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SUSITNA HYDROELECTRIC PROJECT

FEDERAL ENERGY REGULATORY COMMISSION
PROJECT No. 7114

INSTREAM ICE
CALIBRATION OF COMPUTER MODEL

FINAL REPORT

HARZA-EBASCO
SUSITNA JOINT VENTURE

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INSTREAM ICE
CALIBRATION OF COMPUTER MODEL

Report by

Harza-Ebasco Susitna Joint Venture

Prepared for

Alaska Power Authority

Final Report
April 1984

NOTICE

ANY QUESTIONS OR COMMENTS CONCERNING
THIS REPORT SHOULD BE DIRECTED TO
THE ALASKA POWER AUTHORITY
SUSITNA PROJECT OFFICE

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1.0 INTRODUCTION

As a part of the on-going environmental studies for the project, we have completed the calibration phase of the computer modelling studies for instream ice. This report deals with the reach from the confluence at Talkeetna to Gold Creek, as shown on Exhbit 1. This reach includes a number of the more important sloughs, and is expected to experience a greater change in winter regime than the Lower River area. Data has been collected in this reach since 1980 and includes the most complete data available on the river for ice modelling purposes.

The calibration studies have been restricted to freeze-up since we expect that this will lead to the most significant staging with project, and since break-up modelling is generally considered beyond present state-of-the-art. The break-up of an ice cover depends on complex, highly variable and unpredictable structural characteristics of ice. In addition, the ice jams resulting from break-up can result in unsteady flow which is not included in our present model.

We believe that this limitation of the ice model is acceptable because:

1. With project, break-up in the middle reach will be more gradual and controlled compared to pre-project because power flows can be regulated during the break-up period.

2. Maximum ice jam stages can be estimated with present analytical techniques if the likely locations of jams are known.

1.1 ENVIRONMENTAL WORK PLAN

The sequence of enviromental studies in progress for the river is shown on Exhibit 2. According to this exhibit, the critical input data for the instream ice model are the discharge hydrograph and temperature time history for releases at the dam(s). The instream temperature model (AEIDC) will also be required for final instream ice runs. However, for preliminary runs, the instream ice model will also include computations for ice-free temperature profiles for convenience.

2.0 DESCRIPTION OF MODEL

The basic program, ICECAL, has been developed by Darryl Calkins of the Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Corps of Engineers. The program documentation is included in Appendix A. Mr. Calkins provided assistance in installing the program on the H-E system and continues to provide advice on assessment of program output.

In summary, the program requires the following daily input data:

Upstream Boundary

- Water Discharge
- Water Temperature, or
- Frazil Ice Discharge

Within the Reach

- Channel Cross-sections
- Channel Roughness
- Air Temperature
- Wind Velocity

Downstream Boundary

- Stage Hydrograph
- Water Discharge

For the first day of the simulation period, the program computes the ice-free water surface profile and temperature profile. During each day, including the first day, the model determines the total ice produced and determines advance of the leading ice edge from a pre-determined location and thickening of the cover. In addition, lateral ice growth is determined at various open-water sections in accordance with calibrated coefficients. After the ice front advances from one cross-section to the next upstream section, or if the water discharge changes from one day to the next, the water surface profile is re-computed.

The ice production in the reach is computed based on open-water heat exchange using a linear approximation of the heat transfer coefficient with wind velocity as the major independent variable. The ice cover starts at a pre-determined location at the downstream boundary. The advance of the leading edge is based on water velocity at the front and relative thickness of ice to water depth.

The critical parameters which must come from the ice hydraulics calibration are as follow:

1. Ice-free heat transfer coefficients.

2. Cohesion coefficient for frazil slush accumulation.

3. Critical value of Froude Number for progression of the leading edge.

4. Critical velocity for erosion/deposition under ice cover.

5. Lateral ice growth coefficients.

The model uses the following fundamental equations for the ice processes, based on references 7-11:

1. Ice inflow at upstream boundary:

$$Q_i = C_i \, V \, B \, t \, (1-e)$$

where

Q_i = ice discharge, m^3/s.

C_i = surface ice concentration, %.

V = mean velocity, (m/s).

B = ice-free water width, (m).

t = mean thickness of the floating slush (m).

e = porosity of the floating slush.

2. Ice production in open water:

$$Q_i = \frac{h_i \, A \, T_a}{\rho \lambda}$$

where

Q_i = ice discharge, m^3/s.

h_i = ice production heat transfer coefficient, W/m^2-°C.

A = ice-free water surface area, m^2.

T_a = air temperature below 0°C.

ρ = density of water, 1000 kg/m^3.

λ = heat of fusion, 3.34×10^5 N-m/kg.

3. Lateral ice growth:

$$L_i = K\,V^N$$

where

L_i = ice growth in m/day.

K = coefficient based on observation.

V = mean flow velocity, m/sec.

N = exponent based on observation.

4. Criterion for progression of leading edge:

$$F = \frac{V}{\sqrt{2gH}} \leq Fc$$

where

F = computed modified Froude Number.

Fc = critical Froude Number.

V = mean flow velocity, m/sec.

H = hydraulic depth, m.

If $F > F_c$, leading edge cannot advance and ice is drawn under cover for possible deposition downstream.

5. Progression by Hydraulic Thickening:

$$V = \sqrt{2g\ t_h\ (1-\rho'/\rho)}\quad (1-t_h/H)$$

where

V = mean flow velocity just upstream of the leading edge, m/sec.

H = hydraulic depth just upstream of the leading edge, m.

t_h = stable ice thickness required for progression of front, m.

ρ', ρ = density of ice cover (assumed 920 kg/m^3), water (1000 kg/m^3).

6. Progression by Mechanical Thickening (shoving):

$$\frac{B\ Vu^2}{\mu\ C^2 H_u^{\ 2}} \left[1 + \frac{\rho'\ t_s}{\rho\ R}\right] = \frac{2\alpha t_s}{\rho g \mu H_u^{\ 2}} + \frac{\rho'}{\rho}\left[1 - \frac{\rho'}{\rho}\right]\frac{t_s^{\ 2}}{H_u^{\ 2}}$$

where

V_u = mean velocity under ice cover, m/sec.

H_u = mean hydraulic depth under ice cover, m.

B = channel width, m.

μ = coefficient of internal friction for ice cover, 1.28.

C = Chezy coefficient of friction, based on average of bed friction and n_i = 0.050.

$\rho'\rho$ = density of ice cover, (same as 5, above).

R = hydraulic radius under ice cover, m.

α = cohesion of ice cover, N/m^2.

t_s = stable ice thickness required for shoving stability, m.

7. Underice Deposition:

V_u-c = critical velocity beneath ice cover for deposition of ice under cover when front cannot advance, m/sec.

Temp.	Vu-c (m/s)
0° to -7°C	Vu-c
-7° to -18°C	Vu-c/0.95
-18° to -30°C	Vu-c/0.90

8. Solid Ice Growth:

$$\Delta t_i = T_a \times 86{,}400/(\rho' + \lambda e)/(t_i^{-1}/k_i + 1/H_a)$$

where

t_i^{-1} = previous day ice thickness, m.

Δt_i = incremental ice thickness growth per day, m.

T_a = reach ave. air temp below 0°C.

K_i = thermal conductivity, 2.23 W/m- °C.

H_a = surface heat exchange coef, W/m^2-°C.

e = porosity of ice cover (assumed 0.3).

λ = heat of fusion of ice, 3.34 N-m/kg.

ρ' = density of ice, 920 kg/m^3.

3.0 DATA AVAILABLE FOR CALIBRATION

The data available for model calibration has been accumulated primarily by R&M Consultants over the past four years. This information is available in R&M reports (See References 1-3, and 6). In addition, channel cross-sections from Talkeetna to Watana, and ice-free stage-discharge observations are available in R&M's report on "Hydraulic and Ice Studies," (Reference 4).

The information included in these reports is as follows:

1. Descriptions of the ice processes,
2. Photos of river ice phenomena,
3. Weather data,
4. Discharge data,
5. Surface ice concentration,
6. Water surface profiles,
7. Ice thickness,
8. Leading edge progression,
9. Ice jam locations and effects,
10. Channel cross-sections,
11. Ice-free stage-discharge ratings.

Based on the above information, the freeze-up for 1982-83 and 1983-84 were selected for calibration of the freeze-up portion of the model, since this represents the most useful information required for calibration. While this data is not complete, the following information in the reach from Talkeetna to Gold Creek was sufficient for preliminary calibration:

1. Progression of the leading edge,

2. Water surface profiles and maximum ice elevations,

3. Ice thickness after formation of cover,

4. Estimate of surface ice inflow at Gold Creek.

4.0 CALIBRATION OF ICE-FREE TEMPERATURE PROFILE

The ice-free temperature profile is not important for the calibration of the freeze-up portion of the model, since the simulation period begins after the river has reached 0°C, and air temperatures are generally below 0°C. Therefore, no attempt has been made to calibrate this portion of the model.

However, for post-project production runs, discharges from the dam(s) will be above freezing and it is very important to determine the location of the 0°C point in order to estimate the ice production and limit of ice cover.

Therefore for post-project operation, we plan to use results of the AEIDC temperature profile model, SNTEMP, which has been calibrated to the Susitna. Until SNTEMP results are available, however, we will use the temperature profile as computed by ICECAL, realizing that adjustments may be necessary when the final SNTEMP data is available.

5.0 CALIBRATION OF ICE-FREE WATER SURFACE PROFILE

This portion of the model must be calibrated since velocity and depth are crucial to the development of an ice cover and the mechanics of the ice front advance.

Ice-free stage data is available on the river for Gold Creek discharges of 3000 cfs, 9700 cfs, and higher flows. Since the normal pre-project winter flow during freeze-up is approximately 3000 cfs, and with-project freeze-up flows are expected to be approximately 10,000 cfs, both discharges were used for calibration purposes. Tables 1 and 2 show the comparison of computed and observed water surface elevations. All computed water surface elevations are within 0.5 foot of the observed values, which is considered acceptable for the ice model. Exhibit 3 includes profiles showing the same information. Tables 1 and 2 also show the water surface elevations computed with the HEC-2 model, as reported in reference 5. These values demonstrate that the ice-free surface profile computation in ICECAL compares favorably with HEC-2, which is the standard model for open-water profiles.

The resulting Manning's "n" values for the river bed at the various cross-sections are shown on Table 3 and range from 0.022 to 0.065, with contraction and expansion losses of 0.1 and 0.3, respectively. This is considered to be a normal range of "n" values for a river such as the Susitna. These calibrated roughness factors were then used for the river bed for all succeeding freeze-up simulations.

6.0 CALIBRATION OF FREEZE-UP PROCESSES

The simulation of freeze-up for 1982-83 is based primarily on data given in the R&M 1982-83 Ice Observation Report. The information taken from that report is as follows:

1. Table 4 contained water discharge, mean daily air temperature, and ice concentration at the upstream model boundary. (Gold Creek). Since wind velocity was not available at Gold Creek, the record at Devil Canyon was used, shown in Table 5. The ice concentration was converted to ice discharge based on estimated thickness, porosity, and flow velocity.

2. Table 6 provided the downstream boundary conditions (Talkeetna), mean daily air temperature and wind velocity.

3. Table 7 listed the river stage after the ice front passed various locations in the reach between Talkeetna and Gold Creek.

4. Table 8 gave the ice thickness following freeze-up at Gold Creek, Curry, and Talkeetna (LRX-3).

5. Exhibit 4 in this report was used to determine the location of the leading edge with time.

Results of final simulation trials are shown on Exhibit 5, and 7 and Tables 9 and 10. Exhibit 5 shows a profile of the maximum water surface elevations computed after the ice front has passed the various sections in the reach, along with corresponding observed ice elevations at locations reported in Table 7. Table 9 shows a comparison of the computed and observed maximum water/ice elevations at the observation locations. Exhibit 5 also shows the computed slush ice thickness in the reach, after the cover has progressed to Gold Creek, with observed ice thickness included for comparison. It should be pointed out here that a quantitative comparison of ice thickness is difficult. Exhibit 6 shows a typical ice-covered cross section versus the model approximation of the same section. The actual flow distribution and ice deposition pattern are complex 3-dimensional processes, whereas the model computation is one-dimensional. The observed ice thicknesses, based on 1-3 corings typically, cannot be expected to define an average ice thickness which would be indicative of the ice volume stored, which is ultimately our goal in the modelling effort. However, based on our studies to date, we believe the computed ice thicknesses are indications of the ice volumes, and are probably somewhat conservative (high). Exhibit 7 shows the computed location of the ice front with time, compared to the observed location. The calibration coefficients resulting from the final simulation for the 1982 freeze-up are shown in Table 10. These values are within normal tolerances, as indicated.

The simulation of freeze-up for 1983-84 was based on data provided by R&M in their Preliminary Ice Report for 1983-84. The information used is as follows:

1. Table 11 was used for water discharge at Gold Creek.

2. Tables 12 and 13 were used for air temperature and wind velocity at Talkeetna and Sherman thru December 1983. For the first week of January, Gold Creek temperature and Talkeetna wind velocity were used for the entire reach, since no other data was available at that time.

3. Table 14 was used to estimate ice inflow at Gold Creek. A porosity value of 0.6 was assumed for this computation.

4. Table 15 was used to define the maximum water/ice profile during the progression of the leading edge from Talkeetna to Gold Creek.

5. Tables 16 and 17 were used to define the observed ice thicknesses at selected locations following freeze-up of the Talkeetna-Gold Creek reach, in early January and late January, respectively.

6. Table 18 provides the location of the observed leading edge(s) with time from Cook Inlet to Gold Creek.

Results of final simulations are shown on Exhibits 8 and 9, and Tables 19 and 20. Exhibit 8 shows the computed maximum water/ice profile and computed maximum ice thicknesses, along with corresponding observed values. Table 19 shows the comparison of computed and observed maximum water/ice elevations at the observation locations. Exhibit 9 shows the computed leading edge progression versus time for various assumed values for the critical Froude number at the leading edge, along with the observed leading edge progression. It should be noted that in the 1983 freeze-up, two intermediate ice bridges formed in the reach. The present model does not consider intermediate bridges and therefore does not simulate the multiple cover progressions as observed. The simulations varied the critical Froude criteria in order to match the range of progression rates observed. As shown on Table 20, we have selected run 84-15, with a critical Froude number of 0.096, as representative of an average progression rate for the 1983 freeze-up. Table 20 shows the other final calibration coefficients for the 1982 and 1983 freeze-ups. All of the factors are common except F_c, which was slightly different for the two years. For with-project simulations, we will use $F_c = 0.095$, the average of these two simulations.

7.0 DISCUSSION OF RESULTS

Based on the results of the simulations to date, we conclude the following:

1. The ice-free water surface profile calibration yields computed values within 0.5 foot of observed values for 3000 cfs and 9700 cfs. This is considered acceptable for ice modelling purposes.

2. The maximum water/ice elevations computed and observed for the 1982 and 1983 freeze-ups are compared in Tables 9 and 19 respectively. In general, the differences are within $\pm$ 2 feet which is the order of accuracy which could be expected in modelling the phenomena. However, there are some locations where the disagreement is significantly greater than this. For example, at RM 127.0 and 130.9 in 1982, and RM 113.0, 123.3, and 128.7 in 1983, the differences range from + 3 to over + 8 ft. In all cases when these large differences occur, the computed values are higher than the observed values. One possible explanation for this is that the higher levels cannot actually obtain in the field because of overflow into sloughs which are not included in the model. In addition to this, the model may be overpredicting the stages, particularly in the 1983 simulation, because the model does not consider intermediate bridges, which can interrupt ice supply to downstream reaches. It appears then than the model will produce conservative results for with-project operation, in that overtopping of berms will be indicated when they occur, but actual stages will likely be less than the model prediction.

3. Ice thickness computed and observed following the 1982 freeze-up agree very well. The field observations were made in February when discharges and stages had decreased, and some

solid ice had developed. However, the total ice thickness is very similar to the computed slush thickness.

The thickness observations following the 1983 freeze-up agree reasonably well with model simulations except at LRX-24 and LRX-27. Here the observed thicknesses are significantly higher than computed. However, it should be pointed out again that the observations are limited to 2 or 3 measurements in a 400 ft. ± cross section and therefore cannot be expected to completely define the ice in the section. The only other explanation for the discrepancy is the intermediate ice bridge which formed at LRX-24 and led to the second leading edge progression. This may have led to the "hanging dam" observed in the reach from LRX-24 to LRX-27. The model simulation did not assume the intermediate bridge and therefore the leading edge moved thru this reach at higher stage with less deposition of ice.

4. The computed leading edge progression compares reasonably well with the observed rates for the 1982 freeze-up as shown on Exhibit 7 except for the observed "stall" near Gold Creek. The observed progression from RM 134 to 136.5 took over one month, while the computed advance in this area took only about one week. This indicates the model simulation will be conservative in that it will probably show a somewhat higher advance rate that actual. The 1983 freeze-up advance rates are shown on Exhibit 9. This comparison was complicated by the observed development of intermediate bridges which were not modelled. The model was run with varying values of critical Froude number, F_c, such that the limits of observed rates were simulated. Run 84-15 used an intermediate value of F_c, 0.096, and produced a progression rate which was a reasonable approximation of the observed, without using an intermediate bridge. Again as in

the 1982 simulation, we expect model predictions to be conservative with high predictions of stage during progression of the leading edge.

8.0 FURTHER STUDIES

These studies conclude the calibration portion of the modelling effort. We will now extend the model to with-project studies which will include the following:

1. With Watana only.

2. With Watana and Devil Canyon.

3. Wet, Dry, Average River Flow.

4. Hot, Cold, Warm Winters.

5. Various Power Demand Schedules.

6. Case C Environmental Flow Release Schedule.

The studies will include the reach from the dam(s) to Talkeetna, for the period from November thru April. An estimate will be made of the period required to fill the lower river with ice, which will permit ice progression up the middle reach. We will use a conservative estimate for this period in order that we obtain a conservative estimate of ice cover development in the middle reach. A future report will deal with results of these studies.

REFERENCES

REFERENCES

1. R&M Consultants, Susitna Hydroelectric Project, Ice Observations, 1980-81, August 1981.

2. R&M Consultants, Susitna Hydroelectric Project, Ice Observations Report, Winter 1981-82, December 1982.

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6. R&M Consultants, Susitna Hydroelectric Project, Preliminary Susitna River Ice Report, 1983-84, February 1984.

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9. Ashton, George D., "River Ice", Annual Review of Fluid Mechanics, 1978.

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11. Ashton, George D., "Suppression of River Ice by Thermal Effluents", U.S. Army CRREL Report 79-30, December 1979.

TABLES

Table 1
ICE-FREE WATER SURFACE PROFILE
Q = 3000 cfs at Gold Creek

Section No.	River Mile	Harza HEC-2[1]	R&M Observed[2]	Harza Instream Ice Model
LRX-3	98.59	339.7	340.2	340.2
LRX-4	99.58	347.1	--	346.8
LRX-9	103.22	374.9	375.1	374.6
LRX-24	120.66	519.2	519.1	518.9
LRX-28	124.41	551.6	--	551.6
LRX-35	130.87	615.0	614.7	614.5
LRX-45	136.68	681.1	681.4	681.0
LRX-62	148.94	831.4	831.9	831.4
LRX-68	150.19	847.3	--	847.1

References:

1. "Water Surface Profiles and Discharge Rating Curves," Harza-Ebasco, October, 1983. Table 5.

2. R&M Correspondence No. 052306, September 11, 1981.

Table 2
ICE-FREE WATER SURFACE PROFILES
Q = 9700 cfs at Gold Creek

Section No.	River Mile	Harza HEC-2 [1]	R&M Observed [2]	Harza River Ice Model
LRX-3	98.59	344.1	--	344.0
LRX-4	99.58	348.6	348.1	348.6
LRX-9	103.22	378.0	378.4	378.9
LRX-24	120.66	521.2	521.3	521.8
LRX-28	124.41	554.4	553.8	553.8
LRX-35	130.87	617.4	617.3	617.4
LRX-45	136.68	684.0	684.1	684.5
LRX-62	148.94	835.4	835.4	835.9
LRX-68	150.19	851.0	851.4	851.4

References:

1. "Water Surface Profiles and Discharge Rating Curves," Harza-Ebasco, October, 1983. Table 5.

2. "Hydraulic and Ice Studies," R&M Consultants, March 1982, Table 4.18.

Ice-free Calibrated "n" Values

CROSS SECTION DATA

STATION	PTS	Q-FACT	BED-N	ICE-N
98.57	4	1.03	0.005	0.005
98.58	4	1.03	0.005	0.005
98.59	18	1.03	0.022	0.050
98.84	13	1.03	0.022	0.050
99.09	13	1.03	0.022	0.050
99.34	13	1.03	0.022	0.050
99.58	18	1.03	0.022	0.050
100.38	15	1.03	0.040	0.050
100.98	15	1.03	0.040	0.050
101.52	14	1.03	0.062	0.050
102.38	11	1.03	0.062	0.050
103.22	18	1.03	0.062	0.050
104.75	14	1.03	0.055	0.050
106.66	16	1.03	0.055	0.050
108.41	14	1.03	0.055	0.050
110.38	17	1.03	0.055	0.050
110.89	16	1.03	0.055	0.050
111.83	15	1.03	0.045	0.050
112.34	17	1.03	0.040	0.050
112.69	16	1.03	0.040	0.050
113.02	18	1.03	0.040	0.050
113.88	15	1.03	0.040	0.050
114.73	15	1.03	0.040	0.050
115.59	15	1.03	0.040	0.050
116.44	14	1.03	0.040	0.050
117.19	14	1.03	0.040	0.050
119.15	11	1.03	0.040	0.050
119.32	18	1.03	0.030	0.050
120.28	18	1.03	0.030	0.050
120.60	14	1.00	0.030	0.050
121.30	13	1.00	0.030	0.050
121.83	11	1.00	0.030	0.050
122.57	12	1.00	0.035	0.050
123.31	13	1.00	0.025	0.050
124.41	16	1.00	0.025	0.050
126.11	15	1.00	0.035	0.050
127.50	19	1.00	0.038	0.050
128.66	16	1.00	0.038	0.050
129.67	9	1.00	0.038	0.050
130.12	15	1.00	0.036	0.050
130.47	19	1.00	0.030	0.050
130.87	18	1.00	0.030	0.050

Contraction Loss = $0.1\ \Delta\ V^2/2g$

Expansion Loss = $0.3\ \Delta\ V^2/2g$

Ice-free Calibrated "n" Values

CROSS SECTION DATA

STATION	PTS	U-FACT	BED-N	ICE-N
131.19	19	1.00	0.043	0.050
131.80	14	1.00	0.036	0.050
132.90	14	1.00	0.036	0.050
133.33	11	1.00	0.036	0.050
134.26	14	1.00	0.036	0.050
134.72	13	1.00	0.036	0.050
135.30	13	1.00	0.036	0.050
135.72	17	1.00	0.040	0.050
135.99	20	1.00	0.040	0.050
136.40	14	1.00	0.045	0.050
136.60	12	1.00	0.045	0.050
136.90	12	1.00	0.045	0.050
137.15	14	1.00	0.040	0.050
137.41	10	1.00	0.040	0.050
138.23	15	1.00	0.040	0.050
138.46	11	1.00	0.045	0.050
138.69	14	0.98	0.050	0.050
139.44	16	0.98	0.050	0.050
140.15	14	0.98	0.050	0.050
140.83	14	0.98	0.055	0.050
141.49	14	0.98	0.055	0.050
142.13	15	0.98	0.055	0.050
142.34	15	0.98	0.050	0.050
143.10	14	0.98	0.050	0.050
144.83	14	0.98	0.050	0.050
147.56	14	0.98	0.055	0.050
148.73	13	0.98	0.063	0.050
148.94	12	0.94	0.063	0.050
149.15	13	0.94	0.055	0.050
149.35	11	0.94	0.055	0.050
149.48	12	0.94	0.055	0.050
149.51	9	0.94	0.055	0.050
149.81	13	0.94	0.065	0.050
150.19	12	0.94	0.065	0.050

Contraction Loss = $0.1 \Delta V^2/2g$

Expansion Loss = $0.3 \Delta V^2/2g$

s5/dd2

TABLE 4.4

SUSITNA RIVER AT GOLD CREEK
FREEZE-UP OBSERVATIONS ON THE MAINSTEM
November 1982

Date	Discharge (1) (cfs)	Gold Creek Mean Air Temperature (2) (°C)	Water Temperature (3) (°C)	Ice in Channel (4) (%)	Border Ice Thickness (ft)	Snow Depth (ft)	Weather
Nov. 1	4800	-2.2	0.00	70	0.9	1.5	Windy/Cloudy
2	4700	1.1	0.10	20	0.9	1.5	Snow
3	4600	-6.9	0.20	50	0.9	1.7	Cloudy
4	4500	-3.3	0.30	15	0.9	1.8	Cloudy
5	4400	-6.7	0.40	10	0.9	1.8	Cloudy
6	4300	-16.9	0.30	50	0.9	1.8	Sunny
7	4300	-17.8	0.20	55	1.0	1.8	Sunny
8	4200	-7.5	0.15	55	1.2	1.8	Snow
9	4100	-5.6	0.15	55	1.2	2.6	Cloudy
10	4000	-5.0	0.30	50	1.2	2.5	Cloudy
11	4000	-1.1	0.20	50	1.2	2.5	Snow
12	3900	-1.9	0.20	35	1.3	3.3	Cloudy
13	3800	-3.1	0.20	35	1.3	3.3	Sunny
14	3800	-1.9	0.20	30	1.5	3.4	Cloudy
15	3700	-12.2	-	40	1.5	3.4	Sunny
16	3600	-15.8	-	60	1.6	3.4	Sunny
17	3600	-15.0	-	70	1.6	3.4	Sunny
18	3500	-22.8	0.30	70	1.6	3.3	Sunny
19	3500	-25.7	0.20	75	1.7	3.3	Sunny
20	3400	-10.0	0.30	70	1.6	3.3	Snow
21	3400	-6.4	0.30	60	1.6	4.1	Snow
22	3300	-5.0	0.40	55	1.6	4.1	Sunny
23	3300	-4.4	0.30	45	1.3	4.0	Sunny
24	3200	-3.1	0.30	30	1.3	4.0	Sunny
25	3200	-2.8	0.50	40	1.2	3.9	Sunny
26	3100	-3.1	0.40	50	1.2	3.8	Sunny
27	3100	-8.3	0.40	50	1.2	3.8	Sunny
28	3100	-12.8	0.50	60	1.3	3.8	Sunny
29	3000	-9.7	0.30	60	1.3	3.8	Snow
30	3000	-8.9	0.20	40	1.3	3.8	Cloudy

1. Provisional data subject to revision by the U.S. Geological Survey, Water Resources Division, Anchorage, Alaska.
2. Average value of the days minimum and maximum temperature.
3. Based on one instantaneous measurement, usually taken at 9 a.m. daily.
4. Visual estimate based on one instantaneous observation, usually at 9 a.m. daily.

From R&M Report: Susitna River Ice Study, 1982-83

Table 4

TABLE 4.5

SUSITNA RIVER AT GOLD CREEK
FREEZE-UP OBSERVATIONS ON THE MAINSTEM
December 1982

Date	Discharge (1) (cfs)	Gold Creek Mean Air Temperature (2) (°C)	Water Temperature (3) (°C)	Ice in Channel (4) (%)	Border Ice Thickness (ft)	Snow Depth (ft)	Weather
Dec. 1	3000	-7.8	0.10	30	1.3	3.4	Cloudy
2	2900	-16.9	0.10	55	1.3	3.3	Cloudy
3	2900	-16.9	0.00	70	1.3	3.3	Windy/Sunny
4	2900	-10.0	0.10	75	1.3	3.3	Cloudy
5	2800	-8.3	0.20	75	1.3	3.3	Cloudy
6	2800	-1.7	0.20	65	1.3	3.0	Sunny
7	2800	2.5	0.30	40	1.3	3.0	Windy/Cloudy
8	2700	3.6	0.20	15	1.1	3.8	Snow
9	2700	-1.9	0.20	25	1.1	3.9	Cloudy
10	2700	-16.1	0.10	60	1.2	3.9	Sunny
11	2600	-6.1	0.00	40	1.3	3.9	Sunny
12	2600	-3.1	0.00	60	1.3	3.8	Cloudy
13	2600	-1.7	0.10	40	1.3	3.8	Sunny
14	2600	-5.0	0.20	25	1.2	3.8	Sunny
15	2600	-0.3	0.20	10	1.2	3.8	Sunny
16	2500	-3.3	0.10	10	-	3.7	Sunny
17	2500	-6.7	0:10	10	-	3.7	Sunny
18	2500	-10.6	0.00	50	-	3.7	Sunny
19	2400	-11.7	0.00	40	-	3.7	Sunny
20	2400	-7.2	0.00	40	-	3.7	Sunny
21	2400	-21.1	0.00	50	0.5	3.7	Sunny
22	2400	-23.1	0.00	50	0.5	3.7	Sunny
23	2400	-15.6	0.00	30	0.5	3.7	Sunny
24	2400	-11.9	0.00	30	0.5	3.6	Sunny
25	2300	-9.2	0.10	30	0.6	3.6	Sunny
26	2300	-5.6	0.10	30	0.6	3.5	Sunny
27	2400	-1.7	0.10	35	0.6	3.5	Snow
28	2400	0.6	-	-	-	5.0	Snow
29	2600	1.7	0.10	5	overflow	3.1	Rain
30	2800	-0.3	0.10	25	overflow	3.2	Rain
31	2900	-	0.10	5	1.3	3.2	Sunny

1. Provisional data subject to revision by the U.S. Geological Survey, Water Resources Division, Anchorage, Alaska.
2. Average value of the days minimum and maximum temperature.
3. Based on one instantaneous measurement usually taken at 9 a.m. daily.
4. Visual estimate based on one instantaneous observation, usually at 9 a.m. daily.

