SUS
251

DRAFT

JANUARY 12, 1984

SUSITNA HYDROELECTRIC PROJECT
INSTREAM ICE
CALIBRATION OF COMPUTER MODEL

Prepared by
HARZA-EBASCO Susitna JOINT VENTURE

For
Alaska Power Authority

JANUARY, 1984

TABLE OF CONTENTS

Comments:
1. Page numbers are screwed up...

LIST OF TABLES

LIST OF EXHIBITS

1.0 INTRODUCTION

As a part of the on-going environmental studies for the project, we have completed the first phase of the calibration of the computer model for instream ice. This report deals with the freeze-up in the reach from the confluence at Talkeetna to Gold Creek for the 1982-83 season, as shown on Exhibit 1. This reach includes a number of the more important sloughs, and is expected to experience a greater change in winter regime than the downstream river reach. Data has been collected in this reach since 1980 and includes the most complete data on the river.

Calibration studies will continue and will be reported later. These further studies will include:

1. Additional simulations for the freeze-up from Talkeetna to Gold Creek based on 1983-84 data now being collected.

2. Complete winter simulation, including freeze-up, ice cover thickening and ice cover melting. The break-up of the ice cover can only be qualitatively estimated since modelling of this highly complex phenomenon is not presently reliable. Ice jam stages may be estimated with present analytical techniques, if the location 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 hydraulic model (HARZA-EBASCO) and instream temperature model (AEIDC) will also be required for final instream ice runs. However, for preliminary runs, the instream ice model will include computations for open-water surface and 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.

Apparently, is a private consultant

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

Upstream Boundary

Water Discharge

Water Temperature

Frazil Ice Discharge ← required input! - where does it come from? [Schock notes that w/project this is 0.0]

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 open-water surface profile and temperature profile. During each day, including the first day, the model determines the total ice produced, evaluates potential ice bridging sites, and advance of the leading ice edge and thickening of the cover. In addition, the border ice is simulated 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 "bridge" location at the downstream boundary or an intermediate section. 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. Open-water heat transfer coefficients.

2. Cohesion coefficient for frazil slush accumulation thickness.

3. Critical value of Froude No. 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:

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 = open water width, (m).

t = mean thickness of the floating (assummed 0.17m)

e = porosity of the floating slush, (assummed 0.5) (Carl Sams 0.4 [illegible])

2. Ice production in open water:

$$Q_i = \frac{h_i \; A \; T_a}{\rho \lambda} \; (m^3/s).$$

where

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

A = open water 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:

$$L_i = K \; V^{-N}$$

L_i = ice growth in m/day.

K = coefficient based on observation.

V = mean flow velocity, m/sec.

N = exponent based on observation.

n for progression of leading edge:

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

uted modified Froude Number.

ical Froude Number.

flow velocity, m/sec.

hydraulic depth, m.

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

5. Progression by Hydraulic Thickening:

$$V = \sqrt{2g\, t_H \left(1-\rho'/\rho\right)} \left(1-t_H/H\right)$$

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 (assummed 920 kg/m^3), water (1000 kg/m^3).

6. Progression by Mechanical Thickening:

$$\frac{B\, V_u^2}{\mu C^2 H_u^2} \left(1 + \frac{\rho' t_s}{\rho R}\right) = \frac{2 c\, t_s}{\rho g \mu H_u^2} + \frac{\rho'}{\rho}\left(1 - \frac{\rho'}{\rho}\right) \frac{t_s^2}{H_u^2}$$

where

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

Hu = mean hydraulic depth under ice cover, m.

B = channel width, m.

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

4. Criterion for progression of leading edge:

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

F = computed modified Froude Number.

Fc = critical Froude Number.

V = mean flow velocity, m/sec.

H = hydraulic depth, m.

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

5. Progression by Hydraulic Thickening:

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

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 (assummed 920 kg/m³), water (1000 kg/m³).

6. Progression by Mechanical Thickening:

$$\frac{B\, V_u^2}{\mu C^2 H_u^2} \left(1 + \frac{\rho' t_s}{\rho R}\right) = \frac{t_s}{\rho g \mu H_u^2} + \frac{\rho'}{\rho}\left(1 - \frac{\rho'}{\rho}\right) \frac{t_s^2}{H_u^2}$$

where

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

Hu = 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 $n_i = 0.050$.

ρ', ρ = 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	V_{u-c}
0° to -7°C	V_{u-c}
-7 to -19°C	V_{u-c}/0.95 m/s
-18 to -30°C	V_{u-c}/0.90 m/s

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 (assummed 0.5).

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 three years. This information is available in R&M reports for the past 3 winters (see reference list). Observation for the 1983 freeze-up will be available in early 1984. In addition, channel cross-sections from Talkeetna to Watana, and open-water stage-discharge observations are available in R&M's report on "Hydraulic and Ice Studies."

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. Ice front progression,
9. Ice jam locations and effects,
10. Channel cross-sections,
11. Open-water stage-discharge ratings.

