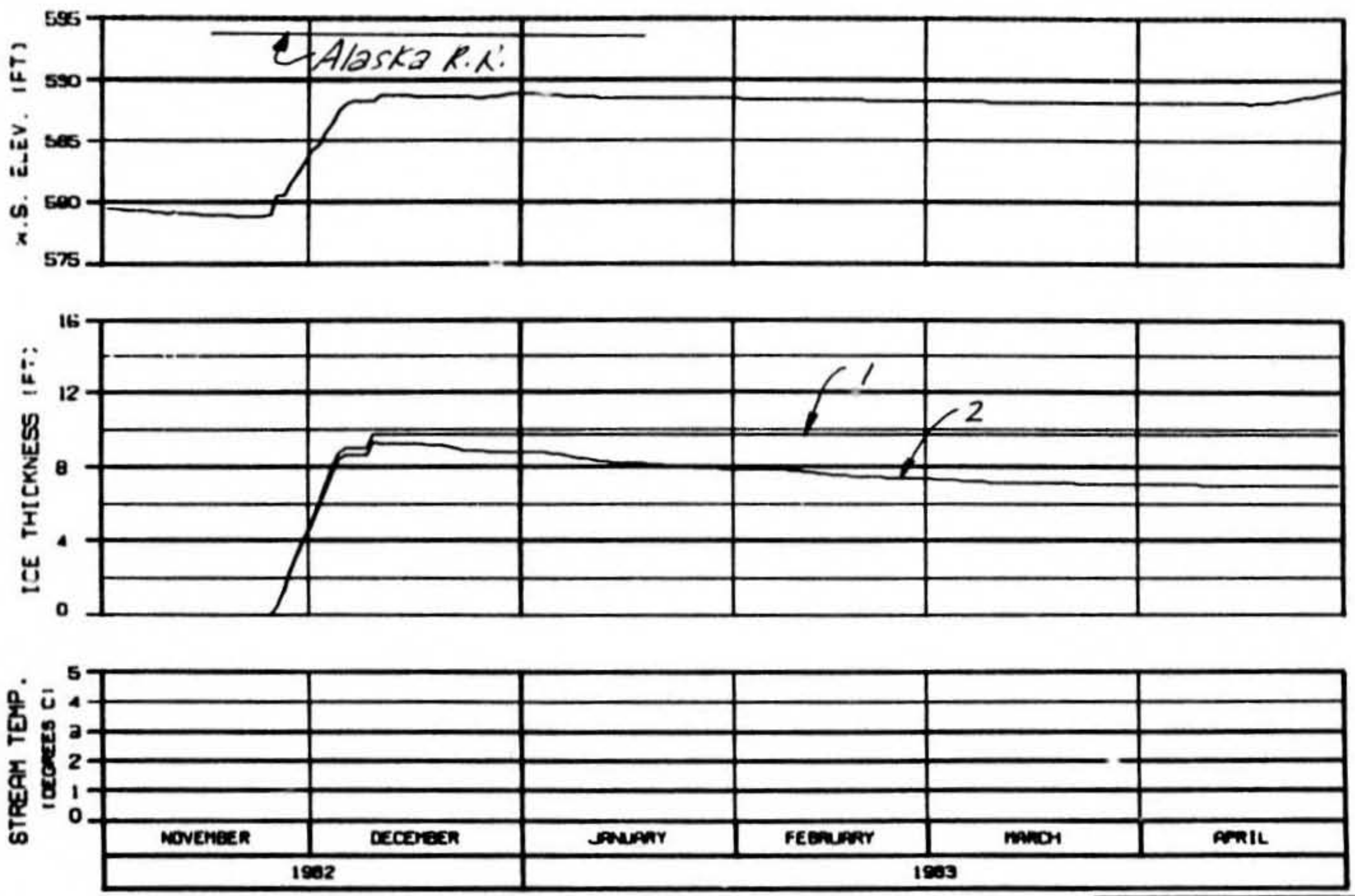
WEATHER PERIOD : 1 NOV 82 TO 30 APR 83
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : 8296VS6