TABLE 4.6

SUSITNA RIVER AT GOLD CREEK
FREEZE-UP OBSERVATIONS ON THE MAINSTEM
January 1983

Date	Discharge (1) (cfs)	Gold Creek Mean Air Temperature (2) (°C)	Water Temperature (3) (°C)	Ice in Channel (4) (%)	Border Ice Thickness (ft)	Snow Depth (ft)	Weather
Jan. 1	2900	-2.8	0.00	8	1.3	3.2	Sunny
2	2800	-2.8	0.00	10	1.3	3.2	Sunny
3	2800	-3.9	0.00	30	1.3	3.5	Cloudy
4	2700	-5.0	0.00	60	1.4	3.5	Sunny
5	2700	-13.9	0.10	65	1.3	3.5	Sunny
6	2600	-19.1	0.10	65	1.3	3.5	Sunny
7	2500	-	0.00	70	1.3	3.5	Sunny
8	2500	-25.3	0.00	65	1.3	3.3	Sunny
9	2400	-22.2	0.00	60	1.4	3.3	Sunny
10	2400	-20.6	0.00	70	1.4	3.0	High Winds
11	2400	-16.7	0.00	85	1.4	3.0	Sunny
12	2300	-18.6	0.00	90	1.5	3.0	Sunny
13	2300	-16.7	0.00	90	1.5	3.0	Sunny
14	2200	-13.1	0.00	100	1.5	3.0	Sunny
*							

1. Provisional data subject to revision by the U.S. Geological Survey, Water Resources Division, Anchorage, Alaska.
2. Average value of the days minimum and maximum temperature.
3. Based on one instantaneous measurement, usually taken at 9 a.m. daily.
4. Visual estimate based on one instantaneous observation, usually at 9 a.m. daily.

* Channel frozen over.

From R&M Report: Susitna River Ice Study, 1982-83

R & M CONSULTANTS, INC.

SUSITNA HYDROELECTRIC PROJECT

MONTHLY SUMMARY FOR DEVIL CANYON WEATHER STATION
DATA TAKEN DURING November, 1982

DAY	MAX. TEMP. DEG C	MIN. TEMP. DEG C	MEAN TEMP. DEG C	RES. WIND DIR. DEG	RES. WIND SPD. M/S	AVG. WIND SPD. M/S	MAX. GUST DIR. DEG	MAX. GUST SPD. M/S	P'VAL DIR.	MEAN RH %	MEAN DP DEG C	PRECIP MM	DAY'S SOLAR ENERGY WH/SQM	DAY
1	.2	-9.1	-4.5	120	1.5	1.8	113	7.6	ESE	73	-7.5	****	653	1
2	-.6	-9.6	-5.1	120	.6	.9	085	3.2	S	75	-5.8	****	615	2
3	-2.7	-12.9	-7.8	116	.5	.9	070	3.8	ENE	70	-14.5	****	440	3
4	-.3	-5.5	-2.9	125	.9	1.1	170	6.3	ESE	75	-7.2	****	568	4
5	-2.6	-14.3	-8.5	135	.6	.8	132	2.5	SE	89	-8.7	****	605	5
6	-11.7	-18.1	-14.9	082	1.6	1.7	082	4.4	E	88	-16.8	****	423	6
7	-11.9	-18.5	-15.2	094	2.1	2.3	120	5.1	ESE	80	-18.1	****	423	7
8	-7.4	-13.6	-10.5	104	1.7	1.8	090	5.7	ESE	82	-11.3	****	340	8
9	-5.7	-8.5	-7.1	194	.1	.5	120	2.5	WSW	13	-38.1	****	310	9
10	-5.9	-13.7	-9.8	088	1.6	1.7	075	4.4	ESE	79	-10.3	****	305	10
11	-3.6	-6.5	-5.1	100	1.3	1.4	117	3.8	ESE	40	-24.3	****	318	11
12	-.5	-6.8	-3.7	130	1.1	1.4	137	4.4	SE	83	-4.3	****	493	12
13	-.7	-6.5	-3.6	121	1.1	1.3	115	4.4	ESE	88	-4.2	****	540	13
14	-3.2	-9.2	-6.2	076	.7	.9	089	3.8	ENE	20	-34.8	****	400	14
15	-6.7	-15.3	-11.0	093	1.6	1.6	095	4.4	E	71	-13.1	****	365	15
16	-13.0	-16.8	-14.9	087	2.0	2.0	088	4.4	E	92	-16.5	****	350	16
17	-15.7	-21.4	-18.6	088	2.3	2.4	097	5.1	E	87	-19.9	****	350	17
18	-15.9	-22.2	-19.1	092	2.2	2.3	090	4.4	E	78	-23.0	****	390	18
19	-15.2	-21.4	-18.3	115	2.8	2.8	115	7.0	ESE	63	-23.2	****	418	19
20	-10.1	-15.3	-12.7	115	2.9	3.0	123	6.3	ESE	79	-15.4	****	330	20
21	-5.8	-10.7	-8.3	093	1.5	1.7	125	4.4	ENE	85	-10.4	****	393	21
22	-4.6	-7.5	-6.1	103	1.6	1.8	119	5.1	ENE	80	-8.9	****	378	22
23	-.8	-6.0	-3.4	112	1.1	1.3	113	3.8	ESE	84	-4.4	****	348	23
24	-1.0	-4.7	-2.9	136	1.4	1.4	138	3.8	SE	91	-3.4	****	335	24
25	.5	-6.7	-3.1	138	1.4	1.5	159	3.8	SE	79	-5.2	****	358	25
26	-4.9	-7.3	-6.1	116	2.4	2.4	110	5.7	ESE	76	-9.7	****	358	26
27	-3.8	-11.8	-7.8	086	1.5	1.6	114	4.4	E	88	-8.5	****	363	27
28	-10.3	-14.7	-12.5	080	2.7	2.7	070	4.4	E	95	-13.8	****	368	28
29	-5.4	-10.1	-7.8	097	1.1	1.2	131	3.8	ENE	31	-15.5	****	258	29
30	-5.8	-12.0	-8.9	259	.4	.7	276	3.8	W	69	-12.2	****	273	30
MONTH	.5	-22.2	-8.9	104	1.4	1.6	113	7.6	ESE	77	-13.6	****	12060	

GUST VEL. AT MAX. GUST MINUS 2 INTERVALS 5.1
GUST VEL. AT MAX. GUST MINUS 1 INTERVAL 5.7
GUST VEL. AT MAX. GUST PLUS 1 INTERVAL 5.7
GUST VEL. AT MAX. GUST PLUS 2 INTERVALS 3.8

NOTE: RELATIVE HUMIDITY READINGS ARE UNRELIABLE WHEN WIND SPEEDS ARE LESS THAN ONE METER PER SECOND. SUCH READINGS HAVE NOT BEEN INCLUDED IN THE DAILY OR MONTHLY MEAN FOR RELATIVE HUMIDITY AND DEW POINT.

**** SEE NOTES AT THE BACK OF THIS REPORT ****

R & M CONSULTANTS, INC.

SUSITNA HYDROELECTRIC PROJECT

NTI .Y SUMMARY FOR DEVIL CANYON WEATHER STATION
TA TAKEN DURING December, 1982

DAY	MAX. TEMP. DEG C	MIN. TEMP. DEG C	MEAN TEMP. DEG C	RES. WIND DIR. DEG	RES. WIND SPD. M/S	AVG. WIND SPD. M/S	MAX. GUST DIR. DEG	MAX. GUST SPD. M/S	P'VAL DIR.	MEAN RH %	MEAN DP DEG C	PRECIP MM	DAY'S SOLAR ENERGY WH/SQM	DAY
1	-11.1	-19.9	-15.5	117	.5	.8	280	3.2	SE	92	-17.7	****	268	1
2	-15.1	-21.6	-18.4	121	1.5	1.7	133	5.1	SE	86	-20.1	****	283	2
3	-11.9	-21.4	-16.7	107	1.2	1.6	125	4.4	ESE	80	-18.9	****	293	3
4	-13.1	-18.7	-15.9	108	2.3	2.5	125	6.3	ESE	75	-20.5	****	343	4
5	-4.7	-13.1	-8.9	108	1.3	1.3	098	4.4	ESE	83	-10.3	****	305	5
6	-1.5	-7.5	-4.5	122	1.7	1.9	110	7.0	SE	80	-7.9	****	333	6
7	1.8	-1.9	-.1	107	2.3	2.4	107	9.5	ESE	81	-2.7	****	300	7
8	0.0	-1.8	-.9	134	.7	1.0	305	5.1	SE	11	-36.5	****	258	8
9	-.6	-14.4	-7.5	067	1.0	1.7	277	5.1	ENE	93	-9.1	****	270	9
10	-4.3	-19.1	-11.7	110	1.6	1.9	141	6.3	ESE	86	-13.3	****	273	10
11	-4.8	-8.7	-6.8	129	2.0	2.1	108	6.3	ESE	77	-10.1	****	295	11
12	-2.3	-6.8	-4.6	130	1.5	1.6	124	5.1	ESE	77	-7.2	****	310	12
13	-.1	-5.1	-2.6	145	1.3	1.5	109	6.3	SSE	83	-5.0	****	328	13
14	-.9	-9.0	-5.0	142	1.1	1.2	124	4.4	SE	83	-6.9	****	318	14
15	.3	-5.5	-2.6	130	1.5	1.7	102	5.7	ESE	73	-6.1	****	308	15.
16	-.3	-5.0	-2.7	134	1.4	1.5	115	4.4	SE	74	-6.7	****	315	16
17	-2.6	-10.5	-6.6	107	1.8	1.9	117	4.4	ESE	92	-7.5	****	303	17
18	-10.2	-13.9	-12.1	089	1.7	1.8	077	4.4	E	78	-13.0	****	308	18
19	-6.6	-13.0	-9.8	113	1.1	1.3	122	4.4	SE	80	-12.3	****	300	19
20	-5.6	-15.3	-10.5	124	1.6	1.8	123	5.1	ESE	74	-13.5	****	315	20
21	-15.0	-18.8	-16.9	083	2.6	2.6	071	5.1	E	91	-17.7	****	310	21
22	-16.0	-20.6	-18.3	075	2.6	2.7	072	5.7	ENE	87	-20.5	****	305	22
23	-11.8	-17.8	-14.8	099	1.8	2.0	101	4.4	ESE	75	-18.1	****	328	23
24	-8.0	-16.8	-12.4	105	2.3	2.5	119	5.7	ESE	80	-14.6	****	308	24
25	-7.8	-12.7	-10.3	102	2.1	2.3	116	6.3	ESE	81	-13.5	****	310	25
26	-.8	-8.7	-4.8	130	1.2	1.4	101	4.4	ESE	80	-8.4	****	300	26
27	.4	-2.9	-1.3	143	.8	1.0	098	3.2	SSE	70	-9.0	****	253	27
28	.9	-.4	.3	145	.3	.4	087	1.9	SE	10	-28.4	****	240	28
29	1.7	-.3	.7	179	.6	1.0	252	3.2	SE	11	-27.5	****	268	29
30	-.1	-9.3	-4.7	***	****	****	***	****	***	5	-37.6	****	253	30
31	-6.6	-10.4	-8.5	***	****	****	***	****	***	1	-46.0	****	250	31
MONTH	1.8	-21.6	-8.2	111	1.4	1.7	107	9.5	ESE	59	-15.7	****	9143	

GUST VEL. AT MAX. GUST MINUS 2 INTERVALS 7.0
GUST VEL. AT MAX. GUST MINUS 1 INTERVAL 6.3
GUST VEL. AT MAX. GUST PLUS 1 INTERVAL 9.5
GUST VEL. AT MAX. GUST PLUS 2 INTERVALS 8.9

TE- RELATIVE HUMIDITY READINGS ARE UNRELIABLE WHEN WIND SPEEDS ARE LESS THAN ONE METER PER SECOND. SUCH READINGS HAVE NOT BEEN INCLUDED IN THE DAILY OR MONTHLY MEAN FOR RELATIVE HUMIDITY AND DEW POINT.

** SEE NOTES AT THE BACK OF THIS REPORT ****

R & M CONSULTANTS, INC.

SUSITNA HYDROELECTRIC PROJECT

MONTHLY SUMMARY FOR DEVIL CANYON WEATHER STATION
DATA TAKEN DURING January, 1983

DAY	MAX. TEMP. DEG C	MIN. TEMP. DEG C	MEAN TEMP. DEG C	RES. WIND DIR. DEG	RES. WIND SPD. M/S	AVG. WIND SPD. M/S	MAX. GUST DIR. DEG	MAX. GUST SPD. M/S	P'VAL DIR.	MEAN RH %	MEAN DP DEG C	PRECIP MM	DAY'S SOLAR ENERGY WH/SQM	DAY
1	-1.1	-7.2	-4.2	***	****	****	***	****	***	82	-4.8	****	265	1
2	-1.4	-4.2	-2.8	114	2.1	2.1	101	5.1	ESE	78	-8.9	****	268	2
3	-4.2	-11.7	-8.0	115	.9	1.0	107	4.4	ESE	71	-11.4	****	253	3
4	-11.3	-21.0	-16.2	097	1.3	1.5	092	4.4	ENE	67	-18.6	****	278	4
5	-17.9	-24.9	-21.4	102	1.5	1.7	092	4.4	E	79	-25.0	****	278	5
6	-16.3	-21.1	-18.7	112	2.4	2.5	106	8.9	ESE	67	-22.5	****	290	6
7	-17.2	-25.4	-21.3	110	2.5	2.6	094	8.9	ESE	67	-25.4	****	340	7
8	-22.4	-27.0	-24.7	124	1.2	1.5	086	5.1	ESE	66	-29.1	****	363	8
9	-23.2	-26.4	-24.8	133	2.3	2.4	109	5.7	SE	57	-30.4	****	363	9
10	-20.2	-26.2	-23.2	123	2.2	2.3	121	5.7	SE	52	-29.7	****	365	10
11	-18.2	-31.6	-24.9	115	1.7	2.0	140	6.3	E	68	-32.1	****	311	11
12	*****	*****	*****	***	****	****	***	****	***	**	*****	****	******	12
13	*****	*****	*****	***	****	****	***	****	***	**	*****	****	******	13
14	*****	*****	*****	***	****	****	***	****	***	**	*****	****	******	14
15	*****	*****	*****	***	****	****	***	****	***	**	*****	****	******	15
16	*****	*****	*****	***	****	****	***	****	***	**	*****	****	******	16
17	*****	*****	*****	***	****	****	***	****	***	**	*****	****	******	17
18	*****	*****	*****	***	****	****	***	****	***	**	*****	****	******	18
19	-5.8	-7.4	-6.6	102	.6	.9	274	2.5	SE	50	-16.8	****	269	19
20	-5.8	-12.3	-9.1	119	1.5	1.6	111	5.1	ESE	82	-10.1	****	358	20
21	-4.4	-11.3	-7.9	128	1.6	1.7	124	4.4	SE	54	-14.4	****	428	21
22	-8.8	-18.0	-13.4	084	2.6	2.6	089	7.0	E	63	-19.2	****	418	22
23	1.6	-15.0	-6.7	120	2.3	2.7	131	8.3	ESE	37	-19.2	****	583	23
24	-3.8	-9.9	-6.9	108	2.3	2.6	100	9.5	ESE	33	-20.5	****	663	24
25	-5.8	-9.9	-7.9	104	2.2	2.3	102	8.3	ESE	42	-18.8	****	550	25
26	-1.9	-7.3	-4.6	115	1.8	2.0	123	7.6	ESE	59	-11.3	****	503	26
27	-5.5	-10.6	-8.1	099	2.2	2.6	113	6.3	ENE	74	-12.3	****	470	27
28	-3.9	-12.2	-8.1	109	1.9	2.1	137	4.4	ESE	61	-10.5	****	530	28
29	-5.4	-13.9	-9.7	091	2.1	2.3	124	5.1	E	81	-11.8	****	490	29
30	-4.0	-9.7	-6.9	121	1.7	1.9	104	6.3	ESE	82	-8.7	****	533	30
31	1.9	-5.3	-1.7	137	1.1	1.3	115	4.4	SE	73	-4.9	****	573	31
MONTH	1.9	-31.6	-12.0	112	1.8	1.5	100	9.5	ESE	65	-17.3	****	9735	

GUST VEL. AT MAX. GUST MINUS 2 INTERVALS 7.6
GUST VEL. AT MAX. GUST MINUS 1 INTERVAL 8.9
GUST VEL. AT MAX. GUST PLUS 1 INTERVAL 7.0
GUST VEL. AT MAX. GUST PLUS 2 INTERVALS 5.1

NOTE: RELATIVE HUMIDITY READINGS ARE UNRELIABLE WHEN WIND SPEEDS ARE LESS THA ONE METER PER SECOND. SUCH READINGS HAVE NOT BEEN INCLUDED IN THE DAIL OR MONTHLY MEAN FOR RELATIVE HUMIDITY AND DEW POINT.

**** SEE NOTES AT THE BACK OF THIS REPORT ****

Table 6

From R&M Report: Susitna River Ice Study, 1982-83

NOV 1982 TALKEETNA, ALASKA

NOV 1982 26528
TALKEETNA, ALASKA
TALKEETNA AIRPORT

ISSN 0198-0424

LOCAL CLIMATOLOGICAL DATA

Monthly Summary

WEA SVC CONTRACT MET OBST

LATITUDE 62° 18' N LONGITUDE 150° 06' W ELEVATION (GROUND) 345 FEET TIME ZONE ALASKAN WBAN #26528

DATE 1	TEMPERATURE °F: MAXIMUM 2	MINIMUM 3	AVERAGE 4	DEPARTURE FROM NORMAL 5	AVERAGE DEW POINT 6	DEGREE DAYS BASE 65°F: HEATING (SEASON BEGINS WITH JUL) 7A	COOLING (SEASON BEGINS WITH JAN) 7B	WEATHER TYPES (1 FOG, 2 HEAVY FOG, 3 THUNDERSTORM, 4 ICE PELLETS, 5 HAIL, 6 GLAZE, 7 DUSTSTORM, 8 SMOKE, HAZE, 9 BLOWING SNOW) 8	SNOW ICE PELLETS OR ICE ON GROUND AT 08AM INCHES 9	PRECIPITATION: WATER EQUIVALENT (INCHES) 10	SNOW, ICE PELLETS (INCHES) 11	AVERAGE STATION PRESSURE IN INCHES ELEV. 356 FEET ABOVE M.S.L. 12	WIND (M.P.H.): RESULTANT DIR. 13	RESULTANT SPEED 14	AVERAGE SPEED 15	FASTEST MILE: SPEED 16	DIRECTION 17	SUNSHINE: MINUTES 18	PERCENT OF TOTAL POSSIBLE 19	SKY COVER (TENTHS): SUNRISE TO SUNSET 20	MIDNIGHT TO MIDNIGHT 21	DATE 22
1	31	19	25	1	22	40	0		15	.12	2.1	29.29	01	8.7	9.6	16	01			10		1
2	33	14	24	7		41	0	1	16	.02	.4					6	28			10		2
3	21	7	14	-9	11	51	0		15	0	0	28.76	05	1.8	3.7	8	21			9		3
4	22	8	15	-7	12	50	0		14	T	T	28.80	33	.4	.4	4	33			10		4
5	23	4	14	-8	11	51	0	1	14	.03	.3	29.24	00	.0	.0	5	01			10	8	5
6	13	-8	3	-18	0	62	0		14	0	0	29.51	01	1.4	1.4	5	04			2	3	6
7	14	-11	2	-19	-6	63	0		14	0	0	29.67	02	3.8	4.2	13	35			0	1	7
8	21	14	18	-3	15	47	0	1	14	.29	4.4	29.28	01	7.0	9.6	16	36			10		8
9	26	18	22	2		43	0		17	0	0					9	02			10		9
10	27	18	23	3	17	42	0	1	17	.06	1.8	29.73	03	8.5	8.9	17	01			10		10
11	30	25	28	9	26	37	0	1 6	19	.20	3.8	29.78	02	7.0	7.3	16	36			10		11
12	33	27	30	11	24	35	0		20	.02	T	29.48	02	9.6	10.2	17	03			10	10	12
13	35	22	29	11	27	36	0		20	.03	.8	29.16	34	5.3	5.9	9	04			10	9	13
14	33	9	21	3	26	44	0	1	21	.07	1.3	29.28	01	.4	.4	6	31			10	8	14
15	15	-4	6	-11	1	59	0		22	0	0	29.47	05	2.7	3.6	6	36			0		15
16	16	-5	6	-11		59	0		22	0	0					7	35			0		16
17	21	3	12	-5	2	53	0		21	0	0	29.25	36	8.2	8.8	16	02			0		17
18	6	-21	-8*	-24	-16	73	0		21	0	0	29.41	04	3.6	3.7	12	34			0		18
19	11	-25*	-7	-23	-21	72	0		21	0	0	29.66	03	5.0	5.3	14	02			1	4	19
20	21	10	16	0	8	49	0	1	21	.03	.9	29.81	01	12.2	12.9	17	36			10	10	20
21	25	21	23	8	17	42	0	1	22	.01	.7	29.79	35	7.4	7.9	14	01			10	10	21
22	31	23	27	12	18	38	0		22	0	0	29.66	01	9.8	10.2	16	01			10		22
23	34	29	32	18		33	0		22	T	T					10	36			10		23
24	37*	28	33*	19	27	32	0		21	T	T	29.51	34	7.1	7.5	12	36			7		24
25	34	16	25	11	20	40	0		21	0	0	29.07	35	6.9	7.6	17	02			10		25
26	30	16	23	10	16	42	0		20	0	0	28.93	36	10.3	10.5	17	35			4	3	26
27	28	7	18	5	17	47	0		20	0	0	28.95	35	5.5	6.3	10	32			8	5	27
28	10	0	5	-8	-1	60	0		20	0	0	28.74	05	3.9	4.0	6	03			1	3	28
29	23	8	16	4	17	49	0		20	.57	7.4	28.65	05	.9	.9	5	05			10		29
30	20	8	14	2		51	0		28	.25	3.1					5	19			10		30

SUM	SUM				TOTAL	TOTAL	NUMBER OF DAYS	TOTAL	TOTAL	FOR THE MONTH:							TOTAL	% FOR MONTH	SUM	SUM
724	280				1441	0		1.70	27.0					17	35			212	
AVG.	AVG.	AVG.	DEP.	AVG.	DEP.	DEP.	PRECIPITATION	DEP.						DATE: 26+		POSSIBLE		AVG.	AVG.
24.1	9.3	16.7	-0.8		16	0	> .01 INCH 13	-0.09										7.1	

NUMBER OF DAYS				SEASON TO DATE			GREATEST IN 24 HOURS AND DATES				GREATEST DEPTH ON GROUND OF SNOW, ICE PELLETS OR ICE AND DATE	
MAXIMUM TEMP.		MINIMUM TEMP.		TOTAL	TOTAL	SNOW, ICE PELLETS > 1.0 INCH 7	PRECIPITATION		SNOW, ICE PELLETS			
≥ 90°	≤ 32°	≤ 32°	≤ 0°	3834	1	THUNDERSTORMS 0	.67	29-30	8.1	29-30	29	30
0	23	30	7	DEP.	DEP	HEAVY FOG 0						
				280	-5	CLEAR 8 PARTLY CLOUDY 2 CLOUDY 20						

* EXTREME FOR THE MONTH - LAST OCCURRENCE IF MORE THAN ONE.
T TRACE AMOUNT.
+ ALSO ON EARLIER DATE(S).
HEAVY FOG: VISIBILITY 1/4 MILE OR LESS.
BLANK ENTRIES DENOTE MISSING DATA.
HOURS OF OPS. MAY BE REDUCED ON A VARIABLE SCHEDULE.

DATA IN COLS 6 AND 12-15 ARE BASED ON 7 OR MORE OBSERVATIONS AT 3-HOUR INTERVALS. RESULTANT WIND IS THE VECTOR SUM OF WIND SPEEDS AND DIRECTIONS DIVIDED BY THE NUMBER OF OBSERVATIONS. ONE OF THREE WIND SPEEDS IS GIVEN UNDER FASTEST MILE: FASTEST MILE - HIGHEST RECORDED SPEED FOR WHICH A MILE OF WIND PASSES STATION (DIRECTION IN COMPASS POINTS). FASTEST OBSERVED ONE MINUTE WIND - HIGHEST ONE MINUTE SPEED (DIRECTION IN TENS OF DEGREES). PEAK GUST - HIGHEST INSTANTANEOUS WIND SPEED (A / APPEARS IN THE DIRECTION COLUMN). ERRORS WILL BE CORRECTED AND CHANGES IN SUMMARY DATA WILL BE ANNOTATED IN THE ANNUAL PUBLICATION.

I CERTIFY THAT THIS IS AN OFFICIAL PUBLICATION OF THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, AND IS COMPILED FROM RECORDS ON FILE AT THE NATIONAL CLIMATIC CENTER, ASHEVILLE, NORTH CAROLINA, 28801.