Based on the above information, the freeze-up of 1982-83 was selected for calibration of the freeze-up portion of the model;

since it represents the most useful information required for calibration. While this data set 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. Approximate staging,

3. Approximate solid ice thicknesses (slush not included),

4. Estimate of surface ice concentration at Gold Creek.

4.0 CALIBRATION OF OPEN-WATER TEMPERATURE

The open-water 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 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 OPEN-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.

Open-water 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 post-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 feet 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 open-water 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 and porosity.

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 solid ice thickness following freeze-up at Gold Creek, Curry, and LRX-3 (did not include slush).

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 5,6, and 7 and Table 9. 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. Exhibit 5 also shows the open-water stage corresponding to the flow during passage of the ice front, indicating "staging." Exhibit 6 shows the computed slush ice thickness in the reach, after the cover has progressed to Gold Creek, with observed solid ice thickness included for comparison. As discussed in Section 7, below, the observed solid ice thicknesses do not include slush deposited beneath the solid ice and will therefore not correspond to the total slush thicknesses computed by the model. 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 9. These values are within normal tolerances, as indicated.

7.0 DISCUSSION OF RESULTS

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

1. The open-water 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 levels computed and observed "maximum ice elevations" are in good agreement generally, with the exceptions of RM 127.0 and 130.9. Here the observed maximum ice elevation are significantly lower than computed.

   We have no explanation for these differences other than the possibility of bad data. In particular, the observation at RM 127.0 is suspicious because is it very near the open-water level, indicating little staging (about 1.5 feet). Observed staging in the remainder of the reach ranges from 4 to 8 feet. At RM 130.9, the observed staging was about 5 feet, compared to about 10 feet computed. On the other hand, at RM 103.2, the observed staging was about 8 feet compared to about 5 feet computed. It appears that there is no systematic error in the simulation, but rather possible errors in observation as well as computation. It also appears that the simulation results are generally on the conservative side.

3. Ice thickness simulations apparently do not agree with observed values. However, the observed values of February 4, 1983 are for "solid ice" only and do not include the "slush ice" which can be deposited in significant amounts beneath the solid layer. The simulated thicknesses are largely slush which

deposited during passage of the front or slightly thereafter. Unfortunately, the amount of slush beneath the solid ice was not documented for the 1982 freeze-up, thereby making a direct comparison impossible. The elevations of the ice cover observed are below the top of ice computed because of the decreased flow and consequent "sagging" of the ice cover in February.

As with stage simulations, we believe the ice thicknnesses simulated are conservative and will yield a high estimate of post-project impact in the middle reach.

The field observations for 1983 freeze-up should produce a better estimate of total ice in the cross-section where measurements are made.

4. The simulation of the leading edge progression rate was in good agreement with observations for the first 30 miles, as shown on Exhibit 7. However, where the field observation shows a more gradual decrease in rate of progression, the computed rate seems to have a sudden decrease to a slower constant rate at RM 130. Since the first 30 miles are likely to be the more important reach for post-project, the upper end near Gold Creek is not of great concern. Observations note that the continuous ice cover progression does not extend upstream of Gold Creek, but is replaced by a series of localized ice bridges separated by open water.

   Again, the simulation is conservative, since the observed rate of advance at the upper end is slower.

8.0 FURTHER STUDIES

Further calibration studies will be made to extend the model simulations into the full winter season. We do not expect that break-up will be modellable. However, locations of maximum ice thickness and flow velocities during spring thaw may correlate with portions of the river which are particularly susceptible to jamming. Maximum jam elevations may be estimated for the jam susceptible reaches, but probability of occurrence may not be reliable.

Additional calibration runs will be made as soon as the freeze-up data from 1983 ~~is~~ are available. Following this further calibration of the model, we will proceed with project production runs as output from the reservoir simulations become available.

REFERENCES

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

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

3. Susitna Hydroelectric Project, Susitna River Ice Study, 1982-83, R&M Consultants, Preliminary Draft, August 1983.

4. Susitna Hydroelectric Project, Hydraulic and Ice Studies, R&M Consultants, March 1982.

5. Susitna Hydroelectric Project, Water Surface Profiles and Discharge Rating Curves for Middle and Lower Susitna River, Harza-Ebasco Joint Venture, December, 1983.