Whiskers Slough

ALASKA POWER AUTHORITY

SUSITNA RIVER
ICE SIMULATION
TIME HISTORY

HARZA-EBASCO JOINT VENTURE



RIVER MILE : 127.10

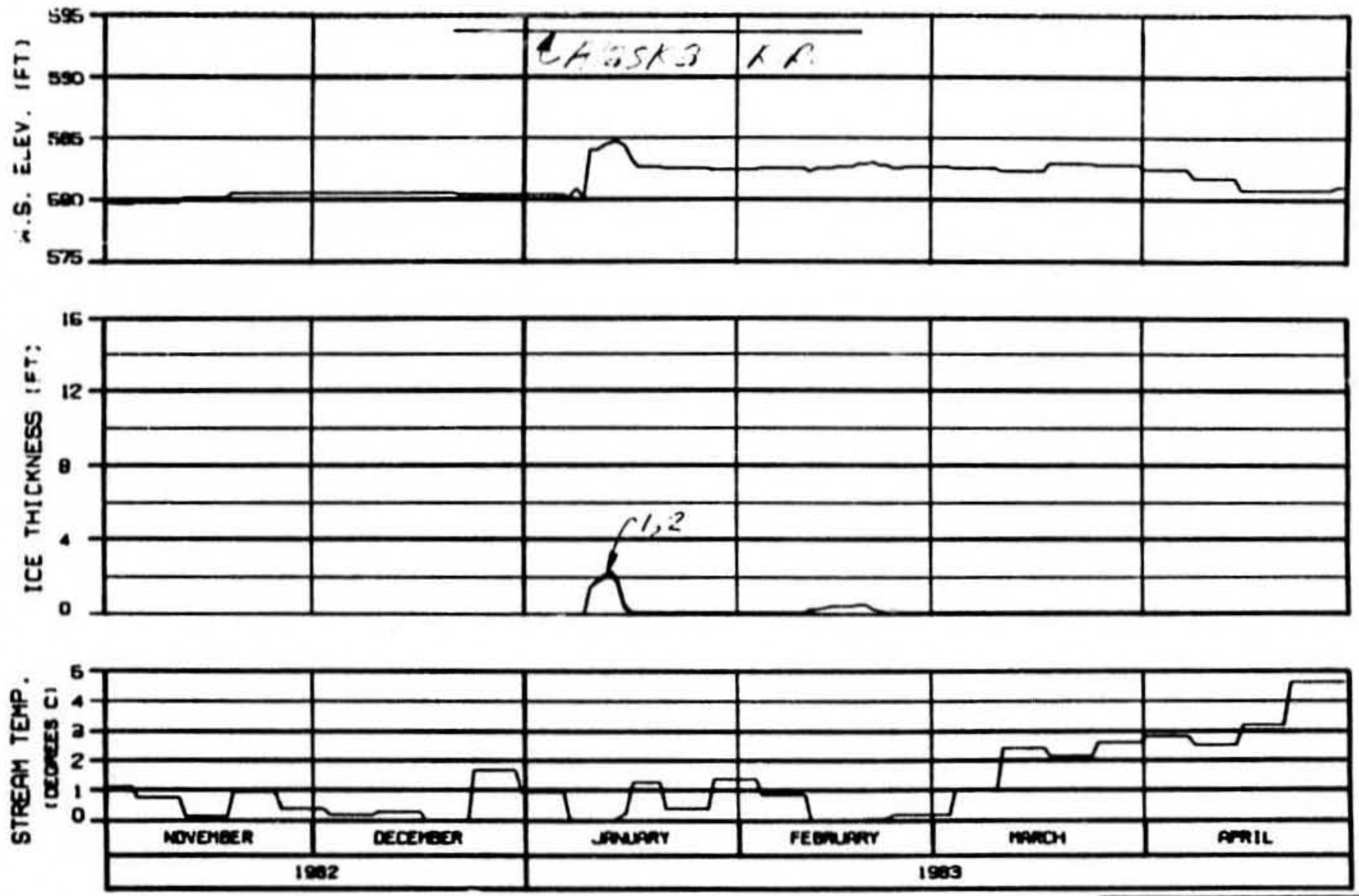
ICE THICKNESS LEGEND:

1. TOTAL THICKNESS
2. SLUSH COMPONENT

WEATHER PERIOD : 1 NOV 82 TO 30 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE82

Slough 8A

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
ICE SIMULATION
TIME HISTORY
HARZA-EBASCO JOINT VENTURE



ICE THICKNESS LEGEND:

1. TOTAL THICKNESS
2. SLUSH COMPONENT

RIVER MILE : 127.10

WEATHER PERIOD : 1 NOV 82 TO 30 APR 83
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : B296VS6

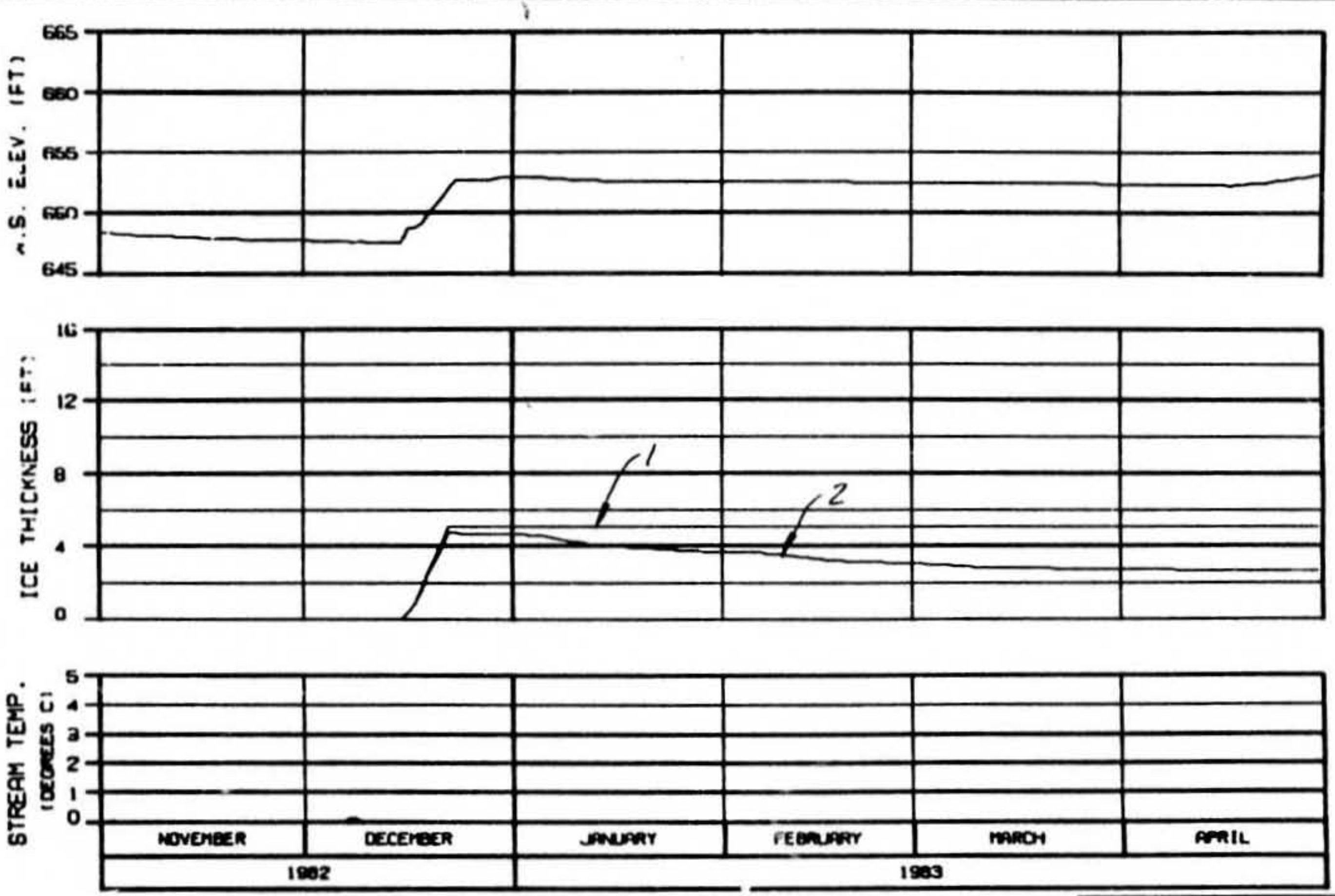
Slough 8A

ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
ICE SIMULATION
TIME HISTORY

HARZA-EBASCO JOINT VENTURE



RIVER MILE : 133.70

ICE THICKNESS LEGEND:

1. TOTAL THICKNESS
2. SLUSH COMPONENT

WEATHER PERIOD : 1 NOV 82 TO 30 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE82