L. Ray Hoxit
ACTING DIRECTOR
NATIONAL CLIMATIC CENTER

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA AND INFORMATION SERVICE / NATIONAL CLIMATIC CENTER ASHEVILLE, NORTH CAROLINA

DEC 1982 26528
TALKEETNA, ALASKA
TALKEETNA AIRPORT

ISSN 0198-0424

LOCAL CLIMATOLOGICAL DATA

Monthly Summary

WEA SVC CONTRACT MET OBSY

LATITUDE 62° 18' N LONGITUDE 150° 06' W ELEVATION (GROUND) 345 FEET TIME ZONE ALASKAN WBAN #26528

DATE 1	TEMPERATURE °F: MAXIMUM 2	MINIMUM 3	AVERAGE 4	DEPARTURE FROM NORMAL 5	AVERAGE DEW POINT 6	DEGREE DAYS BASE 65°F: HEATING (SEASON BEGINS WITH JUL) 7A	COOLING (SEASON BEGINS WITH JAN) 7B	WEATHER TYPES (1 FOG, 2 HEAVY FOG, 3 THUNDERSTORM, 4 ICE PELLETS, 5 HAIL, 6 GLAZE, 7 DUSTSTORM, 8 SMOKE, HAZE, 9 BLOWING SNOW) 8	SNOW ICE PELLETS OR ICE ON GROUND AT 09AM INCHES 9	PRECIPITATION: WATER EQUIVALENT (INCHES) 10	SNOW, ICE PELLETS (INCHES) 11	AVERAGE STATION PRESSURE IN INCHES ELEV. 356 FEET ABOVE M.S.L. 12	WIND (M.P.H.): RESULTANT DIR. 13	RESULTANT SPEED 14	AVERAGE SPEED 15	FASTEST MILE: SPEED 16	DIRECTION 17	SUNSHINE: MINUTES 18	PERCENT OF TOTAL POSSIBLE 19	SKY COVER (TENTHS): SUNRISE TO SUNSET 20	MIDNIGHT TO MIDNIGHT 21	DATE 22
1	10	-4	3	-9	0	62	0	1	29	.04	.9	29.11	01	.4	.4	4	01			10		1
2	8	-19*	-6*	-17	-11	71	0		29	0	0	29.13	01	2.8	2.9	16	02			0		2
3	8	-17	-5	-16	-11	70	0		29	0	0	29.06	01	4.2	5.6	12	01			0	0	3
4	16	-17	-1	-12	-7	66	0		29	0	0	29.43	01	12.0	12.5	20	36			9	6	4
5	28	16	22	11	13	43	0		29	T	T	29.54	01	11.5	11.8	20	03			10	10	5
6	31	27	29	19	18	36	0		28	0	0	29.59	01	9.8	9.9	14	36			3		6
7	36	29	33	23		32	0		27	.17	1.1					12	36			10		7
8	34	31	33	23	33	32	0	1	27	.59	3.7	29.30	07	3.3	7.3	16	15			10		8
9	33	17	25	15	21	40	0		26	.02	.8	29.82	04	3.5	8.6	16	15			9		9
10	17	4	11	1	4	54	0		25	0	0	29.56	01	5.0	6.0	8	03			5	3	10
11	28	0	14	5	15	51	0		25	0	0	28.92	35	8.9	9.2	17	34			10	6	11
12	32	25	29	20	21	36	0		24	0	0	28.57	36	10.2	10.8	16	36			10	9	12
13	32	22	27	18	20	38	0		24	0	0	28.63	01	9.4	9.6	16	36			10		13
14	34	21	28	19		37	0		24	0	0					13	02			9		14
15	35	20	28	19	21	37	0		24	0	0	28.51	01	7.9	8.2	16	02			10		15
16	33	22	28	20	21	37	0		24	0	0	28.64	02	10.6	10.9	16	03			9		16
17	31	11	21	13	21	44	0		24	T	T	29.04	35	6.3	6.5	12	33			10	7	17
18	12	3	8	0	4	57	0		24	0	0	29.20	04	4.1	4.2	6	04			6	4	18
19	26	3	15	7	9	50	0		24	0	0	29.00	36	9.8	10.2	23	02			10	7	19
20	28	10	19	11	13	46	0		24	0	0	29.00	01	9.3	9.5	16	01			7		20
21	10	-3	4	-4		61	0		24	0	0					6	03			2		21
22	3	-10	-4	-12	-11	69	0		24	0	0	28.85	01	3.8	5.3	7	33			0		22
23	15	2	9	1	-2	56	0		24	0	0	28.93	01	9.8	10.2	15	36			2		23
24	22	12	17	9	9	48	0		24	0	0	29.09	35	7.1	7.8	12	01			7	7	24
25	23	12	18	10	10	47	0		24	0	0	29.37	35	7.0	7.3	14	01			10	8	25
26	33	22	28	20	16	37	0		24	0	0	29.39	02	13.1	13.4	17	01			10	10	26
27	34	30	32	24	29	33	0	1	24	.30	2.5	29.48	01	5.4	6.3	16	01			10		27
28	38	32	35	27		30	0		25	.64	.8					12	02			10		28
29	42*	32	37*	29	34	28	0		24	.04	.5	29.41	01	1.9	4.2	13	16			10		29
30	35	26	31	23	29	34	0		23	T	T	29.55	05	2.2	4.2	9	01			10		30
31	31	25	28	20	21	37	0		23	0	0	29.52	35	7.0	7.6	10	33			8	10	31

	Maximum	Minimum	Average	Departure	Avg. Dew Point	Heating	Cooling		Water Equivalent	Snow, Ice Pellets	For the Month: Fastest Speed	Direction	Sunshine Total	% of Possible	Sky Sunrise to Sunset	Midnight to Midnight
	SUM	SUM				TOTAL	TOTAL	NUMBER OF DAYS	TOTAL	TOTAL			TOTAL	% FOR MONTH	SUM	SUM
	798	384				1419	0		1.80	10.3	23	02			236	
	AVG.	AVG.	AVG.	DEP.	AVG.	DEP.	DEP.	PRECIPITATION	DEP.		DATE: 19		POSSIBLE		AVG.	AVG.
	25.7	12.4	19.1	10.1		-317	0	> .01 INCH. 7	0.09						7.6	

NUMBER OF DAYS: MAXIMUM TEMP. ≥ 90°	MAXIMUM TEMP. ≤ 32°	MINIMUM TEMP. ≤ 32°	MINIMUM TEMP. ≤ 0°	SEASON TO DATE: HEATING TOTAL	COOLING TOTAL
				5253	1
				DEP.	DEP.
0	20	31	7	-37	-5

NUMBER OF DAYS	
SNOW, ICE PELLETS > 1.0 INCH	3
THUNDERSTORMS	0
HEAVY FOG	0
CLEAR 6 PARTLY CLOUDY 4 CLOUDY 21	

GREATEST IN 24 HOURS AND DATES: PRECIPITATION	DATES	SNOW, ICE PELLETS	DATES
.81	27-28	4.4	7- 8

GREATEST DEPTH ON GROUND OF SNOW, ICE PELLETS OR ICE AND DATE	
30	1

* EXTREME FOR THE MONTH - LAST OCCURRENCE IF MORE THAN ONE.
T TRACE AMOUNT.
+ ALSO ON EARLIER DATE(S).
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DEC 1982 TALKEETNA ALASKA

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1	33	27	30	22	23	35	0		23	0	0	29.24	01	5.8	5.9	12	02			10	9	1
2	34	25	30	22	23	35	0		23	0	0	29.07	35	6.4	6.5	10	01			9	10	2
3	27	24	26	18	22	39	0	1	23	.16	3.8	29.10	36	8.7	9.2	15	01			10		3
4	26	-7	10	2		55	0		26	0	0					12	02			3		4
5	10	-10	0	-8	-10	65	0		26	0	0	29.10	01	7.3	7.6	14	03			0		5
6	-2	-18	-10	-18	-16	75	0		26	T	T	28.56	01	3.2	3.3	9	03			2		6
7	-2	-21	-12	-20	-14	77	0		26	.01	.2	28.48	30	2.1	3.2	7	31			6	7	7
8	-2	-30*	-16*	-24	-30	81	0		26	0	0	29.18	02	3.1	3.5	17	03			0	0	8
9	1	-12	-6	-14	-19	71	0		26	0	0	29.58	02	8.5	9.2	17	03			0	0	9
10	6	-12	-3	-11	-18	68	0		26	0	0	29.48	01	10.6	11.4	21	01			0		10
11	11	4	8	0		57	0		26	0	0					21	03			0		11
12	9	-3	3	-5	-12	62	0		25	0	0	28.98	03	9.4	9.5	17	02			7		12
13	6	-1	3	-6	-16	62	0		25	0	0	29.19	02	10.9	11.4	17	02			1		13
14	13	-10	2	-7	-9	63	0		25	0	0	29.14	03	3.1	3.2	13	03			2	4	14
15	36	13	25	16	11	40	0		25	0	0	29.18	01	9.2	9.5	18	35			10	9	15
16	34	25	30	21	20	35	0	1	25	.12	2.3	28.86	36	5.2	7.2	13	01			10	10	16
17	25	11	18	9	17	47	0	1	27	.07	1.2	28.84	36	1.0	1.2	6	34			10		17
18	36	13	25	16		40	0		28	T	T					15	03			10		18
19	35	20	28	18	23	37	0	1	28	.10	4.4	29.13	14	2.2	6.6	13	15			10		19
20	26	21	24	14	14	41	0		32	0	0	29.57	01	9.1	9.5	14	02			9		20
21	28	3	16	6	7	49	0		32	0	0	29.57	36	7.3	7.8	13	35			9	8	21
22	8	-8	0	-10	-8	65	0		30	0	0	29.56	03	2.7	2.7	7	03			0	0	22
23	11	-11	0	-10	-7	65	0		30	0	0	29.27	05	2.0	2.2	6	21			0	0	23
24	25	-14	6	-5	-6	59	0		30	0	0	29.06	01	4.8	5.9	13	03			7		24
25	25	19	22	11		43	0		29	0	0					17	36			4		25
26	31	25	28	17	15	37	0		29	0	0	28.56	01	11.4	11.8	16	02			10		26
27	29	14	22	11	16	43	0		29	0	0	28.75	35	4.3	4.9	14	03			9		27
28	29	7	18	7	16	47	0		29	0	0	29.14	36	4.1	4.5	9	01			6	6	28
29	29	4	17	5	10	48	0		29	0	0	28.93	35	5.1	5.3	10	33			0	0	29
30	29	4	17	5	14	48	0		29	0	0	28.96	01	11.5	11.7	16	01			9	6	30
31	38*	27	33*	21	23	32	0		29	0	0	29.22	36	6.5	7.8	14	02			9		31
	SUM	SUM				TOTAL	TOTAL	NUMBER OF DAYS		TOTAL	TOTAL	FOR THE MONTH:						TOTAL	% FOR MONTH	SUM	SUM	
	644	129				1621	0			.46	11.9					21	03			169		
	AVG.	AVG.	AVG.	DEP.	AVG.	DEP.	DEP.	PRECIPITATION		DEP.						DATE: 11+		POSSIBLE		AVG.	AVG.	
	20.8	4.2	12.5	4.1		-103	0	≥ .01 INCH. 5		-0.99										5.5		

NUMBER OF DAYS: MAXIMUM TEMP ≥ 90°	MAXIMUM TEMP ≤ 32°	MINIMUM TEMP ≤ 32°	MINIMUM TEMP ≤ 0°	SEASON TO DATE TOTAL	TOTAL
				6874	0
				DEP.	DEP.
0	24	31	13	-140	0

NUMBER OF DAYS	
SNOW, ICE PELLETS ≥ 1.0 INCH	4
THUNDERSTORMS	0
HEAVY FOG	0
CLEAR 12	PARTLY CLOUDY 5 CLOUDY 14

GREATEST IN 24 HOURS AND DATES: PRECIPITATION		SNOW, ICE PELLETS		GREATEST DEPTH ON GROUND OF SNOW, ICE PELLETS OR ICE AND DATE	
.19	16-17	4.4	19	33	19

* EXTREME FOR THE MONTH - LAST OCCURRENCE IF MORE THAN ONE.
T TRACE AMOUNT.
+ ALSO ON EARLIER DATE(S).
HEAVY FOG: VISIBILITY 1/4 MILE OR LESS.
BLANK ENTRIES DENOTE MISSING OR UNREPORTED DATA.
HOURS OF OPS. MAY BE REDUCED ON A VARIABLE SCHEDULE.

DATA IN COLS 6 AND 12-15 ARE BASED ON 7 OR MORE OBSERVATIONS AT 3-HOUR INTERVALS. RESULTANT WIND IS THE VECTOR SUM OF WIND SPEEDS AND DIRECTIONS DIVIDED BY THE NUMBER OF OBSERVATIONS. ONE OF THREE WIND SPEEDS IS GIVEN UNDER FASTEST MILE: FASTEST MILE - HIGHEST RECORDED SPEED FOR WHICH A MILE OF WIND PASSES STATION (DIRECTION IN COMPASS POINTS). FASTEST OBSERVED ONE MINUTE WIND - HIGHEST ONE MINUTE SPEED (DIRECTION IN TENS OF DEGREES). PEAK GUST - HIGHEST INSTANTANEOUS WIND SPEED (A / APPEARS IN THE DIRECTION COLUMN). ERRORS WILL BE CORRECTED AND CHANGES IN SUMMARY DATA WILL BE ANNOTATED IN THE ANNUAL PUBLICATION.

I CERTIFY THAT THIS IS AN OFFICIAL PUBLICATION OF THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, AND IS COMPILED FROM RECORDS ON FILE AT THE NATIONAL CLIMATIC DATA CENTER, ASHEVILLE, NORTH CAROLINA, 28801

L. Ray Hoxit
ACTING DIRECTOR
NATIONAL CILMATIC DATA CENTER

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION · NATIONAL ENVIRONMENTAL SATELLITE, DATA AND INFORMATION SERVICE · NATIONAL CLIMATIC DATA CENTER ASHEVILLE NORTH CAROLINA

TABLE 4.8

RIVER STAGES AT FREEZEUP MEASURED FROM TOP OF ICE ALONG BANKS AT SELECTED LOCATIONS

River Mile	Location	Approximate Date of Freezeup	Elevation Top of River Bank (ft)	Maximum Ice Elevation* (ft)	Open Water Discharge Corresponding to Stage (cfs)	Actual Discharge at Gold Creek (cfs)
148.9	Portage Creek	12/23/82	843.0	839.5	27,000	2,400
142.3	Slough 21, H9	-	758.3	755.5	-	-
140.8	Slough 21, LRX-54	-	735.3	733.3	-	-
136.6	Gold Creek	1/14/83	687.0	685.3	16,000	2,200
135.3	Slough 11, Mouth	12/6/82	671.5	-	-	2,800
130.9	Slough 9, Sherman	12/1/82	622.4	620.1	30,000	3,000
128.3	Slough 9, Mouth	11/29/82	-	[6.9]	-	3,000
127.0	Slough 8, Head	11/22/82	-	579.3	-	3,300
124.5	Slough 8, LRX-28	11/20/82	556.2	559.3	44,000 (aufeis)	3,400
120.7	Curry	11/20/82	527.0	524.6	28,000	3,400
116.7	McKenzie Creek	11/18/82	-	493.3	-	3,500
113.7	Lane Creek	11/15/82	-	[6.7]	-	3,700
106.2	LRX-11	11/9/82	-	[5.3]	-	4,100
103.3	LRX-9	11/8/82	384.1	383.9	41,000	4,200
98.5	LRX-3	11/5/82	346.4	345.5	-	4,400

* Values in brackets [ ] represent relative elevations based on an assumed datum from a temporary benchmark adjacent to the site.

From R&M Report: Susitna River Ice Study 1982-83

Table 7

From "Preliminary Susitna River Ice Report, 1983-84," R&M Consultants, Feb. 84.

TABLE 8
SUSITNA RIVER HISTORICAL ICE THICKNESSES

1983

Date	Location	Distance from Left Bank (Feet)	Solid Ice	Slush
Feb. 5	LRX-45 (Gold Creek)	36	1.8	0
	W.S.E. = 684.50	92	1.4	0.5
		148	1.3	3
		232	1.9	3
		288	1.7	
Feb. 5	LRX-24 (Curry)	229	-	-
	W.S.E. = 522.60	291	1.8	12
		337	2.1	12
		377	1.8	0
		416	2.0	0
Feb. 5	LRX-3 (Talkeetna)	138	3.7	0
	W.S.E. = 342.80	210	2.0	0
		312	2.6	4
		464	3.9	2
		721	2.1	0

Table 9
MAXIMUM WATER/ICE PROFILE
1982 FREEZE-UP

Station (RM)	Maximum Water/Ice El.-Ft. Computed	Observed	Diff.
LRX-3 (98.5)	345.5	345.5	0.0
LRX-9 (103.3)	382.4	383.9	-1.5
McKenzie Creek (116.7)	492.6	493.3	-0.7
Curry (120.7)	526.0	524.6	+1.4
LRX-28 (124.5)	560.9	559.3	+1.6
Slough 8 (127.0)	588.0	579.3	+8.7
Slough 9 (130.9)	625.1	620.1	+5.0
Gold Creek (136.6)	684.4	685.3	-0.9
		Avg.	+1.7

Table 10
1982 FREEZE-UP
INSTREAM ICE MODEL
CALIBRATION COEFFICIENTS

	Parameter	Final Value From Simulation	Normal Range of Value
1.	Open-water-heat-transfer coefficient	$(20+2V_W) W/m^2$-°C where V_w=Wind Velocity-m/s	12-20 W/m^2°C
2.	Cohesion coefficient for frazil slush	700 N/m^2	500-2000 N/m^2
3.	Critical Froude No. for Leading Edge Progression	0.0935	0.06-0.11
4.	Critical Velocity for under ice deposition	0.9 m/s	0.6-1.4 m/s
5.	Lateral ice coefficients	0.1 $V^{-2.8}$ m/day where V=Water Velocity, m/s	--

Notes: 1. Ice inflow at Gold Creek based on assumed slush thickness = 0.15 m and slush porosity = 0.6.

From "Preliminary Susitna River Ice Report, 1983-84," R&M Consultants, Feb. 84.

TABLE 2 (cont.)
GOLD CREEK WIRE WEIGHT READINGS (FEET)
with corresponding values in USGS
Datum (feet), Mean Sea Level (feet) and Discharge (cf/sec)

Date	WW	USGS	MSL	Q
December, 1983				
1	56.92	5.29	681.61	3500
2	56.96	5.33	681.65	3550
3	56.72	5.09	681.41	3100
4	56.92	5.29	681.61	3400
5	56.93	5.30	681.62	3400
6	57.07	5.44	681.76	3750
7	57.04	5.41	681.73	3700
8	56.97	5.34	681.66	3550
9	56.90	5.27	681.59	3400
10	56.95	5.32	681.64	3400
11	56.97	5.34	681.66	3450
12	56.92	5.29	681.61	3400
13	56.90	5.27	681.59	3400
14	56.88	5.25	681.57	3350
15	56.90	5.27	681.59	3400
16	57.01	5.38	681.70	3600
17	57.13	5.50	681.82	*
18	57.22	5.59	681.91	*
19	57.30	5.67	681.99	*
20	57.45	5.82	682.14	*
21	57.52	5.89	682.21	*
22	57.27	5.64	681.96	*
23	57.50	5.87	682.19	*
24	57.60	5.97	682.29	*
25	57.65	6.02	682.34	*
26	57.87	6.24	682.56	*
27	57.85	6.22	682.54	*
28	57.82	6.19	682.71	*
29	58.04	6.41	682.93	*
30	58.15	6.52	683.04	*
31	58.33	6.70	683.22	*

Assumed 3600 cfs until Jan. 6, 84.

* Backwater effect from ice bridge at LRX-43 and advancing ice cover.

From "Preliminary Susitna River Ice Report, 1983-84," R&M Consultants, Feb. 84.

WS FORM F-6

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

PRELIMINARY LOCAL CLIMATOLOGICAL DATA

STATION: WSCMO, TALKEETNA, ALASKA

MONTH: December YEAR: 1983

LATITUDE: 62° 18' N LONGITUDE: 150° 06' W GROUND ELEVATION (ft): 345 FT. STANDARD TIME: Yukon

Day	Temperature °F: Maximum	Minimum	Average	Departure from normal	Degree days (Base 65°): Heating	Cooling	Precipitation (In.): Total (Water equivalent)	Snowfall, ice pellets	+ Snow, ice pellets or ice on ground at 0300Y	Wind: * Average speed (m.p.h.)	Fastest mile: # Speed (m.p.h.)	Direction	Sunshine: Total (Hrs.)	* Percent of possible	Sky cover sunrise to sunset (Tenths)	Weather occurrences	2/ 0300Y	2/ 0900Y		
1	2	3	4	5	6a	6b	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	38	28	33	+21	32	0	0	0	7	5.2	14	02		23	10					
2	30	16	23	+11	42	0	0	0	7	0.9	6	05			9	1				
3	28	24	26	+15	39	0	.01	T	7	1.3	5	04			9	16				
4	27	24	26	+15	39	0	.27	2.7	7	6.1	10	36			10	1				
5	31	27	29	+18	36	0	.06	1.0	10	6.4	12	36		23	10					
6	32	14	23	+12	42	0	0	0	10+	3.5	6	02		18	10	1	0	9		
7	19	5	12	+2	53	0	0	0	10	3.9	7	35		23	9	1				
8	7	-4	2	-8	63	0	0	0	10	2.9	6	05		23	0					
9	11	-5	3	-7	62	0	0	0	10	11.9	20	01			5					
10	20	10	15	+5	50	0	T	T	10	14.9	21	01			10					
11	24	18	21	+12	44	0	.01	0.2	10	14.1	21	04			10					
12	22	6	14	+5	51	0	0	0	10	7.2	14	02		23	7					
13	21	6	14	+5	51	0	.09	1.8	10+	(5.7)	12	02		18	10	1	0	9		
14	8	-11	-2	-11	67	0	T	T	12	(2.1)	5	04		23	3	1				
15	6	-14	-4	-12	69	0	T	T	12	4.1	7	33		23	0					
16	13	-4	5	-3	60	0	T	T	12	6.6	17	04			10					
17	20	12	16	+8	49	0	.11	1.7	12	4.8	13	02			10	16				
18	23	6	15	+7	50	0	T	T	12	(3.7)	7	33			7	16				
19	24	4	14	+6	51	0	0	0	12	(4.6)	12	03		23	10					
20	30	23	27	+19	38	0	0	0	12+	7.2	10	35		18	10		0	9		
21	32	23	28	+20	37	0	.02	0.2	12	8.6	13	35		23	10	1				
22	28	-3	13	+6	52	0	0	0	12	5.3	13	02		23	0					
23	0	-8	-4	-11	69	0	0	0	11	3.1	6	04			0					
24	42	-9	17	+10	48	0	0	0	11	5.0	13	04			2					
25	45	35	40	+33	25	0	0	0	10	13.6	20	02			0					
26	41	5	23	+16	42	0	0	0	9	(6.6)	17	05		23	0					
27	9	-2	4	-3	61	0	0	0	9+	3.5	6	03		18	0	1	0	9		
28	-1	-8	-5	-12	70	0	0	0	9	3.8	6	06		23	0	1				
29	-4	-13	-9	-16	74	0	0	0	4	4.2	5	06		23	0	1				
30	9	-15	-3	-10	68	0	0	0	9	3.3	9	35			2					
31	21	9	15	+8	50	0	0	0	9	6.4	4	36			8					
SUM	656	199	—	—	1584	0	0.57	7.6	—	181.0	—	—		—	181	—				
AVG	21.2	6.4	—	—	—	—	—	—	—	5.8	Fastest	Direction	Possible	%	5.8	—				
										Dec. —	21	04				—				

TEMPERATURE DATA

AVERAGE MONTHLY: 13.8
DEPARTURE FROM NORMAL: +5.1
HIGHEST: 45 ON: 25
LOWEST: -15 ON: 30
NUMBER OF DAYS WITH –
MAX. 32° OR BELOW: 27
MAX. 70° OR ABOVE: 0
MIN. 32° OR BELOW: 30
MIN. 0° OR BELOW: 12
HEATING DEGREE DAYS (Base 65°)
TOTAL THIS MONTH: 1584
DEPARTURE FROM NORMAL: -161
SEASONAL TOTAL: 5085
DEPARTURE FROM NORMAL: -218
COOLING DEGREE DAYS (Base 65°)
TOTAL THIS MONTH: 0
DEPARTURE FROM NORMAL: 0
SEASONAL TOTAL: 0
DEPARTURE FROM NORMAL: 0

PRECIPITATION DATA

TOTAL FOR THE MONTH: 0.57 IN.
DEPARTURE FROM NORMAL: -0.84 IN.
GREATEST IN 24 HRS.: .28 ON: 4-5
SNOWFALL, ICE PELLETS
TOTAL FOR THE MONTH: 7.6 IN.
GREATEST IN 24 HRS.: 3.2 ON: 4-5
GREATEST DEPTH ON GROUND: 13 ON: 17
PRESSURE DATA
HIGHEST SEA-LEVEL: 31.08 IN. ON: 23
LOWEST SEA-LEVEL: 29.31 IN. ON: 1

WEATHER

NUMBER OF DAYS –
CLEAR (Scale 0–3): 12
PARTLY CLOUDY (Scale 4–7): 3
CLOUDY (Scale 8–10): 16
WITH 0.01 INCH OR MORE PRECIP.: 7
WITH 0.10 INCH OR MORE PRECIP.: 2
WITH 0.50 INCH OR MORE PRECIP.: 0
WITH 1.00 INCH OR MORE PRECIP.: 0

SYMBOLS USED IN COLUMN 16

1 = FOG
2 = FOG REDUCING VISIBILITY TO 1/4 MILE OR LESS
3 = THUNDER
4 = ICE PELLETS
5 = HAIL
6 = GLAZE OR RIME
7 = BLOWING DUST OR BLOWING SAND REDUCING VISIBILITY TO 1/4 MILE OR LESS
8 = SMOKE OR HAZE
9 = BLOWING SNOW
X = TORNADO

MAXIMUM PRECIPITATION

Δt (Minutes)	5	10	15	20	30	45	60	80	100	120	150	180
PRECIPITATION (Inches)												
ENDED: DATE												
TIME												

*Average wind speed is based on 24 hours unless otherwise indicated.
#Fastest one minute wind speed and its direction.
+Snow data is obtained at 0900Y where indicated.
1/ Indicates only the last of several occurrences.
2/ Synoptic data is based on 6 hours unless otherwise indicated.

From "Preliminary Susitna River Ice Report, 1983-84," R&M Consultants, Feb. 84.

SUSITNA HYDROELECTRIC PROJECT

MONTHLY SUMMARY FOR SHERMAN WEATHER STATION
DATA TAKEN DURING December, 1983

DAY	MAX. TEMP. DEG C	MIN. TEMP. DEG C	MEAN TEMP. DEG C	RES. WIND DIR. DEG	RES. WIND SPD. M/S	AVG. WIND SPD. M/S	MAX. GUST DIR. DEG	MAX. GUST SPD. M/S	P'VAL DIR.	MEAN RH %	MEAN DP DEG C	PRECIP MM	DAY'S SOLAR ENERGY WH/SQM	DAY
1	2.2	-3.1	-.5	059	.7	.7	064	2.5	ENE	63	-5.7	0.0	265	1
2	-2.9	-8.5	-5.7	026	.2	.3	075	1.9	NNW	**	*****	0.0	280	2
3	-3.4	-6.5	-5.0	042	.1	.1	059	1.3	N	**	*****	0.0	265	3
4	-2.8	-8.8	-5.8	052	.2	.2	046	1.9	NE	**	*****	0.0	170	4
5	-2.4	-3.8	-3.1	058	.3	.2	062	1.9	NE	**	*****	0.0	155	5
6	-1.5	-10.7	-6.1	071	.2	.2	067	1.3	ENE	**	*****	0.0	245	6
7	-10.7	-15.6	-13.2	***	0.0	0.0	025	.6	***	**	*****	0.0	290	7
8	-11.4	-20.6	-16.0	***	0.0	0.0	034	.6	***	**	*****	0.0	255	8
9	-12.9	-22.9	-17.9	054	.4	.4	049	3.8	ENE	68	-19.4	0.0	280	9
10	-6.1	-14.5	-10.3	070	1.8	1.8	066	5.1	ENE	63	-15.3	0.0	290	10
11	-4.5	-9.5	-7.0	067	1.6	1.6	081	4.4	ENE	67	-11.6	0.0	265	11
12	-7.2	-16.1	-11.7	046	.8	.9	038	3.2	NE	80	-13.9	0.0	240	12
13	-5.5	-14.3	-9.9	059	.9	1.0	066	4.4	ENE	71	-11.6	0.0	215	13
14	-16.0	-21.2	-18.6	057	.3	.3	045	1.9	NE	**	*****	0.0	215	14
15	-18.4	-25.7	-22.1	072	.2	.2	072	2.5	ENE	**	*****	0.0	270	15
16	-12.5	-17.7	-15.1	054	.8	.8	059	3.8	NE	73	-17.1	0.0	255	16
17	-8.5	-12.6	-10.6	052	.9	1.0	059	3.2	ENE	85	-13.0	0.0	170	17
18	-7.7	-17.8	-12.8	050	.7	.7	075	2.5	ENE	93	-13.9	0.0	215	18
19	-6.8	-17.5	-12.2	067	.5	.5	065	1.9	ENE	91	-16.6	0.0	190	19
20	-3.3	-7.1	-5.2	064	.5	.6	051	2.5	ENE	**	*****	0.0	180	20
21	-2.2	-5.8	-4.0	059	.5	.5	046	1.9	ENE	**	*****	0.0	175	21
22	-4.3	-19.8	-12.1	062	.5	.5	022	1.9	ENE	**	*****	0.0	220	22
23	-16.5	-21.3	-18.9	057	.3	.4	061	1.9	ENE	**	*****	0.0	245	23
24	-9.4	-19.5	-14.5	066	.6	.6	074	1.9	ENE	**	*****	0.0	250	24
25	.6	-10.0	-4.7	051	1.0	1.1	039	4.4	NE	67	-8.6	0.0	290	25
26	-7.7	-17.0	-12.4	080	.8	.8	053	2.5	ENE	77	-13.4	0.0	240	26
27	-13.3	-22.2	-17.8	052	.4	.4	082	1.9	NE	91	-15.6	0.0	250	27
28	-20.7	-23.9	-22.3	044	.3	.4	009	1.9	NE	**	*****	0.0	255	28
29	-21.7	-26.0	-23.9	057	.3	.3	042	1.3	NE	**	*****	0.0	265	29
30	-16.7	-27.3	-22.0	051	.1	.1	085	1.3	NNE	**	*****	0.0	265	30
31	-10.2	-16.3	-13.3	054	.5	.6	039	1.9	ENE	**	*****	0.0	240	31
MONTH	2.2	-27.3	-12.1	059	.5	.6	066	5.1	ENE	71	-13.5	0.0	7405	

GUST VEL. AT MAX. GUST MINUS 2 INTERVALS 3.8
GUST VEL. AT MAX. GUST MINUS 1 INTERVAL 4.4
GUST VEL. AT MAX. GUST PLUS 1 INTERVAL 3.8
GUST VEL. AT MAX. GUST PLUS 2 INTERVALS 4.4

NOTE: RELATIVE HUMIDITY READINGS ARE UNRELIABLE WHEN WIND SPEEDS ARE LESS THAN ONE METER PER SECOND. SUCH READINGS HAVE NOT BEEN INCLUDED IN THE DAILY OR MONTHLY MEAN FOR RELATIVE HUMIDITY AND DEW POINT.