TABLES

Table 1

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT Open Water Calibration River Ice Model	FILE NO. 1563.142
	COMPUTED NWP CHECKED	DATE 1/3/84 PAGE 1 OF 3 PAGES

WSEl.'s for 3000 cfs @ Gold Creek

Section No.	River Mile	Harza[1] HEC-2	R&M[3] Observed	Harza River 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. "Hydraulic and Ice Studies", R&M Consultants, March, 1982 . Table 4.18

3. R&M Correspondence No. 052306, Sept. 11, 1981

Table 2

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT Open Water Calibration River Ice Model	FILE NO. 1563.142
	COMPUTED NWP CHECKED	DATE 1/3/84
		PAGE 2 OF 3 PAGES

WSEl.'s for **9700** cfs @ Gold Creek

Section No.	River Mile	Harza[1] HEC-2	R&M[2] Observed	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

Table 3

STATION	PTS	CROSS SECTION DATA N-FACT	BED-N	ICE-N	BRIDGING COEF INTERCEPT	BRIDGING COEF SLOPE
98.57	4	1.03	0.005	0.005	30.5	0.00
98.58	4	1.03	0.005	0.005	30.5	0.00
98.59	18	1.03	0.022	0.050	145.0	0.00
98.84	13	1.03	0.022	0.050	30.5	0.00
99.09	13	1.03	0.022	0.050	30.5	0.00
99.34	13	1.03	0.022	0.050	30.5	0.00
99.58	18	1.03	0.022	0.050	30.5	0.00
100.36	15	1.03	0.040	0.050	30.5	0.00
100.98	15	1.03	0.040	0.050	30.5	0.00
101.52	14	1.03	0.062	0.050	30.5	0.00
102.30	11	1.03	0.062	0.050	30.5	0.00
103.22	18	1.03	0.062	0.050	30.5	0.00
104.75	14	1.03	0.055	0.050	30.5	0.00
106.66	18	1.03	0.055	0.050	30.5	0.00
108.41	14	1.03	0.055	0.050	30.5	0.00
110.36	17	1.03	0.055	0.050	30.5	0.00
110.89	16	1.03	0.055	0.050	30.5	0.00
111.83	13	1.03	0.045	0.050	30.5	0.00
112.34	17	1.03	0.040	0.050	30.5	0.00
112.69	16	1.03	0.040	0.050	30.5	0.00
113.02	18	1.03	0.040	0.050	30.5	0.00
113.86	15	1.03	0.040	0.050	30.5	0.00
114.73	15	1.03	0.040	0.050	30.5	0.00
115.59	15	1.03	0.040	0.050	30.5	0.00
116.44	14	1.03	0.040	0.050	30.5	0.00
117.19	14	1.03	0.040	0.050	30.5	0.00
119.15	11	1.03	0.040	0.050	30.5	0.00
119.32	18	1.03	0.030	0.050	30.5	0.00
120.26	18	1.03	0.030	0.050	30.5	0.00
120.66	14	1.00	0.030	0.050	30.5	0.00
121.30	13	1.00	0.030	0.050	30.5	0.00
121.83	11	1.00	0.030	0.050	30.5	0.00
122.57	12	1.00	0.035	0.050	30.5	0.00
123.31	13	1.00	0.025	0.050	30.5	0.00
124.41	16	1.00	0.025	0.050	30.5	0.00
126.11	15	1.00	0.035	0.050	30.5	0.00
127.50	19	1.00	0.038	0.050	30.5	0.00
128.66	16	1.00	0.038	0.050	30.5	0.00
129.67	9	1.00	0.038	0.050	30.5	0.00
130.12	15	1.00	0.036	0.050	30.5	0.00
130.47	19	1.00	0.030	0.050	30.5	0.00
130.87	18	1.00	0.030	0.050	30.5	0.00
131.19	19	1.00	0.043	0.050	30.5	0.00
131.80	14	1.00	0.036	0.050	30.5	0.00
132.90	14	1.00	0.036	0.050	30.5	0.00
133.33	11	1.00	0.036	0.050	30.5	0.00
134.28	14	1.00	0.038	0.050	30.5	0.00
134.72	13	1.00	0.038	0.050	30.5	0.00
135.36	13	1.00	0.038	0.050	30.5	0.00
135.72	17	1.00	0.040	0.050	7.6	0.00
135.99	20	1.00	0.040	0.050	30.5	0.00
136.40	14	1.00	0.045	0.050	30.5	0.00
136.68	12	1.00	0.045	0.050	30.5	0.00
136.98	12	1.00	0.045	0.050	30.5	0.00
137.15	14	1.00	0.040	0.050	30.5	0.00
137.41	10	1.00	0.040	0.050	30.5	0.00
138.23	15	1.00	0.040	0.050	30.5	0.00
138.46	11	1.00	0.045	0.050	30.5	0.00
138.69	14	0.98	0.050	0.050	30.5	0.00
139.44	16	0.98	0.050	0.050	30.5	0.00
140.15	14	0.98	0.050	0.050	30.5	0.00
140.83	14	0.98	0.055	0.050	30.5	0.00
141.49	14	0.98	0.055	0.050	30.5	0.00
142.13	15	0.98	0.055	0.050	30.5	0.00
142.34	15	0.98	0.050	0.050	30.5	0.00
143.10	14	0.98	0.050	0.050	30.5	0.00
144.83	14	0.98	0.050	0.050	30.5	0.00
147.50	14	0.98	0.055	0.050	30.5	0.00
148.73	13	0.98	0.063	0.050	30.5	0.00
148.99	12	0.99	0.063	0.050	30.5	0.00
149.15	13	0.99	0.055	0.050	30.5	0.00
149.33	11	0.99	0.055	0.050	30.5	0.00
149.48	12	0.99	0.055	0.050	30.5	0.00
149.51	9	0.99	0.055	0.050	30.5	0.00
149.81	13	0.99	0.065	0.050	30.5	0.00
150.19	12	0.99	0.065	0.050	30.5	0.00

Expansion Losses = .3 $\Delta \frac{V^2}{2g}$

Contraction Losses = .1 $\Delta \frac{V^2}{2g}$

Table 3

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

Table 4.

