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ASSESSMENT OF THE EFFECTS OF WITH-PROJECT INSTREAM TEMPERATURES ON SUSITNA RIVER ICE PROCESSES IN THE DEVIL CANYON TO TALKEETNA REACH.

DRAFT REPORT

ARCTIC ENVIRONMENTAL INFORMATION AND DATA CENTER

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INTRODUCTION

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PURPOSE

Changes in the instream temperatures in the Susitna River with the Susitna River Hydroelectric Project in place would cause significant alteration of the processes and timing of instream ice formation and decay. This report summarizes instream ice processes as they have been observed under natural conditions for each year since 1980 (R&M Consultants, Inc., 1980-81; 1982; 1983; 1984). These are compared with simulations of natural and with-project instream ice processes as produced by Harza-Ebasco Susitna Joint Venture, utilizing the ICECAL computer model (Harza-Ebasco Susitna Joint Venture 1984a). The objective of running the computer model simulations was to determine the effects of the proposed Watana and Devil Canyon dams on river ice processes and the corresponding water surface elevations (staging) during the winter season in the Susitna River downstream of the dams. The simulations are limited to the middle reach of the Susitna River (from the Susitna-Chulitna confluence to Devil Canyon), where the greatest changes due to the project are expected to occur.

The ICECAL computer model generated all of the simulated river ice conditions shown in this report. The model simulates a daily summary of hydraulic, temperature, and ice conditions throughout the middle reach of the Susitna

River. The hydraulic and ice operations performed by ICECAL include the following:

a. Hydraulic profiles are computed daily for the study reach.

b. Temperatures for ice-covered portions of the river are computed.

c. Frazil ice generation is computed for turbulent, open reaches where water temperature has dropped to 0 C, and frazil ice flow rates are tabulated as the ice is carried downstream.

d. Shore ice (border ice) growth proceeding from shore is computed.

e. As frazil ice coalesces into loosely-consolidated slush floes, hydraulic conditions at the ice cover are analyzed to determine whether the floes will accumulate at the upstream edge, or leading edge, of the ice cover. If not, the ice may be swept under the ice cover, or subducted, and deposited on the underside of the ice cover downstream.

f. Computations are made of the slush and solid ice component thicknesses of the river ice cover.

g. Meltout of the ice cover is simulated by computing the melting of the ice cover and retreat of the ice front when warm water, above 0 C, reaches the ice cover.

Input data utilized by ICECAL includes the following:

a. River cross-sectional geometry and bed roughness for the study reach.

b. Weather conditions (daily air temperature and wind velocity) for the study reach.

c. Water inflow hydrograph at upstream boundary of study reach.

d. Daily frazil ice discharges at upstream boundary of study reach.

e. Water temperature profiles between the upstream boundary and the location of the 0 C isotherm.

Calibration of ICECAL was carried out using the observations of natural ice processes during 1982-83 and 1983-84 by R&M Consultants, Inc. (Harza-Ebasco Susitna Joint Venture 1984b). ICECAL modeling runs utilized AEIDC's SYNTEMP model predictions of the location of the 0 C instream isotherm (Alaska, Univ., AEIDC 1984) as input. The model then computed water temperatures in ice-affected reaches of the river and simulated natural and with-project ice conditions under the same hydrologic and climatic conditions used in the instream temperature simulations.

This report briefly discusses only the effects of instream temperatures, under natural and with-project conditions, on instream ice processes. A later report, to be produced by AEIDC with comprehensive input and review by a team composed of several participants in the Susitna aquatic studies group, will thoroughly describe all river ice processes and conditions, and will address the effects of with-project instream ice processes on aquatic habitats and fishery resources.

Throughout this report, the textual explanations of both natural and with-project river ice processes and conditions will be generalized, in order to give the reader a good picture of the general processes that occur now, or would occur with-project, from year to year. Details of processes that have occurred naturally in specific years, or were simulated to occur in specific years with-project, can be found in the accompanying figures.

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 on the north, the Chulitna and Talkeetna Mountains on 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 1). The Yentna River enters the Susitna at river mile (RM) 28 (28 miles upstream from the mouth at Cook Inlet). The Chulitna River rises in the glaciers on the south slope of Mount McKinley and flows south, entering

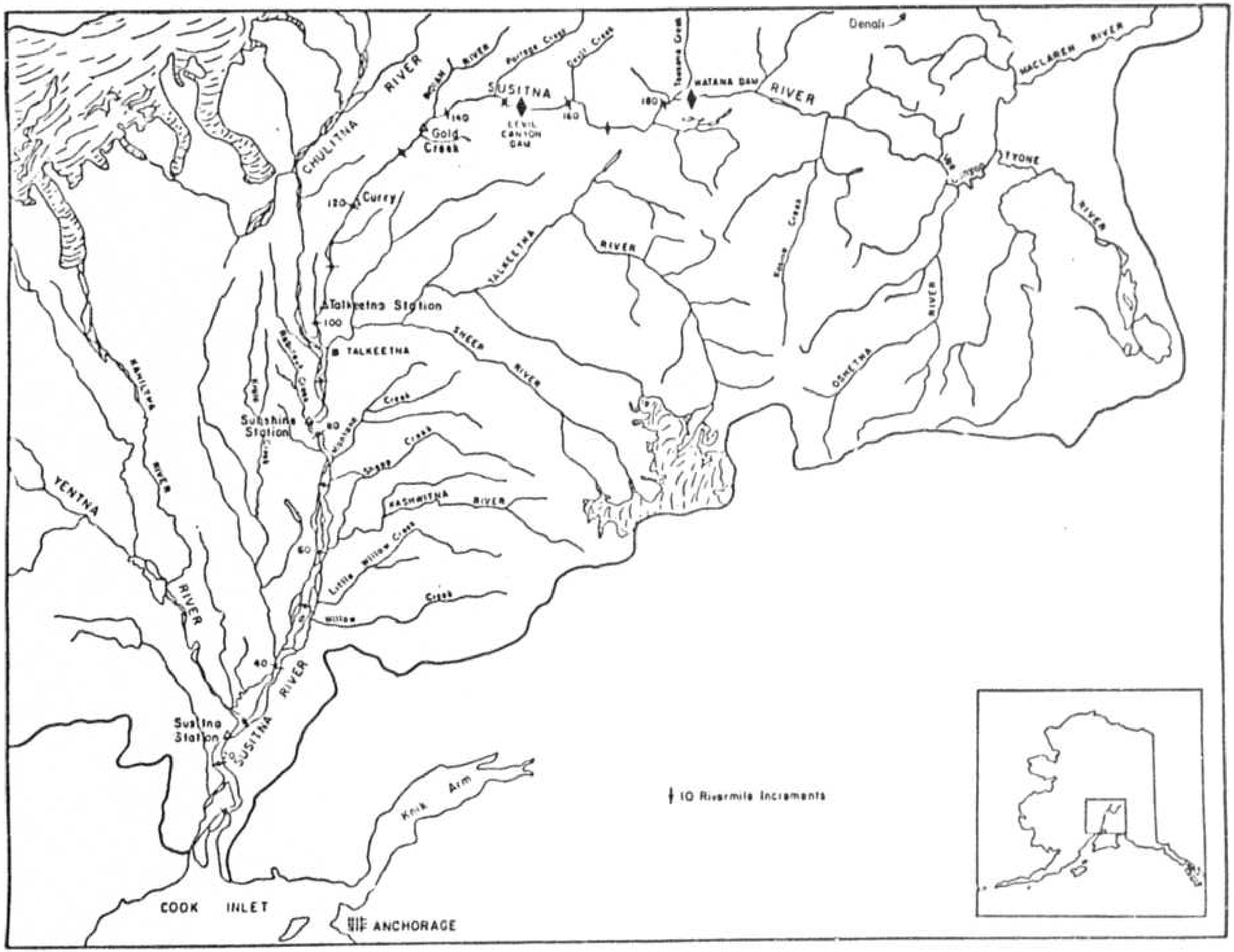

Figure 1. Map of the Susitna basin study region.

the Susitna River near Talkeetna (RM 99). The Talkeetna River rises in the Talkeetna Mountains, flows west, and joins the Susitna near Talkeetna (RM 97).

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 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, averaging 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 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 multipole 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.

Construction and subsequent operation of the Susitna dams are expected to alter the normal thermal regime of the river. Mainstem water temperatures downstream from the project would be cooler in the summer and warmer in the winter than under natural conditions. A change in the river ice regime downstream from the project is expected due to altered temperatures and increased winter flows.

SCOPE

This report describes the expected changes in instream ice processes that would result from Susitna Hydroelectric Project operations. Natural ice processes summarized in this report include observations made during the winters of 1980-81, 1981-82, 1982-83, and 1983-84. Computer simulations of natural and with- project ice processes were run for the winters of 1971-72, 1976- 77, 1981-82, and 1982-83. The winters of 1971-72 and 1981-82 are relatively cold, whereas the winter of 1982-83 is average in temperature. The winter of 1976-77 is warmer than average. Climatic data for these years is summarized in Figure 2. Natural streamflows for these years at Gold Creek are shown in Appendix A.

Figure 2: Average winter monthly air temperatures at Talkeetna, selected years. (Data summarized from National Weather Service).

	1971-72	1976-77	1980-81	1981-82	1982-83	1983-84
November	-11.9	-2.2	-3.5	-6.8	-8.5	-5.2
December	-13.4	-7.1	-20.1	-11.7	-7.2	-10.1
January	-17.8	-2.6	-1.8	-17.1	-10.8	-11.6
February	-12.8	-2.3	-6.1	-10.0	-7.5	-9.6
March	-12.3	-8.8	-0.4	-4.9	-3.5	0.6
April	-6.1	-0.7	-0.1	0.0	1.9	1.7
Avg	-12.4 (cold)	-4.0 (warm)	-5.3 (warm)	-8.4 (cold)	-5.9 (avg.)	-5.7 (avg.)

With-project ice processes simulations summarized in this report include several operations scenarios, shown in Figure 3. These include the following principal scenarios, each simulated under several different climatic conditions.

(a) Watana dam, operating alone, in a manner that would most closely match natural fall and winter stream temperatures in the Susitna River (inflow matching) for high and low power generation (1996; 2001).

(b) Watana and Devil Canyon dams, operating together, in a manner that would most closely match natural fall and winter stream temperatures in the Susitna River (inflow matching) for high and low power generation (2002; 2020).

These scenarios would utilize the coldest water available and would provide downstream temperatures allowing the greatest opportunity for an instream ice cover to form on the Susitna River.

(c) Watana dam, operating alone, in a manner that would allow a constant release of 4 C water for low power generation (1996). This scenario would provide downstream temperatures allowing the least opportunity for the formation of instream ice on the Susitna River. This scenario was provided principally as a sensitivity test.

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Figure 3. With-project instream ice simulations (Harza-Ebasco Susitna Joint Venture, 1984a)

All scenarios use Case C flow requirements

	Project status	Watana only operating			Watana and Devil Canyon operating	
	Release temperature	Inflow matching	Inflow matching	Warm 4C	Inflow matching	Inflow matching
	Energy demand	1996	2001	1996	2002	2020
1971-72 (cold)		X	X	X	X	X
1976-77 (warm)		X			X	
1981-82 (cold)		X			X	
1982-83 (average)		X	X		X	X

All computer model simulations discussed in this report address only the Case C flow requirements (Acres American, Inc. 1983). If another flow regime is considered, new ICECAL runs would have to address that regime.

NATURAL RIVER ICE PROCESSES

Winter ice conditions and processes on the Susitna River have been observed for several years by R&M Consultants, Inc. The following is a synthesis of general ice processes on the Susitna River as they have been observed under natural conditions from 1980 through 1984 (R&M Consultants, In., 1980-81, 1982, 1983, 1984).

FREEZEUP

FRAZIL ICE GENERATION

Most river ice covers are formed as a result of the formation and concentration of frazil ice. When river water becomes slightly supercooled (§0 C), frazil crystals begin to form, usually by nucleation. Fine suspended sediments in the water during freezeup season may be the nucleating agent in the Susitna River. Frazil crystals initially form principally as small discoid crystals only a few milimeters in diameter. These grow rapidly to larger size and begin to accumulate as frazil slush masses, often contributed to by snowfall into the river which forms floating snow slush. The combined slush usually breaks up in turbulence into individual slush floes that continue drifting downriver until stopped by jamming at river constrictions (Ashton 1978; Michel 1971; Ostercamp 1978).

Frazil ice generally first appears in the river between Denali and Vee Canyon by mid-September. This ice drifts downriver, often accumulating into loosely-bonded slush floes, until it melts away or exits into Cook Inlet. During freezeup, generally about 80 percent of the ice passing Talkeetna into the lower river is produced in the upper Susitna River, while the remaining 20 percent is produced in the Talkeetna and Chulitna Rivers. Below the Yentna confluence, usually more than 50 percent of the ice is generally produced by the Yentna River.

COOK INLET TO TALKEETNA (LOWER RIVER)

Observed ice processes for this reach are summarized in Figure 4.

During a period of severe cold and heavy frazil ice production, floating slush ice accumulates rapidly and bridges the river in the vicinity of RM 9, generally between mid- October and early November, when minimum daily air temperatures are less than or equal to 0 C. This is sufficiently cold to maintain high ice concentrations down to RM 9. Flow discharge at Sunshine during this period in 1982 ranged between 14,000 and 16,000 cfs. This bridge forms a barrier against which slush ice drifting downriver accumulates and forms an advancing leading edge moving upstream. The advancing leading edge, also called the ice front, typically reaches the Yentna River confluence by late October or early November. In 1982, the leading edge advanced at about 11.5 miles per day for the first 57 miles. Temperatures in the lower river are usually not cold enough for a long enough period of time to form a continuous ice cover before the rapid advance of the slush ice cover.

Figure 4. Observed Natural Ice Processes
Susitna River from Cook Inlet to Talkeetna (Lower River)
(R&M Consultants, Inc., 1980-81, 1982, 1983, 1984)

	1980-81	1981-82	1982-83	1983-84
FREEZE UP				
Avg. winter climate	Warm	Cold	Avg.	Avg.
Ice bridge forms at RM 9-date	Unknown	Early Nov.	Oct. 22	Oct. 26
RM 9-28.5				
Avg. gradient, ft/mi	-----	-----	-----	1.5
App. freezing date	-----	-----	-----	Oct. 31
Avg. ice thickness, ft	-----	-----	-----	4.0
Avg. staging, ft	-----	-----	<2	2.5
Shore ice width, ft	-----	-----	-----	0
RM 28.5-42.5				
Avg. gradient, ft/mi	-----	-----	-----	2.6
App. freezeup date	-----	-----	-----	Nov. 4
Avg. ice thickness, ft	-----	-----	-----	5.5
Avg. staging, ft	-----	-----	-----	3.5
Shore ice width, ft	-----	-----	-----	0
RM 42.5-51				
Avg. gradient, ft/mi	-----	-----	-----	2.9
App. freezing date	-----	-----	-----	Nov. 6
Avg. ice thickness, ft	-----	-----	-----	4.0
Avg. staging, ft	-----	-----	-----	2.8
Shore ice width, ft	-----	-----	-----	0
RM 51-78				
Avg. gradient, ft/mi	-----	5.6	-----	5.6
App. freezeup date	-----	Early Nov.	-----	Nov. 16
Avg. ice thickness, ft	-----	-----	-----	6.8
Avg. staging, ft	-----	-----	2-4	5.1
Shore ice width, ft	-----	-----	-----	0-2
RM 78-98.5				
Avg. gradient, ft/mi	-----	5.0	-----	5.0
App. freezing date	-----	Late Nov.-mid-Dec.	-----	Dec. 8
Avg. ice thickness, ft	-----	-----	-----	6.3
Avg. staging, ft	-----	-----	>4	4.6
Shore ice width, ft	-----	-----	-----	3-6
Sloughs breached at freezeup	-----	-----	-----	Alexander slough Goose Creek slough Sunshine slough Birch Creek slough
Breakup	early May	Late Apr. to early May	Late Apr. to early May	Late Apr. to early May

Staging, the increase in water surface elevation of the river caused by river ice impeding flow, is usually low during freezeup in the lower river, with staging generally about 2-4 feet as far north as Sunshine. Staging increases, generally to more than 4 feet, at Talkeetna. Several sloughs below Talkeetna are normally breached, but with minimal flow and little ice. Some surface flow is diverted into side channels. Tributaries in this reach generally continue flowing for several weeks after the Susitna River ice cover has formed, keeping large areas near their confluences free of ice.

As discharges decrease after freezeup, the ice cover sags, with much of it becoming grounded and conforming to the shape of the underlying channel. In the winter of 1982-83, minimum discharges measured at Sunshine were about 5,000 cfs. Open leads persist in high velocity zones throughout the winter. Some side channels and sloughs probably remain ice free due to relatively warm (above 0 C) groundwater upwelling. Flooded side channels build up shore ice, also called border ice, layers that reduce the open water area in these locations.

Minimal shore ice develops in the mainstem because of insufficiently cold air temperatures for long enough periods before the slush ice covers this reach. However, continuing cold air temperatures throughout the winter cause a buildup of a thickness of clear ice beneath the slush ice cover. In this report, "total" ice thickness refers to the combined thickness of the slush ice and clear ice layers; "solid" ice thickness refers only to the clear ice. Historical total ice thicknesses for various dates at Talkeetna are shown in Figure 5.