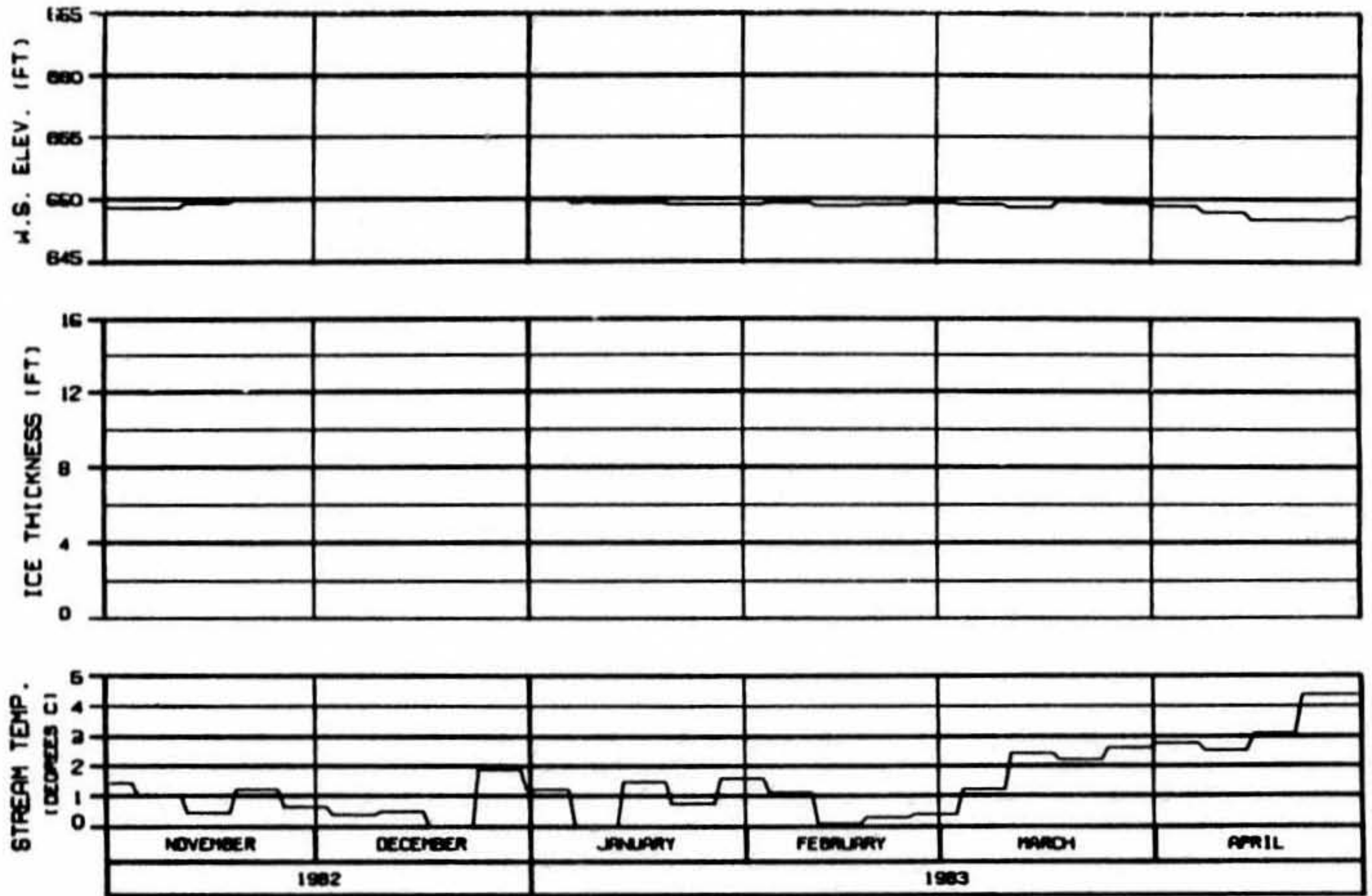
Slough 9A

ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
ICE SIMULATION
TIME HISTORY

HARZA-EBASCO JOINT VENTURE



RIVER MILE : 133.70

ICE THICKNESS LEGEND:

1. TOTAL THICKNESS
2. SLUSH COMPONENT

WEATHER PERIOD : 1 NOV 82 TO 30 APR 83
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : 8296VS6