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.

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.

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	-7.1	-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

N__LY 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	96	-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	97	-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	-9.4	****	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	097	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	69	-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	088	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.[illegible]	-13.4	084	2.6	2.6	089	7.0	E	63	-19.2	****	418	22
23	1.6	-15.0	[illegible].7	120	2.3	2.7	131	8.3	ESE	37	-19.2	****	563	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	[illegible]	ESE	61	-10.5	****	530	28
29	-5.4	-13.9	-9.7	091	2.1	2.3	124	5.1	[illegible]	81	-11.8	****	490	29
30	-4.0	-9.7	-6.9	121	1.7	1.9	104	6.3	ESE	62	-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 DAILY OR MONTHLY MEAN FOR RELATIVE HUMIDITY AND DEW POINT.

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

From R&M Report: Susitna River Ice Study 1982-83 Table 6.

NOV 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

NOV 1982
TALKEETNA, ALASKA

DATE	TEMPERATURE °F: MAXIMUM	MINIMUM	AVERAGE	DEPARTURE FROM NORMAL	AVERAGE DEW POINT	DEGREE DAYS BASE 65°F: HEATING (SEASON BEGINS WITH JUL 1)	COOLING (SEASON BEGINS WITH JAN 1)	WEATHER TYPES (1 FOG, 2 HEAVY FOG, 3 THUNDERSTORM, 4 ICE PELLETS, 5 HAIL, 6 GLAZE, 7 DUSTSTORM, 8 SMOKE, HAZE, 9 BLOWING SNOW)	SNOW, ICE PELLETS OR ICE ON GROUND AT 08AM INCHES	PRECIPITATION: WATER EQUIVALENT (INCHES)	SNOW, ICE PELLETS (INCHES)	AVERAGE STATION PRESSURE IN INCHES ELEV. 356 FEET ABOVE M.S.L.	WIND (M.P.H.): RESULTANT DIR.	RESULTANT SPEED	AVERAGE SPEED	FASTEST MILE: SPEED	FASTEST MILE: DIRECTION	SUNSHINE: MINUTES	PERCENT OF TOTAL POSSIBLE	SKY COVER (TENTHS): SUNRISE TO SUNSET	MIDNIGHT TO MIDNIGHT	DATE
1	2	3	4	5	6	7A	7B	8	9	10	11	12	13	14	15	16	17	18	19	20	21	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	1		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	29.20	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		29	.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 724	SUM 280				TOTAL 1441	TOTAL 0	NUMBER OF DAYS		TOTAL 1.70	TOTAL 27.0	FOR THE MONTH:				17	35	TOTAL	% FOR MONTH	SUM 212	SUM	
	AVG. 24.1	AVG. 9.3	AVG 16.7	DEP -0.8	AVG.	DEP. 16	DEP 0	PRECIPITATION ≥ .01 INCH 13		DEP -0.09						DATE: 26+		POSSIBLE		AVG 7.1	AVG	

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. 280	DEP -5	HEAVY FOG	0						
						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 8 (1 FOG, 2 HEAVY FOG, 3 THUNDERSTORM, 4 ICE PELLETS, 5 HAIL, 6 GLAZE, 7 DUSTSTORM, 8 SMOKE, HAZE, 9 BLOWING SNOW)	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	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
	SUM 798	SUM 384				TOTAL 1419	TOTAL 0	NUMBER OF DAYS		TOTAL 1.80	TOTAL 10.3	FOR THE MONTH:				23	02	TOTAL	% FOR MONTH	SUM 236	SUM	
	AVG. 25.7	AVG. 12.4	AVG. 19.1	DEP. 10.1	AVG.	DEP. -317	DEP. 0	PRECIPITATION > .01 INCH 7		DEP. 0.09						DATE: 19		POSSIBLE		AVG. 7.6	AVG.	