Figure 5. Historic records of ice thickness measurements on the Susitna River at Talkeetna (Bilello (1980)

TALKEETNA

Measurements made on Susitna River

1961-1962

Date	Thickness (inches)
Nov. 11	No ice
Nov. 18	4.0
Nov. 25	6.0
Dec. 30	36.0
Jan. 27	38.0
Feb. 24	42.0
Mar. 10	61.0
Mar. 31	51.0
Apr. 7	48.0
Apr. 28	11.0
May 5	2.0
May 25	River open

1962-1963

Date	Thickness (inches)
Oct. 9	First ice
Nov. 10	Freeze over
Nov. 30	4.0
Jan. 11	33.0
Feb. 1	33.5
Feb. 22	24.0
Mar. 29	43.5
Apr. 26	48.5
May 3	44.0
May 15	Ice free

1963-1964

Date	Thickness (inches)
Nov. 8	Some ice
Nov. 22	4.5
Nov. 23	6.0
Dec. 28	32.0
Jan. 25	26.0
Feb. 15	33.0
Mar. 14	38.0
Mar. 21	34.0
Apr. 25	30.0

1964-1965

Date	Thickness (inches)
Oct. 24	Shore ice
Nov. 28	8.0
Dec. 26	23.0
Jan. 30	38.0
Feb. 6	38.0
Feb. 27	32.0
Mar. 27	26.0
Apr. 3	22.0
Apr. 10	18.0
Apr. 30	Channel open

1965-1966

Date	Thickness (inches)
Oct. 11	First ice
Oct. 30	2/3 freeze over
Nov. 20	7.0
Nov. 27	11.0
Dec. 25	18.0
Jan. 15	20.0
Jan. 29	18.0
Feb. 26	18.0
Mar. 26	20.0
Apr. 23	18.0
Apr. 30	15.0
May 21	Ice out

1966-1967

Date	Thickness (inches)
Oct. 22	First ice
Oct. 29	Freeze over
Dec. 3-24	Channel open
Dec. 31	4.5
Jan. 28	18.0
Feb. 25	23.0
Mar. 25	28.0
Apr. 22	25.0
Apr. 29	21.5
Apr. 30	Ice breaking up

TRAPPERS CREEK

Measurements made on Susitna River

1967-1968

Jan. 27	33.0
Feb. 3	37.0
Feb. 24	36.0
Mar. 30	30.0
Apr. 20	20.0
May 4	Open areas
May 11	Ice jams broke

1968-1969

Nov. 20	Ice jamming
Dec. 5	4.0
Dec. 28	24.0
Feb. 1	30.0
Feb. 22	33.5
Mar. 29	24.0
Apr. 19	16.0
Apr. 26	Ice breaking up

1969-1970

Dec. 20	2.0
Dec. 27	4.0
Jan. 10	12.0
Jan. 31	27.0
Mar. 7	28.0
Mar. 21	32.0
Mar. 29	27.0
Apr. 11	25.0
Apr. 18	Ice breaking up
Apr. 26	Channel opening up

1970-1971

Date	Thickness (inches)
Nov. 7-21	Ice jams
Nov. 28	2.0
Dec. 26	16.0
Jan. 30	30.0
Feb. 27	30.0
Mar. 20	36.0
Mar. 27	32.0

1971-1972

Date	Thickness (inches)
Oct. 13	First ice
Nov. 13	Freeze over
Nov. 27	4.0
Dec. 18	6.0
Jan. 1	18.0
Jan. 15	21.0
Feb. 5	28.0
Feb. 26	30.0

TALKEETNA TO GOLD CREEK (MIDDLE RIVER)

Observed freezeup processes for this reach are summarized in Figure 6. Since there were no observations of natural processes for the years 1971-72 and 1976-77, two of the years for which simulations of with-project conditions were run, ICECAL simulations of natural processes for these years were produced after calibrating the model against years of observation. Simulated natural freezeup effects on river stages and ice thicknesses are summarized in Figures 17 to 19.

An ice bridge usually forms just upstream of the confluence of the Susitna and Chulitna Rivers sometime between early November and early December . In 1982, the flow discharge at Gold Creek during this period was about 4,900 cfs. The ice bridge forms a new leading edge of ice front progression moving upstream from the confluence to the vicinity of Gold Creek. In 1982, the ice front progressed initially at a rate of 3.5 miles per day. Depending on climatic conditions, this bridge may form either when ice cover progression in the lower river reaches the confluence, or is well short of it. In some years with severe cold periods occurring during ice front progression, one or more secondary bridges may form upstream of the confluence bridge, forming secondary leading edges.

Border ice usually begins to form in this reach by the accumulation of frozen slush layers along shore before the passage of the ice front. This narrows the mainstem open water area, through which the slush ice leading edge progresses.

Figure 6. Observed Natural Ice Processes - Susitna River from Talkeetna to Devil Canyon (Middle River) (R&M Consultants, Inc., 1980-81, 1982, 1983, 1984)

		1980-81	1981-82	1982-83	1983-84
FREEZEUP					
Avg. winter climate		Warm	Cold	Avg.	Avg.
Avg. gradient, ft/mi		9.8	9.8	9.8	9.8
Ice bridge forms at Susitna/Chulitna Confluence		Nov. 29	Nov. 18	Nov. 5	Dec. 8
Ice leading edge located near Gold Creek		Dec. 12	Dec. 31	Dec. 27	Jan. 5
Approx. freezeup dates					
Confluence	RM 98.6	-----	mid-Nov.	Nov. 5	Dec. 9
	RM 103.3	-----	-----	Nov. 8	-----
	RM 104.3	Dec. 1	-----	-----	-----
	RM 106.2	-----	-----	Nov. 9	-----
	RM 108.0	Dec. 2	-----	-----	-----
	RM 112.9	Dec. 3	-----	-----	-----
Lane Creek	RM 113.7	-----	-----	Nov. 15	-----
	RM 115.9	Dec. 4	-----	-----	-----
McKenzie Cr.	RM 116.7	-----	-----	Nov. 18	-----
	RM 118.8	Dec. 5	-----	-----	-----
Curry	RM 120.7	-----	-----	Nov. 20	Dec. 21
Slough 8	RM 124.5	-----	-----	Nov. 20	-----
	RM 126.5	Dec. 8	-----	-----	-----
Sl. 8, head	RM 127.0	-----	mid-Dec.	Nov. 22	-----
Sl. 9, mouth	RM 128.3	-----	-----	Nov. 29	-----
Sl. 9, Sherman	RM 130.9	-----	-----	Dec. 1	Jan. 5
Sl. 11, mouth	RM 135.3	-----	-----	Dec. 6	-----
Gold Creek	RM 136.6	Dec. 12	Early Jan.	Jan. 14	Jan. 15
Portage Creek	RM 148.9	-----	-----	Dec. 23	-----
Staging elevations during freezeup, ft					
Confluence	RM 98.6	-----	-----	345.5	343.07
	RM 103.3	381.50	-----	384.1	343.57
	RM 106.2	-----	-----	(5.3)	(7.65)
	RM 113.0	460.80	-----	-----	461.87
Lane Creek	RM 113.7	-----	-----	(6.7)	-----
Curry	RM 120.5	-----	-----	524.6	523.89
	RM 123.3	546.80	-----	-----	545.31
Slough 8	RM 124.5	557.99	-----	559.3	-----
	RM 126.1	572.74	-----	-----	573.53
Sl. 8, head	RM 127.0	-----	-----	579.3	-----
Sl. 9, mouth	RM 128.3	-----	-----	(6.9)	-----
	RM 128.7	594.13	-----	-----	596.54
Sl. 9, Sherman	RM 130.9	-----	-----	620.1	618.16
	RM 134.2	-----	-----	-----	657.58
Gold Creek	RM 136.5	-----	-----	685.3	684.64
Portage Creek	RM 148.9	-----	-----	839.5	-----

( ) = Relative elevation from arbitrary bench mark

Figure 6. (Continued).

		1980-81	1981-82	1982-83	1983-84
Average ice thickness, ft (date)					
Confluence	RM 98.6	-----	-----	2.9(2/4)	6.0(1/26)
	RM 103.3	-----	-----	-----	8.2(1/26)
	RM 108	3.7(3/5)	-----	-----	-----
	RM 113.0	-----	-----	-----	6.9(1/26)
Curry	RM 120.6	2.7(2/27)	4.7(3/13)	1.9(2/4)	10.4(1/26)
	RM 123.4	-----	-----	-----	10.6(1/26)
	RM 126.2	-----	-----	-----	5.3(1/26)
	RM 128.5	-----	-----	-----	5.2(1/27)
Sherman	RM 130.9	2.4(3/5)	-----	-----	-----
Gold Creek	RM 136.6	2.9(2/27)	3.5(3/13)	1.6(2/4)	2.2(1/27)
Portage Creek	RM 148.9	3.0(3/5)	4.2(3/13)	2.5(2/4)	-----
Watana		-----	-----	2.4(2/4)	-----
Sloughs breached at freezeup		Unknown	Unknown	8A	8A
Sloughs with observed open water all winter (upwelling groundwater influence)		Unknown	Unknown	7 8A 10 11	Unknown
BREAKUP		May 8	May 10-15	May 10	-----

(   ) = Relative elevation from arbitrary bench mark

Historical breakup dates for the middle Susitna River as observed by Alaska Railroad personnel (R&M Consultants, Inc, 1980-81).

1975 - May 15
1976 - May 17
1977 - May 16
1978 - May 8-9
1979 - May 8
1980 - May 12-13

The ice front progression rate decreases as the ice front moves upriver. In 1982, the progression rate slowed to 0.05 miles per day by the time it reached Gold Creek. This is probably due to the increase in gradient moving upriver and to the reduction in frazil ice generation in the upper river as it develops a continuous ice cover. The upper river freezes over by border ice growth and bridging before the advancing leading edge has an opportunity to reach there.

When staging is sufficiently high as the leading edge passes in the vicinity of a side channel or slough, water may rise high enough to flow over intervening berms, gravel rises that separate the mainstem from the upper ends of side channels and sloughs. When these berms are thus overtopped, water and slush ice are allowed to flow into the side area. Leading edge progression is slowed during an overtopping event because flow relief into the side area prevents a low-velocity backwater area from forming. However, the ice front progression resumes when the side channel or slough becomes filled with water and ice. Important sloughs and side channels in this reach are indicated in Figure 7.

Local groundwater levels are often raised when the leading edge approaches. This is probably due to staging effects raising the water level in the mainstem, which then is propagated through the permeable river sediments into surrounding sloughs and side channels.

Many sloughs that do not become inundated by mainstem water and ice fail to form a continuous ice cover all winter due to upwelling of relatively warm (1-3 C) groundwater. However, ice does form along slough margins, restricting

Figure 7. Important slough and side channel areas in middle Susitna River (Harza-Ebasco Susitna Joint Venture, 1984a)

Area	River Mile Location	Threshold Elevation
Whiskers Slough	101.5^{H}	367
Side Channel at Head of Gash Creek	112.0	Unknown
Slough 6A	112.3^{M}	U
Slough 8	114.1^{H}	476
Side Channel MSII	115.5	482
Side Channel MSII	115.9^{H}	487
Curry Slough	120.0^{H}	Unknown
Moose Slough	123.5^{H}	Unknown
Slough 8A - West Channel	126.1^{H}	573
Slough 8A - East Channel	127.1^{H}	582
Slough 9	129.3^{H}	604
Side Channel Upstream of Slough 9	130.6	Unknown
Side Channel Upstream of 4th July Creek	131.8	Unknown
Slough 9A	133.7^{H}	651
Side Channel Upstream of Slough 10	134.3	657
Side Channel Downstream of Slough 11	135.3	Unknown
Slough 11	136.5^{H}	687
Slough 17	139.3^{H}	Unknown
Slough 20	140.5^{H}	730
Slough 21 - Entrance A6	141.8^{H}	747
Slough 21	142.2^{H}	755
Slough 22	144.8^{H}	788

H - Indicated location r presents the head of the slough or channel

M - Indicated location represents the mouth of the slough or channel

U - "Upland" slough with no upstream head or berm

Figure 7. Important slough and side channel areas in middle Susitna River (Harza-Ebasco Susitna Joint Venture, 1984a)

Area	River Mile Location	Threshold Elevation
Whiskers Slough	101.5 H	367
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Side Channel MSII	115.9 H	487
Curry Slough	120.0 H	Unknown
Moose Slough	123.5 H	Unknown
Slough 8A - West Channel	126.1 H	573
Slough 8A - East Channel	127.1 H	582
Slough 9	129.3 H	604
Side Channel Upstream of Slough 9	130.6	Unknown
Side Channel Upstream of 4th July Creek	131.8	Unknown
Slough 9A	133.7 H	651
Side Channel Upstream of Slough 10	134.3	657
Side Channel Downstream of Slough 11	135.3	Unknown
Slough 11	136.5 H	687
Slough 17	139.3 H	Unknown
Slough 20	140.5 H	730
Slough 21 - Entrance A6	141.8 H	747
Slough 21	142.2 H	755
Slough 22	144.8 H	788

H - Indicated location r presents the head of the slough or channel

M - Indicated location represents the mouth of the slough or channel

U - "Upland" slough with no upstream head or berm the open water area to a narrow, open lead. Some sloughs that do form ice covers after being inundated with mainstem water and ice later melt out because of the groundwater thermal influence. These leads often then remain open all winter.

As slush ice accumulates against the leading edge, it consolidates from time to time through compression and thickening. Staging accompanies this process, which sometimes lifts the ice cover and allows it lateral movement, often extending the ice from bank to bank.

Water flowing under the ice cover throughout the winter often causes frictional erosion of the underside of the ice, opening leads in the cover. This usually occurs rapidly after the initial stabilization of a slush ice cover. These leads usually slowly freeze over with a secondary ice cover, and most leads are closed by March.

The slush ice front progression from the Susitna/Chulitna confluence generally terminates in the vicinity of Gold Creek , about 35 to 40 miles upstream from the confluence, by December or early January. ICECAL model simulations of the progress of the ice front are shown in Appendix B. Different freezeup processes dominate the river above Gold Creek.

GOLD CREEK TO DEVIL CANYON (MIDDLE RIVER)

Freezeup occurs gradually in the reach from Gold Creek to Devil Canyon, with a complete ice cover in place much later than in the reach below Gold Creek, usually not until March. The ice front does not generally progress beyond the vicinity of Gold Creek because of the lack of frazil ice input after the upper river freezes over. Also, ice is late in forming here because of the relatively high velocities in this reach, caused by the steeper gradient . -d single-channel characteristics of the reach.

Wide border ice layers build out from shore throughout the freezeup season, narrowing the open water channel in the mainstem and frequently forming ice bridges across the river, separated by open leads. In the open water areas, frazil ice adheres easily to any object it contacts within the river flow, such as rocks and gravel on the channel bottom, forming anchor ice. Anchor ice may form into low dams in the stream bed, especially in areas narrowed by border ice, increasing local water turbulence which may increase frazil generation. Slight backwater areas are sometimes induced due to a general raising of the effective channel bottom, affecting flow distribution between channels and causing overflow onto border ice. Within the backwater area, slush ice may freeze in a thin layer from bank to bank.

Little staging occurs in this reach during freezeup, and sloughs and side channels are generally not breached at their upper ends. They usually remain open all winter due to groundwater inflow. Open leads occur in the mainstem , especially in high velocity areas between ice bridges, but few new leads open after the formation of the initial ice cover. There is minimal ice cover sag in this reach.

DEVIL CANYON AND ABOVE (UPPER RIVER)

In Devil Canyon, slush ice forming in this turbulent, high velocity reach is often the first to form on the entire Susitna River but is usually unstable, continually alternating between accumulation and disintegration. This process forms massive ice shelves in the canyon, as much as 23 feet high. The reach above Devil Canyon to Denali develops wide shore ice by building successive layers of slush. The channel finally becomes so narrow that flowing slush is entrapped, eventually freezing into an ice cover. However, this process does not occur simultaneously over this reach, causing a discontinuous ice cover to exist with many open leads. Usually, by early March most of these leads freeze over.

ICE COVER AT THE PEAK OF DEVELOPMENT

Once the initial ice cover forms it remains quite dynamic, either thickening or eroding. Slush ice adheres to the underside of the ice cover in low velocity areas and becomes bonded by low temperatures. The ice cover becomes most stable at its height of maturity, generally in March. The only open water at that time is in the numerous leads that persist over turbulent areas and areas of groundwater upwelling, and little frazil slush is generated.

River flows are generally at their minimum, restricted to a shallow, narrow thalweg channel. In the winter of 1982-83, low flows at Gold Creek were about 1,500 cfs by the end of March. The ice cover has usually settled and become grounded, and has an undulating surface. The ice cover is a formation of rigid layers at random levels, separated by unconsolidated layers of slush crystals. The rigid layers represent zones formed during extremely cold periods as the saturated slush ice slowly drained.

BREAKUP

Observed natural river ice breakup dates for 1981-84 for the lower river are summarized in Figure 4, and for the middle river in Figure 6. Additionally, historical river breakup dates for the years 1975-1980 for the middle river are shown in Figure 4.

Under natural conditions, the Susitna River ice cover disintegrates in the spring by a progression beginning with a slow, gradual deterioration of the ice and ending with a dramatic breakup drive accompanied by ice jams, flooding, and erosion. The duration of the breakup period depends on the intensity of solar radiation, air temperatures, and precipitation.

A pre-breakup period occurs as snowmelt begins in the area, usually by early April. Snowmelt begins first at the lower elevations near the Susitna River mouth and slowly works northward up the river. By late April, snow has usually disappeared on the river south of Talkeetna and snowmelt is proceeding into the reach above the Susitna/Chulitna confluence. Tributaries to the lower river have usually broken out in their lower elevations, and open water exists at their confluences with the Susitna River. Increased flows from the tributaries erode the Susitna ice cover for considerable distances downstream from their confluences.

As water levels in the river begin to rise and fluctuate with spring snowmelt and precipitation, overflow often occurs onto the ice since the rigid and impermeable ice cover fails to respond quickly enough to these changes. Standing water appears in sags and depressions on the ice cover. This standing water reduces the albedo, or reflectivity, of the ice surface, and open leads quickly appear in these depressions. As the water level rises and erodes the ice cover, ice becomes undercut and collapses into the open leads, drifting to their downstream ends and accumulating in small ice jams. In this way, leads become steadily wider and longer. This process is especially notable in the reach from Talkeetna to Devil Canyon; in the wide, low- gradient river below Talkeetna open leads occur less frequently and extensive overflow of mainstem water onto the ice cover is the first indicator of rising water levels.