From "Preliminary Susitna River Ice Report, 1983-84," R&M Consultants, Feb. 84.

TABLE 5 (cont.)
SUSITNA RIVER at GOLD CREEK
ICE DISCHARGE COMPUTATIONS

$$Q_i = C_i V_s B_1 t_s (1-\epsilon_s)$$

Date	Ice Concentration C_i (%)	Surface Velocity V_s (m/s)	Channel Width B_1 (m)	Slush Thickness t_s (m)
December 1983				
1	10	0.9	87	0.30
2	10	0.9	87	0.30
3	15	0.9	87	0.30
4	25	0.9	87	0.30
5	15	0.9	87	0.30
6	10	1.1	87	0.30
7	35	1.1	87	0.30
8	40	1.1	87	0.30
9	55	1.1	87	0.30
10	55	0.9	87	0.30
11	65	0.9	87	0.40
12	80	0.9	87	0.40
13	80	0.9	78	0.40
14	80	0.9	78	0.40
15	80	0.9	78	0.40
16	80	0.9	78	0.40
17	60	0.9	78	0.40
18	70	0.9	78	0.40
19	50	0.9	78	0.40
20	35	0.9	78	0.40
21	20	1.1	78	0.40
22	50	1.1	78	0.40
23	50	0.9	78	0.40
24	30	0.9	78	0.40
25	30	0.9	78	0.40
26	40	0.8	78	0.40
27	50	0.8	78	0.40
28	55	0.8	78	0.40
29	60	0.8	78	0.40
30	70	0.8	78	0.40
31	50	0.8	78	0.40

TABLE 5 (cont.)
SUSITNA RIVER at GOLD CREEK
ICE DISCHARGE COMPUTATIONS

$$Q_i = C_i \, V_s \, B_1 \, t_s \, (1 - \epsilon_s)$$

Date	Ice Concentration C_i (%)	Surface Velocity V_s (m/s)	Channel Width B_1 (m)	Slush Thickness t_s (m)
January 1984				
1	-	-	-	-
2	20	0.8	78	0.3
3	10	0.8	78	0.3
4	20	0.6	78	0.3
5	50	0.6	63	0.3
6	30	0.6	63	0.3
7	20	0.6	63	0.3
8	20	0.6	63	0.3
9	20	0.6	63	0.3
10	15	0.6	63	0.3
11	5	0.6	63	0.3
12	5	0.6	63	0.3
13	5	0.6	63	0.3
14	5	0.6	63	0.3
15	-	-	0	-
16	-	-	0	-
17	-	-	0	-
18	-	-	0	-
19	-	-	0	-
20	-	-	0	-
21	-	-	0	-
22	-	-	0	-
23	-	-	0	-
24	-	-	0	-
25	-	-	0	-
26	-	-	0	-
27	-	-	0	-
28	-	-	0	-
29	-	-	0	-
30	-	-	0	-
31	-	-	0	-

From "Preliminary Susitna River Ice Report, 1983-84," R&M Consultants, Feb. 84.

TABLE 1
SUSITNA RIVER Between the CHULITNA CONFLUENCE (RM 98.5) and GOLD CREEK (RM 136.5)
Water Surface Elevations in Feet (MSL)

Location		Date of Survey 10/6	10/17	10/21	11/4	11/18
LRX-45 Gold Creek	RM 136.5	683.59	683.35	683.06	681.84	681.24
LRX-40	RM 134.2			657.21		654.24
Near LRX-35	RM 130.9					614.92
Near LRX-31	RM 128.7					592.86
LRX-29	RM 126.1			569.44		567.55
LRX-27	RM 123.3					541.11
LRX-24	RM 120.5			520.93		520.05
LRX-18	RM 113.0			460.18		457.74
Near LRX-10.3.	RM 106.2*			2.25		
LRX-9	RM 103.3			377.52		375.67
LRX-3	RM 98.6	342.55	341.51	341.30	339.65	339.40
LRX-2.3	RM 98.4	341.24			339.23	
LRX-2.2	RM 98.2	340.86			339.36	
Location of Leading Edge		No Cover	No Cover	No Cover	RM 42.0	RM 82.5
Discharge (USGS Gold Creek)		8800	7800	6900	3900	2800

* Surveyed from Arbitrary Reference Datum of 10 feet.

TABLE 1 (cont.)
SUSITNA RIVER Between the
CHULITNA CONFLUENCE (RM 98.5) and
GOLD CREEK (RM 136.5)
Water Surface Elevations in Feet (MSL)

Location		Date of Survey 12/13	12/22	12/28	1/5	1/27
LRX-45 Gold Creek	RM 136.5	681.59	681.96	682.73	683.49	684.64
LRX-40	RM 134.2		653.86	654.55	655.23	657.58
Near LRX-35	RM 130.9			617.55	617.05	618.16
Near LRX-31	RM 128.7		593.95	596.54	595.58	594.99
LRX-29	RM 126.1	563.49	573.53	572.59	571.53	571.08
LRX-27	RM 123.3		545.31		544.35	544.43
LRX-24	RM 120.5	520.82	522.26		523.58	523.89
LRX-18	RM 113.0	461.87			461.36	461.13
Near LRX-10.3	RM 106.2*	7.65				
LRX-9	RM 103.3	383.57	381.32			381.41
LRX-3[a]	RM 98.6	342.80	343.07	343.00		341.34
LRX-2.3	RM 98.4					
LRX-2.2	RM 98.2					
Location of Leading Edge		RM 108	RM 116.2 RM 127.0	RM 129.5	RM 130.2 RM 136.3	RM 130.2 RM 136.8
Discharge (USGS Gold Creek)		3400	BACKWATER			

* Surveyed from Arbitrary Reference Datum of 10 feet.

a. A maximum stage of 344.63 feet was reached at 1530 on December 9, 1983 coincident with the leading edge of ice cover passing this cross section.

From "Preliminary Susitna River Ice Report, 1983-84," R&M Consultants, Feb. 84.

SUSITNA RIVER ICE THICKNESSES at Selected Cross-Sections on January 5, 1984

Location	Description
LRX-45 at Gold Creek	Drilled one hole through border ice 30 feet from the left bank. Ice thickness 1.7 feet. Open water width is 208 feet. Shore ice width is 40 feet.
LRX-40	Ice thickness was 1.0 feet at edge of 10 foot border ice on right bank.
Near LRX-31	Drilled one hole in ice cover beyond edge of old border ice at mid-channel. Ice thickness 1.7 feet with no slush.
LRX-29	Drilled two holes. The first, 200 feet from the left bank. No water in this hole. Ice thickness 1.5 feet with air pocket, then 3 feet of slush. Second hole drilled at 350 feet from the left bank. Ice thickness 1.7 feet with no slush.
LRX-27	Drilled one hole at last observed location of open water, about 100 feet from right bank. Ice thickness was 1.8 feet and slush ice to bottom at 10.7 feet.
LRX-24 at Curry	Drilled one hole at mid-channel through ice bridge, about 300 feet from left bank. Ice thickness was 1.6 feet with slush ice greater than 12 feet thick as measured from top of ice.
LRX-18	Drilled one hole at last observed location of open water and near an open lead. Ice thickness was 4.5 feet with no slush.
LRX-3	Open lead at mid-channel. Ice thickness at edge was 2.3 feet with no slush.

SUSITNA RIVER
1984 ICE THICKNESSES (Cont.)

Location	Distance From Left Bank	Water Depth	Water Velocity	Solid Ice	Slush Ice	Total Thickness
River Mile 61.2 (near Kashwitna River)	200	13+	-	2.9	5.1	7.0
	400	10.0	-	2.7	5.3	8.0
Date: January 24	600	10.0	-	3.0	4.0	7.0
Total Width = 700 ft. Average Thickness = 7.3 ft.						
River Mile 68.5 (near Sheep Creek)	200	13+	-	2.8	5.2	8.0
	400	13+	-	2.0	3.0	5.0
Date: January 24	600	7.0	-	1.7	5.3	7.0
Total Width = 800 ft. Average Thickness = 6.7 ft.						
River Mile 77.0 (at Montana Creek)	200	7.0	-	2.0	5.0	7.0
	400	6.0	-	2.3	3.7	6.0
Date: January 24	600	13+	-	1.3	0	1.3*
Total Width = 700 ft. Average Thickness = 6.5 ft.						
River Mile 92.6 (near Birch Slough)	200	13+	-	2.3	0	2.3
	400	10.0	2.5 ft/s	1.8	0	1.8
Date: January 24	600	4.4	-	2.3	0	2.3
Total Width = 700 ft. Average Thickness = 2.1 ft.						
River Mile 98.6 (Chulitna Confluence)			OPEN LEAD			
	88	6.2	4.4 ft/s	1.5	4.7	6.0
Date: January 26						
Total Width = 300 ft. Average Thickness = 6.0 ft.						

From "Preliminary Susitna River Ice Report," 1983-84, R&M Consultants, Feb. 84

Table 17

SUSITNA RIVER
1984 ICE THICKNESSES (Cont.)

Location	Distance From Left Bank	Water Depth	Water Velocity	Solid Ice	Slush Ice	Total Thickness
River Mile 103.3 (LRX-9)	313	9.0	-	2.0	7.0	9.0
	439	12.0	1.9 ft/s	1.5	5.0	6.5
Date: January 26	558	10.6	-	2.0	7.0	9.0
Total Width = 600 ft. Average Thickness 8.2 ft.						
River Mile 113.0 (LRX-18)	238	6.6	1.6 ft/s	2.0	0	2.0*
	341	7.6	-	2.5	5.1	7.6
Date: January 26	467	6.0	-	2.3	3.5	5.8
Total Width = 500 ft. Average Thickness = 6.9 ft.						
River Mile 120.6 (LRX-24)	278	12.2	-	2.8	9.4	12.2
	373	11.7	-	2.0	6.6	8.6
Date: January 26	441	8.0	2.3ft/s	1.5	0	1.5*
Total Width = 500 ft. Average Thickness = 10.4 ft.						
River Mile 123.4 (LRX-27)	284	11.5	-	1.8	8.9	10.7
	368	12.2	-	1.8	8.7	10.5
Date: January 26	461	5.0	4 ft/s	2.4	0	2.4*
Total Width = 500 ft. Average Thickness = 10.6 ft.						
River Mile 126.2 (LRX-29)	252	4.5	-	2.3	1.7	4.0
	381	6.5	-	1.8	4.7	6.5
Date: January 26	513	8.0	4.5 ft/s	1.8	0	1.8*
Total Width = 575 ft. Average Thickness = 5.3 ft.						

Table 17 (Cont'd)

SUSITNA RIVER
1984 ICE THICKNESSES (Cont.)

Location	Distance From Left Bank	Water Depth	Water Velocity	Solid Ice	Slush Ice	Total Thickness
River Mile 128.5						
(near LRX-31)	369	4.8	-	1.8	0	1.8*
	469	6.6	-	1.6	3.6	5.2
Date: January 27	569	7.0	4.5 ft/s	1.0	0	1.0*
Total Width = 600 ft.						
Average Thickness = 5.2 ft.						
River Mile 136.6						
(LRX-45)	96	6.0	5 ft/s	1.1	0	1.1
	188	9.5	-	0.9	3.1	4.0
Date: January 27	287	7.1	-	1.0	0.5	1.5
Total Width = 350 ft.						
Average Thickness = 2.2 ft.						

* These values were not included in the average ice thickness. Site evaluations were used to determine the probable representative ice thickness at the time of ice cover progression.

Table 17 (Cont'd)

From "Preliminary Susitna River Ice Report, 1983-84," R&M Consultants, Feb. 84.

SUSITNA RIVER ICE COVER LEADING EDGE LOCATIONS DURING 1983 FREEZE-UP

Cook Inlet = River Mile (RM) 0.0

Date		Leading Edge Location
October	26	Initial Ice Bridge at RM 9.0
	27	RM 15.0
November	1	RM 31.5
	4	RM 42.0
	7	RM 57.0
	9	RM 66.0
	15	RM 77.0
	16	RM 78.5
	17	RM 79.5
	18	RM 82.5
	19	RM 84.5
	21	RM 89.0
	25	RM 91.0
	26	RM 95.5
December	8	RM 98.5
	13	RM 108
	22	RM 116.2
		New Ice Bridge at RM 120.7
		Second Leading Edge at RM 127
	28	RM 129.5
January	5	RM 130.2
		New Ice Bridge at RM 135.7
		Third Leading Edge at RM 136.3
	27	RM 137

Table 19
MAXIMUM WATER/ICE PROFILE
1983 FREEZE-UP

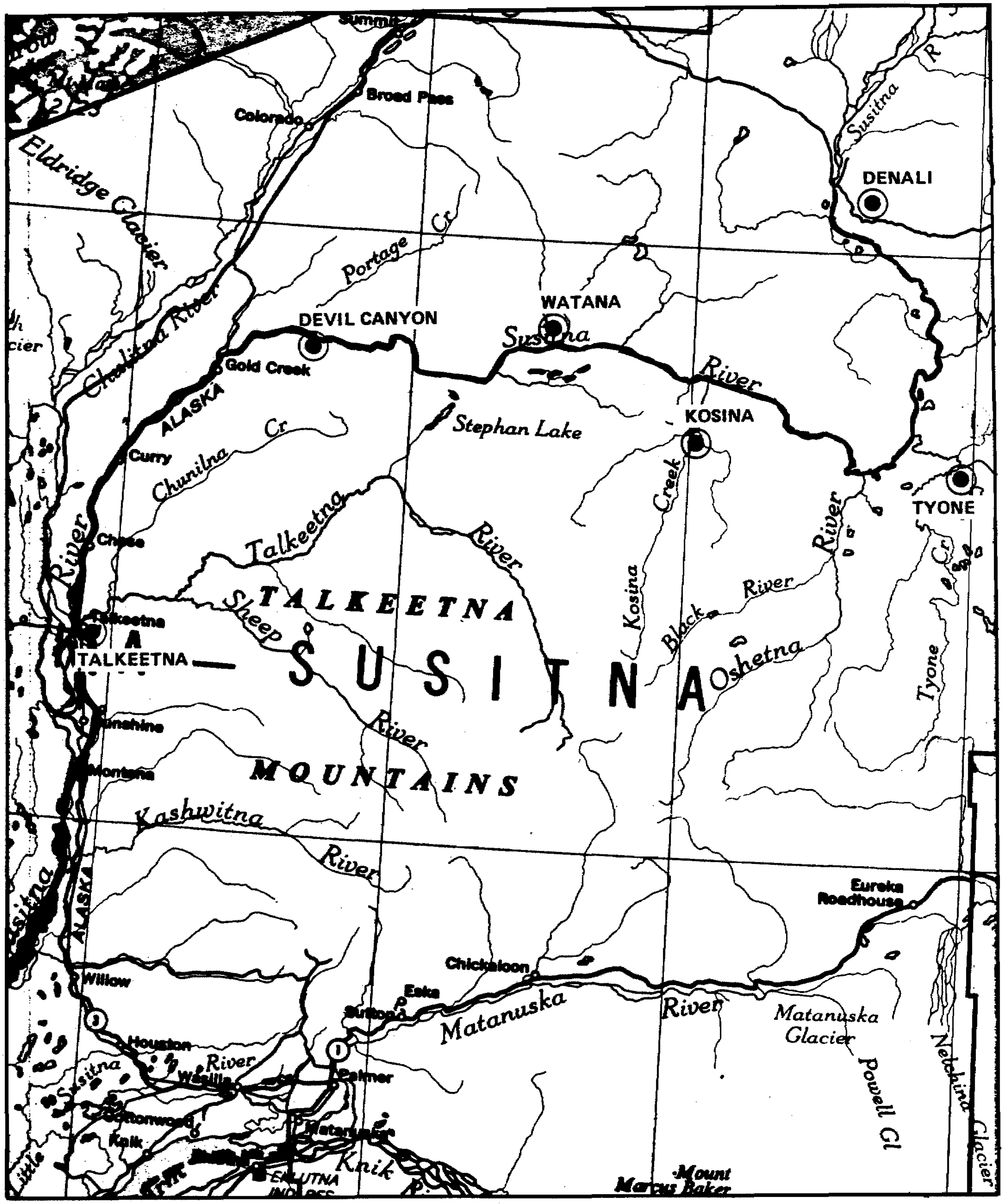
Station (RM)	Maximum Water/Ice Profile Computed	Observed	Diff.
LRX-3 (98.6)	345.2	344.6	+0.6
LRX-9 (103.3)	381.5	383.6	-2.1
LRX-18 (113.0)	465.2	461.9	+3.3
LRX-24 (120.5)	525.2	523.9	+1.3
LRX-27 (123.3)	548.3	545.3	+3.0
LRX-29 (126.1)	574.8	573.5	+1.3
LRX-31 (128.7)	601.3	596.5	+4.8
LRX-35 (130.9)	620.4	618.2	+1.8
		Avg.	+1.75

Table 20
INSTREAM ICE MODEL
CALIBRATION COEFFICIENTS

Parameter	Best Value from Simulations: 1982 Freeze-Up	1983 Freeze-Up
1. Open-water-heat transfer coefficient	$(20+2V_W)W/m^2$-°C where V_w=Wind Velocity in m/s	Same
2. Cohesion coefficient for frazil slush	700 N/m^2	Same
3. Critical Froude No. for Leading Edge Progression	0.0935	0.096
4. Critical Velocity for Underice Depoition	0.9 m/s	Same
5. Lateral Ice Coefficients	0.1 $V^{-2.8}$m/day where V=Water Velocity, m/s	Same

Note: Ice inflow at Gold Creek based on assumed slush thickness = 0.15 m and slush porosity = 0.6.

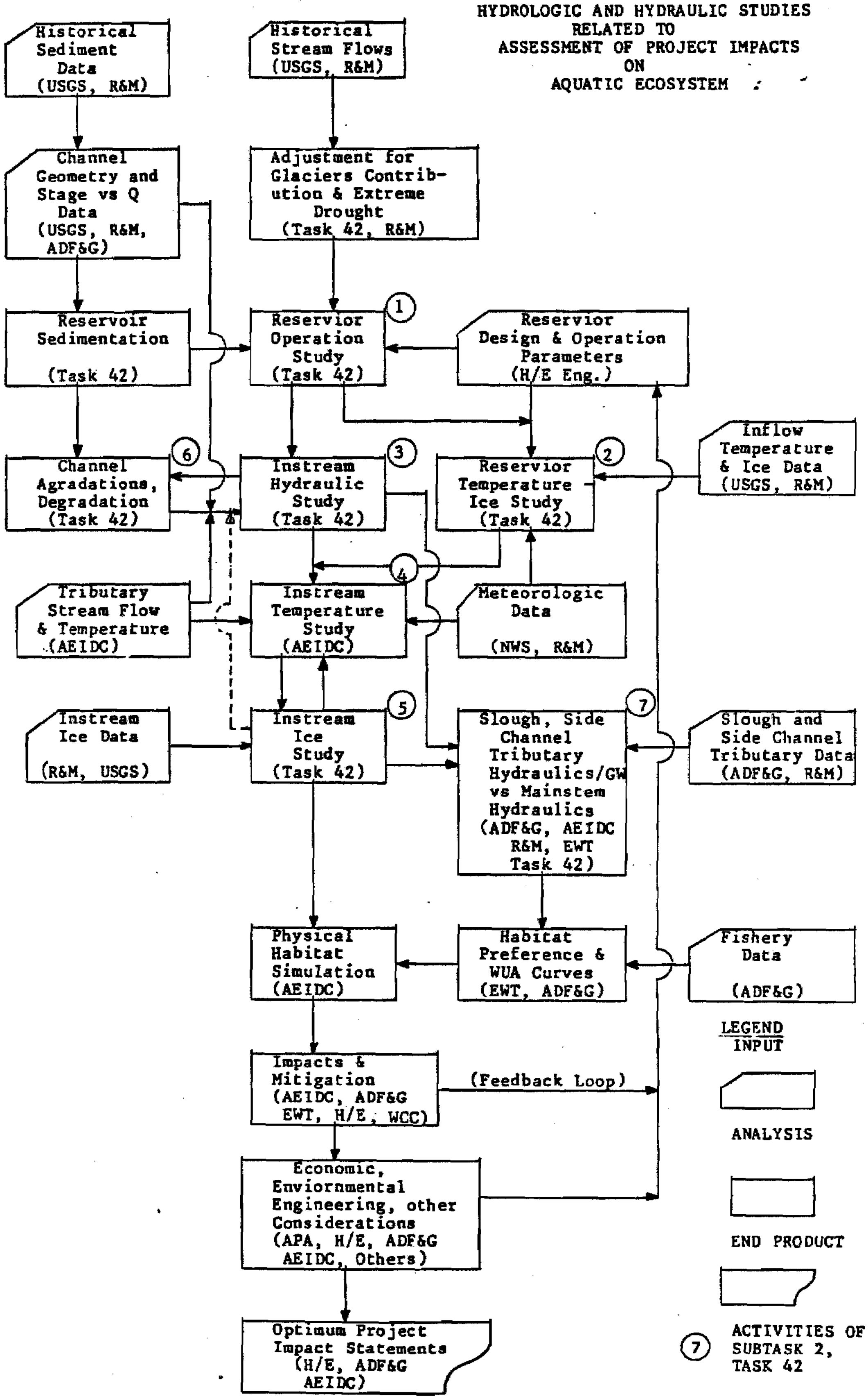
EXHIBITS



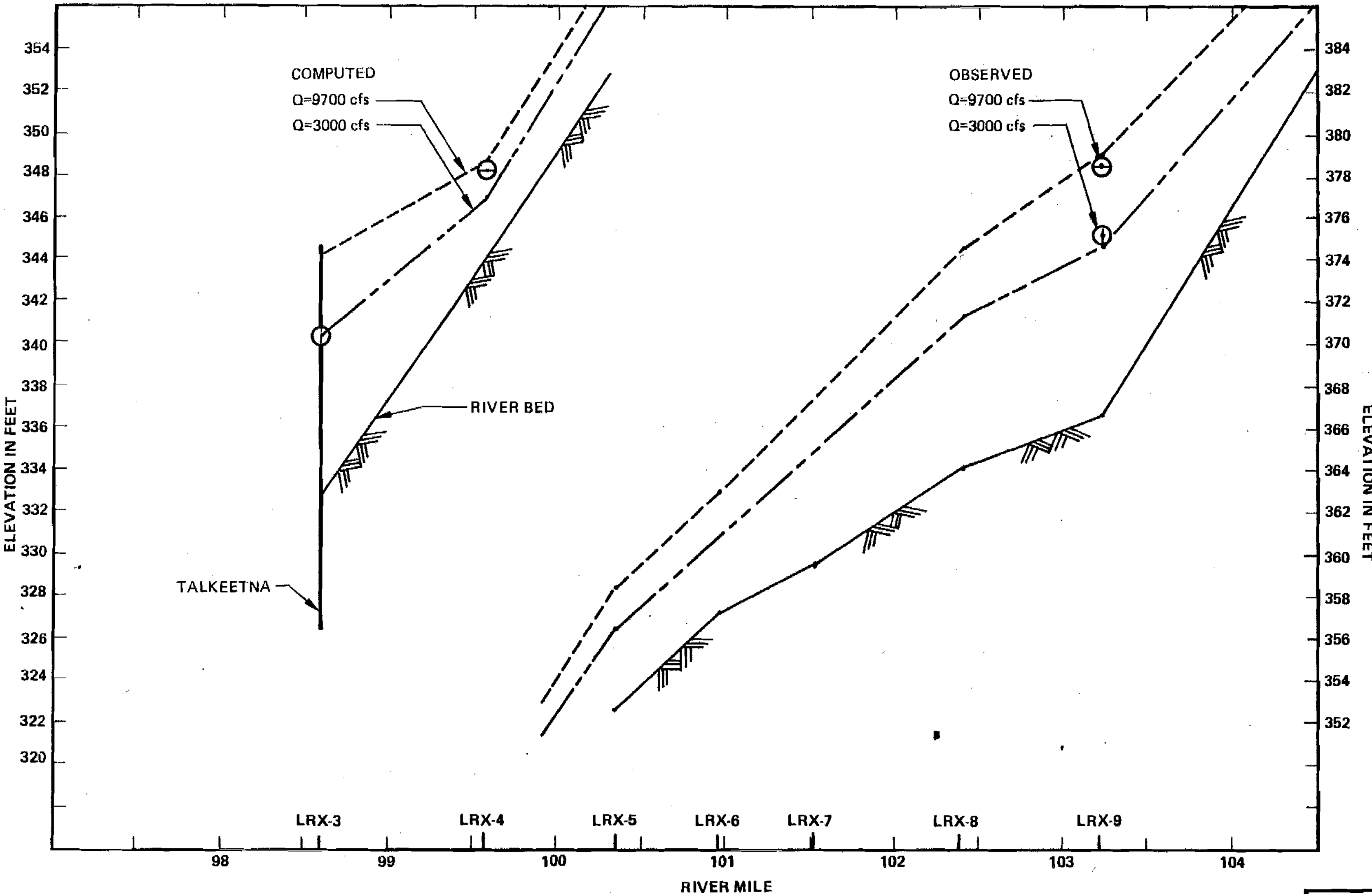
NORTH

SUSITNA BASIN

SUSITNA PROJECT
HYDROLOGIC AND HYDRAULIC STUDIES
RELATED TO
ASSESSMENT OF PROJECT IMPACTS
ON
AQUATIC ECOSYSTEM

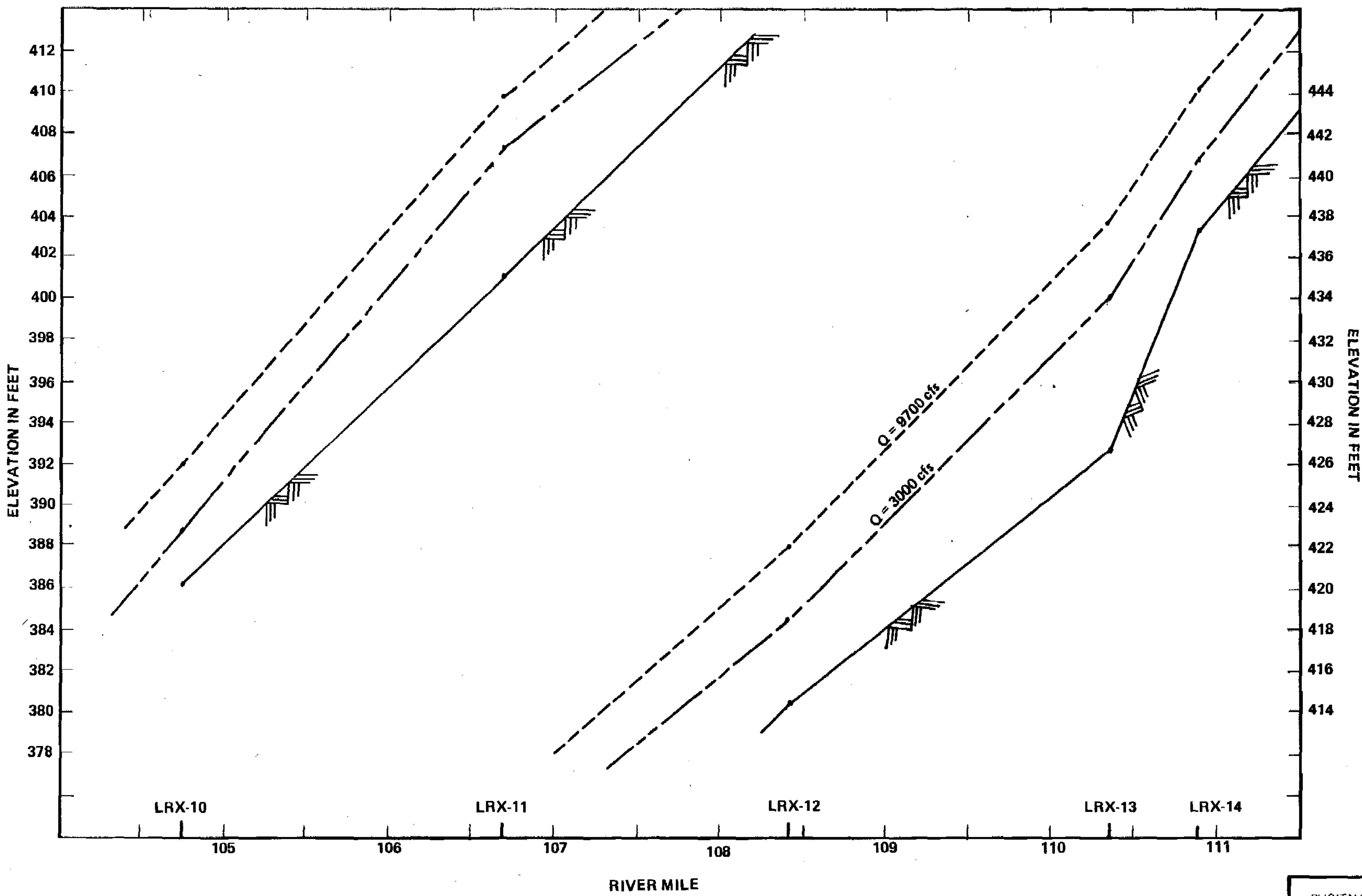


NOTE: Assumes impacts on water chemistry will not be a major issue



SUSITNA HYDROELECTRIC PROJECT INSTREAM ICE MODEL CALIBRATION	
ICE-FREE WATER SURFACE PROFILE TALKEETNA TO DEVIL CANYON	
EXHIBIT 3	Sheet 1 of 8