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

JAN 1983 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 00AM 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	FASTEST MILE DIRECTION 17	SUNSHINE MINUTES 18	PERCENT OF TOTAL POSSIBLE 19	SKY COVER (TENTHS) SUNRISE TO SUNSET 20	MIDNIGHT TO MIDNIGHT 21	DATE 22
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			0		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 644	SUM 129				TOTAL 1621	TOTAL 0	NUMBER OF DAYS		TOTAL 46	TOTAL 11.9	FOR THE MONTH				21	03	TOTAL	% FOR MONTH	SUM 169	SUM	
	AVG 20.8	AVG 4.2	AVG 12.5	DEP 4.1	AVG	DEP -103	DEP 0	PRECIPITATION > .01 INCH	5	DEP -0.99						DATE: 11+		POSSIBLE		AVG 5.5	AVG	

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	4	PRECIPITATION		SNOW, ICE PELLETS			
≥ 90°	≤ 32°	≤ 32°	≤ 0°	6874	0	THUNDERSTORMS	0	19	16-17	4.4	19	33	19
0	24	31	13	DEP -140	DEP 0	HEAVY FOG	0						
						CLEAR 12	PARTLY CLOUDY 5	CLOUDY 14					

* 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

JAN 1983
TALKEETNA, ALASKA

From R&M Report: Susitna River Ice Study 1982-83 Table 7.

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.

TABLE 4.7

1983 SUSITNA RIVER ICE THICKNESS MEASUREMENTS

	Mainstem Ice Thicknesses (ft) Min	Max	Avg	Number of Holes	Water Surface Elevation	Average* Underice Water Velocity
February 4, 1983						
Watana	1.4	3.6	2.4	21	1436.8	2.6
Portage Creek	1.4	3.4	2.5	5	834.1	
Gold Creek	1.3	1.9	1.6	5	684.6	
Curry	1.8	2.1	1.9	4	522.7	
LRX-3	2.0	3.9	2.9	5	342.8	
April 12, 1983						
Watana	1.8	4.2	2.8	19	1436.1	2.2
Portage Creek	3.0	4.0	4.1	6	833.5	4.2
Gold Creek	1.8	2.9	2.3	6	682.9	
Curry	1.3	3.3	2.2	7	521.9	
LRX-3	2.0	3.8	2.8	7	341.5	

* Average underice water velocity was measured at point of most flow and constitutes an average of the vertical velocity profile.

Table 8.

Table 9.

HARZA-EBASCO SUSITNA JOINT VENTURE	SUBJECT River Ice Model 1982-83 Simulation	FILE NO. 1563.142
	COMPUTED NWP CHECKED	DATE 23 Dec 83
		PAGE 1 OF 1 PAGES

ICE CALIBRATION COEFFICIENTS

Parameter	Final Value From Simulation	Normal Range of Values
1. Open-water heat-transfer coefficient	$(4 + 2V_w)$ W/m²-°C (V_w = wind velocity)	12-20 W/m²-°C
2. Cohesion coefficient for frazil slush	700 N/m²	500-2000 N/m²
3. Critical Froude No. for progression of leading edge	0.09	0.06-0.11
4. Critical velocity for underice deposition	0.9 m/s	0.6-1.4 m/s
5. Lateral ice coefficients	$0.1\,V^{-2.8}$ (V = water velocity, m/s)	—

Notes: 1. Ice Inflow at Gold Creek-

Assumed Slush thickness = 0.5'

" Ice Porosity = 0.6

EXHIBITS

Exhibit 1.