The disintegration of the ice cover into individual fragments or floes and the drift of these floes downstream and out of the river is called the breakup drive. The natural spring breakup drive is largely associated with rapid flow increases, due to precipitation and snowmelt, that lift and fracture the ice surface. When the river discharge becomes high enough to break and move the ice sheet, the breakup drive begins. Its intensity is dependent upon meterological conditions during the pre-breakup period. For example, in 1981 a minimal snowpack and light precipitation during spring caused insufficient increase in flow to develop strong forces on the ice cover, and the ice tended to slowly disintegrate in place, producing few significant ice jamming events. Conversely, in 1982 a heavy snowpack with cool early spring temperatures prevented the ice cover from deteriorating significantly during the pre-breakup period, the ice remained strong into the later period of normal spring temperatures and rising flows, and the cover broke dramatically, producing several large ice jams.

Major ice jams generally occur in shallow reaches with a narrow confining thalweg channel along one bank, or at sharp river bends. For example, during the breakup of 1983, stable ice jams occurred at the following locations:

Lane Creek at RM 113.2

Curry at RM 120.5 and RM 119.5

Slough 9 at RM 129

Sherman Creek at RM 131.4

Slough 11 at RM 134.5

Slough 21 at RM 141.8

Major jams are commonly found adjacent to side channels or sloughs, and may have played a part in forming them through catastrophic overflow and scouring at some time in the past. This is known to have happened at slough 11 in 1976, as reported by local residents in the area, when a large ice jam overflow event altered a previously-existing small upland slough into a major side slough.

Breakup ice jams commonly cause rapid, local stage increases that continue rising until either the jam releases or the adjacent sloughs or side channels become flooded. While the jam holds, flow and large amounts of ice are diverted into side channels or sloughs, rapidly eroding away large sections of riverbank and often pushing ice well up into the trees. Old ice scars can be seen on trees in some areas up to 10 feet above the bank top. Sloughs and other channels between Talkeetna and Devil Canyon that are regularly influenced by ice-induced flooding during breakup are shown in Figure 8.

Generally, the final destruction of the ice cover occurs in early to mid-May when a series of ice jams break in succession, adding their mass and momentum to the next jam downstream. This continues until the river is swept clean of ice except for stranded ice flows along shore. Ice that has been

Figure 8. Side channels and sloughs regularly influenced by ice-induced flooding during breakup (R&M Consultants, Inc. 1983)

Slough 22
Slough 21 from RM 142.2 to RM 141
Slough 11 from RM 136.5 to 134.5
Side channels from RM 133.5 to 131.5
Side channels from RM 130.7 to 129.5
Slough 9
Slough 8A and 8
Slough 7

pushed well up onto banks above the water level may last for several weeks before melting away in place.

EFFECTS OF WITH-PROJECT INSTREAM TEMPERATURES ON SUSITNA RIVER ICE PROCESSES

ICECAL modeling runs show that operation of the Susitna River Hydroelectric Project would have significant effects on the ice processes of the Susitna River, especially in the Talkeetna to Devil Canyon reach, due to changes in flows and water temperatures in the river below the dams. Generally, winter flows would be several times greater than they are under natural winter conditions (see Appendix A), and winter water temperatures would be 0.4 C to 6.4 C where they are normally 0 C immediately below the dams (Alaska, Univ, AEIDC 1984). The ICECAL computer model developed by Harza-Ebasco Susitna Joint Venture was used to simulate river ice conditions under various scenarios of project operations, with Watana operating alone and in conjunction with Devil Canyon dam, under varying power demand situations, and with differing climatic conditions (Figure 3) (Harza-Ebasco Susitna Joint Venture 1984a). The results of these simulations are generally summarized here, with more specific details in Figures 9 to 13.

WITH-PROJECT SIMULATIONS, FREEZEUP

Frazil ice that is generated in the upper river area, principally in the Vee Canyon and Denali areas, normally drifts downstream into the lower and middle reaches of the Susitna River and provides the source for initial ice

Figure 9. Icecal Simulations
Watana Alone, 1996 Energy Demand
Inflow Matching Releases
(Harza-Ebasco Susitna Joint Venture, 1984a)

	Years compared: 1971-72, cold 1976-77, warm 1981-82, cold 1982-83, average
Start ice front progression, Susitna-Chulitna confluence	17-40 days later than natural
Maximum upstream ice extent	RM 127-140 (mid-December - late March)
Melt out	37-51 days earlier than natural
Most severe ice conditions & staging	Thickness is similar to natural downstream of ice front Max. stages 3-7 feet higher than natural
Mildest ice conditions & staging	Thickness is similar to natural downstream of ice front Max. stages 2-5 feet higher than natural

Figure 10. Icecal Simulations
Watana Alone, 1996
Warm, 4 C Releases*
(Harza-Ebasco Susitna Joint Venture, 1984a)

Year compared:
1971-72, cold

Start ice front progression, Susitna-Chulitna confluence	42 days later than natural	19 days later than inflow matching
Maximum upstream ice extent	RM 127 (mid-January)	13 miles shorter than inflow matching
Melt out	----------	49 days earlier than inflow matching
Most severe ice conditions & staging	Thickness as much as 6 feet less than natural Max. stages as much as 5 feet higher than natural	Thickness as much as 4 feet less than inflow matching Max. stages 1-7 feet lower than inflow matching

*This scenario, with warm water releases, was run as a sensitivity test, and is compared here with both natural conditions, and inflow matching releases.

Figure 11. Icecal Simulations
Watana Alone, 2001 Energy Demand
Inflow Matching Releases
(Harza-Ebasco Susitna Joint Venture, 1984a)

	Years compared: 1971-72, cold 1982-83, average
Start ice front progression, Susitna Chulitna confluence	23-44 days later than natural
Maximum upstream ice extent	RM 124-142 (late January - late February)
Melt out	Up to 55 days earlier than natural
Most severe ice conditions & staging	Thickness is similar to natural downstream of ice front Max. staging 2-6 feet higher than natural
Average ice conditions & staging	Thickness is similar to natural downstream of ice front Max. staging 1-6 feet higher than natural

Figure 12. Icecal Simulations
Watana and Devil Canyon, 2002 Energy Demand
Inflow Matching Releases
(Harza-Ebasco Susitna Joint Venture, 1984a)

	Years compared: 1971-72, cold 1976-77, warm 1981-82, cold 1982-83, average
Start ice front progression, Susitna-Chulitna confluence	27-47 days later than natural
Maximum upstream ice extent	RM 123-137 (mid-January - Mid-March)
Melt out	51-59 days later than natural
Most severe ice conditions & staging	Thickness as much as 7 feet less than natural. Max. stages as much as 4 feet higher than natural
Mildest ice conditions & staging	Thickness similar to natural downstream of ice front. Max. stages as much as 6 feet higher than natural

Figure 13. Icecal Simulations
Watana and Devil Canyon, 2020 Energy Demand
Inflow Matching Releases
(Harza-Ebasco Susitna Joint Venture, 1984a)

	Years compared: 1971-72, cold 1982-83, average
Start ice front progression, Susitna-Chulitna confluence	28-39 days later than natural
Maximum upstream ice extent	RM 127-133 (mid-January - late January)
Melt out	Up to 59 days sooner than natural
Most severe ice conditions & staging	Thickness as much as 6 feet less than natural Max. stages as much as 4 feet higher than natural
Average ice conditions & staging	Thickness 2-4 feet less than natural Max. stages as much as 4 feet higher than natural

bridging and subsequent ice cover formation for most of the those reaches. With Watana dam and reservoir in place, this frazil would be trapped in the reservoir and be prevented from reaching its normal destinations. Consequently, freezeup of the river below the dam would be delayed. Later, with the construction of Devil Canyon dam and reservoir, most of the frazil-generating rapids within Devil Canyon would be inundated, further reducing frazil production reaching the middle and lower river reaches, and further delaying river freezeup.

Arrival of the ice front at the Yentna River mouth usually occurs in late October or early November under natural conditions. This timing is not expected to be significantly altered with-project in spite of the reduced frazil input from the upper Susitna River because the ice contributions form the Yentna River and other major tributaries would remain the same. Based on this, November 1 was used by ICECAL as a representative date for the passage of the ice front by the Yentna River mouth. However, reduced frazil input would slow the advance rate of the leading edge. These effects would combine with the higher winter flows and warmer water temperatures to produce a delay of initial freezeup at the Susitna/Chulitna confluence ranging from about 2 to 5 weeks with Watana operating alone to 4 to 6 weeks with Watana and Devil Canyon operating together (Figure 14).

The warmer water temperatures released from the dams would not cool to the freezing level for a number of miles (Figures 9 to 13) and would prevent ice from forming all winter there, except for some border ice attached to shore. The maximum upriver extent of ice cover progression below the project, with Watana operating alone, would vary from RM 124 to RM 142 depending on

Figure 14

ICECAL simulated ice front progression and Meltout dates (Harza - Ebasco Susitna Joint Venture, 1984a)

	Starting Date at Chulitna Confluence	Melt-Out Date	Maximum Upstream Extent (River Mile)
Natural Conditions			
1971-72	Nov. 5	--	137[N]
1976-77	Dec. 8	--	137[N]
1981-82	Nov. 18	May 10-15[B]	137[N]
1982-83	Nov. 5	May 10[B]	137[N]
Watana Only - 1996 Demand			
1971-72	Nov. 28	May 15[E]	140
1976-77	Dec. 25	May 3[E]	137
1981-82	Dec. 28	April 3	137
1982-83	Dec. 12	Mar. 20	127
1971-72[W]	Dec. 17	Mar. 27	127
Watana Only - 2001 Demand			
1971-72	Nov. 28	May 15[E]	142
1982-83	Dec. 19	March 16	124
Both Dams - 2002 Demand			
1971-72	Dec. 2	May 3[E]	137
1976-77	Jan. 10	April 20	126
1981-82	Dec. 30	Mar. 12	124
1982-83	Dec. 22	Mar. 20	123'
Both Dams - 2020 Demand			
1971-72	Dec. 3	April 15	133
1982-83	Dec. 14	Mar. 12	127

Legend:

B - Observed natural break-up.

E - Melt-out date is extrapolated from results when occurring beyond April 30.

N - Ice cover for natural conditions extends upstream of Gold Creek (River Mile 137) by means of lateral ice bridging.

I - Computed ice front progression upstream of Gold Creek (River Mile 137) is approximation only. Observations indicate closure of river by lateral ice in this reach for natural conditions.

Notes:

1. "Case C" instream flow requirements are assumed for with-project simulations.

2. 1971-72[W] simulation assumes warm, 4°C reservoir releases. All other with-project simulations assume an "inflow-matching" temperature policy.

winter climate and operational scenario (Figures 9 to 11). Similarly, with both Watana and Devil Canyon operating, the maximum ice cover extent would be from RM 123 to RM 137 (Figures 12 and 13). The ice front would reach its maximum position between mid-December and late March for Watana alone and mid-January to mid-March for Watana and Devil Canyon together, but would fluctuate considerably in position for the rest of the winter depending on prevailing air temperatures (see Appendices C to G).

Under natural conditions, in some years an ice bridge forms at the Susitna/Chulitna confluence before the ice front progression in the lower river has reached there. Also, in severely cold periods secondary bridges form above the confluence causing secondary leading edge progressions. With the project in place these conditions may not occur, and ICECAL simulations are based only on the initiation of an ice bridge at the Susitna/Chulitna confluence after the lower river ice front has reached there. Further, ICECAL assumes only one leading edge progression above the confluence.

Increases in winter discharges in the river below the dams would cause staging levels during freezeup to be significantly higher than natural downstream from the ice front. In that reach, where the ice cover forms, staging is expected to be 2 to 7 feet higher than normal with Watana operating alone (Figures 9 to 11), while with both dams operational, stages should be about 1 to 6 feet higher than normal (Figures 12 and 13). Downstream from the ice front, more sloughs and side channels would be overtopped, more frequently (Figures 15 to 17).

Figure 15
Occurrences[1] where with-project maximum river stages are higher than natural conditions
(Harza - Ebasco Susitna Joint Venture, 1984a)

Slough or Side Channel	River Mile	Watana Only Operating	Watana and Devil Canyon Operating
Whiskers	101.5	6/6	6/6
Gash Creek	112.0	6/6	5/6
6A	112.3	6/6	5/6
8	114.1	6/6	6/6
MSII	115.5	6/6	6/6
MSII	115.9	6/6	6/6
Curry	120.0	6/6	3/6
Moose	123.5	6/6	4/6
8A West	126.1	5/6	4/6
8A East	127.1	4/6	2/6
9	129.3	4/6	2/6
9 u/s	130.6	3/6	0/6
4th July	131.8	3/6	2/6
9A	133.7	3/6	1/6
10 u/s	134.3	4/6	1/6
11 d/s	135.3	3/6	0/6
11	136.5	4/6	2/6

Notes:

1. For example, 4/6 means that 4 of the 6 with-project simulations resulted in a higher maximum river stage than the natural conditions for corresponding winters.

2. "Case C" instream flow requirements and "inflow-matching" reservoir release temperatures are assumed for with-project simulations.

SUSITNA HYDROELECTRIC PROJECT
EXPECTED PROJECT EFFECTS ON WINTER SLOUGH OVERTOPPING

Slough or Side Channel	River Mile	WATANA ONLY							WATANA AND DEVIL CANYON					
		1996 DEMAND					2001 DEMAND		2002 DEMAND				2020 DEMAND	
		1971-72	1976-77	1981-82	1982-83	1971-72W	1971-72	1982-83	1971-72	1976-77	1981-82	1982-83	1971-72	1982-83
Whiskers	101.5		X							X				
8	114.1	X		X	X	X	X	X					X	
MS II	115.5		X							X				
MS II	115.9	X	X	X	X	X	X	X	X	X	X	X	X	X
8A West	126.1	X	X	X			X		X				X	
8A East	127.1		X					O		X	O	O		
9	129.3		X		O	O		O			O	O		O
9A	133.7		X		O	O		O			O	O		O
10 u/s	134.3		X		O	O		O			O	O		O
11	136.5	X		X			X							

LEGEND:

X — Slough is overtopped with project, but not under natural conditions for the corresponding winter.

O — Slough is overtopped with natural conditions, but not overtopped with project.

NOTES:

1. "Case C" instream flow requirements are assumed for with project simulations.
2. 1971-72W simulation assumes warm, 4° C reservoir releases. All other with project simulations assume an "inflow matching" temperature policy.

Figure 16. ICECAL simulations, Slough overtopping. (Harza - Ebasco Susitna Joint Venture, 1984a)

SUSITNA HYDROELECTRIC PROJECT
MAXIMUM SIMULATED WINTER RIVER STAGES[4]

Slough or Side Channel	River Mile	Threshold Elevation	NATURAL CONDITIONS 1971-72	1976-77	1981-82	1982-83	WATANA ONLY 1996 DEMAND 1971-72	1976-77	1981-82	1982-83	1971-72W	WATANA ONLY 2001 DEMAND 1971-72	1982-83	WATANA AND DEVIL CANYON 2002 DEMAND 1971-72	1976-77	1981-82	1982-83	WATANA AND DEVIL CANYON 2020 DEMAND 1971-72	1982-83
Whiskers	101.5	367	369	366	368	367	372	370	371	370	371	372	370	371	368	369	369	372	370
Gash Creek	112.0	Unknown	456	455	455	456	459	457	460	459	460	459	461	458	455	456	457	459	457
6A	112.3	(Upland)	459	457	457	459	462	460	462	462	463	461	463	460	458	458	460	461	459
8	114.1	476	474	472	472	474	478	475	477	476	477	476	478	475	474	475	475	476	475
MS II	115.5	482	484	480	484	484	490	487	488	488	488	489	489	487	485	485	487	490	488
MS II	115.9	487	485	482	486	486	492	489	491	491	490	491	492	489	488	488	490	492	490
Curry	120.0	Unknown	522	520	523	520	526	525	527	525	523	525	521	522	521	520	520	525	523
Moose	123.5	Unknown	552	546	549	548	556	554	555	550	552	555	550	553	550	548	545	555	550
8A West	126.1	573	572	569	571	570	576	575	574	572	572	575	568	574	571	568	568	575	572
8A East	127.1	582	584	581	583	582	587	585	585	582	582	586	581	584	582	580	581	585	582
9	129.3	604	605	603	606	605	609	607	607	603	603	610	603	606	602	601	602	608	603
9 u/s	130.6	Unknown	622	616	620	621	624	622	620	617	617	625	617	620	616	616	616	621	617
4th July	131.8	Unknown	632	626	629	630	635	633	631	628	628	636	628	633	627	627	627	631	628
9A	133.7	651	655	649	651	651	657	655	653	650	650	659	650	652	650	650	650	651	650
10 u/s	134.3	657	662	654	657	658	663	661	659	656	656	665	656	659	655	655	655	657	656
11 d/s	135.3	Unknown	673	667	670	672	675	672	670	668	668	676	668	670	667	667	667	668	668
11	136.5	687	684	681	683	684	688	686	687	683	683	690	683	685	682	682	682	684	684
17	139.3	Unknown	–	–	–	–	717	715	715	715	715	727	715	714	714	714	714	715	715
20	140.5	730	–	–	–	–	732	730	729	729	729	741	729	728	728	728	728	729	729
21 (A6)	141.8	747	–	–	–	–	746	746	746	746	745	751	746	746	746	745	746	747	747
21	142.2	755	–	–	–	–	753	753	753	753	753	755	753	752	752	752	752	753	754
22	144.8	788	–	–	–	–	787	787	787	786	787	787	786	785	785	785	785	787	787

Upstream Boundary of Natural Simulations

Upstream Extent of Ice Cover Progression

NOTES:

1. ☐ Indicates locations where maximum river stage equals or exceeds a known slough threshold elevation.
2. "Case C" instream flow requirements are assumed for with project simulations.
3. 1971-72W simulation assumes warm, 4°C reservoir releases. All other with-project simulations assume an "inflow matching" temperature policy.
4. All river stages in feet.

Figure 17. ICECAL simulations, River stages. (Harza - Ebasco Susitna Joint Venture, 1984a)

Winter discharges would be higher than normal but no freezeup staging would occur upstream from the ice front's maximum position and water levels in that reach would be 1 to 3 feet lower than natural freezeup staging levels with Watana operating alone, and 1 to 5 feet lower with both dams operating. Therefore, no sloughs should be overtopped. However, lack of freezeup staging in this reach of the river may prevent or reduce groundwater upwelling in the sloughs. Natural freezeup staging causes approximately the same hydraulic head to exist between the mainstem and adjacent sloughs as occurs during summer. With the project in place and no freezeup staging occurring, the hydraulic head would be reduced.