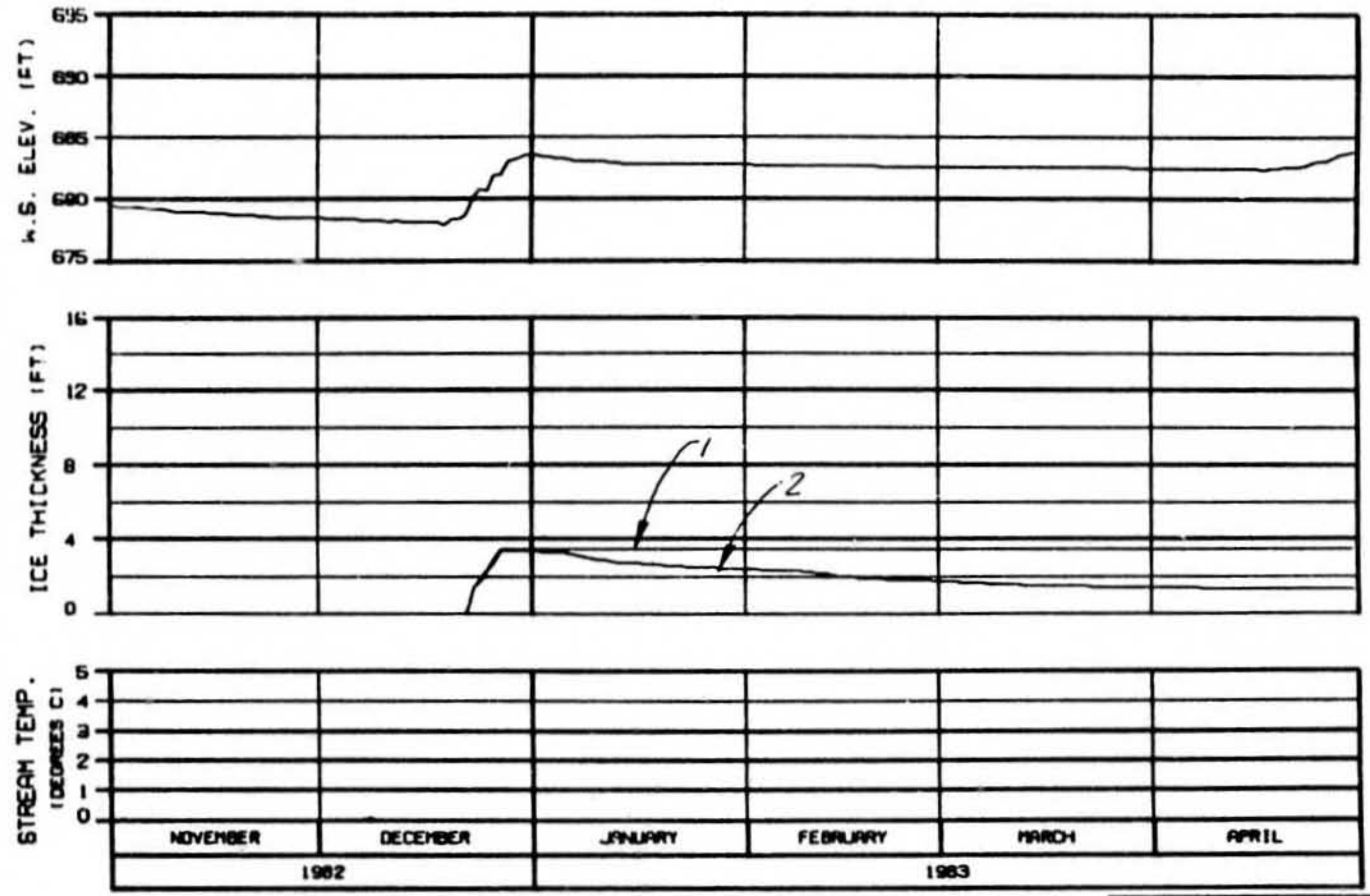
Slough 9A

ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
ICE SIMULATION
TIME HISTORY

HARZA-EBASCO JOINT VENTURE



ICE THICKNESS LEGEND:

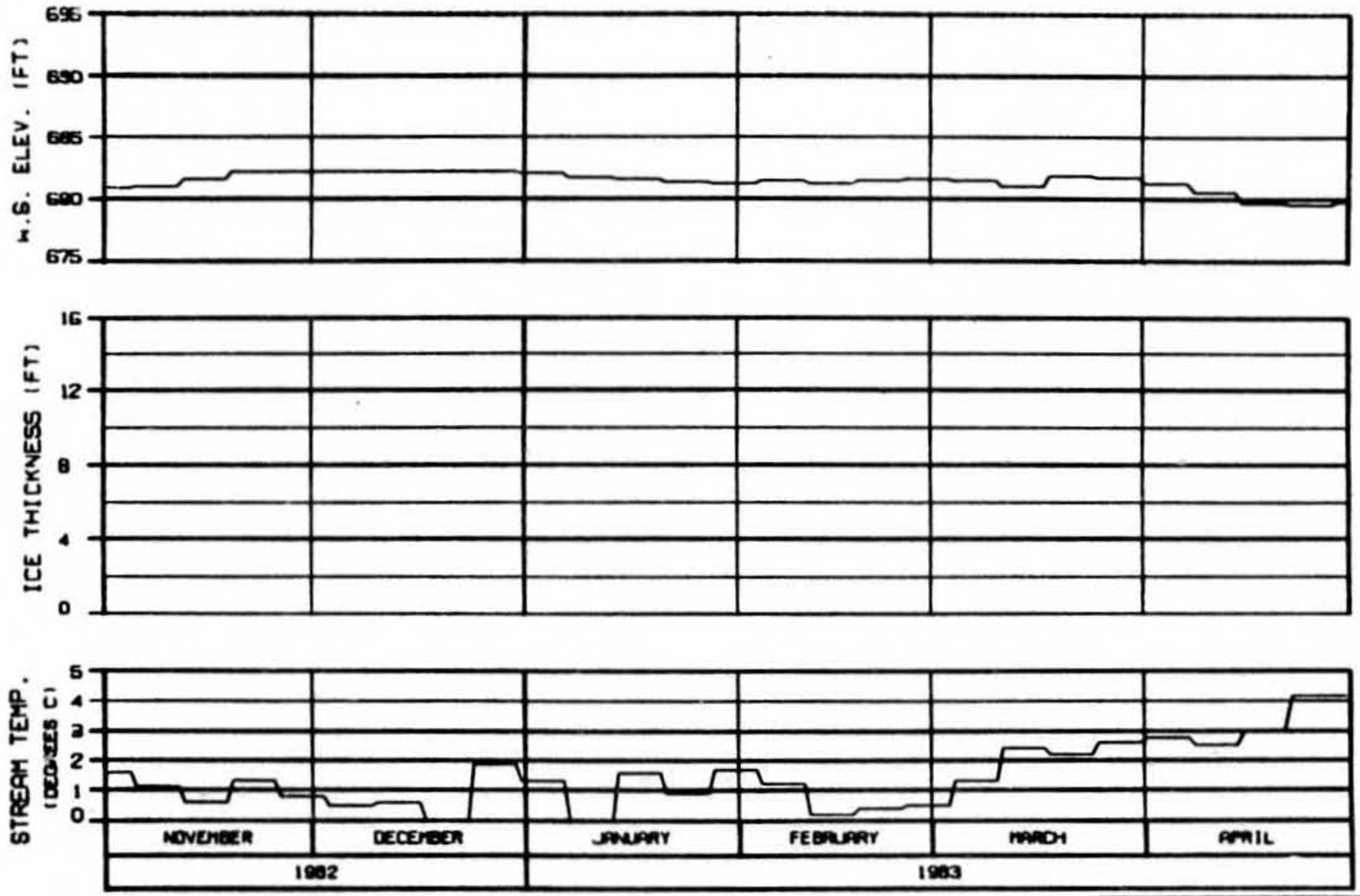
1. TOTAL THICKNESS
2. SLUSH COMPONENT

RIVER MILE : 136.40

WEATHER PERIOD : 1 NOV 82 TO 30 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE82

Slough 11

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER ICE SIMULATION TIME HISTORY
HARZA-EBASCO JOINT VENTURE



RIVER MILE : 136.40

ICE THICKNESS LEGEND:

1. TOTAL THICKNESS
2. SLUSH COMPONENT

WEATHER PERIOD : 1 NOV 82 TO 30 APR 83
RESERVOIR OPERATION : WATANA 1996
REFERENCE RUN NO. : 8296VS6

Slough 11

ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
ICE SIMULATION
TIME HISTORY

HARZA-EBASCO JOINT VENTURE

May 15, 1984

ICE AND TEMPERATURE STUDIES WORKSHOP

ADF&G PRESENTATION

IV. DEVELOPMENT OF TEMPERATURE CRITERIA FOR FISHERY ASSESSMENT

A. Field Studies of Instream Habitat(Temperature Relationships)

-Fish Relationships to Susitna Thermal Regime (preproject),

Conclusions reached to date.....

1. Spawning of the five pacific salmon species does not occur to any appreciable extent in the waters directly affected by the mainstem Susitna during the winter months.

2. Chum and sockeye spawn, apparently selectively, in areas influenced by ground water or upwelling with winter temperatures generally within one degree of three degrees centigrade.

3. Chinook, pink, and coho apparently spawn primarily in tributaries and temperatures during midwinter of less than 1 degree centrigrade. At least chinook and pink obtain much of the thermal units necessary for development by spawning earlier to obtain early fall thermal input.

4. The resident whitefish apparently successfully spawn in mainstem areas in October, burbot in January, and long nose suckers in May or June. Spawning appears to be limited by stable substrate and dewatering rather than temperature.

5. Upper limits on rearing temperatures do not appear to be reached in the Susitna rearing habitats. No correlations of distribution with open water temperatures have been observed.

6. Lower temperatures are associated with increased use of sloughs and gravel substrate for cover. Outmigration from tributaries appears to be extensive and attraction to ground water sources in sloughs appear to correlate with late fall movements of juvenile chinook and coho salmon.

7. Temperatures at chum and sockeye spawning areas are primarily influenced by mainstem water overflows caused by ice processes. A one time event at slough 8A correlated well with reduction in development rates of sockeye and chum embryos.