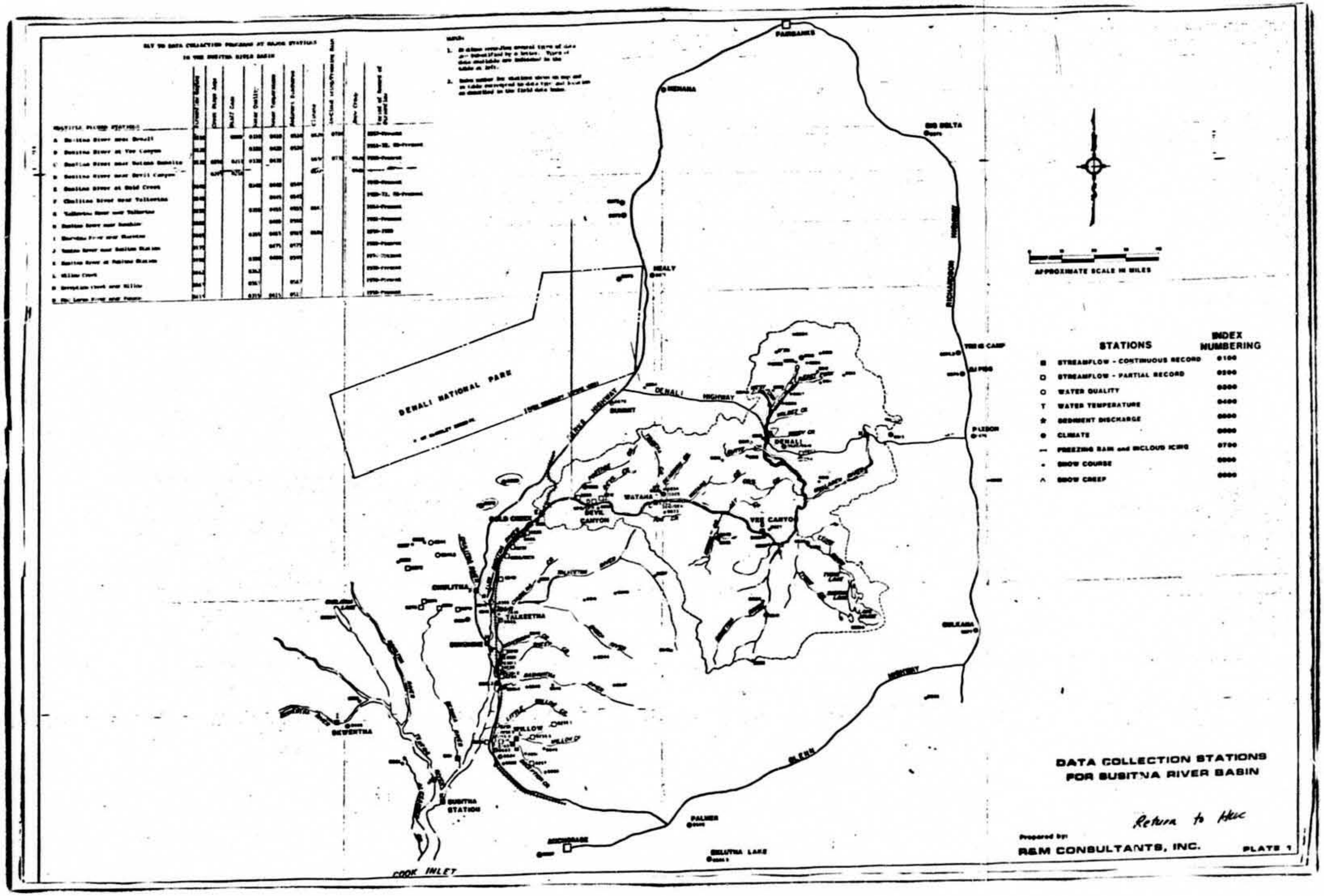
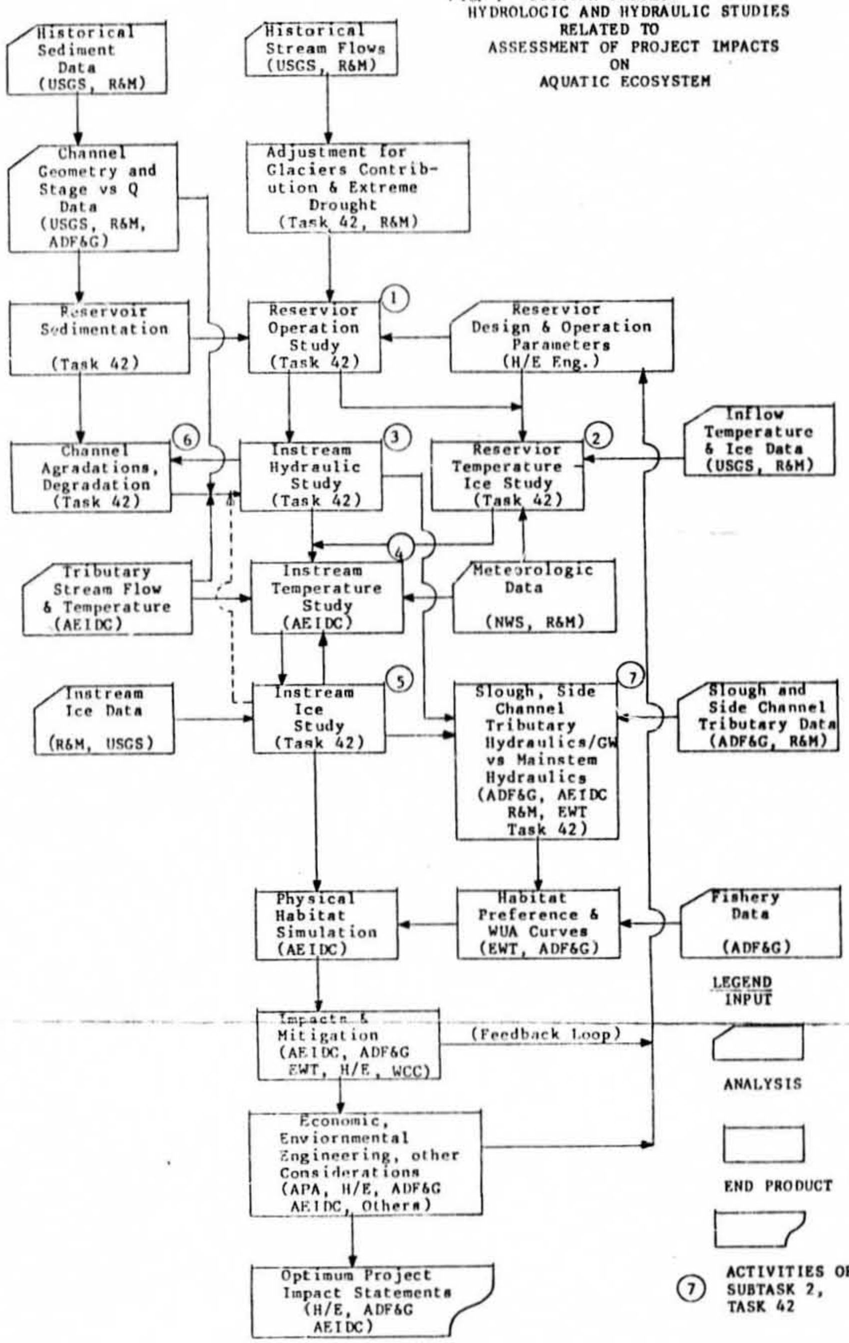