Since the ice edge would not advance as far, or as rapidly, during project operations as during natural conditions, more areas of open water would exist, and they would remain longer than usual. This could cause the incidence of more anchor ice during cold periods. This might cause the formation of slight backwater areas because of the general raising of the channel bottom, possibly affecting flow distribution between channels with low berms.

Where an ice cover forms, the maximum total ice thickness with Watana operating alone are expected to be generally similar to natural ice thickness. With both dams operating, maximum total ice thickness should be about 1 to 2 feet less than natural ice thickness (Figures 18 and 19).

Simulations of 4 C releases from the project, compared to simulations of "inflow matching" releases (Figure 10) show that control of reservoir release temperatures may have a significant effect on river ice processes. Control of release temperatures has been used by some hydroelectric projects to control

SUSITNA HYDROELECTRIC PROJECT
TOTAL ICE THICKNESS
MAXIMUM SIMULATED VALUES[3]

Slough or Side Channel	River Mile	NATURAL CONDITIONS 1971-72	1976-77	1981-82	1982-83	WATANA ONLY 1996 DEMAND 1971-72	1976-77	1981-82	1982-83	1971-72w	WATANA ONLY 2001 DEMAND 1971-72	1982-83	WATANA AND DEVIL CANYON 2002 DEMAND 1971-72	1976-77	1981-82	1982-83	WATANA AND DEVIL CANYON 2020 DEMAND 1971-72	1982-83
Whiskers	101.5	5	2	4	3	5	2	3	2	3	5	2	5	1	2	2	4	1
Gash Creek	112.0	5	4	4	4	5	3	5	5	6	5	7	5	2	2	3	4	1
6A	112.3	6	5	4	5	5	3	5	4	6	5	7	5	2	3	4	4	1
8	114.1	5	2	4	4	5	2	4	3	4	5	5	4	2	3	3	4	1
MSII	115.5	5	2	5	5	6	2	5	5	4	5	6	4	3	3	4	4	2
MSII	115.9	5	3	7	6	7	3	7	6	6	5	8	4	6	4	6	5	3
Curry	120.0	6	5	7	4	7	5	8	5	3	5	1	4	3	1	1	4	2
Moose	123.5	10	4	7	5	9	6	8	2	4	6	2	7	4	1		7	2
BA West	126.1	5	2	3	3	5	3	3	1	1	5		3	1			3	1
BA East	127.1	5	2	3	3	4	3	2	0	0	4		3				3	0
9	129.3	6	4	7	6	5	3	3			6		3				3	
9 u/s	130.6	8	3	6	7	5	4	2			6		3				2	
4th July	131.8	7	1	3	5	5	3	2			7		3				2	
9A	133.7	7	1	3	3	6	4	2			8		3					
10 u/s	134.3	11	1	3	4	7	5	2			9		4					
11 d/s	135.3	6	1	3	5	6	4	2			8		3					
11	136.5	5	1	3	4	3	2	2			5		1					
17	139.3					2					13							
20	140.5					2					12							
21 (A6)	141.8										3							
21	142.2										1							
22	144.8																	

Upstream Boundary of Natural Simulations

Upstream Extent of Ice Cover Progression

NOTES:
1. "Case C" instream flow requirements are assumed for with-project simulations.
2. 1971-72W simulation assumes warm, 4°C reservoir releases.
All other with-project simulations assume an "inflow-matching" temperature policy.
3. All ice thickness in feet.

Figure 18. ICECAL simulations, Total ice thickness. (Harza - Ebasco Susitna Joint Venture, 1984a)

SUSITNA HYDROELECTRIC PROJECT
SOLID ICE THICKNESS
MAXIMUM SIMULATED VALUES[3]

Slough or Side Channel	River Mile	Natural Conditions 1971-72	Natural Conditions 1976-77	Natural Conditions 1981-82	Natural Conditions 1982-83	Watana Only 1996 Demand 1971-72	Watana Only 1996 Demand 1976-77	Watana Only 1996 Demand 1981-82	Watana Only 1996 Demand 1982-83	Watana Only 1996 Demand 1971-72 W	Watana Only 2001 Demand 1971-72	Watana Only 2001 Demand 1982-83	Watana and Devil Canyon 2002 Demand 1971-72	Watana and Devil Canyon 2002 Demand 1976-77	Watana and Devil Canyon 2002 Demand 1981-82	Watana and Devil Canyon 2002 Demand 1982-83	Watana and Devil Canyon 2020 Demand 1971-72	Watana and Devil Canyon 2020 Demand 1982-83
Whiskers	101.5	5	2	4	3	5	2	3	2	3	5	2	5	1	2	2	4	1
Gash Creek	112.0	5	2	4	3	5	2	3	2	2	5	1	5	1	2	1	4	1
6A	112.3	5	2	4	3	5	2	3	2	2	5	1	5	1	2	1	4	1
8	114.1	5	2	4	3	5	2	3	2	2	5	1	5	1	2	1	4	1
MSII	115.5	5	2	4	3	5	2	3	2	1	5	1	4	1	1	1	4	1
MSII	115.9	5	2	4	3	5	2	3	1	1	5	0	4	1	1	1	4	1
Curry	120.0	5	2	4	3	5	2	2	0	1	5	0	4	1	1	0	3	0
Moose	123.5	5	2	4	3	4	1	2	0	0	4	0	4	0	0		2	0
8A West	126.1	5	2	3	3	4	1	1	0	0	4		3	0			1	0
8A East	127.1	5	2	3	3	3	1	1	0	0	4		3				1	0
9	129.3	5	2	3	3	3	1	1			4		3				1	
9 u/s	130.6	5	2	3	3	3	1	1			4		2				0	
4th July	131.8	5	1	3	3	2	1	1			4		2				0	
9A	133.7	5	1	3	2	2	1	0			4		1					
10 u/s	134.3	5	1	3	2	2	0	0			3		1					
11 d/s	135.3	4	1	3	2	2	0	0			3		0					
11	136.5	4	1	3	2	1	0	0			3		0					
17	139.3					0					2							
20	140.5					0					2							
21 (A6)	141.8										1							
21	142.2										0							
22	144.8																	

Upstream Boundary of Natural Simulations

Upstream Extent of Ice Cover Progression

NOTES:
1. "Case C" instream flow requirements are assumed for with-project simulations.
2. 1971-72 W simulation assumes warm, 4°C reservoir releases.
   All other with-project simulations assume an "inflow-matching" temperature policy.
3. All ice thickness in feet.

Figure 19. ICECAL simulations, Solid ice thickness. (Harza - Ebasco Susitna Joint Venture, 1984a)

ice conditions below the dams, especially where riverside towns or other developed areas have been threatened by project- related ice conditions.

WITH-PROJECT SIMULATIONS, BREAKUP

Breakup processes are expected to be different in the Susitna River below the project, especially in the Talkeetna to Devil Canyon reach. Since the maximum upstream extent of the ice cover below the dams would be somewhere between RM 124 and RM 142, there would be no continuous ice cover between this area and the damsite, and consequently no breakup or meltout in that reach. Any border ice attached to shore would probably slowly melt away in place; occasional pieces of border ice might break away from shore and float downstream. Ice in the river reach above the project would break up normally, but would not drift into this area as it normally does because it would be trapped in the reservoirs.

The normal spring breakup drive is usually brought on by rapid flow increases that lift and fracture the ice cover. The proposed project reservoirs would regulate such seasonal flows, yielding a more steady flow regime and resulting in a slow meltout of the ice cover in place.

The warmer-than-normal water temperatures released from the project would cause the upstream end of the ice cover to begin to decay earlier in the season than normal. Gradual spring meltout with Watana operating alone is predicted to be 4 to 6 weeks earlier than normal, and 7 to 8 weeks earlier than normal with both dams operating. By May, flow levels in the river would be significantly reduced as the project begins to store incoming flows from upstream. The result is expected to be that breakup drive processes that now normally occur in the middle river area would be effectively eliminated. Instead, a slow and steady meltout of river ice in this reach would probably occur. Since there would be no extensive volume of broken ice floating downstream and accumulating against the unbroken ice cover, ice jamming in the middle river would usually not occur or would be substantially reduced in severity. This would eliminate or substantially reduce river staging and flooding normally associated with ice jams, thereby eliminating or greatly reducing the overtopping of berms and the flooding of side sloughs.

In the lower river below the Susitna/Chulitna confluence, breakup severity would probably also be reduced due to the lower flows occurring in the river during breakup. Ice thicknesses in this reach, however, may be somewhat thicker than normal because of the higher winter flows from the project.

FURTHER STUDIES

Studies of natural ice processes by R & M Consultants, Inc. are continuing on the Susitna River. Further ICECAL model runs are being carried out by Harza-Ebasco Susitna Joint Venture, to address other with-project scenarios. Also, simulations may be produced for other project flow regimes beside Case C if these are identified as desireable. The results of these observations and simulation studies will be included in the report addressing the effects of altered river ice processes on aquatic habitats and fishery resources, to be completed in the spring of 1985.

33RA-001a

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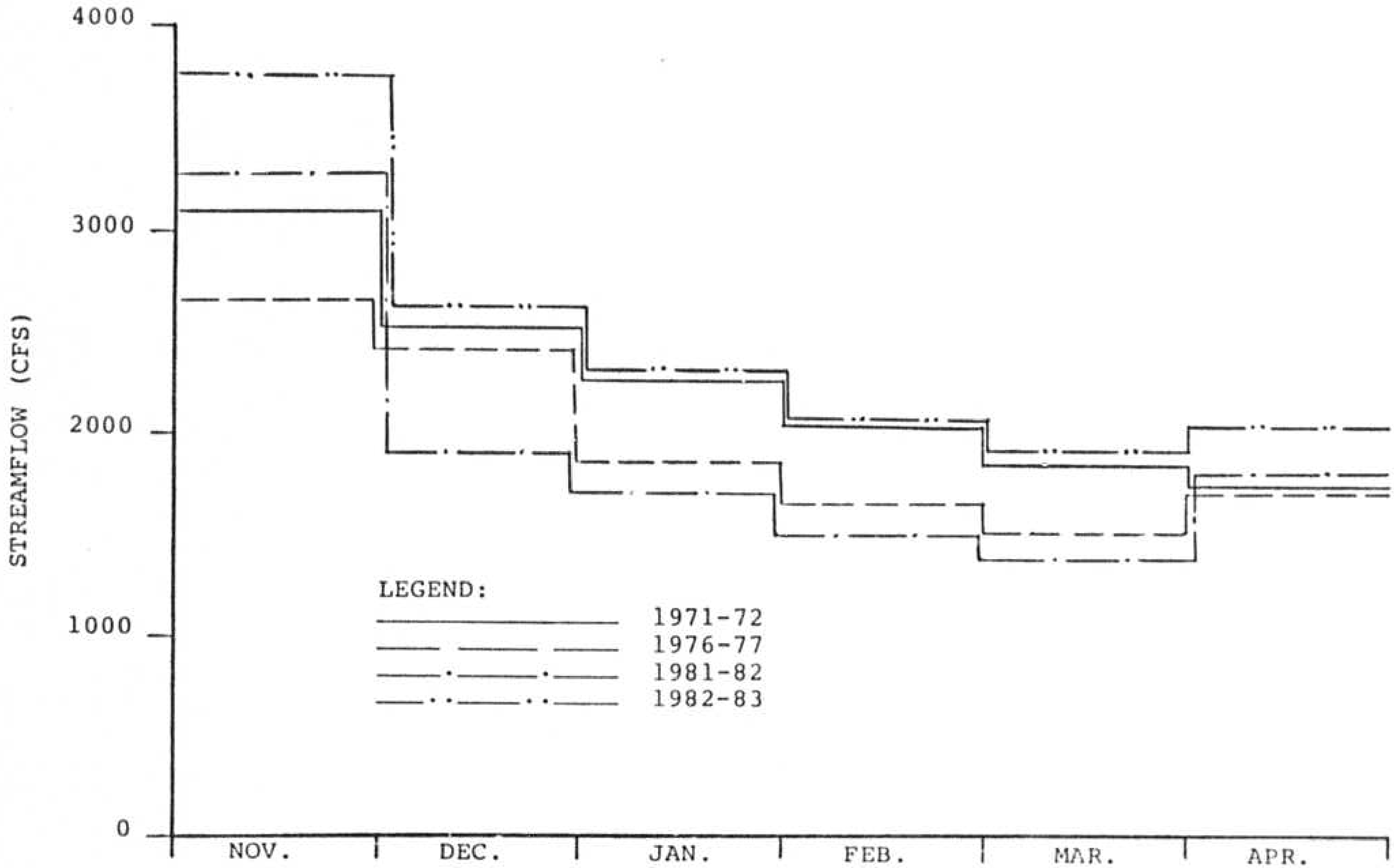
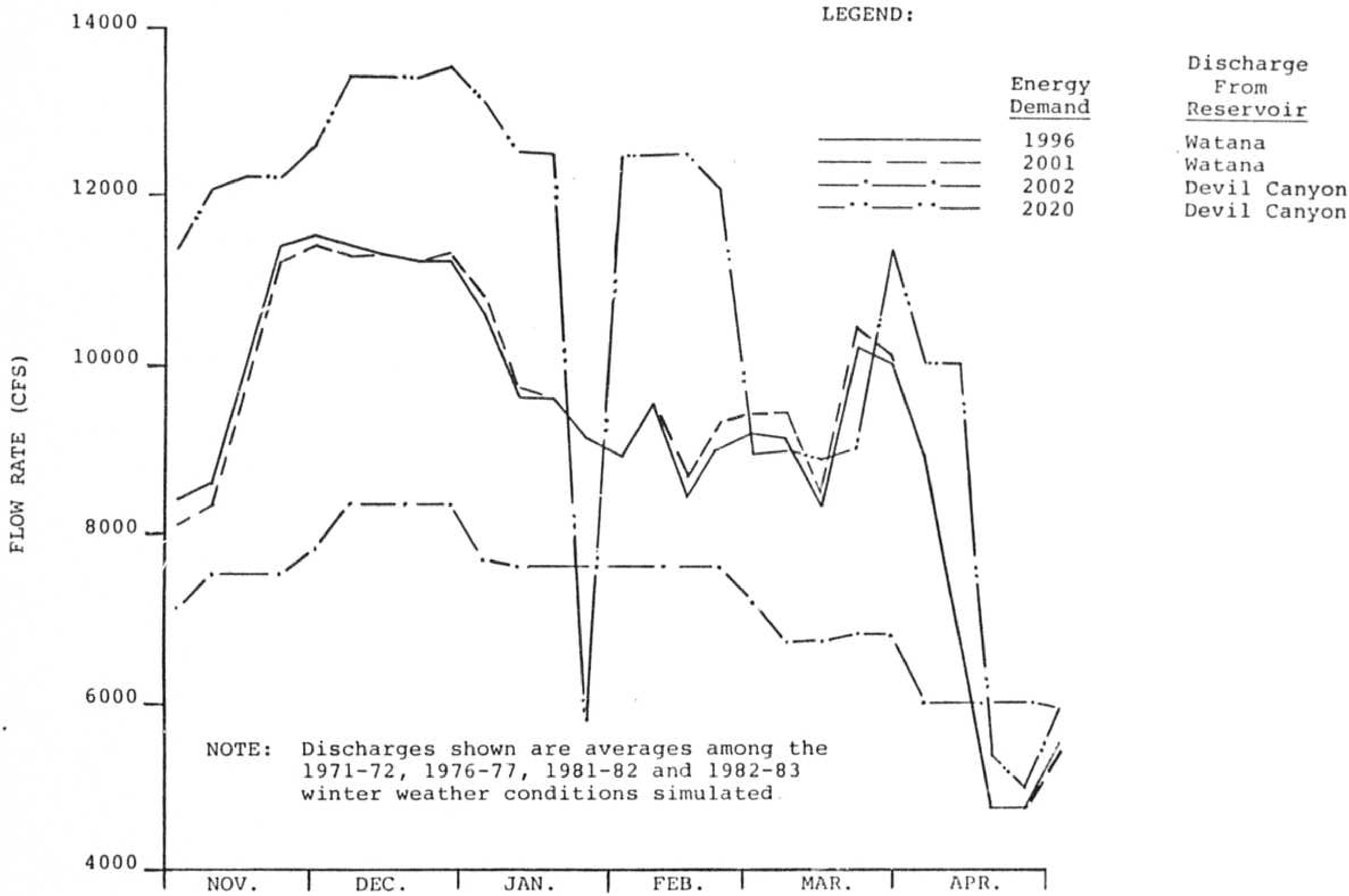
APPENDIX A

Susitna River natural streamflows, and with-project reservoir discharges.