VI. Instream Ice Predictions and Analysis

A. Natural Instream Ice Conditions

Fishery Habitat Investigations.

-fish relationships to Susitna ice regime (preproject), Conclusions reached to date.

1. The further north, the more influence ice processes have on tributary overwintering (apparently) with outmigrations of most resident and juvenile salmon species occurring with the onset of winter.

2. Mainstem Susitna habitats provide stable flows in midwinter, after an ice cover is formed.

3. Slough habitats provide stable conditions apparently associated with thermal input of ground water.

4. Onetime observation of midwinter overflow of slough 8A suggested increased anchor ice and reduced temperatures. Unstable flow conditions associated with ice appear to most the major limiting factor.

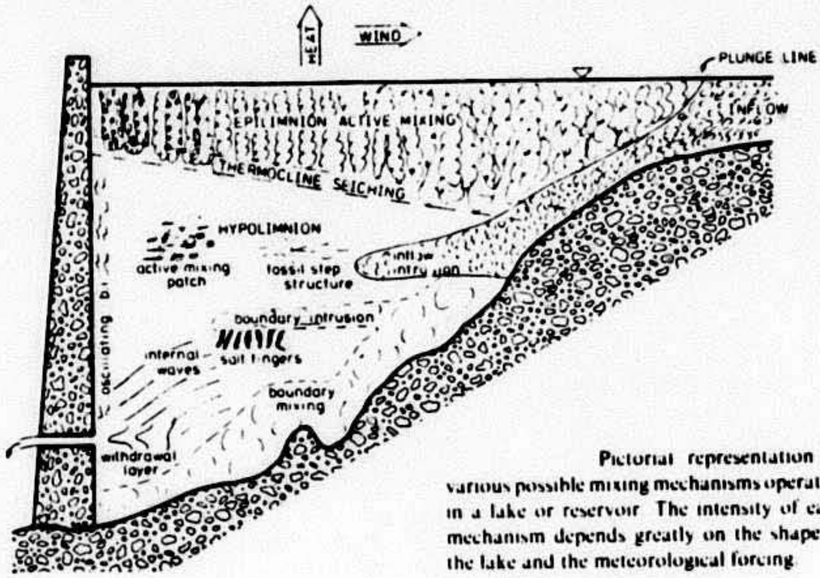
5. Radio tagged resident fish generally move downstream during the course of the winter and corresponds with increasing ice cover.

6. Concentrations of resident fish in the winter appear to be attracted to ground water and thermally affected areas.

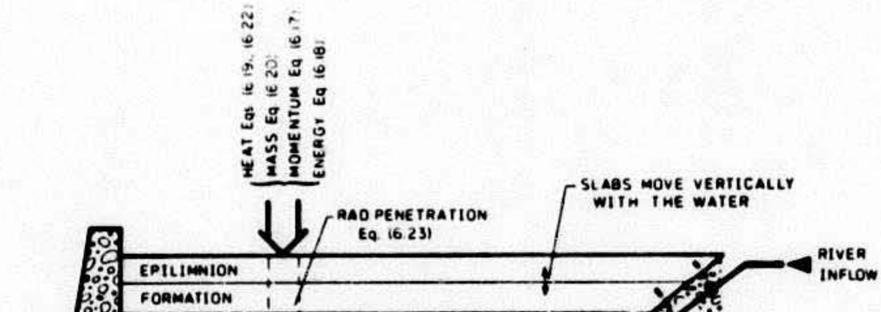
7. Limited burbot spawning may occur at sites directly affected by mainstem flows.

8. Because of the catastrophic nature of ice processes, confirmation data on hypotheses presented is difficult to obtain.

9. Overwintering habitat is probably a major limitation in the production of resident and the rearing juvenile salmon species.



Pictorial representation of various possible mixing mechanisms operative in a lake or reservoir. The intensity of each mechanism depends greatly on the shape of the lake and the meteorological forcing.



A schematic of the numerical model DYRESM. Slab volumes are kept between prescribed limits by slab partitioning and amalgamation.