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

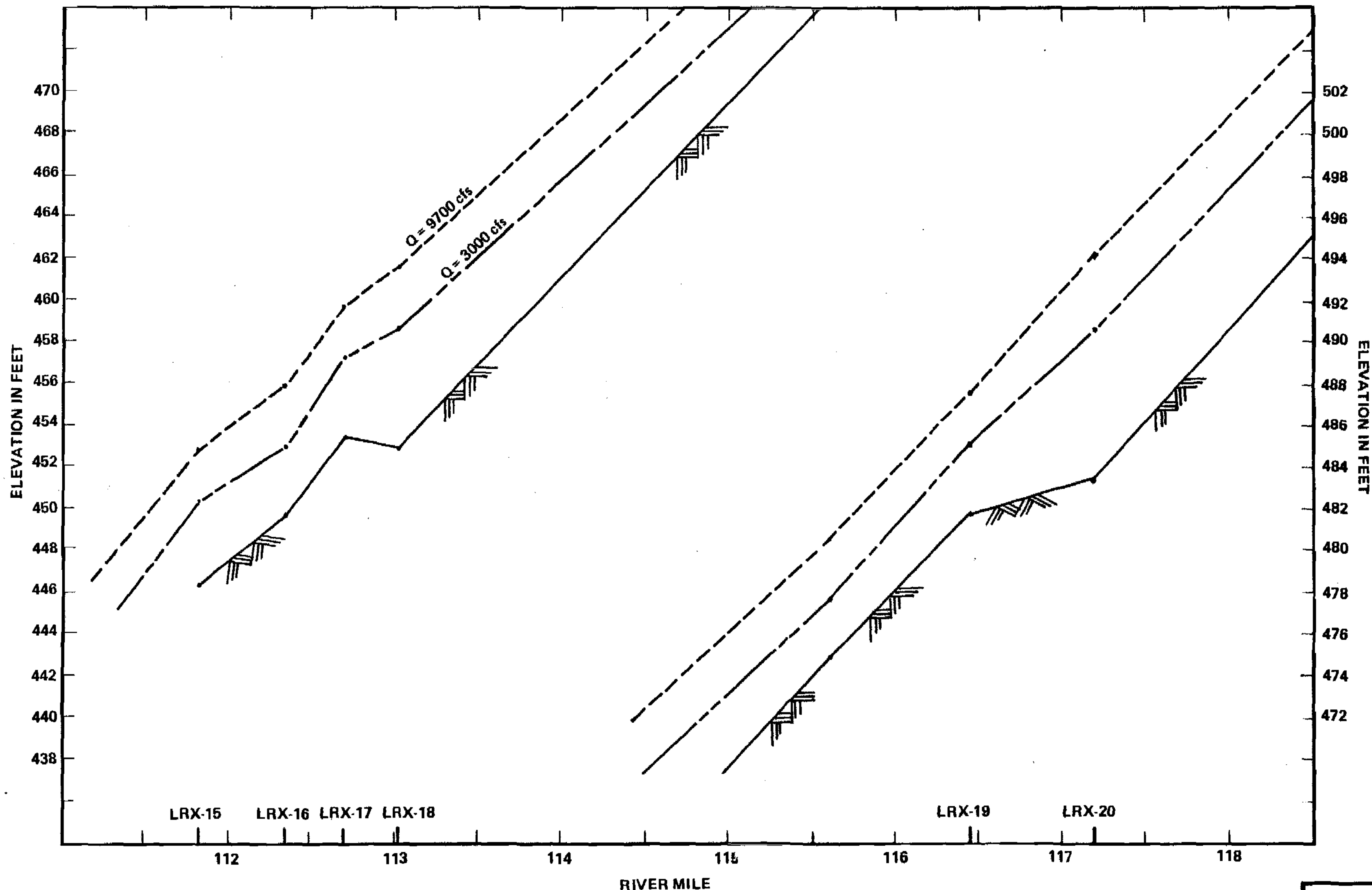


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

ICE-FREE
WATER SURFACE PROFILE
TALKEETNA TO DEVIL CANYON

EXHIBIT 3 | Sheet 2 of 8

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

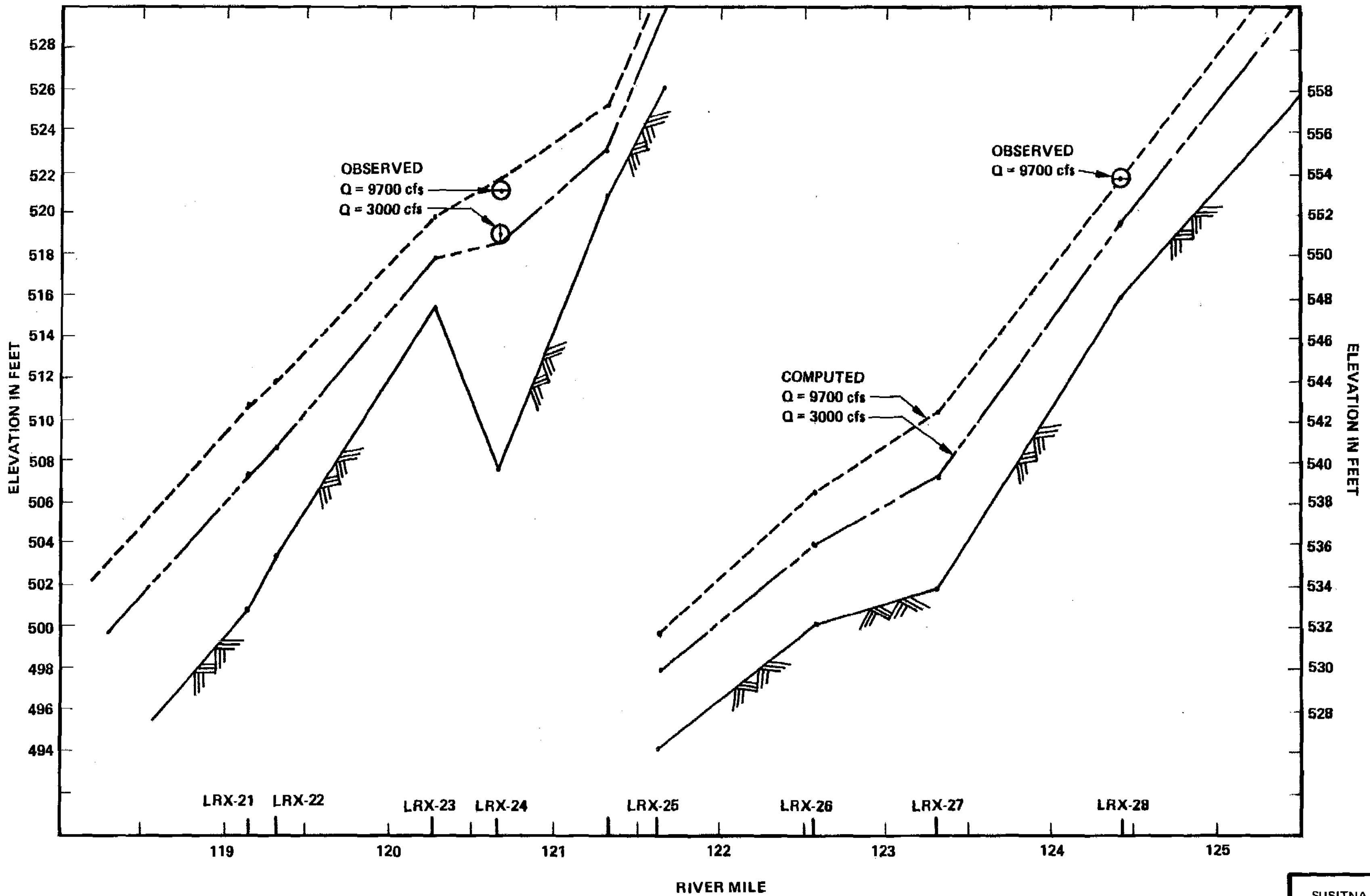


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

**ICE-FREE
WATER SURFACE PROFILE
TALKEETNA TO DEVIL CANYON**

EXHIBIT 3 | Sheet 3 of 8

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984



SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

ICE-FREE
WATER SURFACE PROFILE
TALKEETNA TO DEVIL CANYON

EXHIBIT 3 | Sheet 4 of 8

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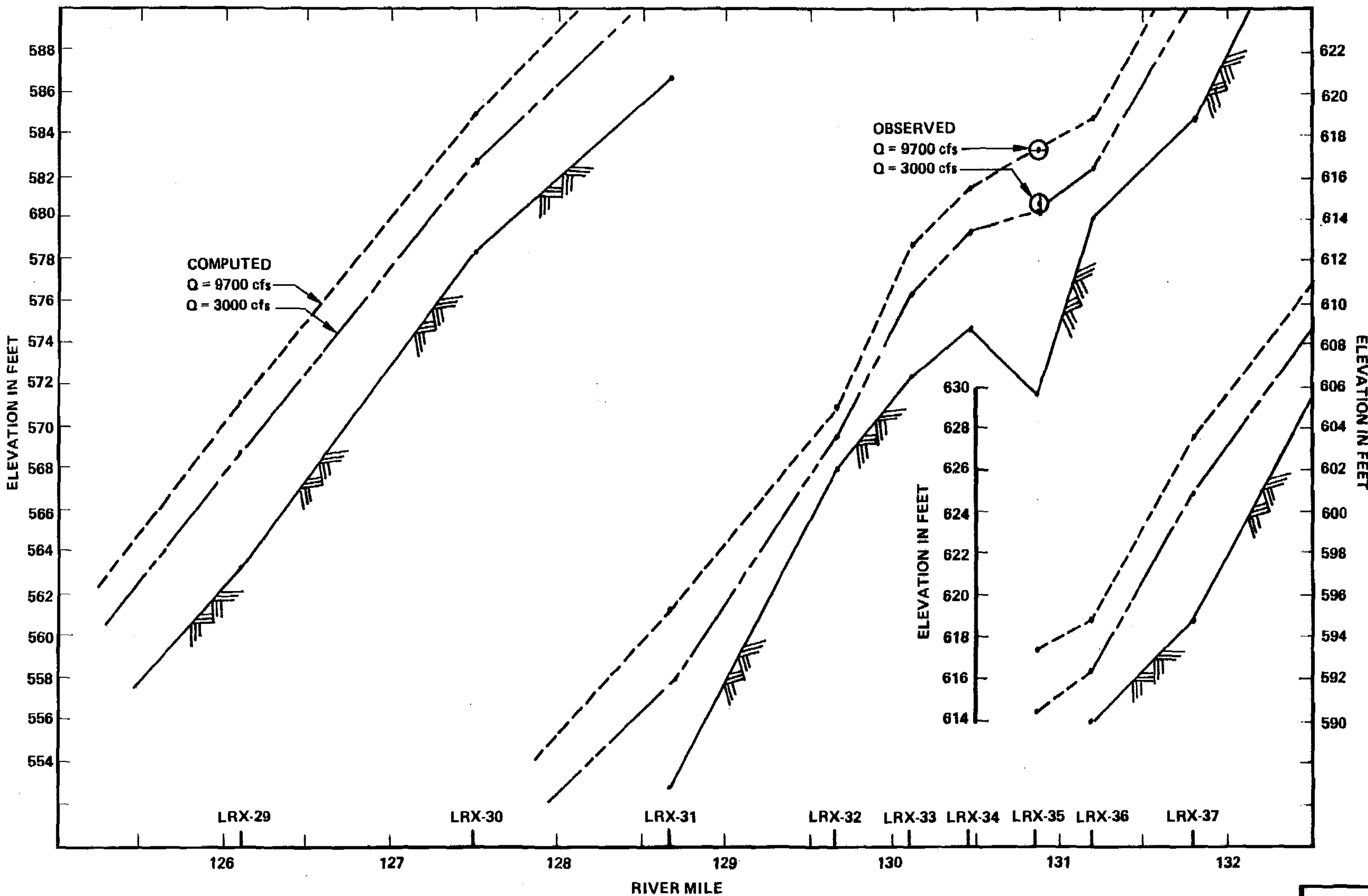

SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

ICE-FREE
WATER SURFACE PROFILE
TALKEETNA TO DEVIL CANYON

EXHIBIT 3 | Sheet 5 of 8

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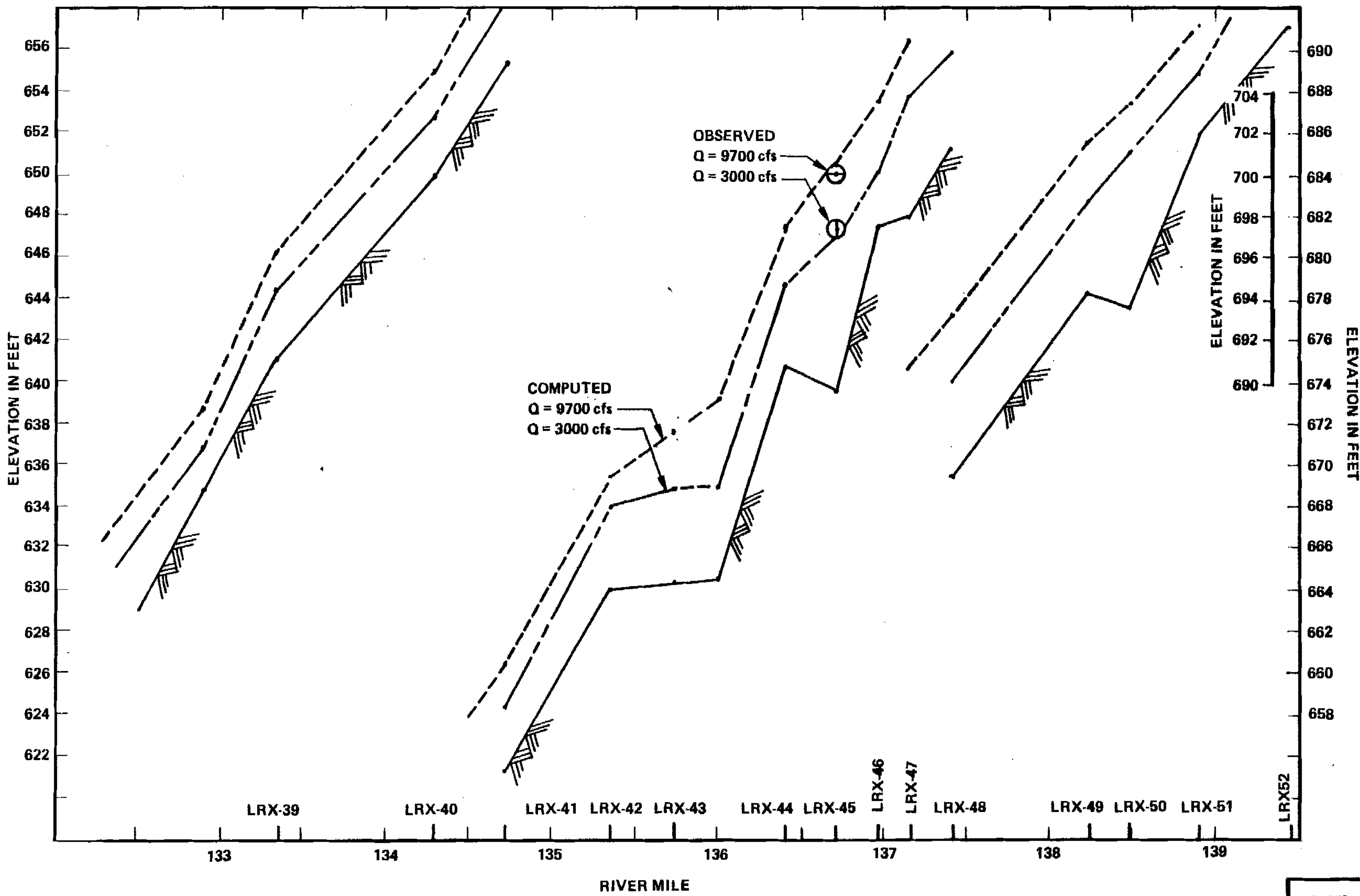

SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

**ICE-FREE
WATER SURFACE PROFILE
TALKEETNA TO DEVIL CANYON**

EXHIBIT 3	Sheet 6 of 8

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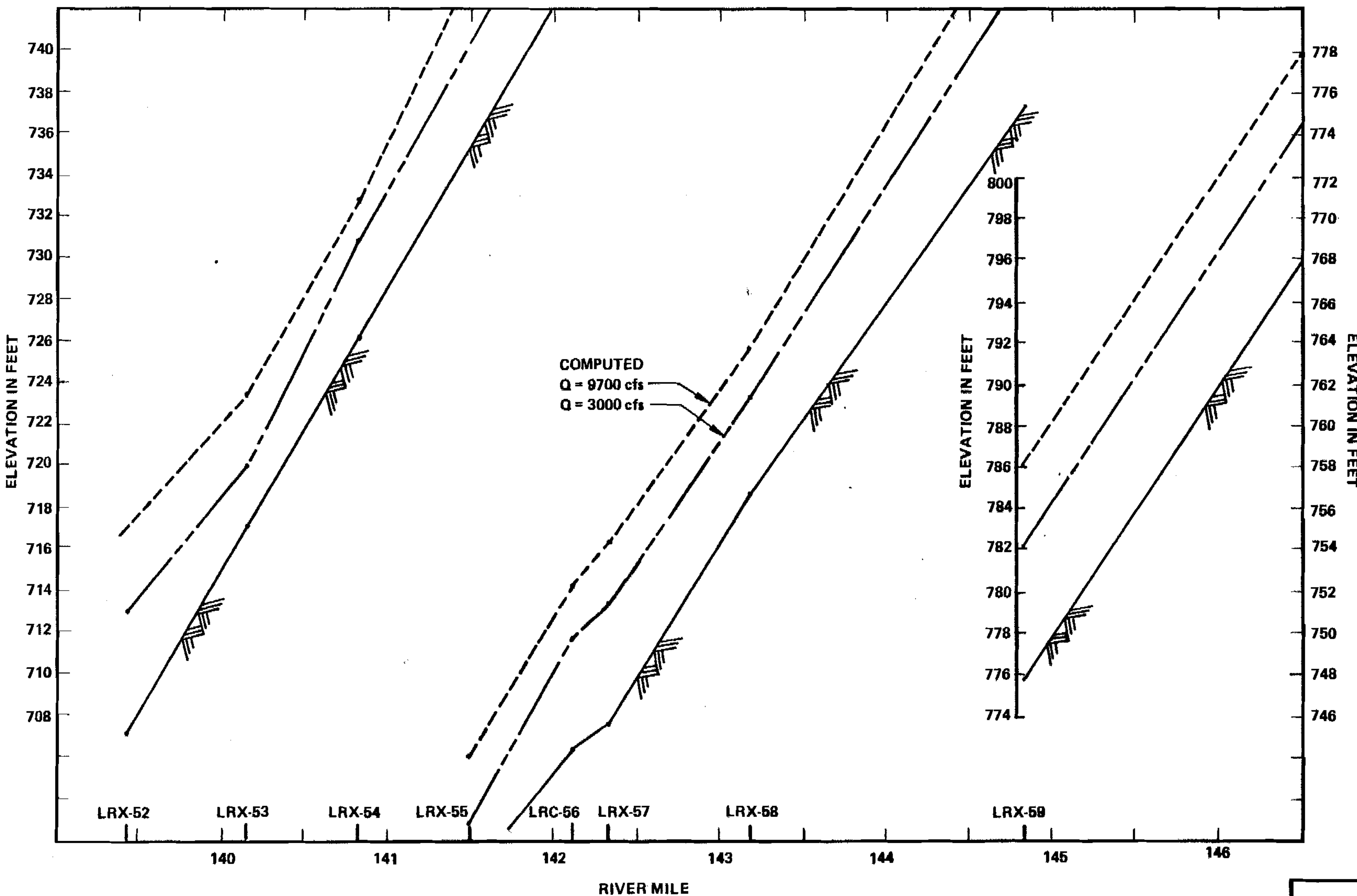

SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

ICE-FREE
WATER SURFACE PROFILE
TALKEETNA TO DEVIL CANYON

EXHIBIT 3 | Sheet 7 of 8

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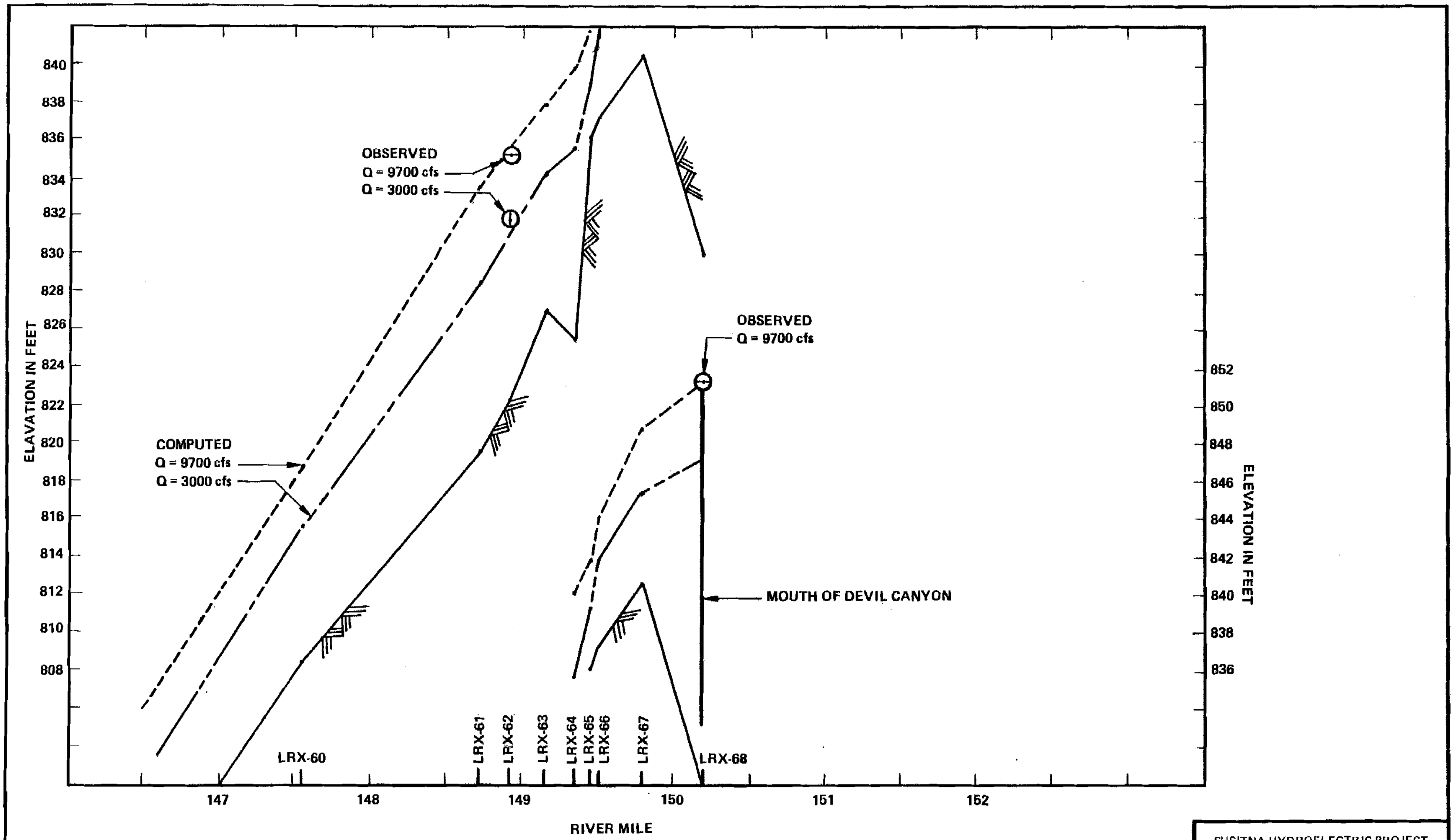


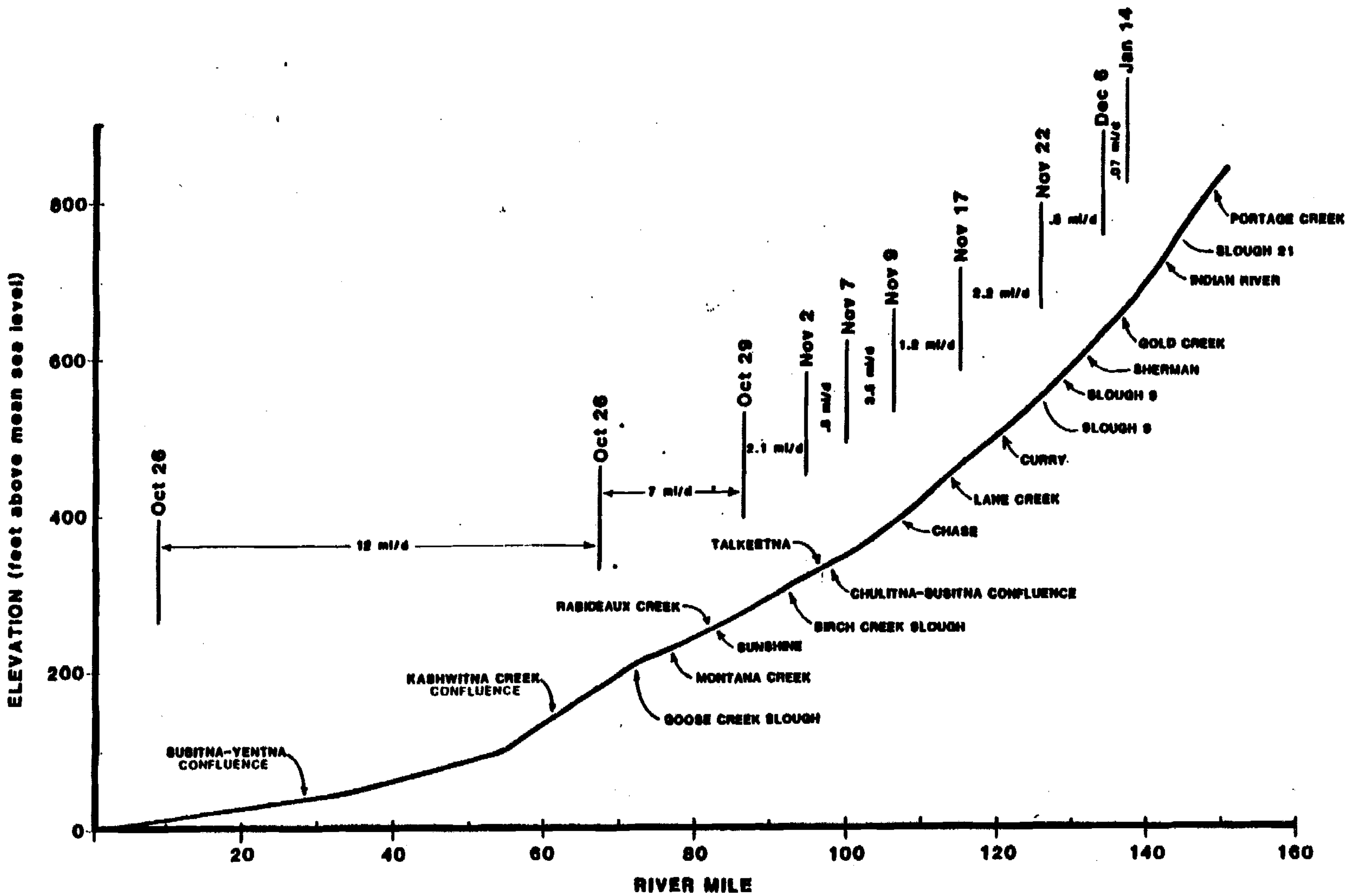
HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