SUSITNA RIVER NATURAL STREAMFLOWS AT GOLD CREEK — AVERAGE MONTHLY VALUES

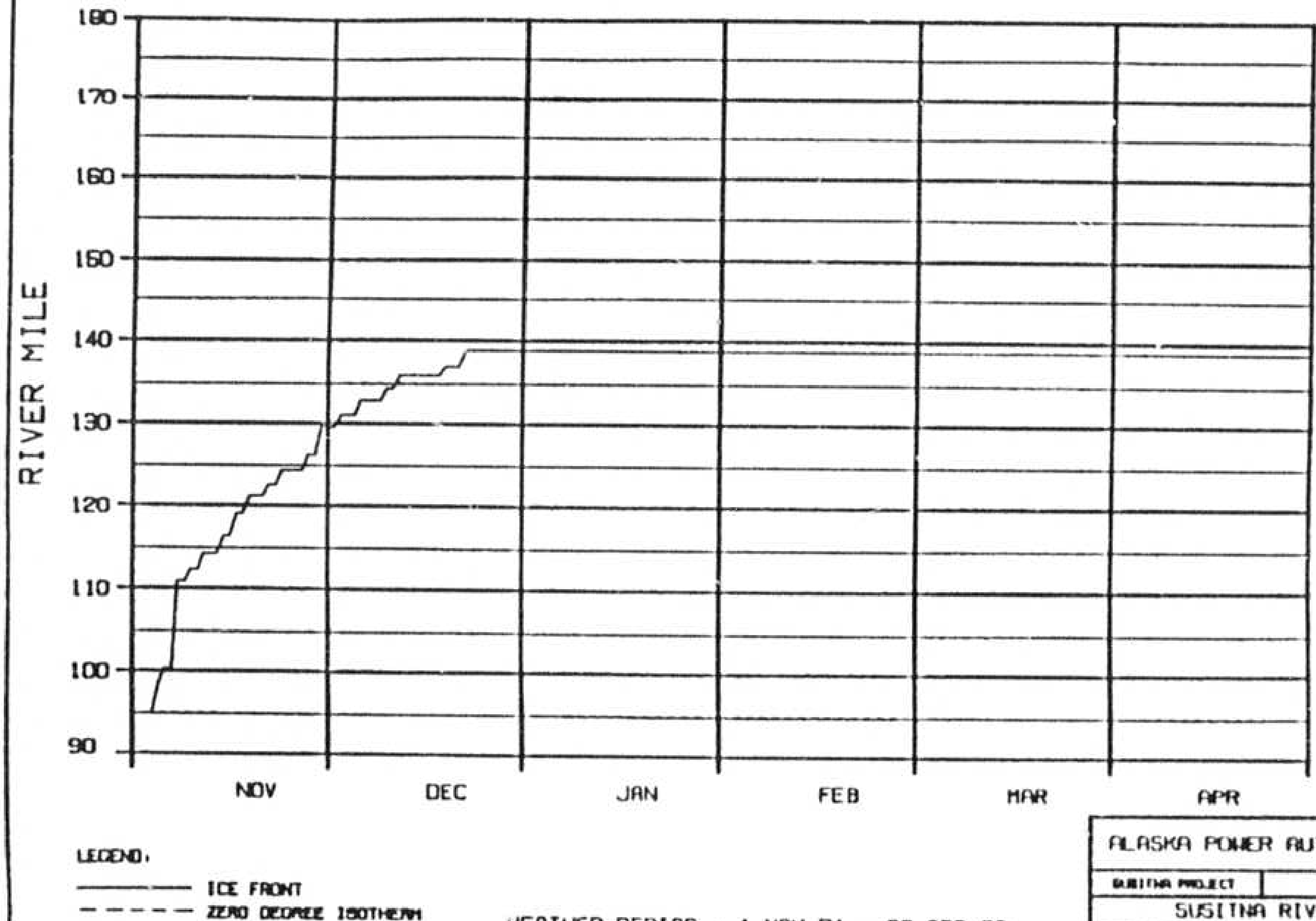


DISCHARGE FROM PROJECT RESERVOIRS

2RA-001b

APPENDIX B

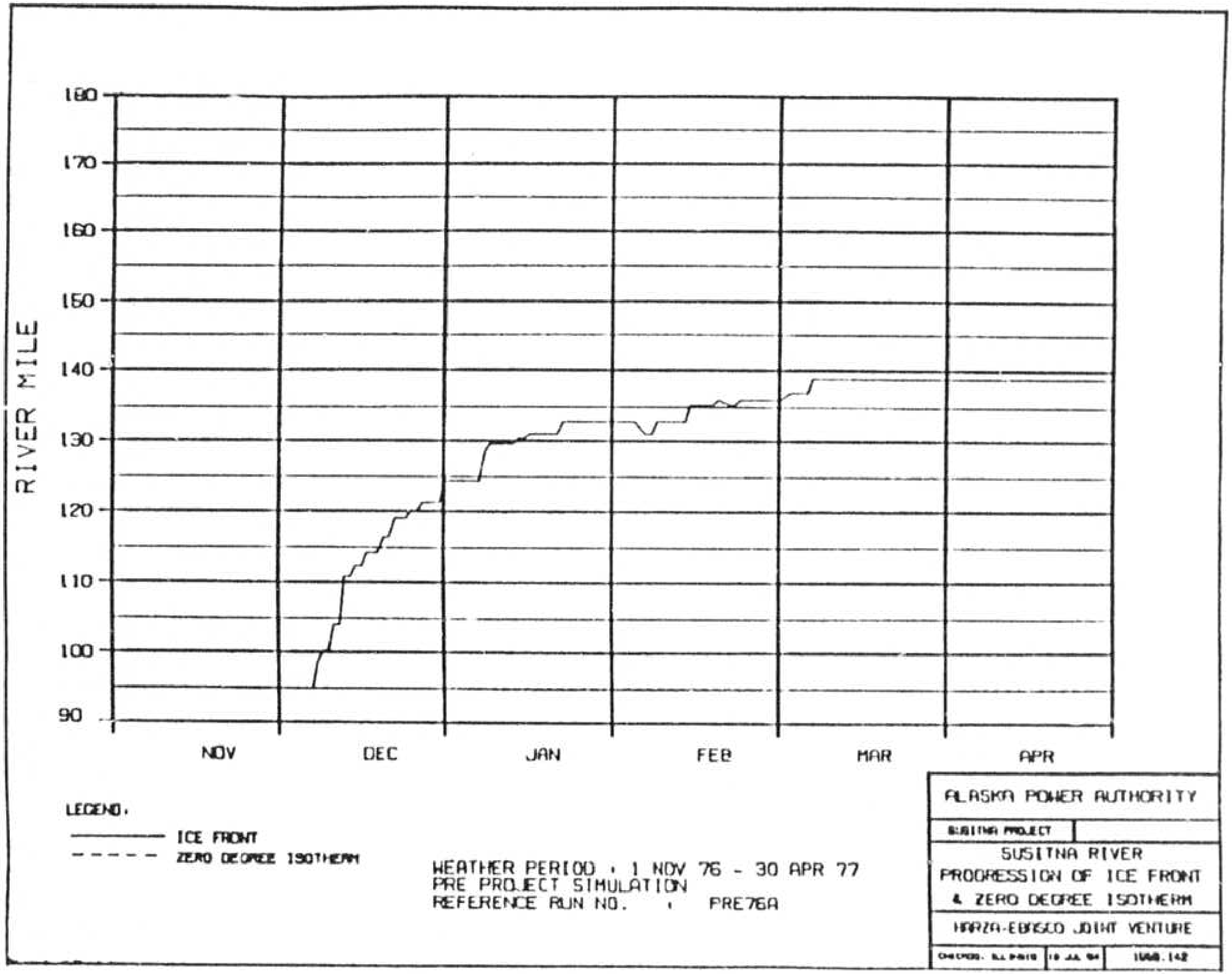
ICECAL Simulations of natural ice front progression in the middle Susitna River, 1971-72, 1976-77, 1981-82, 1982-83, 1983-84. (Harza-Ebasco Susitna Joint Venture, 1984a)



WEATHER PERIOD : 1 NOV 71 - 30 APR 72
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE71A

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER PROGRESSION OF ICE FRONT & ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE

OPTION?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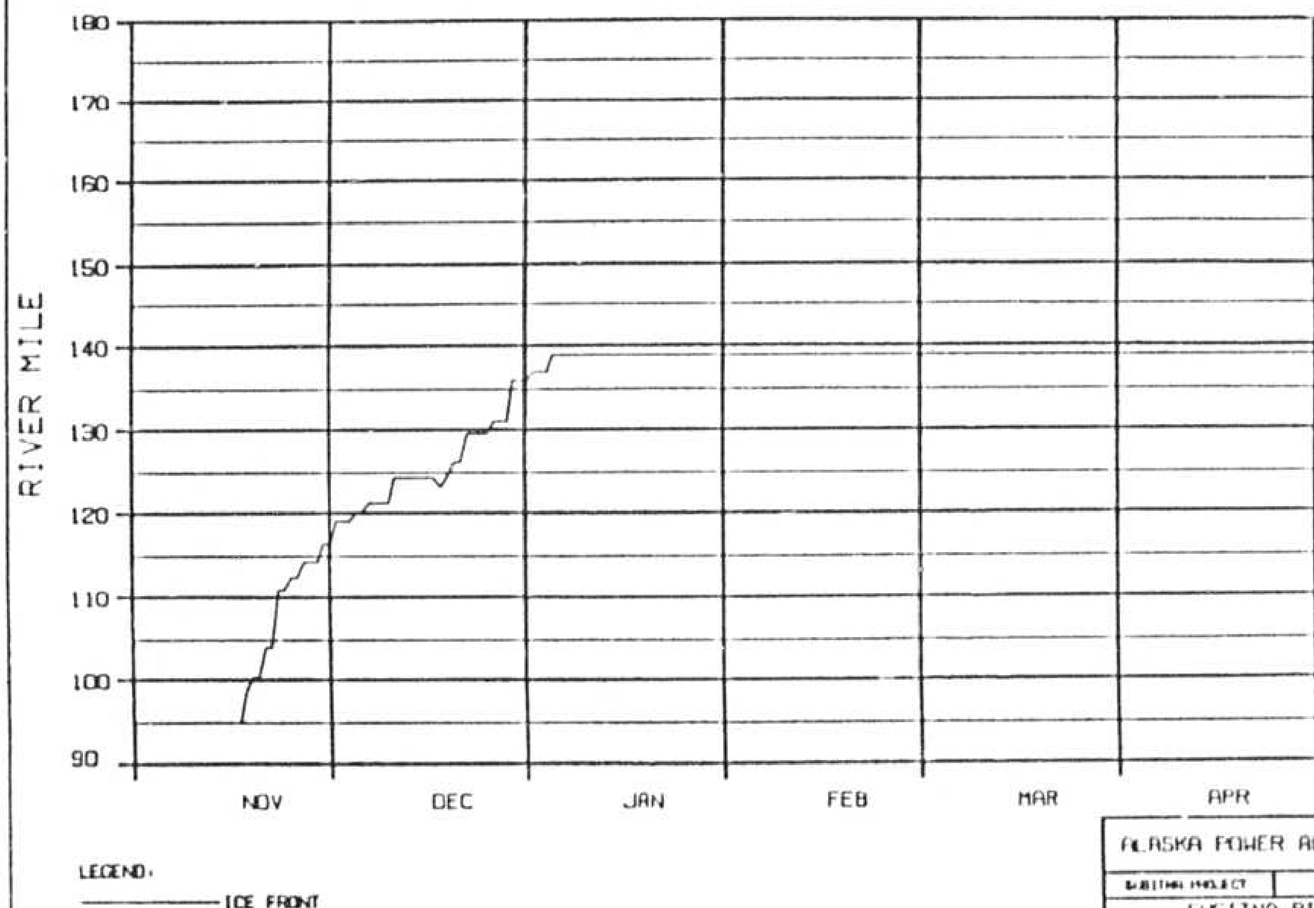
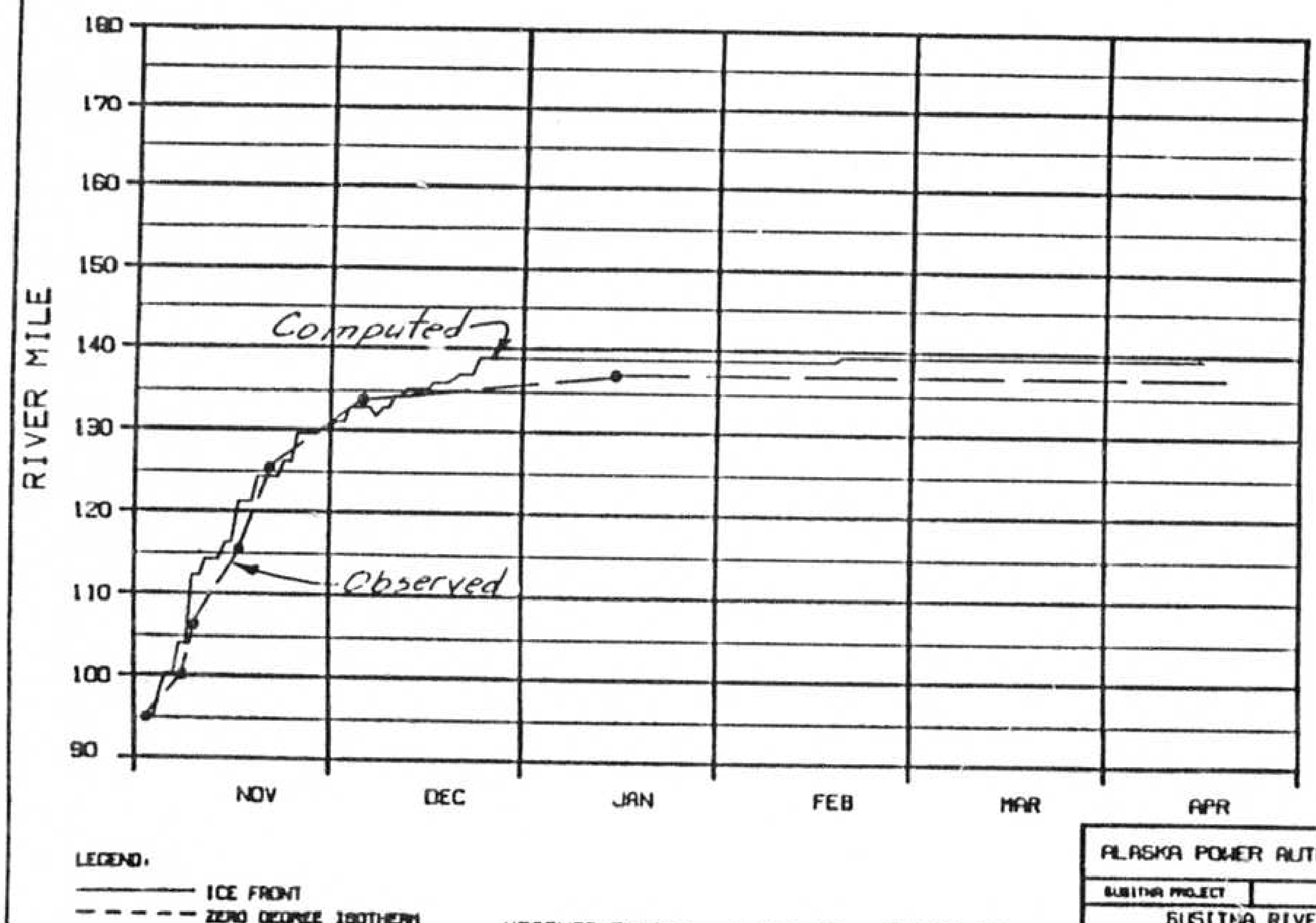
LEGEND:
ICE FRONT
ZERO DEGREE ISOTHERM
WEATHER PERIOD : 1 NOV 76 - 30 APR 77
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE76A
ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE



WEATHER PERIOD : 1 NOV 81 - 30 APR 82
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE818

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER PROGRESSION OF ICE FRONT & ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE
1660.142

OPTION?



WEATHER PERIOD : 1 NOV 82 - 15 APR 83
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE82A

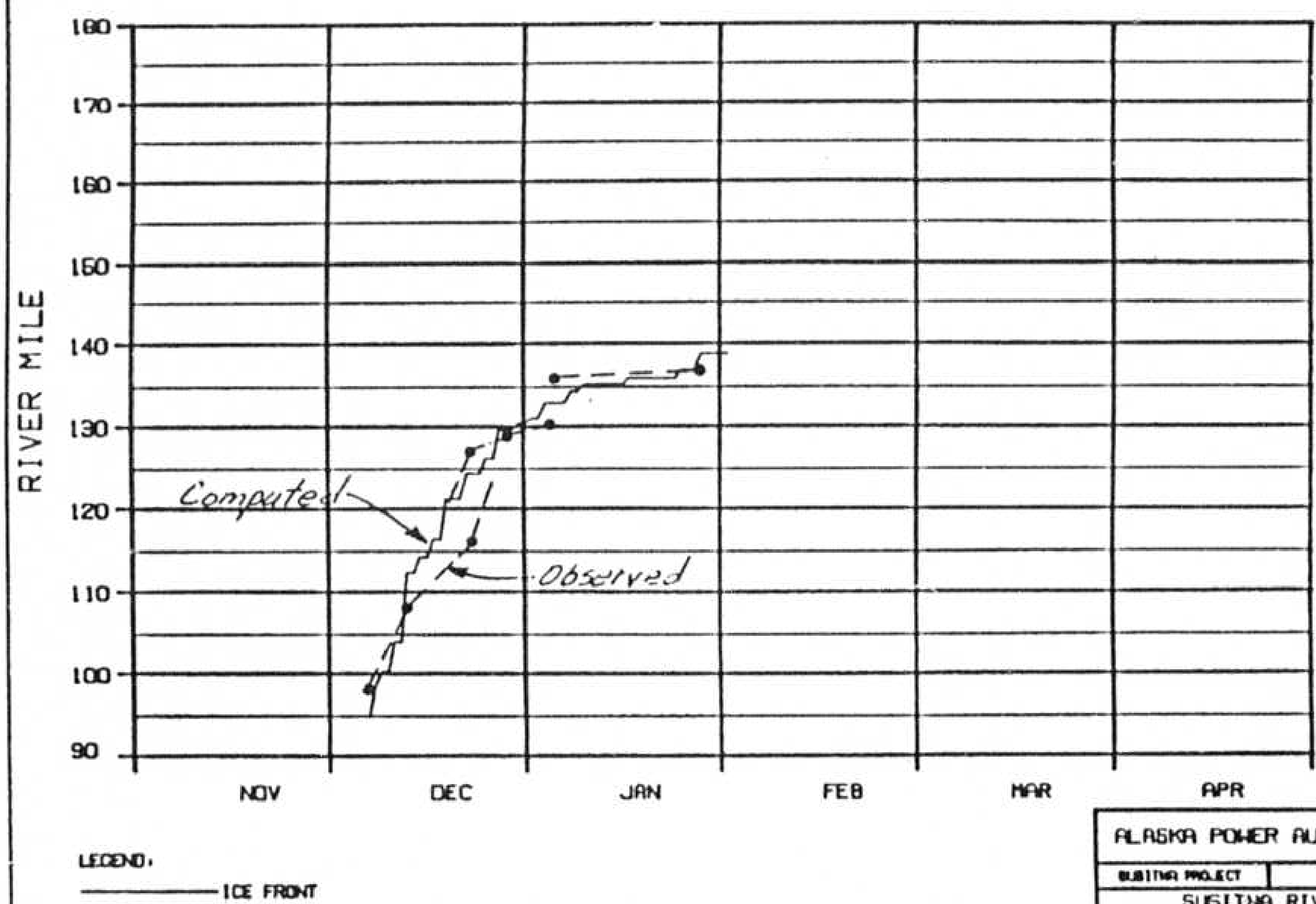
ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM

HARZA-EBASCO JOINT VENTURE

OPTION?