FAIRBANKS
NENANA
BIG DELTA
HEALY
DENALI NATIONAL PARK
DENALI HIGHWAY
RICHARDSON HIGHWAY
PAXSON
DENALI
WATANA
DEVIL CANYON
VEE CANYON
GOLD CREEK
SUSITNA
TALKEETNA
WILLOW
SKWENTNA
SUSITNA STATION
ANCHORAGE
PALMER
GULKANA
GLENN HIGHWAY
COOK INLET
APPROXIMATE SCALE IN MILES
STATIONS
INDEX NUMBERING
STREAMFLOW - CONTINUOUS RECORD 0100
STREAMFLOW - PARTIAL RECORD 0200
WATER QUALITY
WATER TEMPERATURE
SEDIMENT DISCHARGE
CLIMATE
FREEZING RAIN and INCLOUD ICING 0700
SNOW COURSE
SNOW CREEP
DATA COLLECTION STATIONS FOR SUSITNA RIVER BASIN
Prepared by:
R&M CONSULTANTS, INC.
PLATE 1
Return to HEC

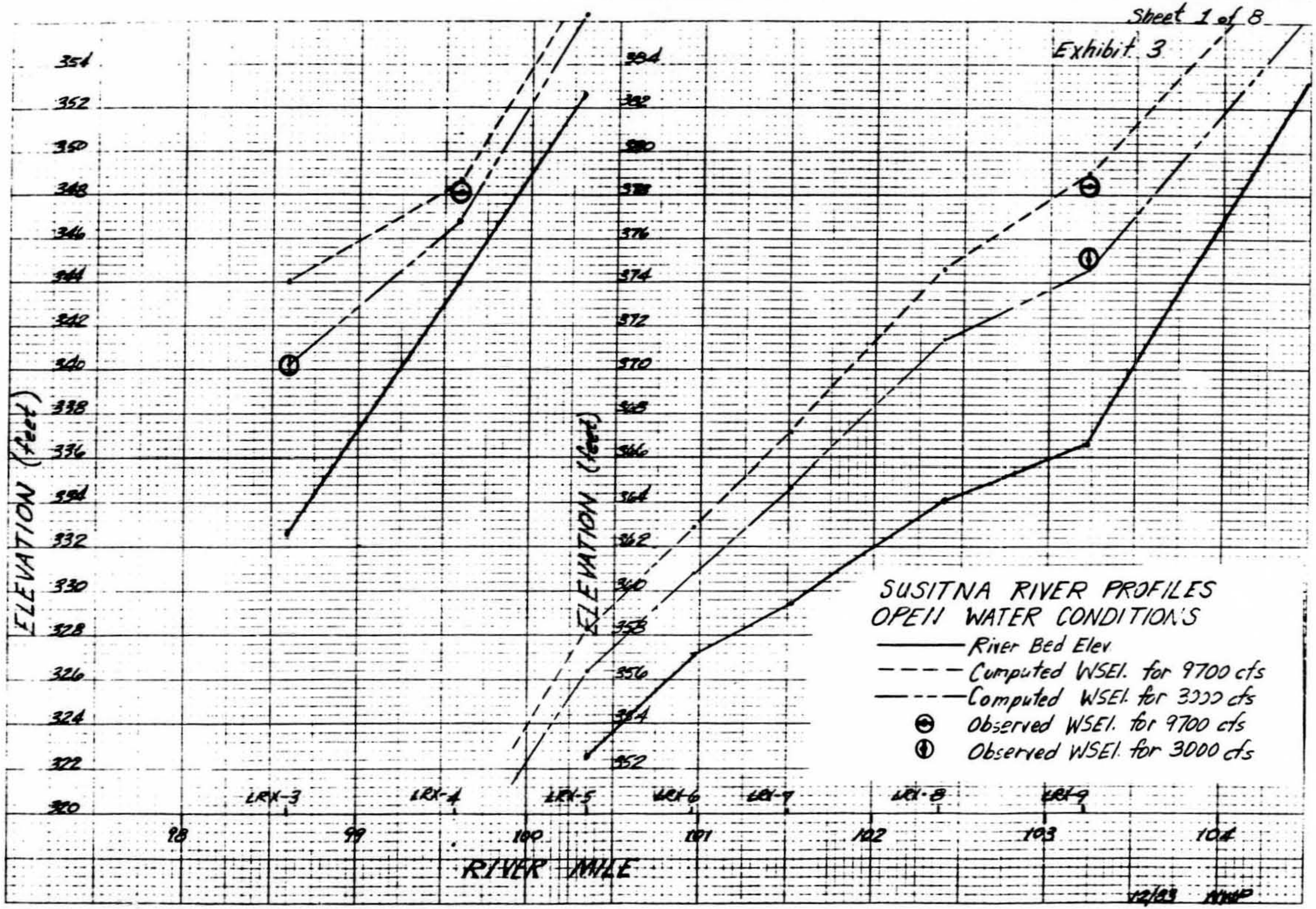
FIG. 1 - SUSITNA PROJECT
HYDROLOGIC AND HYDRAULIC STUDIES
RELATED TO
ASSESSMENT OF PROJECT IMPACTS
ON
AQUATIC ECOSYSTEM