ICE-FREE
WATER SURFACE PROFILE
TALKEETNA TO DEVIL CANYON

EXHIBIT 3	Sheet 8 of 8

From R&M Report: Susitna River Ice Study 1982-83



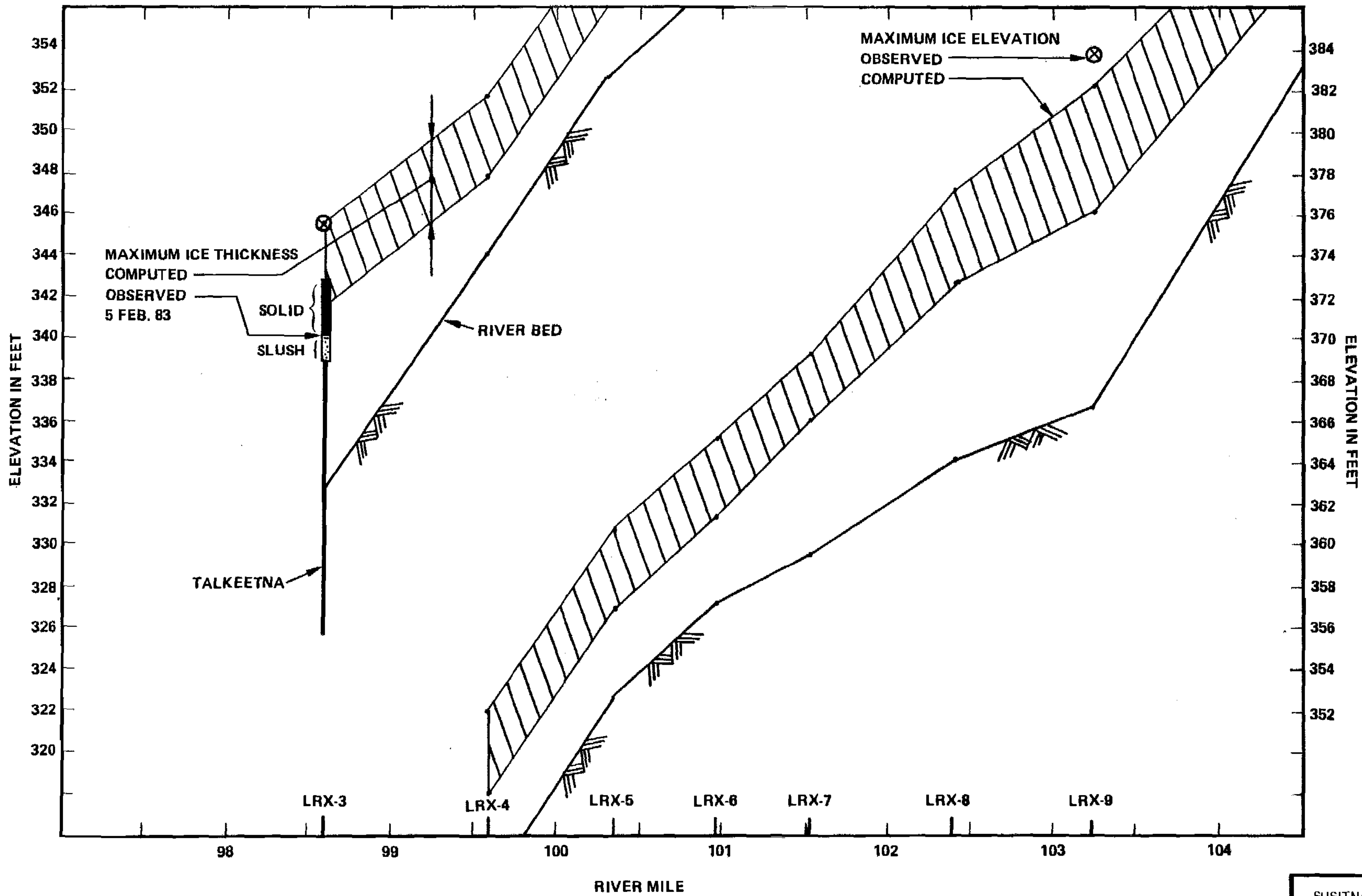
SUSITNA RIVER ICE LEADING EDGE PROGRESSION RATES (miles/day) RELATIVE TO THE THALWEG PROFILE FROM RIVER MILE 0 (Cook Inlet) TO RIVER MILE 155

Figure 4.3

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

HARZA-EBASCO

Exhibit 4

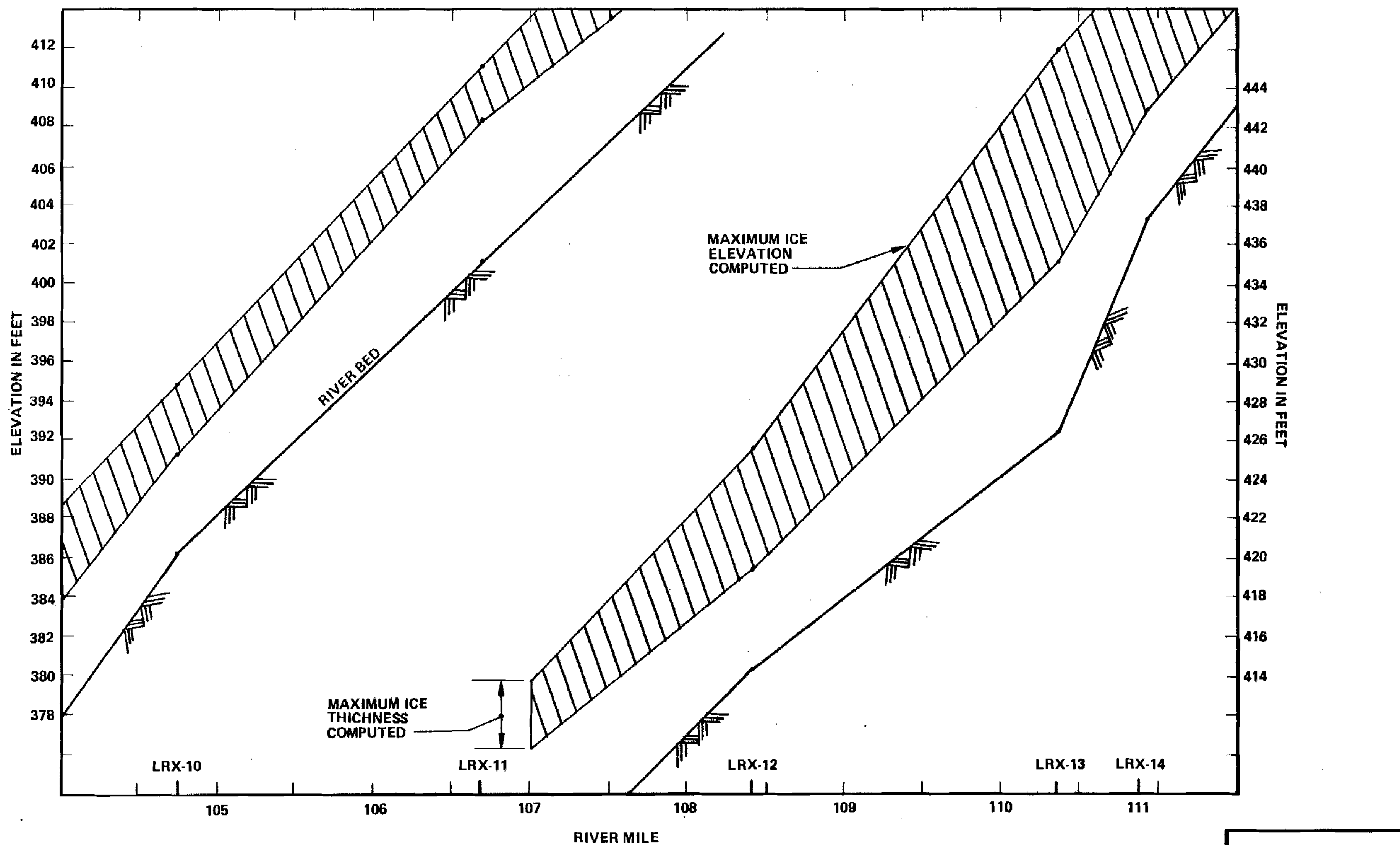


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1982 – 83 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 5 | Sheet 1 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

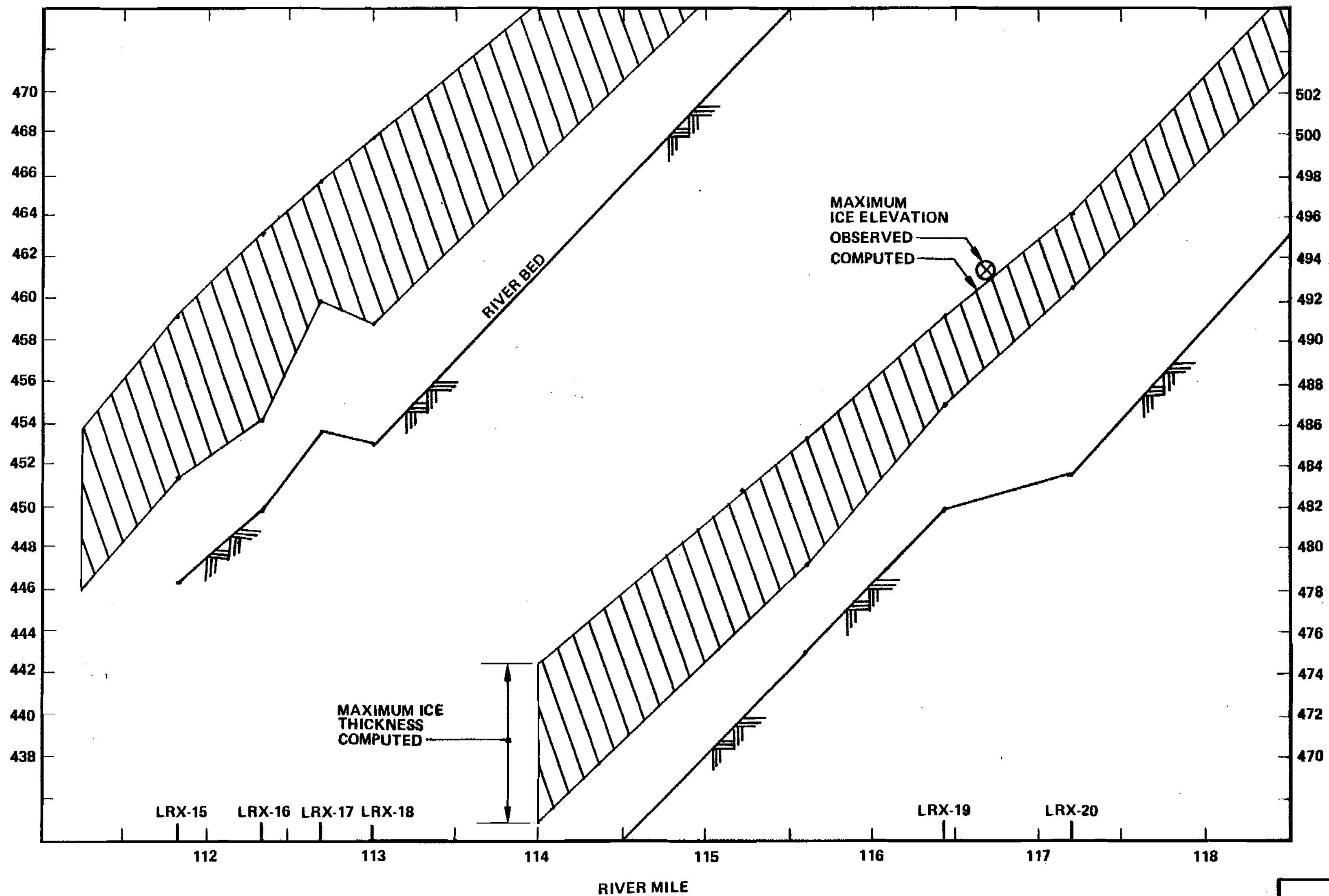


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1982 – 83 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 5 | Sheet 2 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

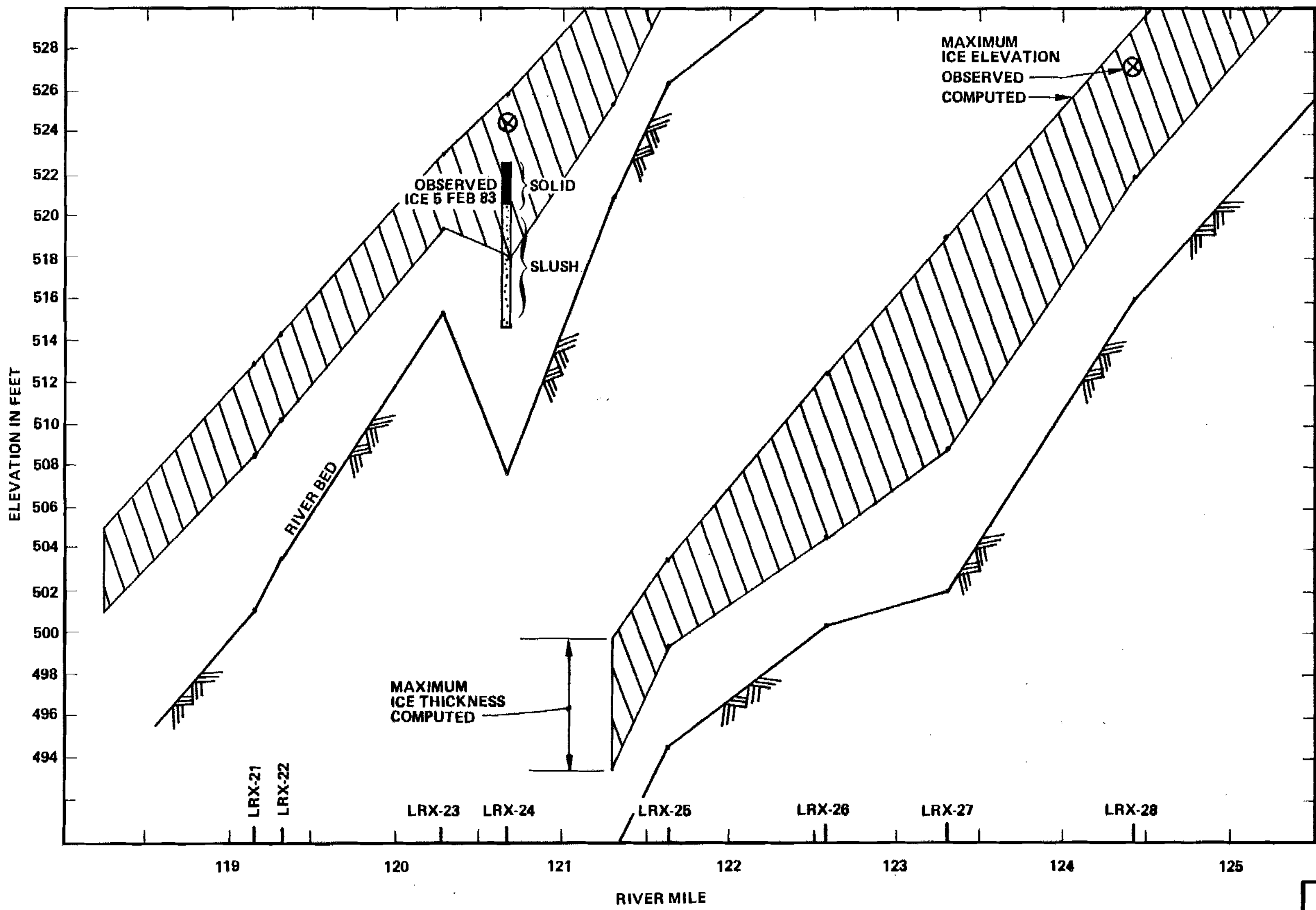


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1982 – 83 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 5 | Sheet 3 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

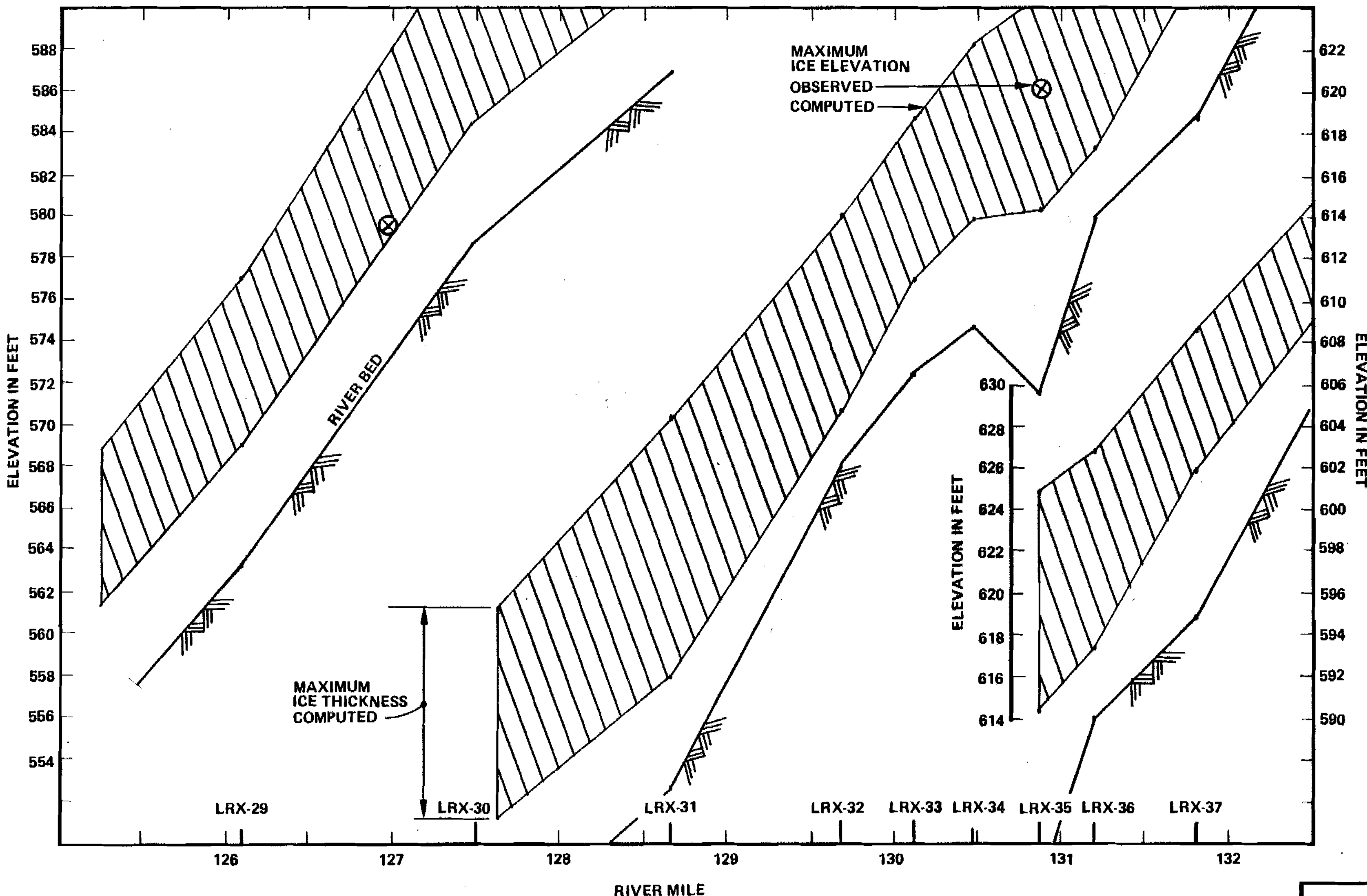


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1982 – 83 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 5 | Sheet 4 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

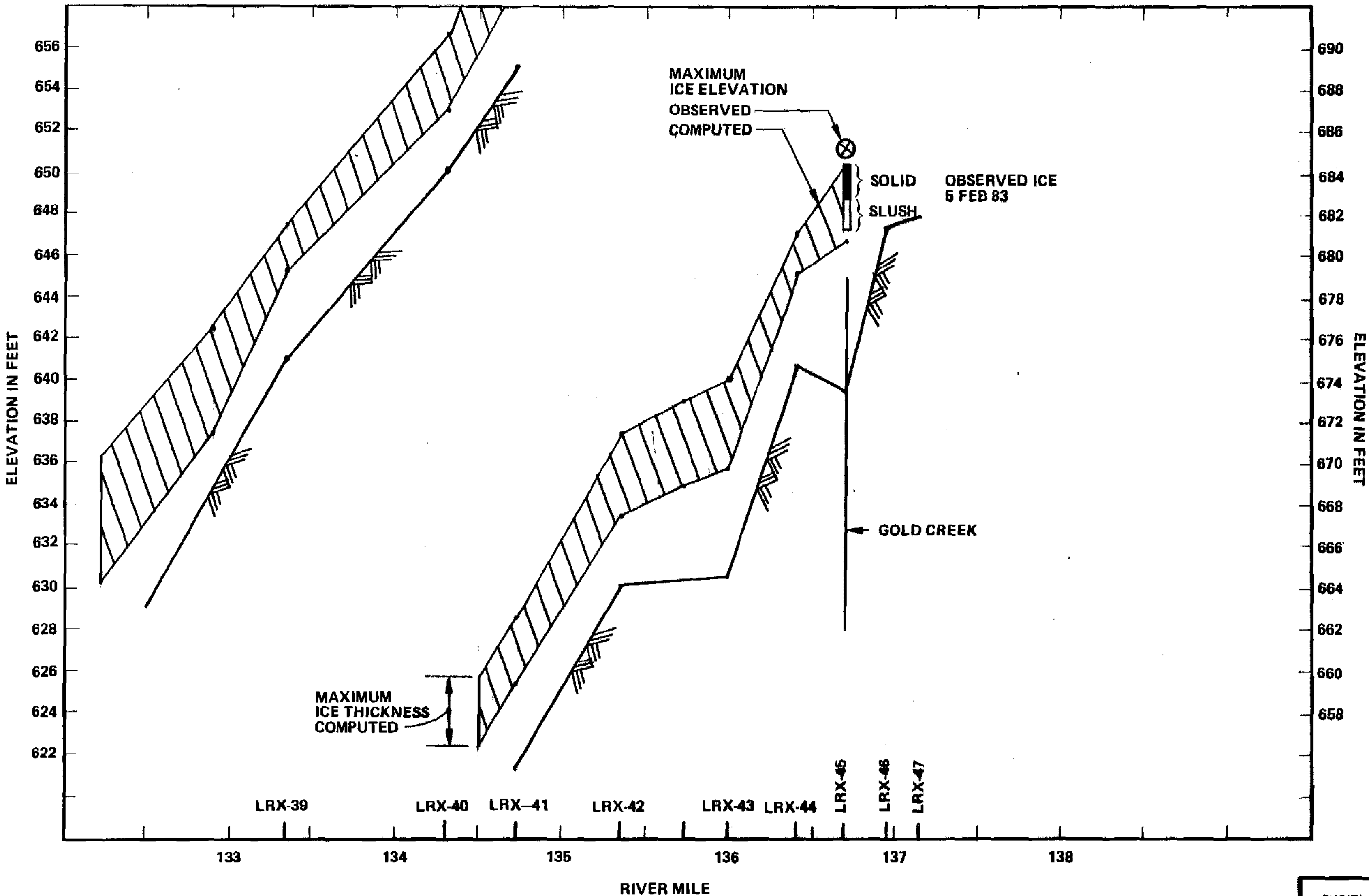


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1982 – 83 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 5 | Sheet 5 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984



SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

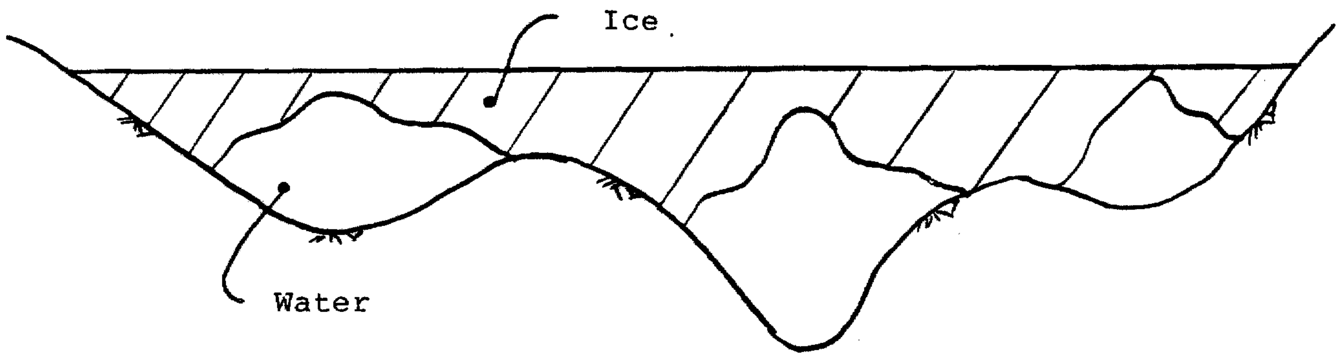
1982 — 83 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 5 | Sheet 6 of 6

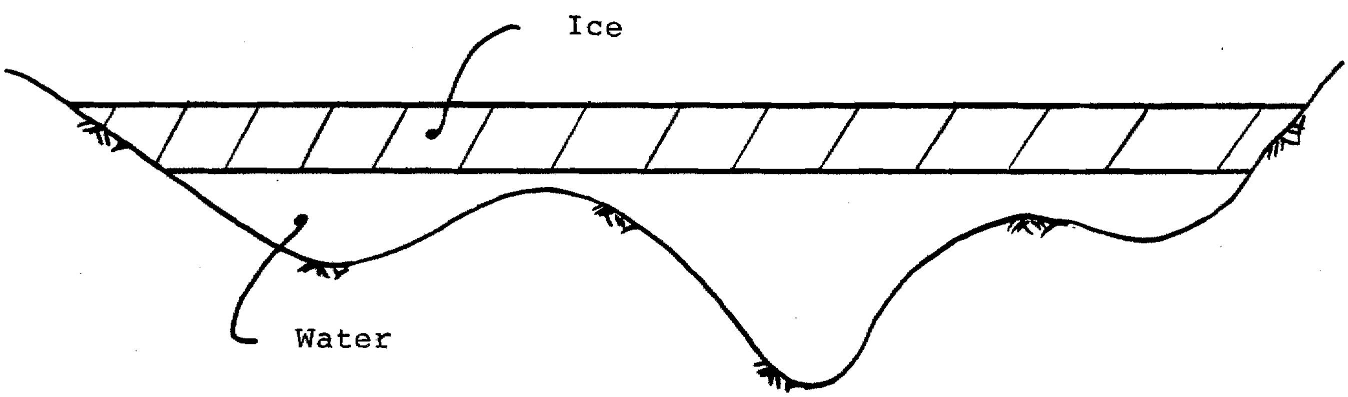
HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