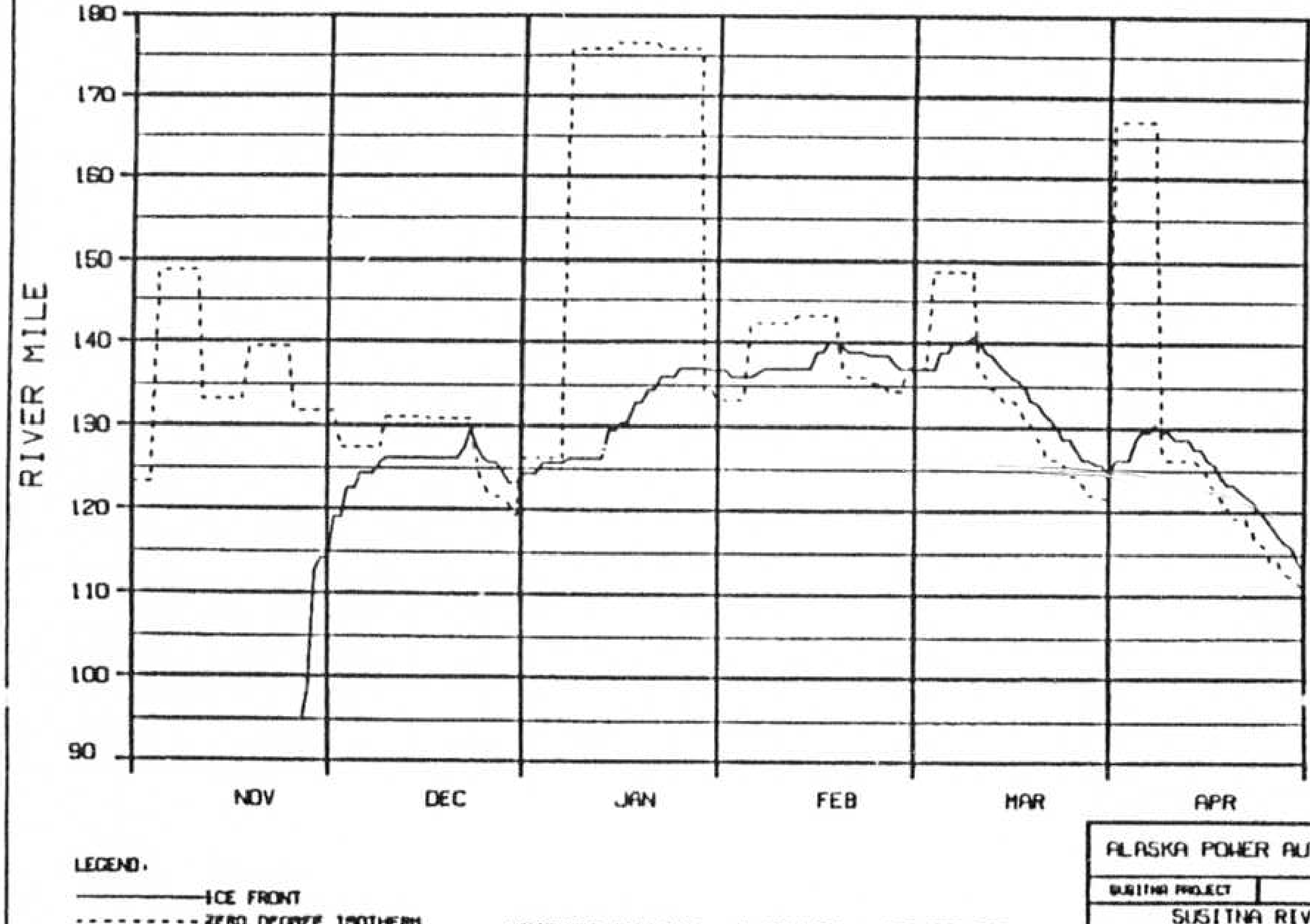


WEATHER PERIOD : 1 NOV 83 - 31 JAN 84
PRE PROJECT SIMULATION
REFERENCE RUN NO. : PRE83A

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER PROGRESSION OF ICE FRONT & ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE
1888.142

APPENDIX C

ICECAL simulations of ice front progression, Watana alone, 1996, inflow matching releases, 1971-72, 1976-77, 1981-82, 1982-83. (Harza-Ebasco Susitna Joint Venture, 1984a)



WEATHER PERIOD : 1 NOV 71 - 30 APR 72
ENERGY DEMAND : WATANA 1996
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 7196CNA

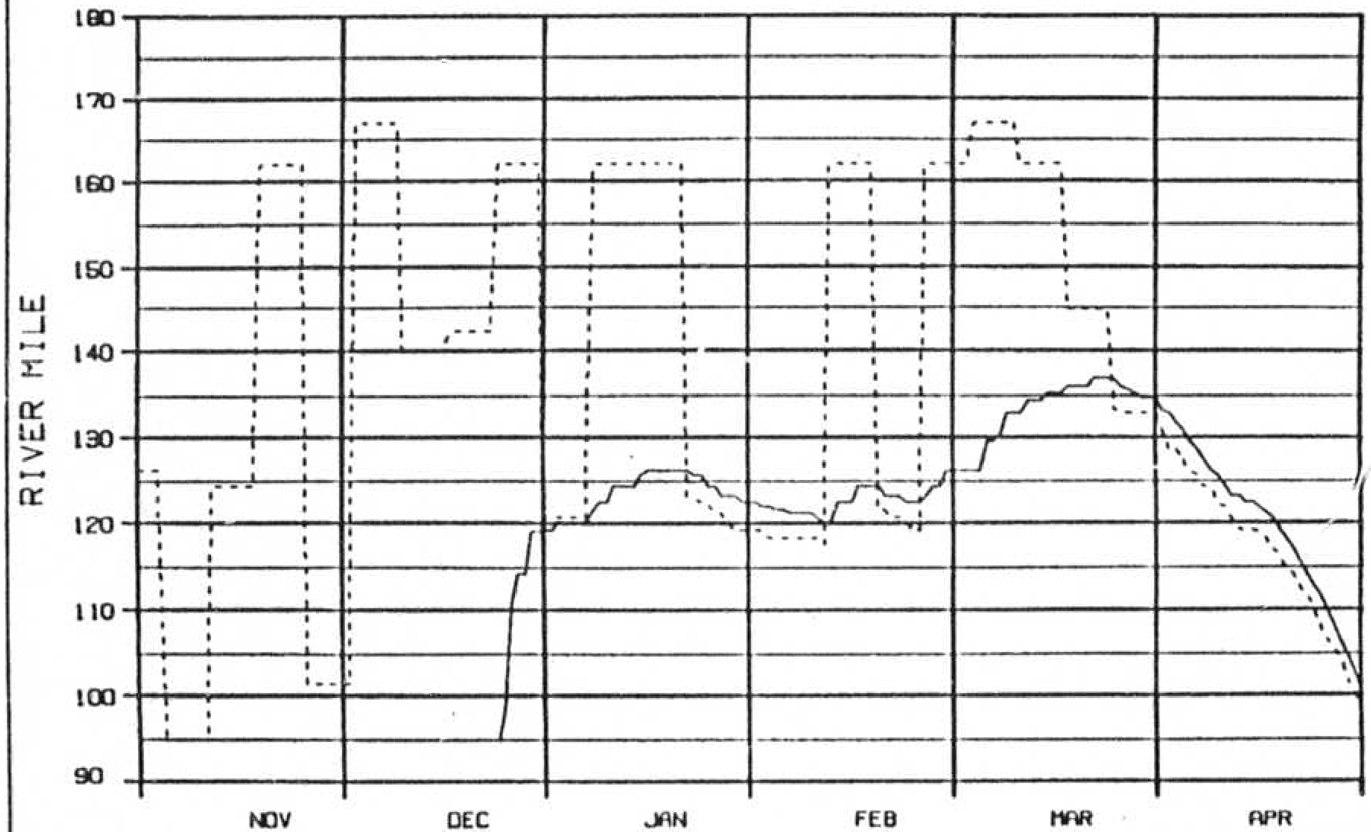
ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM

HARZA-EBASCO JOINT VENTURE

OPTION?



LEGEND:

——— ICE FRONT

- - - - - ZERO DEGREE ISOTHERM

WEATHER PERIOD : 1 NOV 76 - 30 APR 77
ENERGY DEMAND : WATANA 1996
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 7696CNA

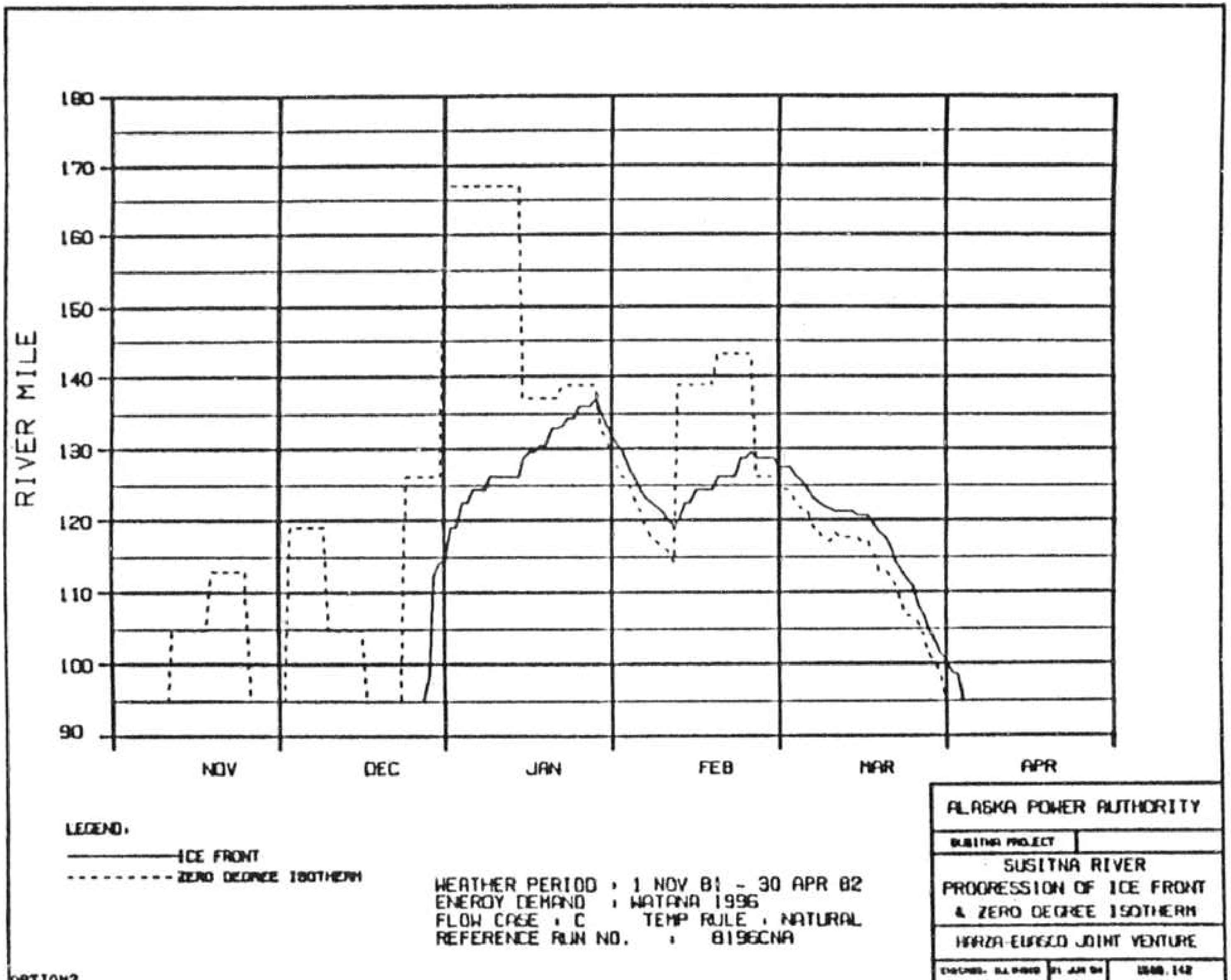
ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM

HARZA-EBASCO JOINT VENTURE

OPTION?OPTION?


RIVER MILE
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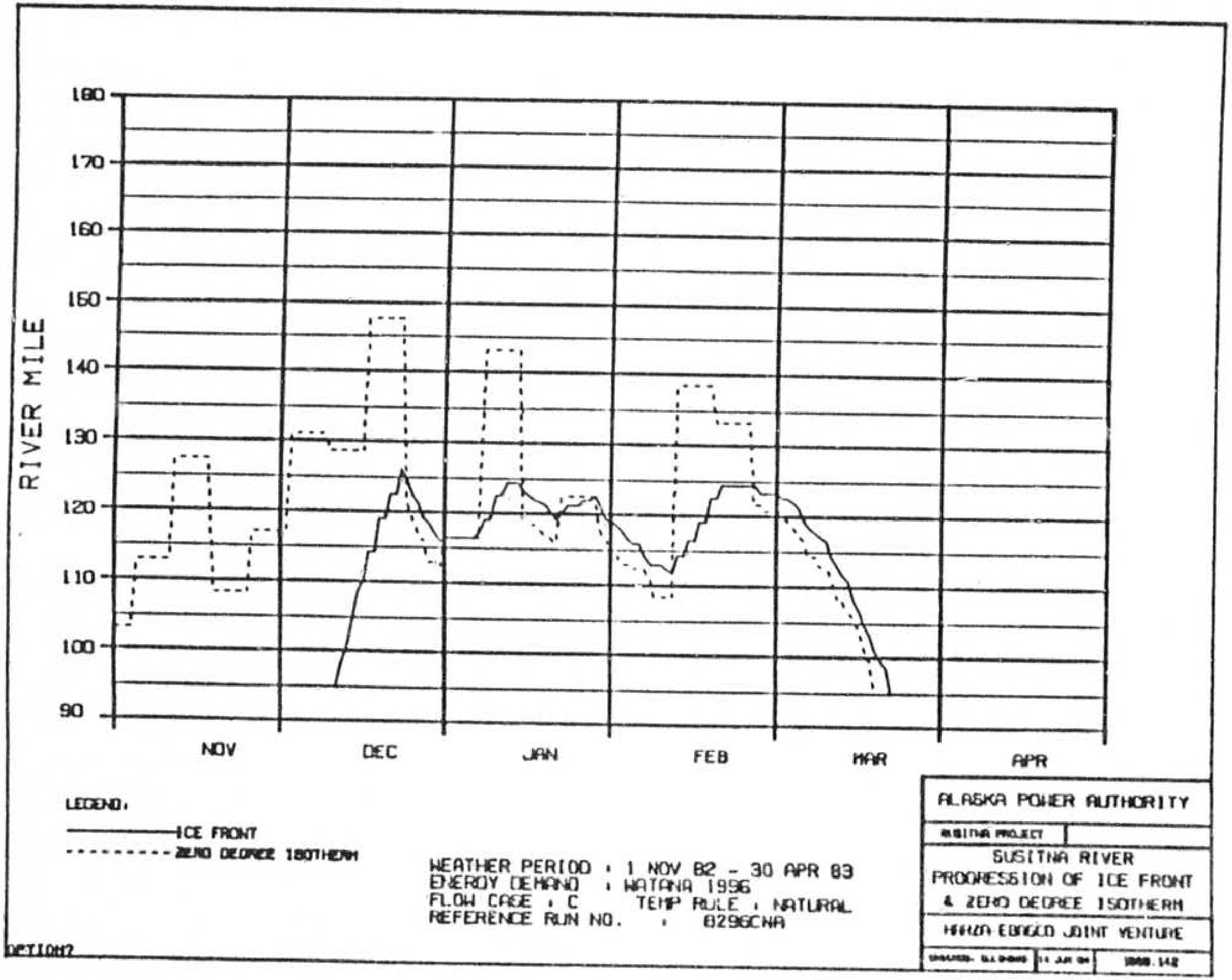
LEGEND:
ICE FRONT
ZERO DEGREE ISOTHERM
WEATHER PERIOD : 1 NOV 81 - 30 APR 82
ENERGY DEMAND : WATANA 1996
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 8196CNA
ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE
OPTION?



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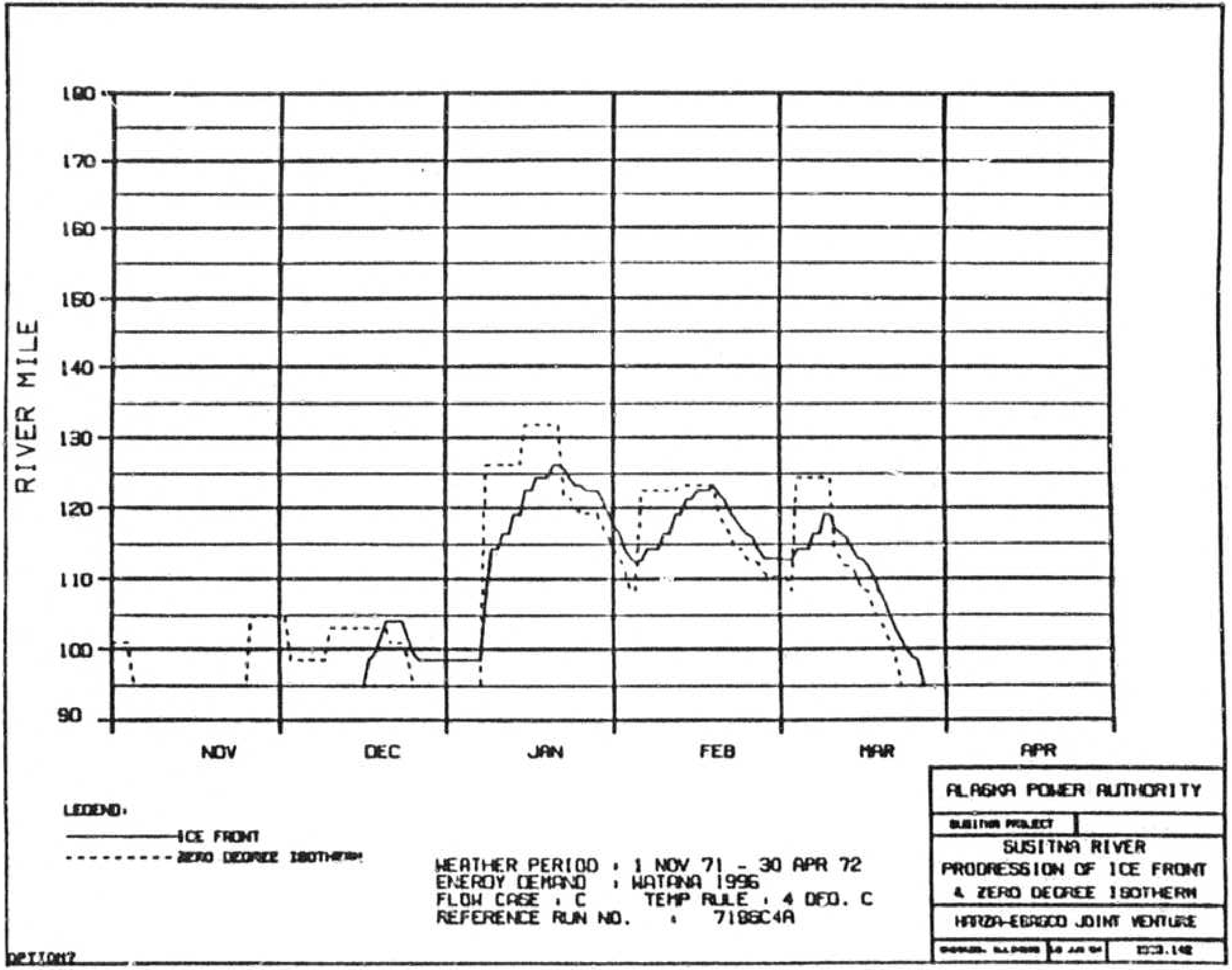
APR
LEGEND:
ICE FRONT
ZERO DEGREE ISOTHERM
WEATHER PERIOD : 1 NOV 82 - 30 APR 83
ENERGY DEMAND : WATANA 1996
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 8296CNA
ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM
HARZA EBASCO JOINT VENTURE
OPTION?

2RA-001b

APPENDIX D

ICECAL simulations of ice front progression,
Watana alone, 1996, 4 C releases, 1971-72
(Harza-Ebasco Susitna Joint Venture, 1984a)



RIVER MILE
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LEGEND:
ICE FRONT
ZERO DEGREE ISOTHERM
WEATHER PERIOD : 1 NOV 71 - 30 APR 72
ENERGY DEMAND : WATANA 1996
FLOW CASE : C TEMP RULE : 4 DEG. C
REFERENCE RUN NO. : 718SC4A
ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE
OPTION2

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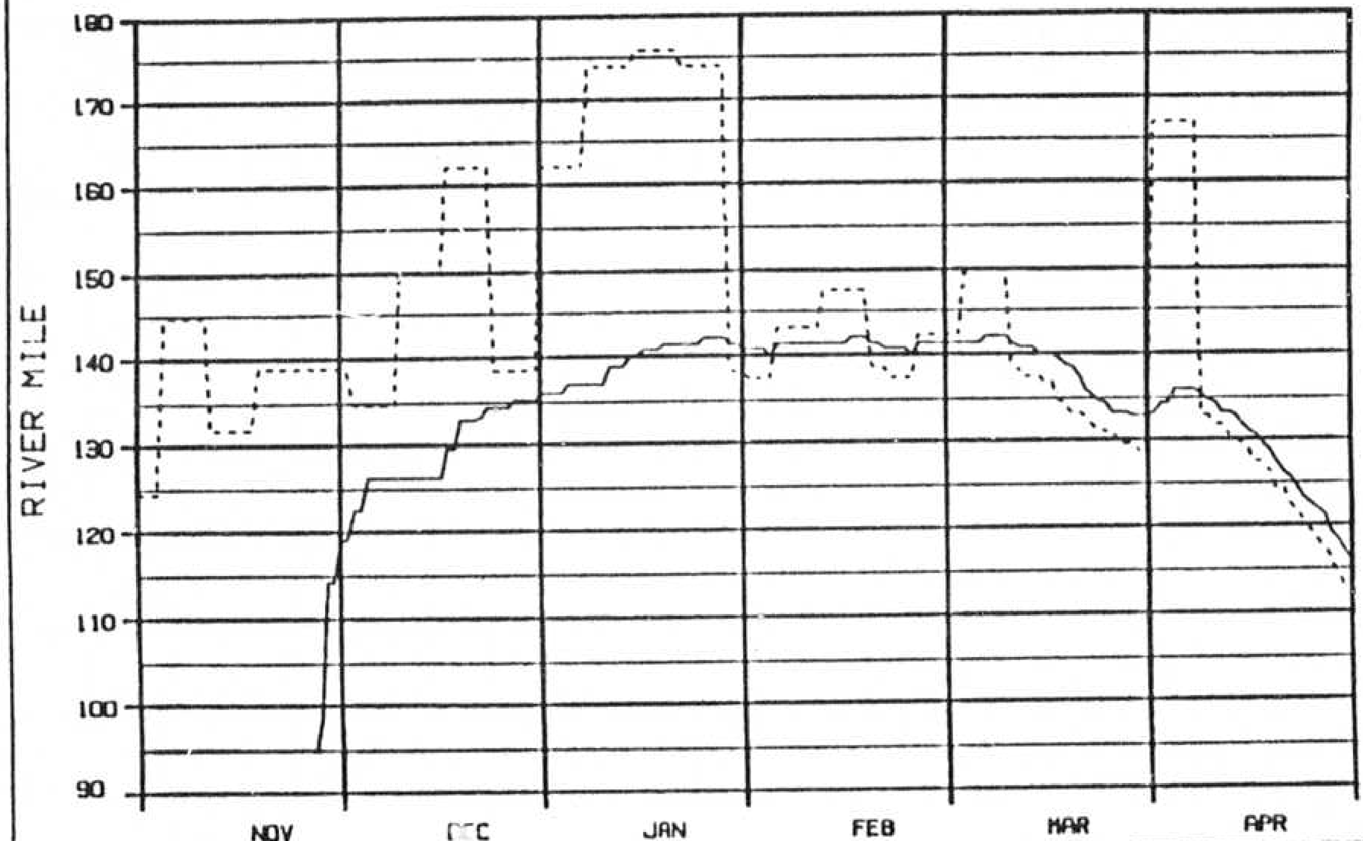
APPENDIX E

ICECAL simulations of ice front progression, Watana alone, 2001, inflow matching releases, 1971-72, 1982-83 (Harza-Ebasco Susitna Joint Venture, 1984a)



LEGEND:

——— ICE FRONT

- - - - - - ZERO DEGREE ISOTHERM

WEATHER PERIOD : 1 NOV 71 - 30 APR 72
ENERGY DEMAND : WATANA 2001
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 7101CNA

ALASKA POWER AUTHORITY

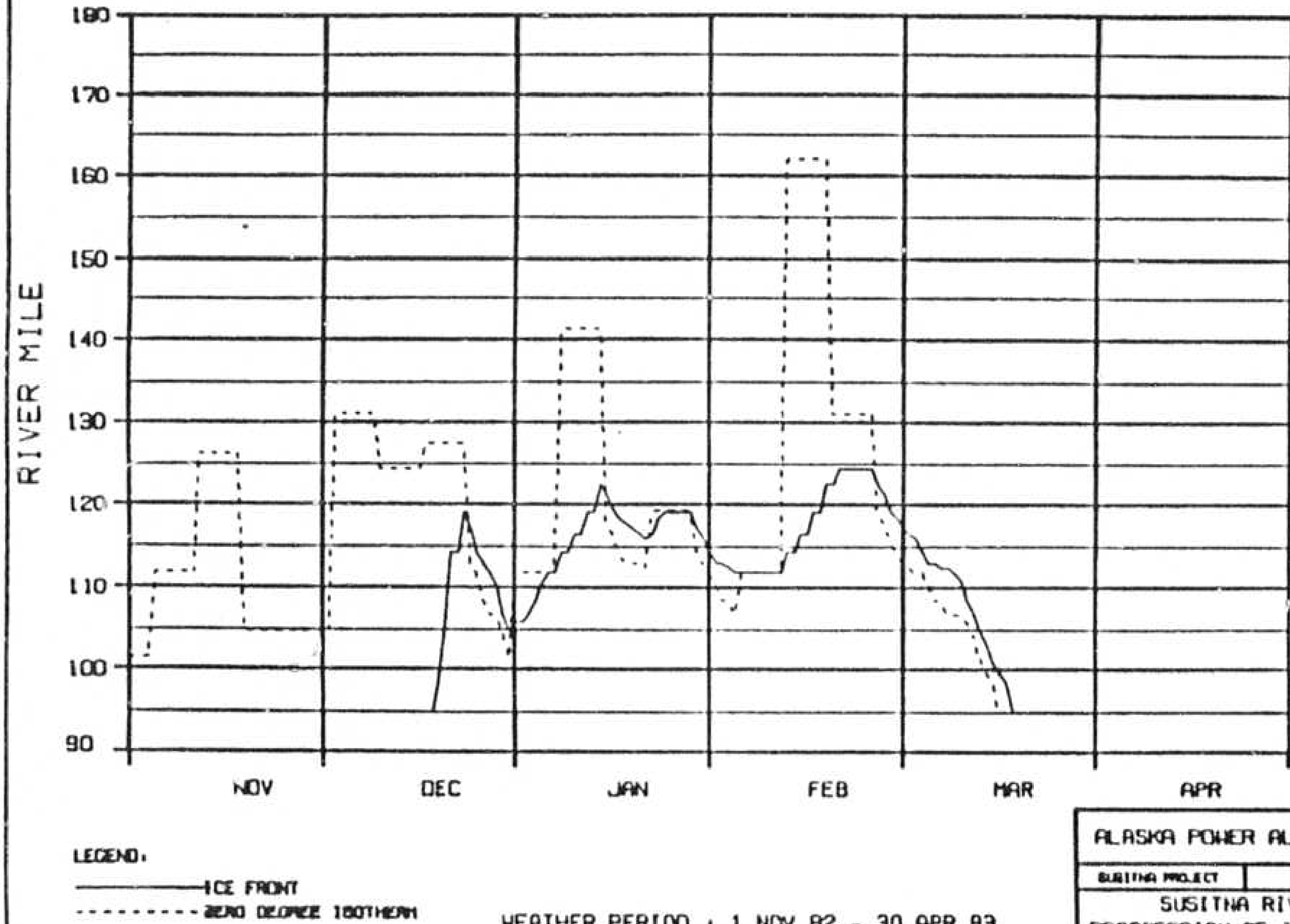
SUSITNA PROJECT

SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM

HARZA-EBASCO JOINT VENTURE

1098.142

OPTION2



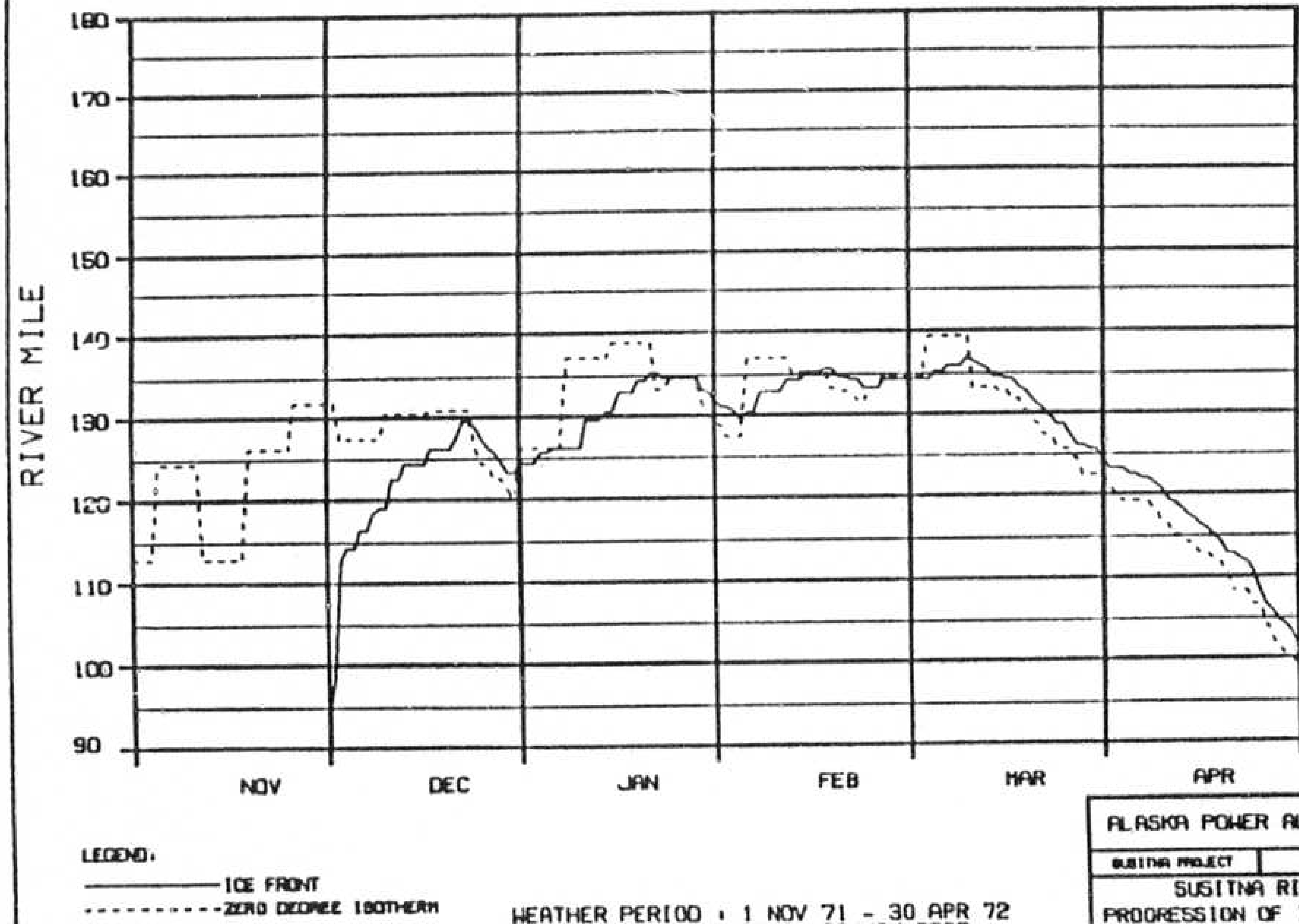
WEATHER PERIOD : 1 NOV 82 - 30 APR 83
ENERGY DEMAND : WATANA 2001
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 8201CNA

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE
1000.142

OPTION?

APPENDIX F

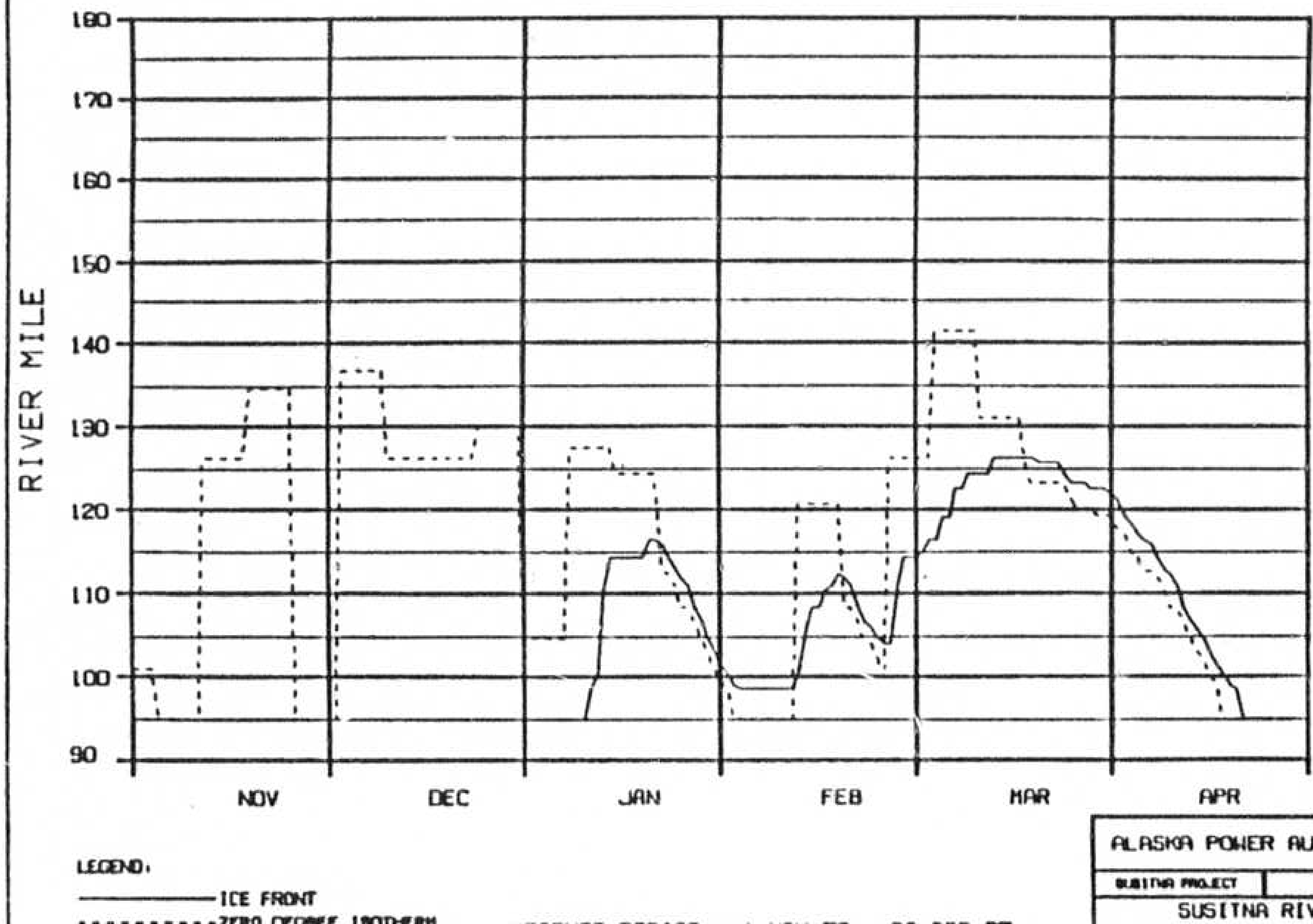
ICECAL simulations of ice front progression, Watana and Devil Canyon, 2002, inflow matching releases, 1971-72, 1976-77, 1981-82, 1982-83 (Harza-Ebasco Susitna Joint Venture, 1984a)