Exhibit 6

Ice-Covered Cross-Sections

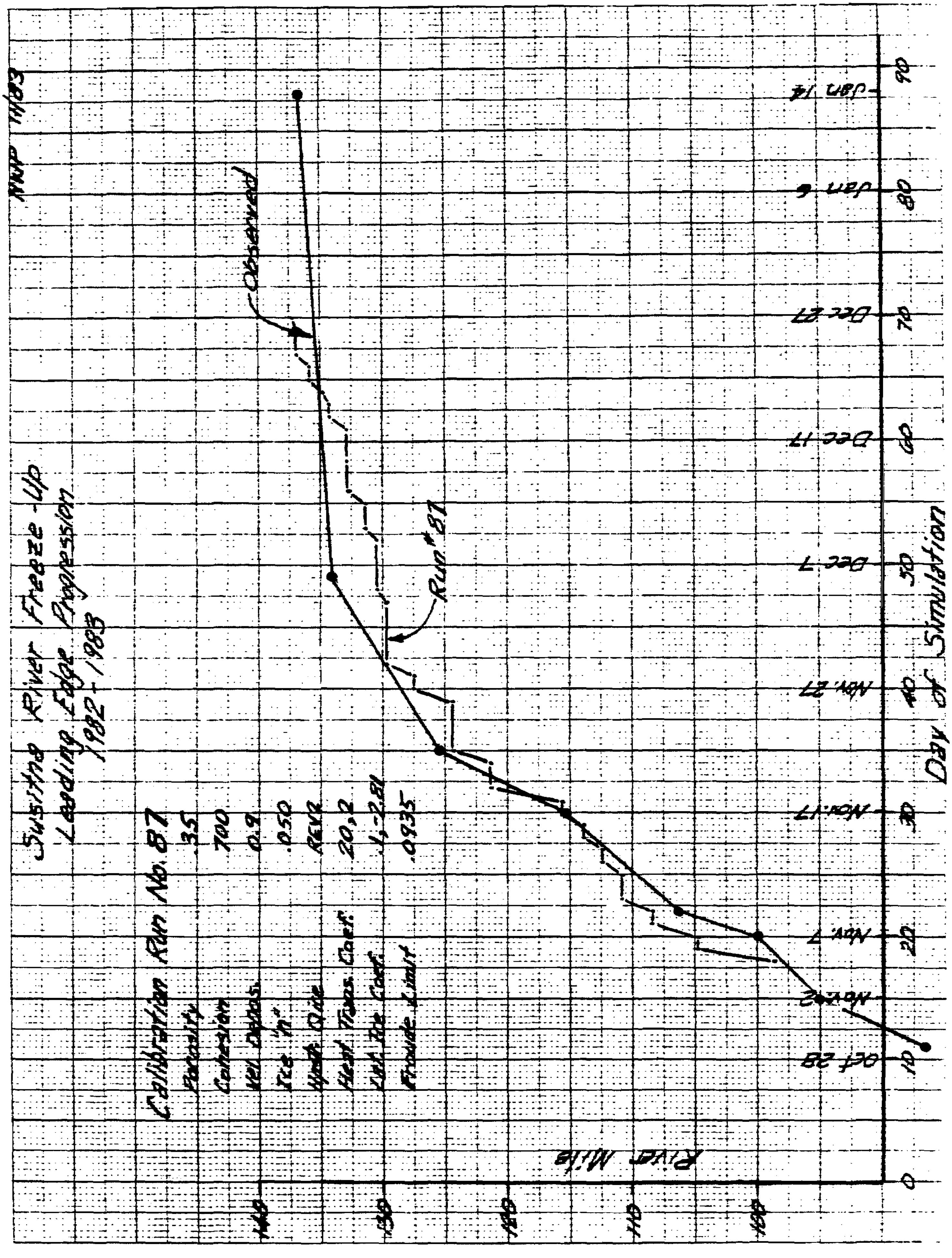


Actual Cross-Section

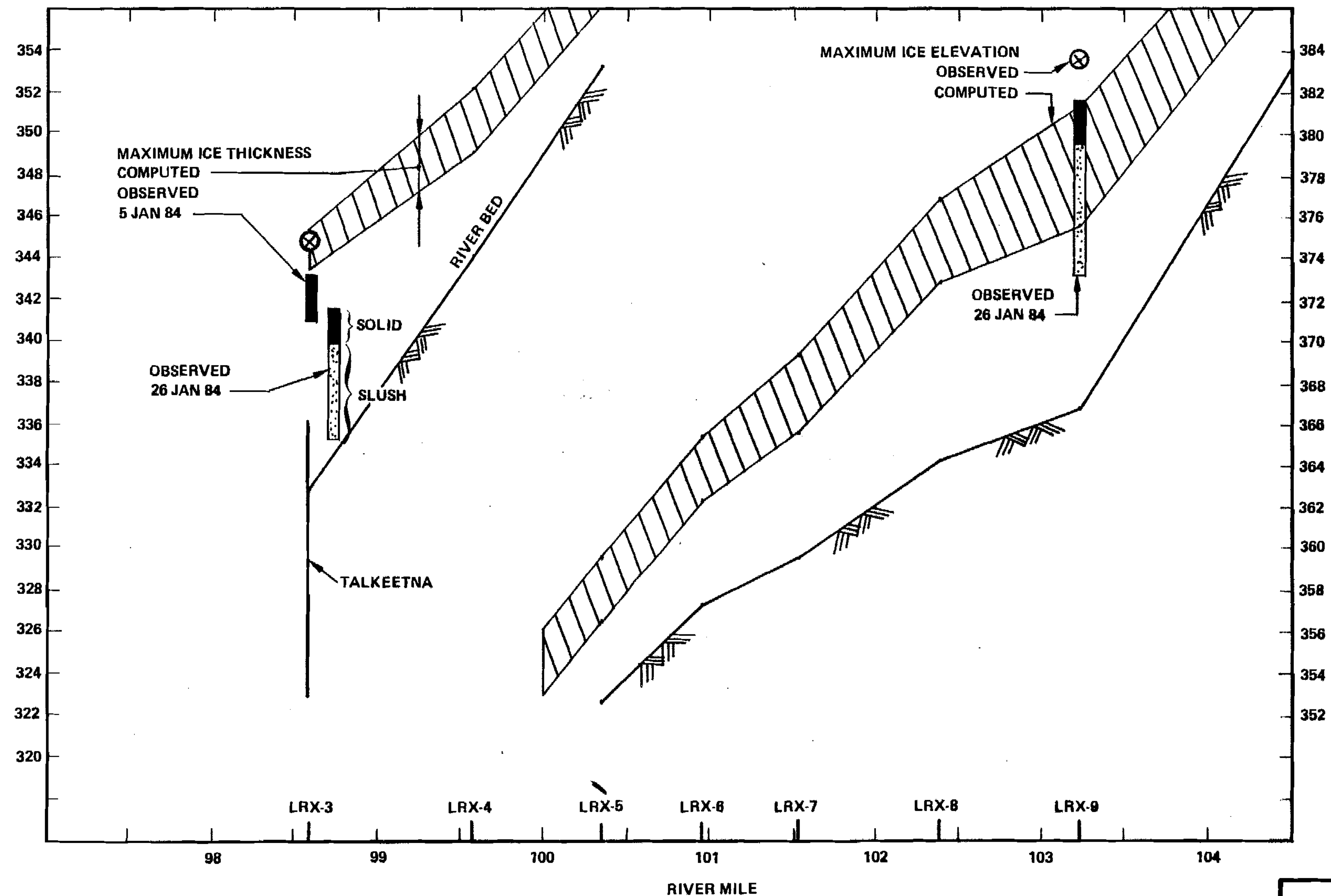


Model Simulation of Cross-Section

Exhibit 7



Susitna River Freeze-Up
Leading Edge Progression
1982-1983
RWP 11/83
Calibration Run No. 87
Cohesion 700
Ice "n" .050
REVR
Heat Trans. Coef. 20.2
1,-2.81
Froude Limit .0935
Observed
Run #87
Day of Simulation
River Mile
Oct 28
Nov 2
Nov 7
Nov 17
Nov 27
Dec 7
Dec 17
Dec 27
Jan 6
Jan 14
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140

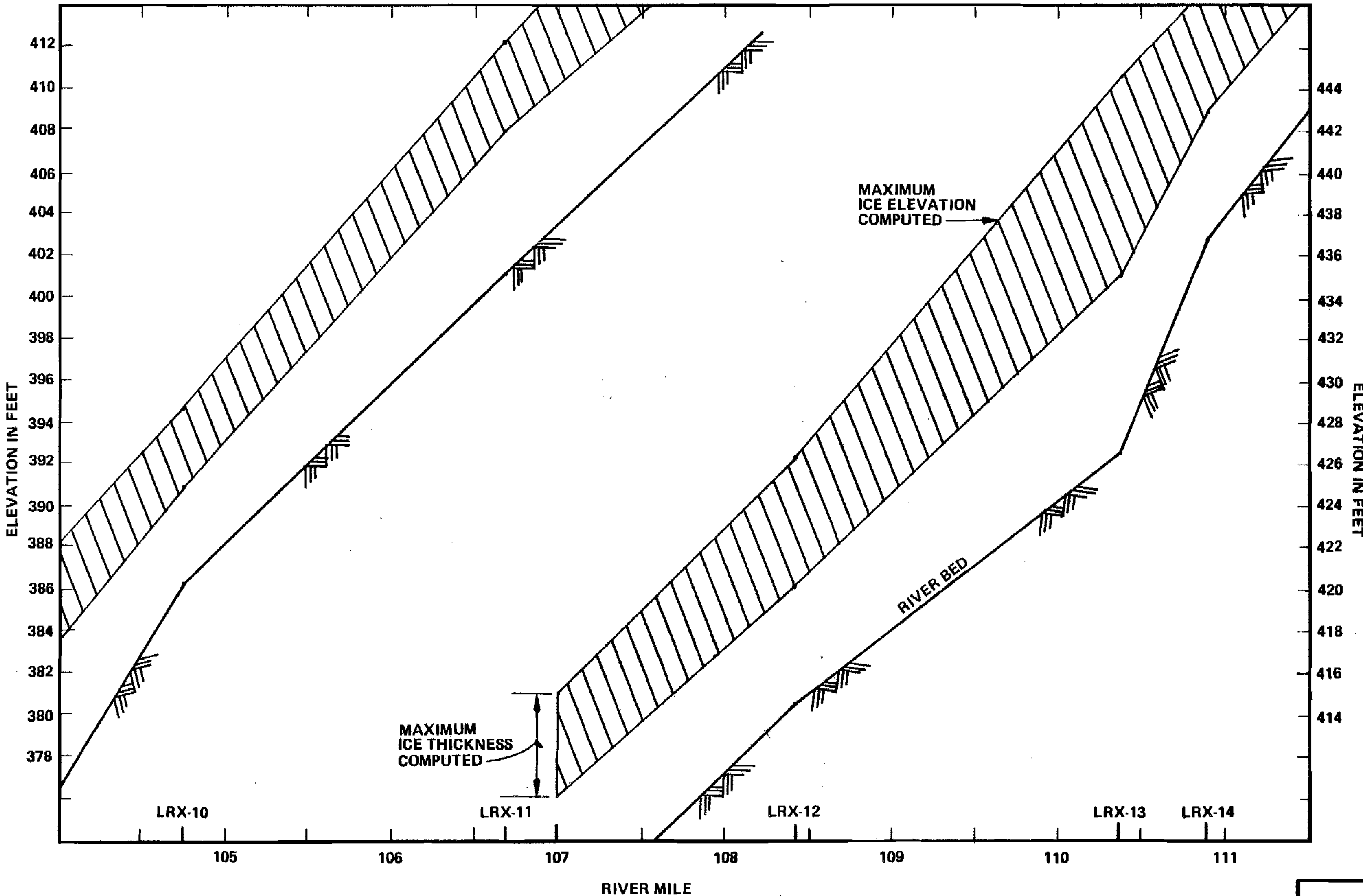


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1983–84 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 8 | Sheet 1 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

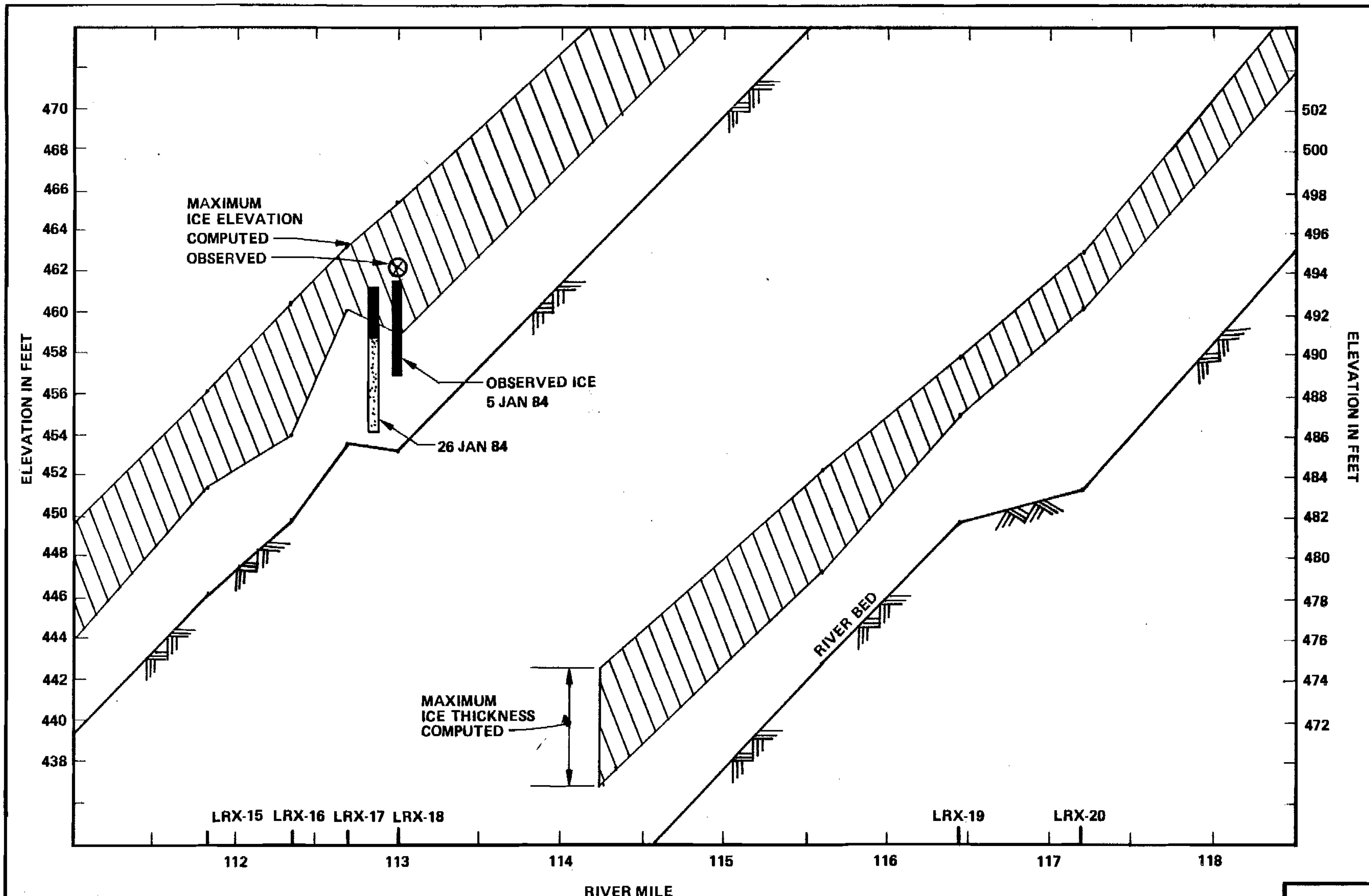


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1983–84 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 8 | Sheet 2 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

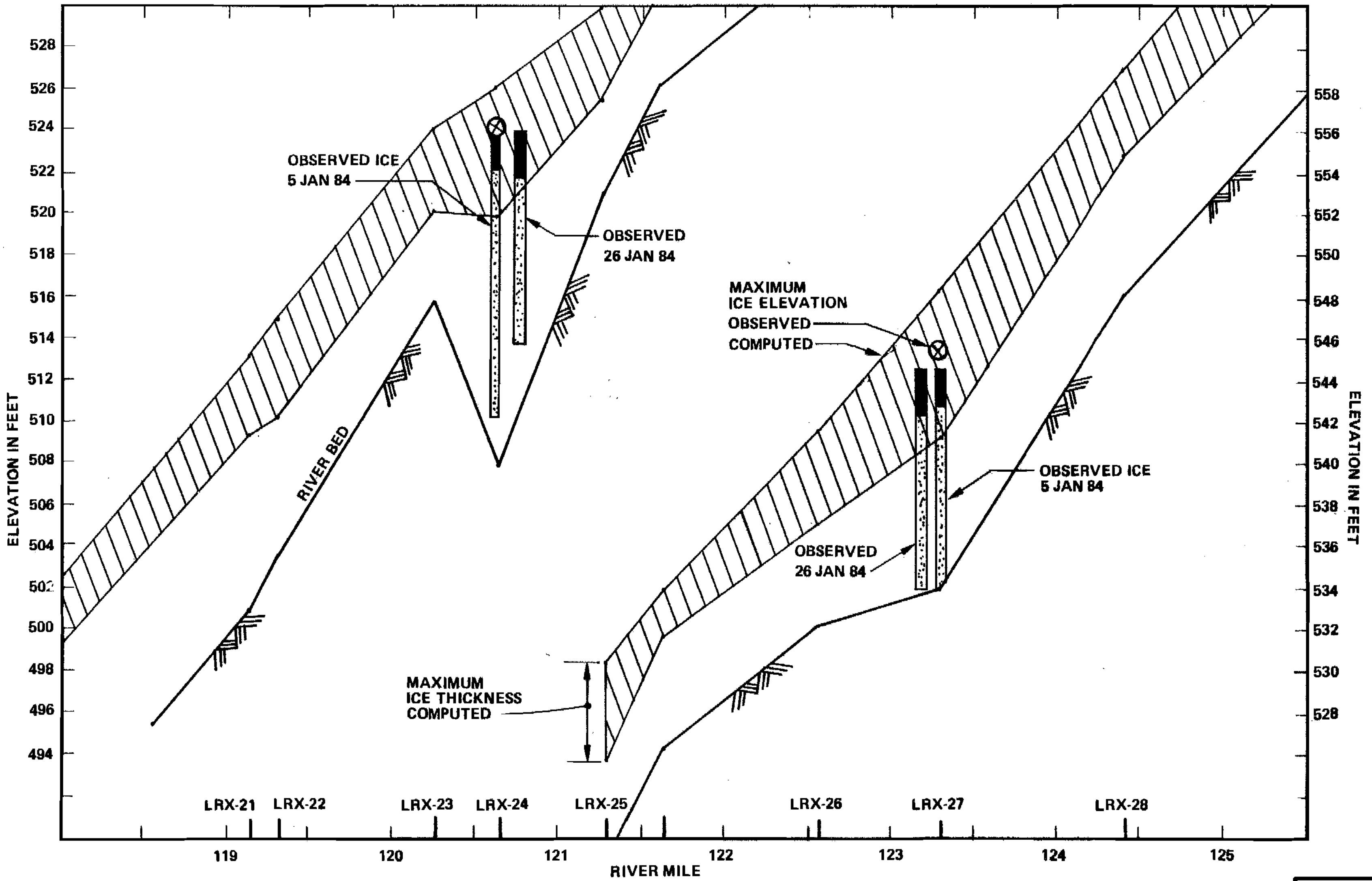


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1983–84 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 8 | Sheet 3 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

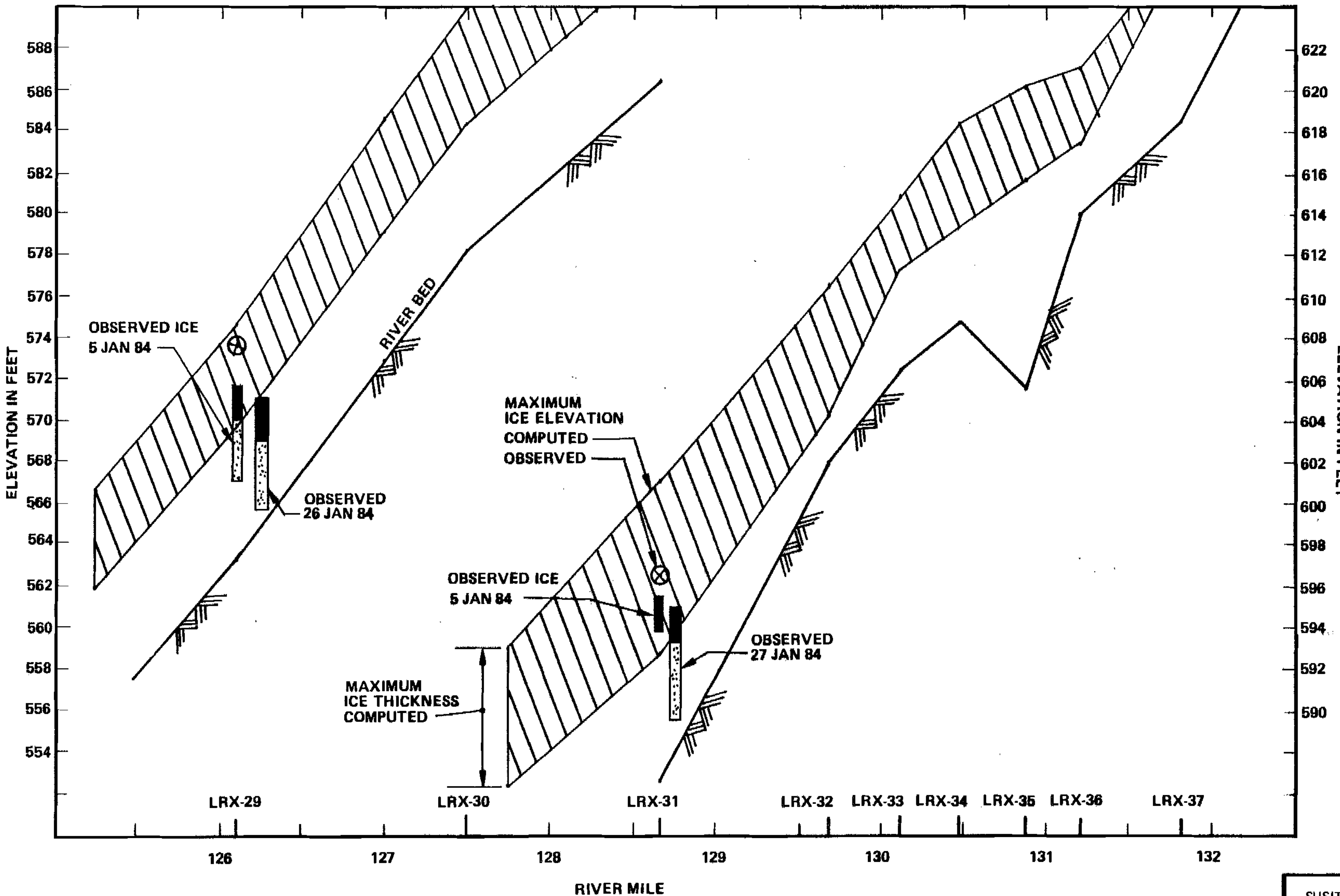


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1983–84 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 8 | Sheet 4 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

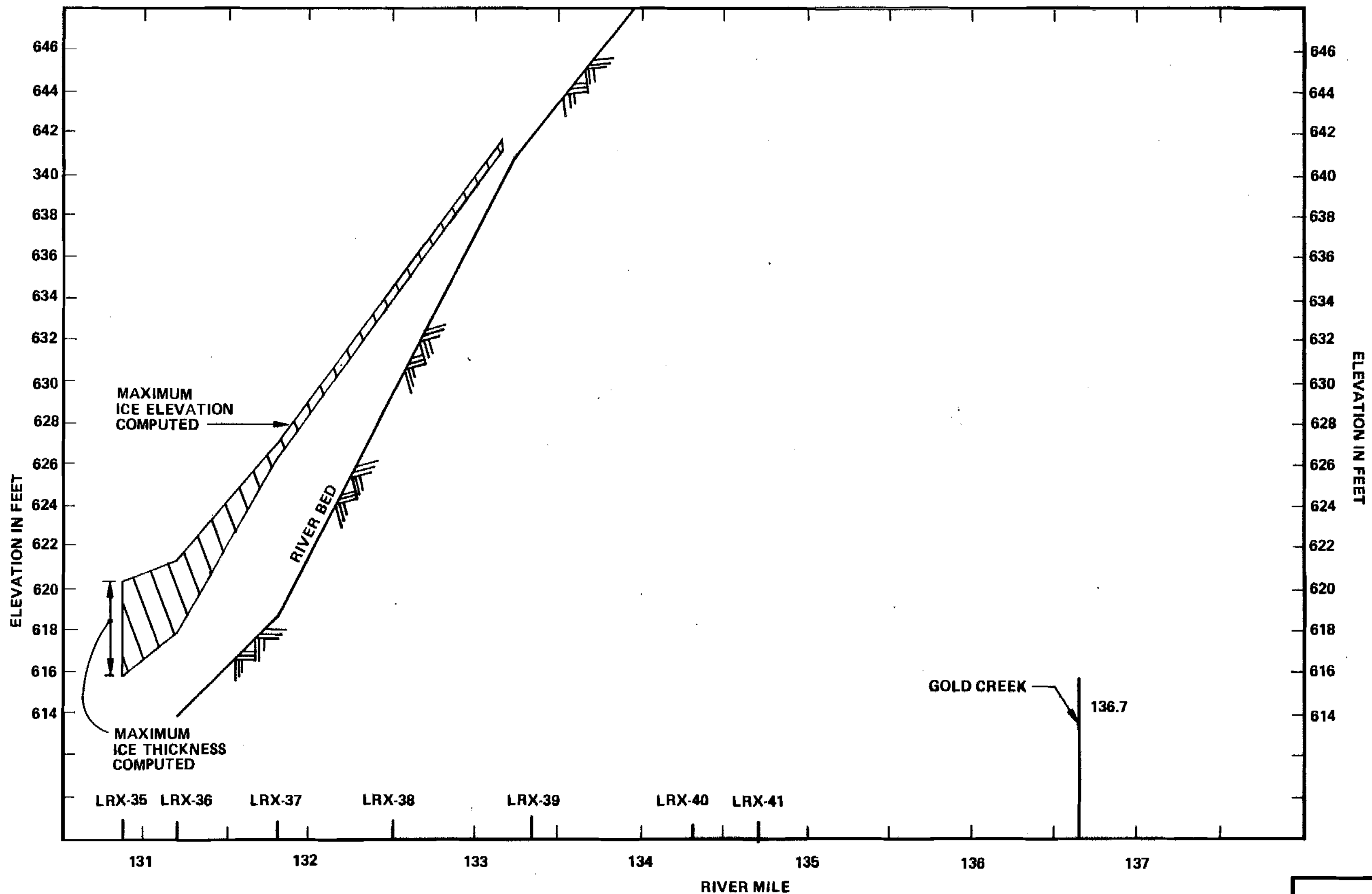


SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1983–84 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 8 | Sheet 5 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984



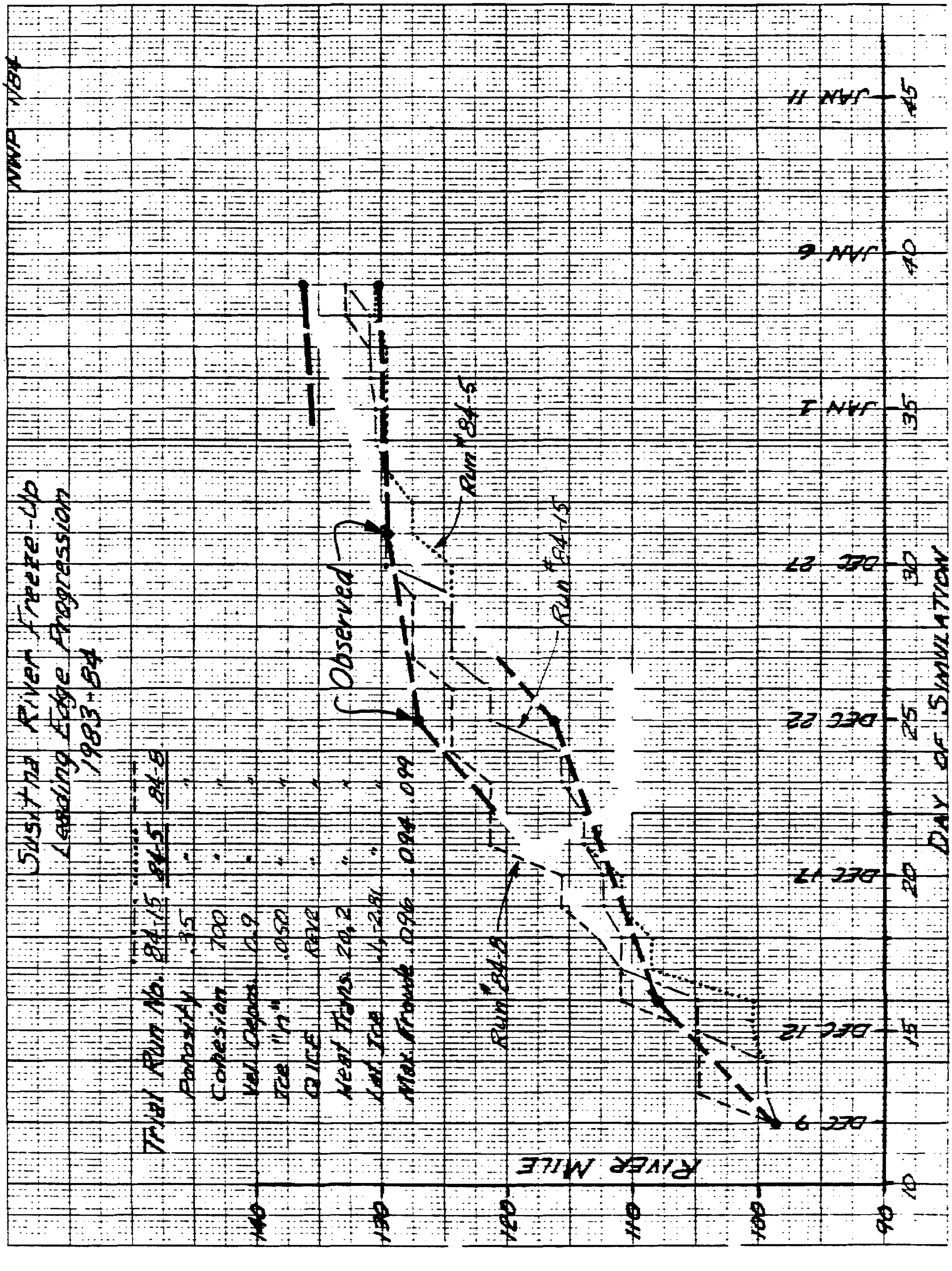
SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE MODEL CALIBRATION

1983–84 FREEZE-UP
TALKEETNA TO GOLD CREEK

EXHIBIT 8 | SHEET 6 of 6

HARZA-EBASCO SUSTINA JOINT VENTURE MARCH 1984

Exhibit 9


NWP 1/84
Susitna River Freeze-Up
Leading Edge Progression
1983-84
Trial Run No. 84-15 84-5 84-8
Porosity .35 " "
Cohesion 700 " "
Vel Depos. 0.9 " "
Ice "n" .050 " "
QICE REVE " "
Heat Trans. 20.2 " "
Lat Ice 1,281 " "
Max Froude .096 .094 .099
Observed
Run #84-5
Run #84-15
Run #84-8
River Mile
140
130
120
110
100
90
Day of Simulation
10
15
20
25
30
35
40
45
DEC 9
DEC 12
DEC 17
DEC 22
DEC 27
JAN 1
JAN 6
JAN 11

APPENDIX

INPUT DESCRIPTIONS - ICECAL

A. Five Read Files for Input Data

1. DESCRP - Set-up for 10 lines of 80 characters each, describing the project.

2. INITIL - Free format input data for:

   a) No. of days in simulation

   b) No. of cross sections

   c) No. of stations

   d) Stationing of meteorological stations (i.e., dist. along river in meters, use same base as river cross sectioning).