WEATHER PERIOD : 1 NOV 71 - 30 APR 72
ENERGY DEMAND : DEVIL CANYON 2002
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 7102CNA

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER PROGRESSION OF ICE FRONT & ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE

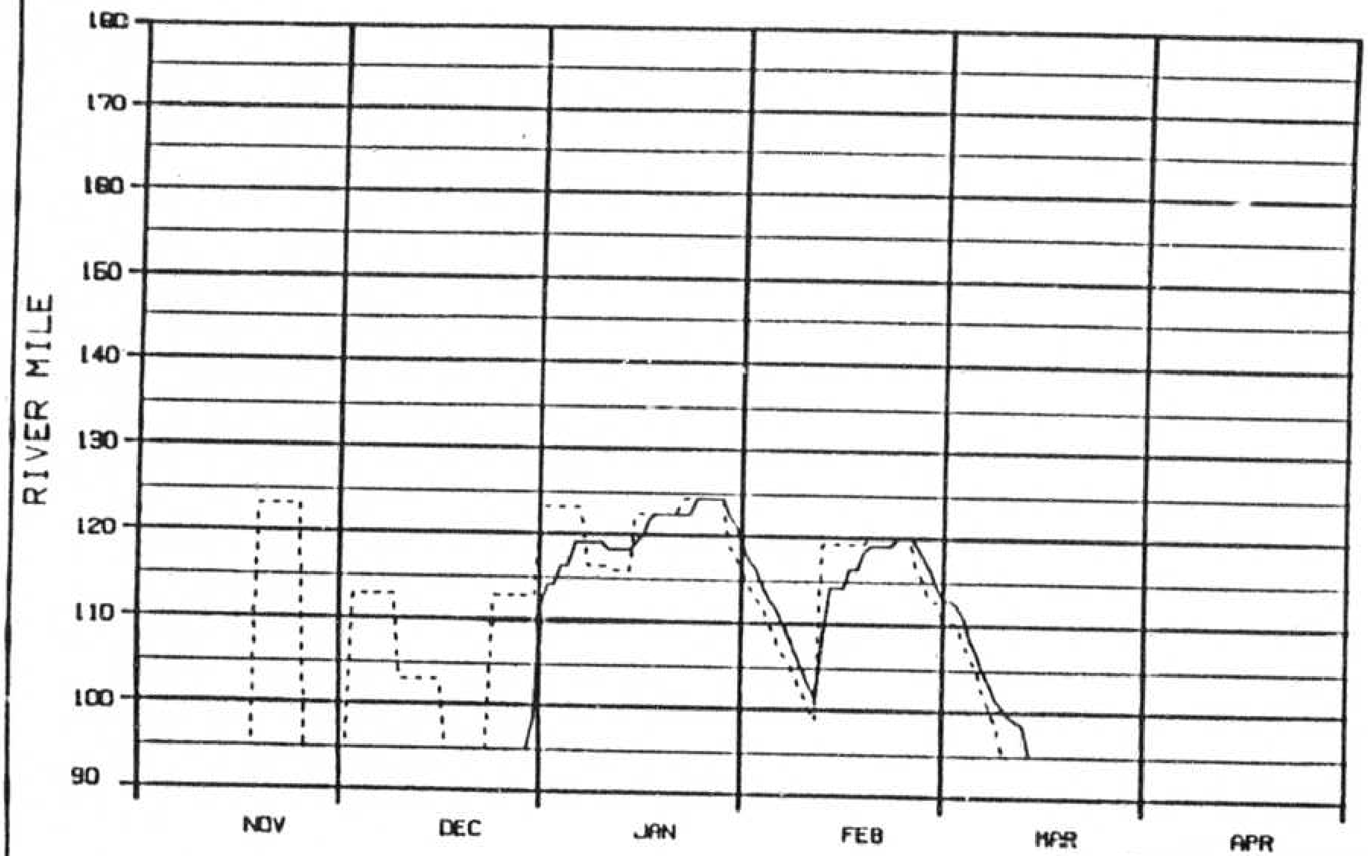
OPTION?



WEATHER PERIOD : 1 NOV 76 - 30 APR 77
ENERGY DEMAND : DEVIL CANYON 2002
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 7602CNA

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE
1668.142

OPTION?



LEGEND:

——— ICE FRONT

- - - - - ZERO DEGREE ISOTHERM

WEATHER PERIOD : 1 NOV 81 - 30 APR 82
ENERGY DEMAND : DEVIL CANYON 2002
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 8102CNA

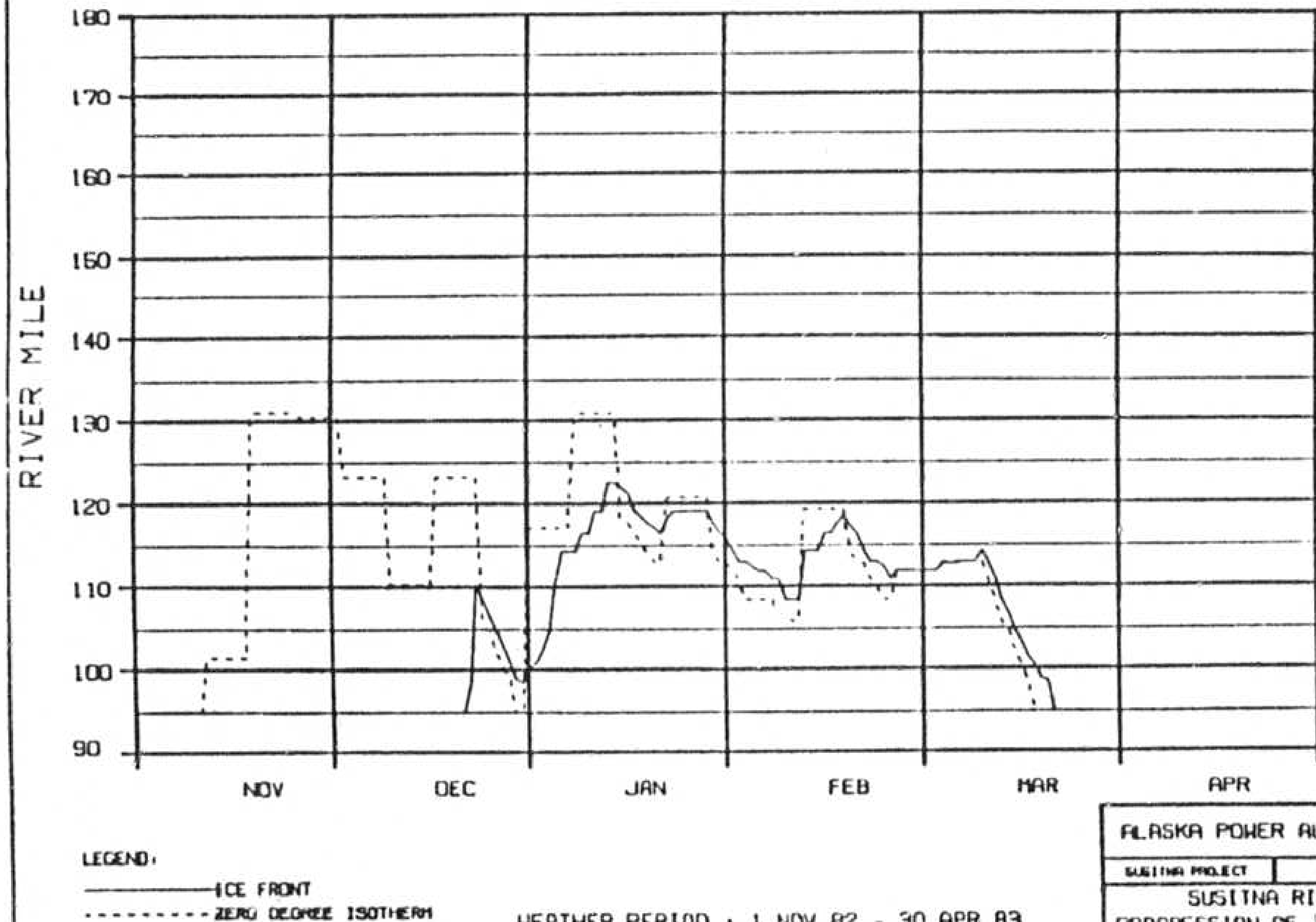
ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM

HARZA-EBASCO JOINT VENTURE

OPTION?



WEATHER PERIOD : 1 NOV 82 - 30 APR 83
ENERGY DEMAND : DEVIL CANYON 2002
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 8202CNA

OPTION7OPTION7

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER
PROGRESSION OF ICE FRONT & ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE

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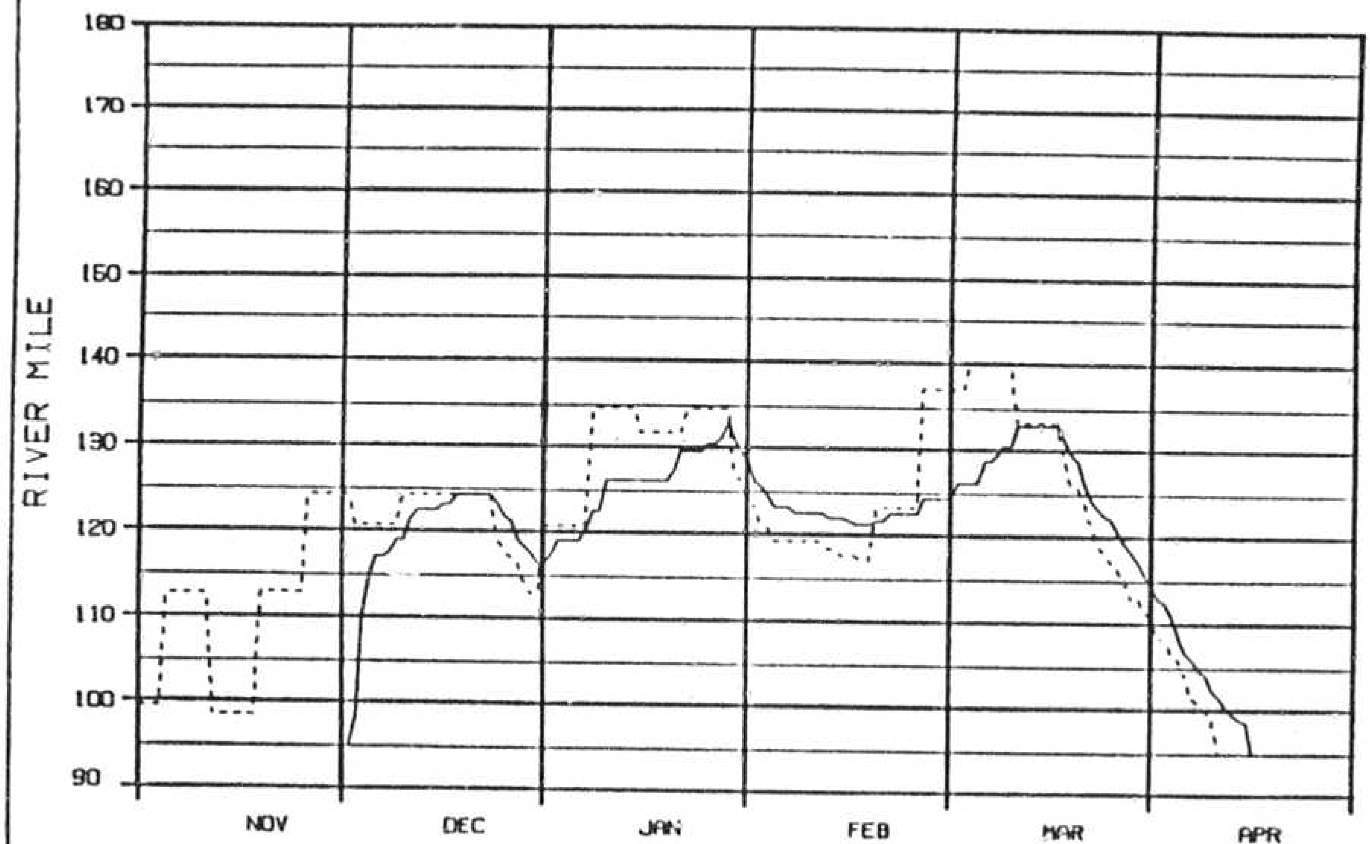
APPENDIX G

ICECAL simulations of ice front progression, Watana and Devil Canyon, 2020, inflow matching releases, 1971-72, 1982-83 (Harza-Ebasco Susitna Joint Venture, 1984a)



LEGEND:

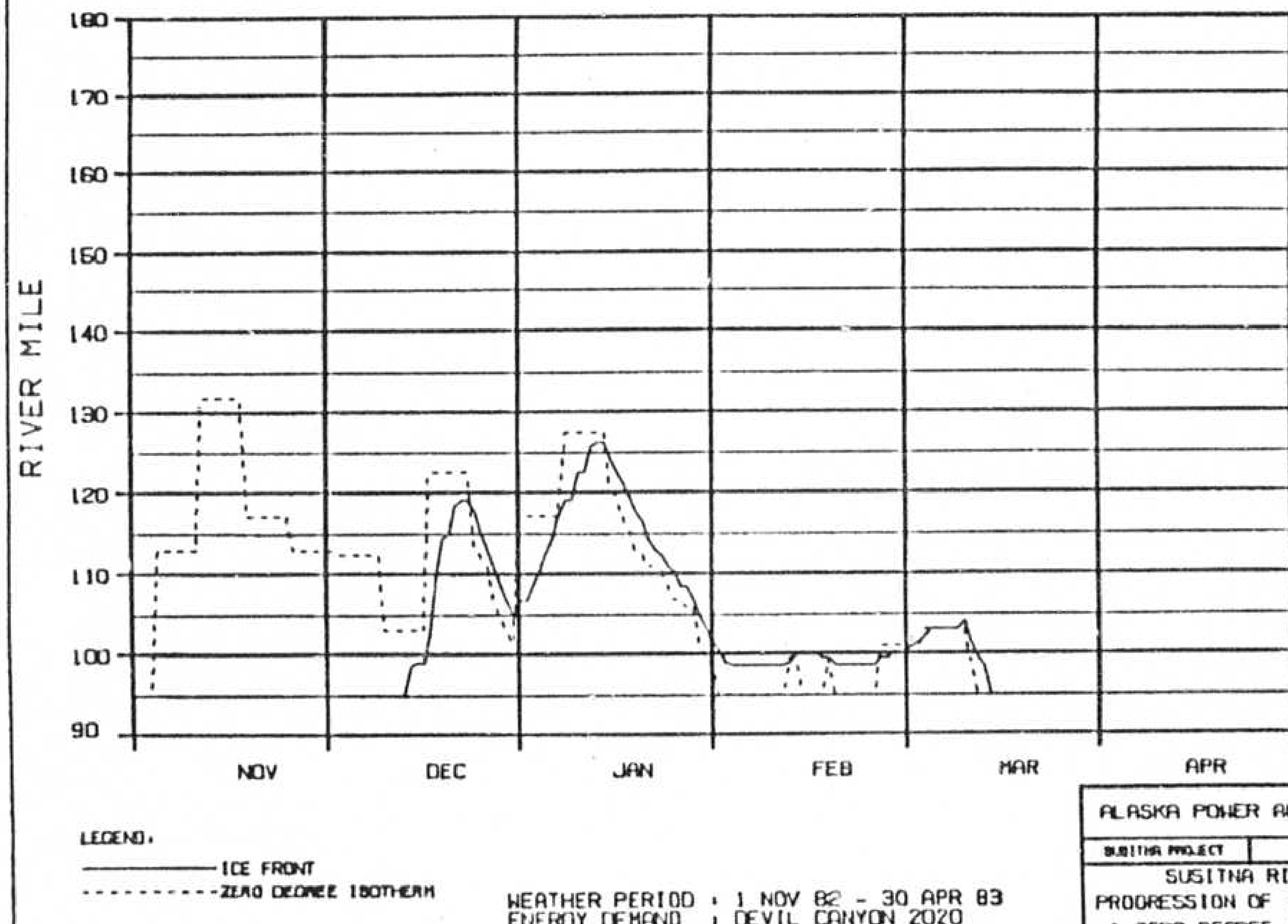
——— ICE FRONT

- - - - ZERO DEGREE ISOTHERM

WEATHER PERIOD : 1 NOV 71 - 30 APR 72
ENERGY DEMAND : DEVIL CANYON 2020
FLOW CASE : C TEMP RULE : NATURAL
REFERENCE RUN NO. : 7120CNA

ALASKA POWER AUTHORITY
SUSITNA PROJECT
SUSITNA RIVER PROGRESSION OF ICE FRONT & ZERO DEGREE ISOTHERM
HARZA-EBASCO JOINT VENTURE
[illegible] / [illegible] / [illegible]

OPTION?



WEATHER PERIOD : 1 NOV 82 - 30 APR 83
ENERGY DEMAND : DEVIL CANYON 2020
FLOW CASE : C TEMP. RULE : NATURAL
REFERENCE RUN NO. : 8220CNA

ALASKA POWER AUTHORITY

SUSITNA PROJECT

SUSITNA RIVER
PROGRESSION OF ICE FRONT
& ZERO DEGREE ISOTHERM

HARZA-EBASCO JOINT VENTURE

OPTION?