3. DISAIR - Free format

   a) Day

   b) Inflow Q (m^3/s)

   c) D/S W.S. Elev (m)

   d) Inflow Ice Discharge (m^3/day)

   e) Inflow Water Temp (^oC)

   f) Air temp, (^oC), up to 10 locations

   g) Wind velocity - (m/s), up to 10 locations

4a. CROSS

   a) Stationing of cross section (meters)

   b) Number of ground points in cross section

   c) Discharge factor as percentage of inflow Q

   d) Bed roughness - n_b

   e) Ice roughness - n_i

4b. CROSS

a) Distance, elevation

b) Distance, elevation

" "

" "

Repeat 4 a & 4b for each cross section

5. ICEMEC

a) Ice cover porosity

b) Erosion velocity (m/s)

c) Cohesion of ice cover (N/m^2)

d) Heat transfer intercept, (W/m^2-C^o)-a

e) Heat transfer slope , $\left(\frac{W\text{-}sec}{M^3\text{-}^oC}\right)$-b

$a + bV_w$

f) Lateral ice growth coefficient - c

g) Lateral ice growth slope - d

$L = cV^d$

SUB DEPOSI

When the ice cover cannot progress upstream, the incoming floating ice must be deposited under the ice cover as the leading edge remains stationary. This condition can occur before 1) a set of rapids such that the water level must rise and drown out the critical or super critical flow depth and then the leading edge can proceed and 2) when the flow velocity beneath the leading edge is too high that ice is transported d/s to increase the u/s water and decrease the velocity below the erosion velocity value.

The ice deposits in a d/s direction, filling each section until the critical velocity is reached. Then it progresses to the next d/s section. This process generates what is called a "hanging dam."

The ice discharge that comes into the section is distributed within the downstream reach, and if the reach cannot accept all incoming ice, it is transported to the next downstream reach and so on.

SUB VELPRO

This routine calculates the progression of the ice cover usptream. The ice cover porosity in the leading edge is assumed to be 0.5. The porosity is probably related to the velocity, but a constant value is normally adequate.

SUB HYDTHC

This subroutine determines the initial thickness of the slush ice cover as it progresses upstream (i.e. prior to any underice deposition). Based on "Formation of Ice Covers and Ice Jams in Rivers" by Pariset, Hausser and Gagnon, 1966, two possible mechanisms for ice cover progression are considered;

(1) Hydraulic Progression, applicable to "narrow" rivers, in which a stable ice thickness is determined by hydraulic conditions at the leading edge of the ice cover. The theoretical governing equation is

$$V = \sqrt{2gt\left(1 - \frac{\rho'}{\rho}\right)}\left(1 - \frac{t}{H}\right)$$

Where V, H = Velocity, depth just upstream of ice cover

t = thickness of advancing ice

ρ' = density of ice cover

It can be shown that a solution exists for the above equation only when a modified Froude No., $V/\sqrt{2gH}$, is less than a certain maximum value which corresponds to t/H = 1/3. When $V/\sqrt{2gH}$ exceeds the maximum value, incoming slush ice is swept underneath the leading edge of the ice cover and no progression takes place. Researchers have suggested that this maximum Froude No. may vary from .06 - .11.

(2) <u>Shoving</u> is applicable to "wide" rivers and is the mechanical consolidation of an existing ice cover which has insufficient thickness to resist the river forces. Successive shoves increase the ice thickness until it reaches a stable level. The governing equation for this stable ice thickness is

$$\frac{BV_u^2}{\mu C^2 H^2}\left(1+\frac{\rho' t}{\rho R}\right)=\frac{2\alpha t}{\rho g \mu H^2}+\frac{\rho'}{\rho}\left(1-\frac{\rho'}{\rho}\right)\frac{t^2}{H^2}$$

where Vu = velocity under ice cover

B = channel width

μ = coefficient of internal friction for ice

C = Chezy coefficient of friction

R = hydraulic radius

α = cohesion of ice cover

The model provides for the following possibilities in determining the ice cover progression:

a. Hydraulic conditions just upstream of the ice cover show a Froude No. greater than the maximum. Therefore, no advancement can occur.

b. Froude No. is less than maximum value. Both Hydraulic Progression and Shoving equations are then solved for t. The mechanism which results in the greater t controls.

SUB UNDAVC

This subroutine determines whether erosion or deposition is occurring beneath the ice cover. The critical velocity is read in as input. Typical values reported in literature range from 0.6 m/s to 1.4 m/s. The high values for the velocity are when the frazil ice is very active and the low values are for inactive frazil ice. The air temperature is sometimes used as a basis for the correction factor to account for this spread in erosion velocities.

Temp	Vc
0^{o} to -7^{o}C	0.9 m/s
-7 to -19^{o}C	0.9/0.95 m/s
-18 to -30^{o}C	0.9/0.9 m/s

SUB ICEPRO

Computes the frazil ice production in the open water reaches. Uses the heat transfer coefficient approach to determine the heat loss from the water surface. The ice discharge (daily) for a reach is computed and printed in the d/s section output.

$$Qi = - h_w B(\Delta X) Ta * 86{,}400 / \rho' \lambda$$

$h_w = a+b\, V_w$ (heat transfer coefficient)

V_w = average wind speed

a = 3 (input)

b = 4 (input)

B = average open water width between cross sections

ρ' = density of ice

λ = heat of fusion for ice

T_a = average air temperature (below 0^{o}C)

ΔX = distance between cross-sections.

SUB LATICE

Lateral ice cover growth. Empirical relationship developed from Newbury's field data for river flowing with a heavy concentration of slush ice and air temperatures - $10^{o}C$.

$$\text{Latic} = aV^{b}$$

Latic = ice growth from both shores

a = constant = 0.1

b = constant = 2.8

V = open water velocity at the cross section

SUB SUMQI

Subroutine keeps track of ice discharge in the downstream direction, i.e., a summation routine for ice continuity.

SUB LCMELT

This subroutine allows for lateral ice cover melting in accordance with Ashton (1979).

SUB ICEGRO

Computes the solid ice growth at each cross section on ice cover forms. When the solid ice growth overtakes the initial cover thickness, the initial cover thickness values are set equal to the solid ice cover value for printout purposes. The ice thickness equation is

$$t_i = t_i^{-1} + \Delta t_i$$

t_i = predicted ice thickness, m.

t_i^{-1} = previous day ice thickness, m.

Δt_i = incremental ice thickness growth per day, m.

$\Delta t_i = T_a * 86400/(\rho * \lambda * e)/(t_i^{-1}/ K_i + 1/H_a)$

T_a = reach ave. air temp below 0°C

K_i = thermal conductivity, W/m-°C

H_a = surface heat exchange coef, W/m^2-°C

e = porosity of ice cover

λ = heat of fusion of ice, J/kg.

ρ = density of ice, kg/m^3.

SUB ICWTDK

Computes the water temperature decay beneath an ice cover and melts the ice cover thickness accordingly. The computation begins at the U/S boundary and progresses downstream. Reach averaged values are used for the hydraulic and meteorological variables.

The equation from Ashton (1979) and Calkins (1983):

1. $T_{wl} = (T_{wo})$ exp $(h_{wi} * \Delta X / \rho C_p$ Vuh

2. $h_{wi} = 2 * k_w * f * Re * Pr / \Delta x (8*D*(1.07 + 12.7 f/8 Pr^{.667} - 1))$

T_{wo} = water temperature at upstream section

T_{wl} = water temperature at downstream section

h_{wi} = heat transfer coefficient at ice/water interface

ΔX = distance between reaches

h = average depth

V_u = average velocity beneath ice cover

R_e = Reynolds Number = $\frac{Vuh}{2\nu}$

f = Darcys friction factor for the ice cover

K_w = thermal conductivity of water

P_r = Prandtl Number = $\mu\ C_p/K_w$

SUB OWTDK

Computes the water temperature in an open water condition beginning at the most u/s section. The u/s boundary condition is a water temperature value.

The temperature preduction at the next d/s cross section is based on the reach average of the hydraulic and meteorological variables. The equation is from Ashton (1979):

$$T_{wl} = (T_{wo} - T_a) * \exp (h_w^* \Delta X / \rho \; C_p V \; H) + \quad Ta$$

T_a = reach average air temperature

T_{wo} = water temperature at upstream section

T_{wl} = water temperature at downstream section

h_w = reach average heat transfer coefficient

Δ X = distance between cross sections

ρ = density of water

C_p = specific heat capacity of water

H,V = reach average depth, velocity

$h_w = a + bV_w$

a = constant = 3

b = constant = 4

V_w = average wind speed

SUB TRAVEL

Computes the travel time from one cross section to another for either open water or ice covered conditions.

SUB AIRDIS

Computes the air temperature and wind speed at every cross section location on a daily basis. The daily air temperature and wind velocity may be input at up to 10 sites along the river. The location along the river for each meteorological site must be input, measured from the downstream cross section. A linear interpoloation between met sites is used to determine intermediate values.

SUB CONVEY

Computes the flow conveyance for each section. The program tests for the ice cover to decide which conveyance will be used, i.e., open water, lateral ice + open water, or fully ice covered.

SUB CHNGEO

Computes the geometric elements for the cross section with or without the ice cover. The intersection pts of the water level with the banks is solved using the surveying procedure of latitudes and departures. The area is solved using the trapezoidal rule both in the open water and beneath the lateral ice cover.

SUBROUTINE BKWTR

Computes a backwater profile using the procedure followed by the HEC-2 program. The program tests if an ice cover is present and computes the profile with or without ice at a particular section.

The program checks for critical depth using the same test as HEC-2 ($V^2/2g > 0.95$ A/2 x Top width). If the test is positive, the program computes critical depth for that section and proceeds upstream.

An ice cover cannot exist with critical or super critical flow. The downstream water levels have to rise to drown out the critical depth section before the leading edge can progress upstream.

During the deposition of ice beneath the cover the program may thicken the ice cover to where the flow hydraulics indicates critical depth. When this occurs, the program reduces the ice thickness at the section until the test for critical depth passes.

HYDRAULICS, MECHANICS AND HEAT TRANSFER FOR

WINTER FREEZE-UP RIVER CONDITIONS

by

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ICE MECHANICS AND HEAT TRANSFER

The study, analysis or prediction of water levels in rivers during the winter requires a knowledge of the flow hydraulics, the ice mechanics and the heat transfer processes in the river system. All three occur simultaneously and to properly analyze or predict a certain quantity such as river stage means they have to be understood to some degree. Figure 1 is a flow chart representing the possible phases a river might follow during the freeze-up condition. See Appendix II for a list of selected reference.

<u>Conditions Leading to Ice Bridging</u>

Basically the river flow must cool to its freezing temperature, ≈0.0°C before any ice production can be significant. Once the river has cooled to its freezing point ice generation begins and the lateral ice cover grows from the shore (shore ice), anchor ice may form on the bed and ice is transported downstream. These processes continue until a section is reached where the ice cover fully bridges the river (also known as ice arching).

The ice cover now can begin to progress upstream as well as continuing to grow laterally in the open water reaches. The rate of upstream progression is a function of the flow hydraulics, and the mechanical properties of the incoming ice and downstream cover. The air temperature has an effect on the physical and mechanical properties of the moving and stationary ice, although it is not well documented.

The following analysis assumes the river flow has been cooled to the freezing temperature. The procedures and analytical developments given by Ashton (1979) can be applied to determine the time at which the river flow reaches 32°F (0°C), or one can develop his own heat loss model.

The following physical processes are occurring simultaneously in a river reach during the freeze-up period.

1a Ice Production: The equation for predicting the volume of ice discharge is

$$Q_i = \frac{h_{iwa} A_o T_a}{\rho \lambda} \quad \left(\frac{m^3}{S}\right) \qquad [7]$$

where h_{iwa} = ice production heat transfer coefficient W/m^2-°C

A_o = open water area m^2

T_a = air temperature below 0°C

ρ = density of water Kg/m^3 (1000)

λ = heat of fusion J/kg (3.34×10^5)

1b Ice Floe Growth, (flocuation): The growth of ice floes traveling downstream is often viewed as a flocuation process, but it is one that is not well understood. The growth of the floes result in larger floe sizes and increased thickness. It is suspected that the flocuation process depends upon the ice discharge (especially at the surface), flow velocity, air temperature and the channel characteristics.

1c Lateral Ice Cover Growth (shore ice): The shore ice or lateral ice cover growth is another area of inadequate documentation. An empirical relationship relating the lateral growth (L_i) to the mean flow velocity (V, m/s) for a Northern Canadian river (Newbury 1968) yielded

$$L_i = 1.8\ V^{-2.85} \quad m/day \qquad [8]$$

where the surface ice concentration was nearly 100% and the thickness of the slush ice cover moving downstream was estimated at 15 cm. Also, the air temperature was less than -20°C. For lower ice concentrations and warmer air temperatures the intercept value will decrease and the negative slope will also decrease in magnitude, i.e. (-2). Recently a study on a small New England stream showed the overall lateral growth rate ranged from 0.1 to 0.2 meters per °C day, where the average freeze-up flow velocity was roughly 0.7 to 0.8 m/s with low surface ice concentrations.

1d <u>Flow Hydraulics with Laterally Growing Ice Cover:</u> The flow velocity distribution in a partially ice covered stream has been evaluated analytically, documented in the field, and experimentally measured in a flume. The flow velocity concentrates in the open water portion and can be described as a ratio

$$\frac{V_2}{V_{\cancel{2}1}} = 0.63\,\frac{n_b}{n_c}\left[1.0 - \frac{\rho_i}{\rho}\,\frac{t}{y_1}\right] \qquad [9]$$

where V_2 = flow velocity beneath ice cover segment

V_1 = flow velocity in open water segment

y_1 = flow depth in open water segment and

t = ice cover thickness.

The paper by Calkins et al. (1982) contains the derivation for the above equation plus additional information on the assumptions used to derive the expression.

Somewhere along the river reach the ice cover will completely bridge from shore to shore. Determining the location of this bridging may be the location of a natural construction; i.e. a wide river bend is a classical site. The asymetric flow distribution leads to a rapid lateral ice cover growth in the bend which causes the open water width to decrease. This in turn creates a surface constriction for the ice floes traveling downstream, where the floe size may be increased which significantly enhances their arching capabilties. Predicting the ice bridging locations from an analytical standpoint is not possible at this time with any confidence.

Once the ice cover bridges, progression upstream of the leading edge is governed by the incoming ice discharge, flow hydraulics, ice mechanics and the air temperature.

Ice Cover Progression and Thickening

The most logical step to determine the progression and thickening of the ice cover would be to write down the continuity equation for ice discharge. The ice inflow to a river reach or to the leading edge of the ice cover is

$$Q_i = C_i V_s B_1 t_s (1-\varepsilon_s) \qquad [10]$$

where Q_i = ice discharge m^3/s

C_i = surface ice concentration %

V_s = surface flow (m/s)

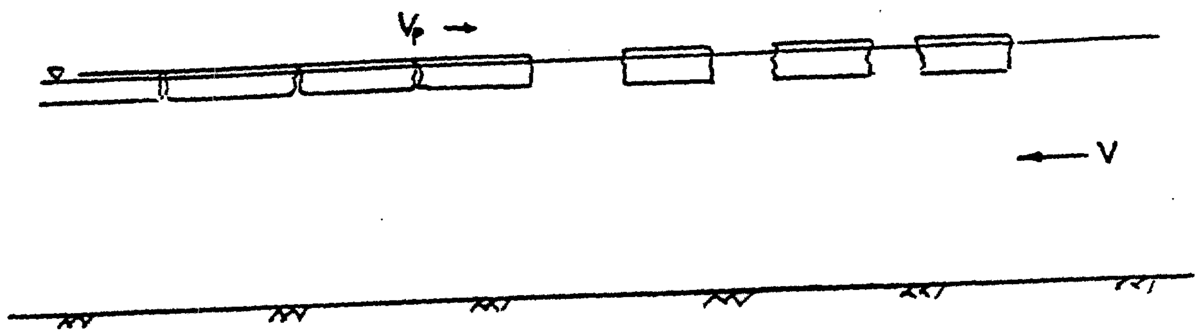
B_1 = open water width (m)

t_s = equivalent thickness of the floating ice (m)

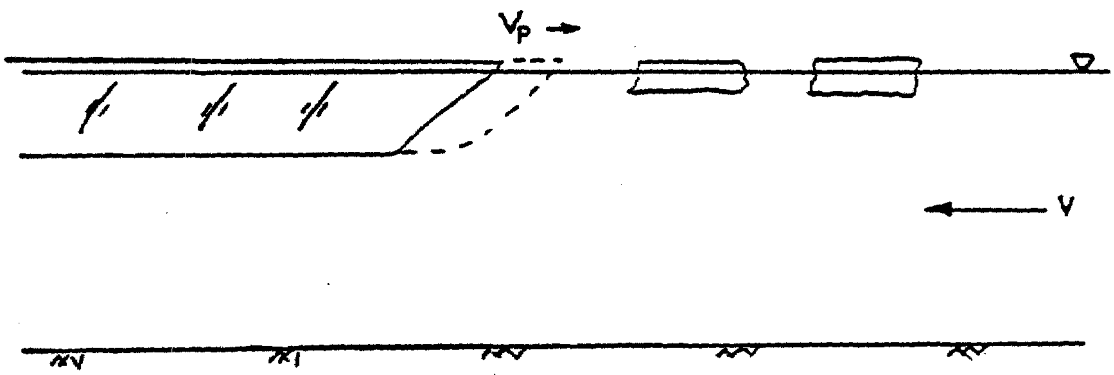
ε_s = porosity of the floating slush.

The amount of ice that is not floating at the water surface is a small quantity and is considered negligible for sub critical flows in channel slopes of 0.002 or milder. There are four possible conditions for the progression of the leading edge, V_p.

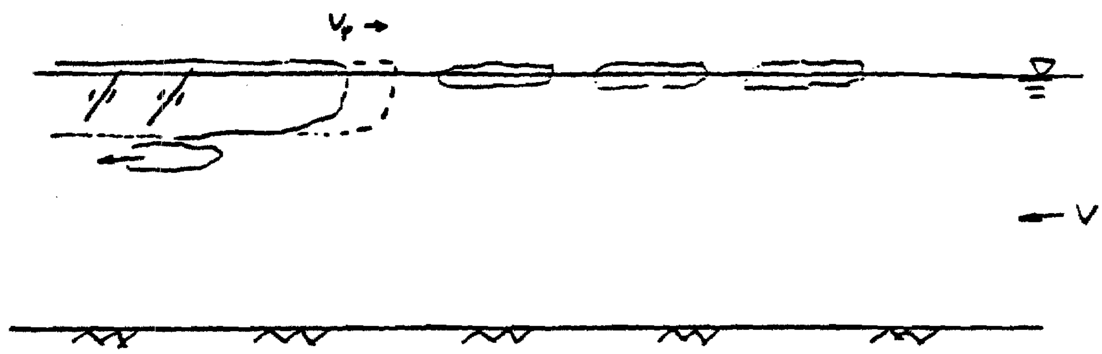
1. Progression by simple juxtaposition of the arriving floes with no thickening.



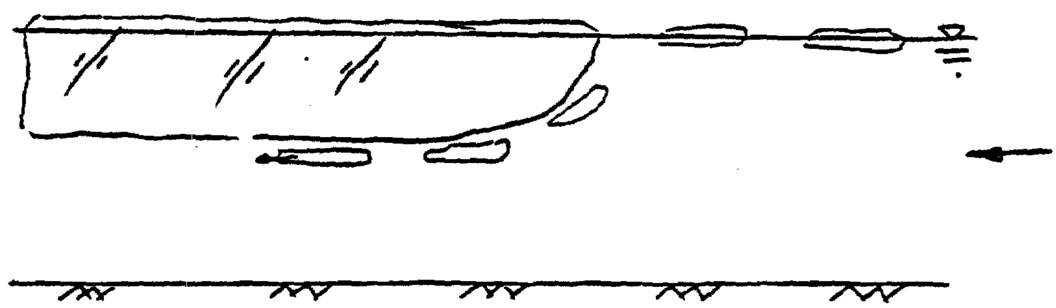
2. Progression, but the arriving floes thicken to values greater than the initial thickness of the arriving ice, $t_j/H < 0.33$, or $t_j/H > .33$.



3. Progression with ice cover thickening and ice also being transported beneath the cover.



4. No progressing of the cover, all ice is transported beneath the cover.



The type of condition encounted above depends upon the flow hydraulics upstream of the cover or beneath the cover, the ice discharge and size of the floes, the mechanics of the ice accumulation and the air temperature.

Juxtaposition:

The progressing of the leading edge by ice floe juxtaposition results in a rapid cover development. Analytical formulations have been put forth and experience usually dictates the choice. If the thickness and planar dimension of the arriving floes can be predicted, their stability can be analyzed. If the flow velocity just upstream of the leading edge is less than some critical velocity for the ice floe to underturn, dive or be entrained; the arriving ice floe will remain stable and come to rest against the leading edge. Ashton (1978) presents this equation

$$V_c = \frac{2\left(1 - \frac{t_s}{H}\right)\left[g t_s \left(1 - \frac{\rho_i}{\rho}\right)\right]^{1/2}}{\left[5 - 3\left(1 - \frac{t_s}{H}\right)^2\right]^{1/2}} \qquad [11]$$

When the river flow velocity $V > V_c$, the solid ice floes (not frazil slush floes) will go under the cover; H = flow depth just upstream of the leading edge.

Progression, Thickening and No Undercover Transport

1. The equation describing the equilibrium thickness of the ice cover (t_j) when the value of t_j/H is less than 0.33 is related to the flow velocity upstream of the cover (Pariset et al., 1961)

$$V = \left(1 - \frac{t_j}{H}\right)\left[2 g t_j \left(1 - \frac{\rho_i}{\rho}\right)\right]^{1/2} \qquad [12]$$

The use of this equation implies the forces along the bank are sufficient to withstand the internal forces within the ice cover which are greater than the driving forces such that no shoving or further thickening can take place. In other words, the thickness at the leading edge is sufficient to transmit the forces to the bank, even when the leading edge at a new time has progressed upstream. The driving forces of water shear stress and the cover weight component are small. The limitation of $t_j/H = 0.33$ must be checked because a different mode of thickening will occur at $t_j/H >$ 0.33. The use of this relationship will be for long backwater reaches where the flow velocity is low and river is not very steep. See Pariset and Hausser (1961, 1966) for further details.

2. The majority of ice cover thickening occurs as a result of crushing or shoving of an ice cover sometimes called staging. The cover may initially progress upstream according to equation [12] just presented, but in order for the leading edge to progress further upstream the ice cover has to thicken by shoves to withstand the larger forces, which creates a larger head loss and in turn higher water levels upstream and lower flow velocities.

There have been several formulations (see references 3, 14, 19, 20, 23) presented to calculate the equilibrium thickness of a cover when the driving forces (water shear stress, maybe wind at times and the cover weight component in the downstream direction) require a cover thickness greater than .33H, to withstand the forces. The basic formulation is

$$(\tau_w + \rho_i g t_j S)\, B = \mu \rho_i \left(1 - \frac{\rho_i}{\rho}\right) g\, t_j^2 - 2ct_j \qquad [13]$$

where μ = ice on ice internal friction type coefficient = 1.3

c = cohesion of the ice cover N/m^2

τ_w = shear stress on the ice cover underside N/m^2

and the other quantities have been previously defined.

The application of this equation requires a knowledge of τ_w (water shear stress) and c (cohesive force within the ice cover). The values of the shear stress may range from 1 to 20 N/m^2 and c could vary from a low of 100 N/m^2 to maybe as high as 2000 N/m^2. The value of c has not been well documented in the field although a conservatively low value (100-200) will yield thick ice covers and produce higher water levels. High values of cohesion will occur during the freeze-up when the air temperatures are low. A composite ice sheet of fragmented ice with a thin upper solid ice cover is very strong in shear while the same cover thickness without the thin solid sheet will be much weaker. For ice jam analyses, c is a low value because of this non-freezing condition during the break-up and jamming process.

3. Thickening and Undercover Transport

This combined process is not well documented analytically, but has been observed in the field. The state of the art has not advanced sufficiently to properly address this combined topic.

4. Undercover Transport and No Thickening

There is very little field data to substantiate the only equation put forth to estimate the ice discharge beneath a cover. Pariset and Hausser (1961) used the Peter-Meyer 1947 equation. Recently researchers at the Univ. of Iowa have looked at the individual ice block stability beneath ice covers, but application to field conditions has not been attempted. The main reason is lack of field data.

There is some field data on the transport of small frazil flocs beneath ice covers in shallow streams and the criteria has been generally related to a minimum flow velocity 0.7 to 1.0 m/s. The value may be even 1.5 m/s.