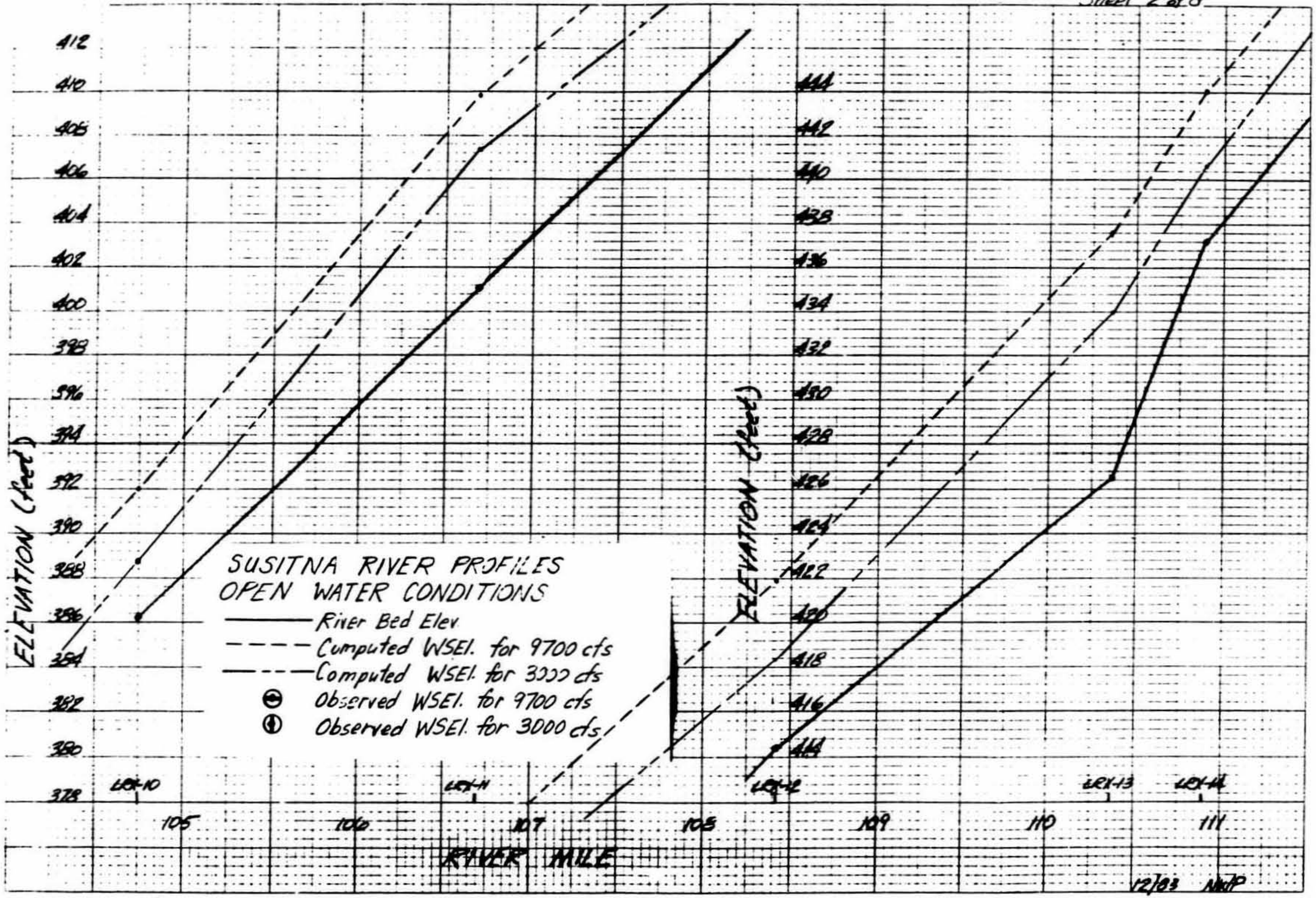
NOTE: Assumes impacts on water chemistry will not be a major issue

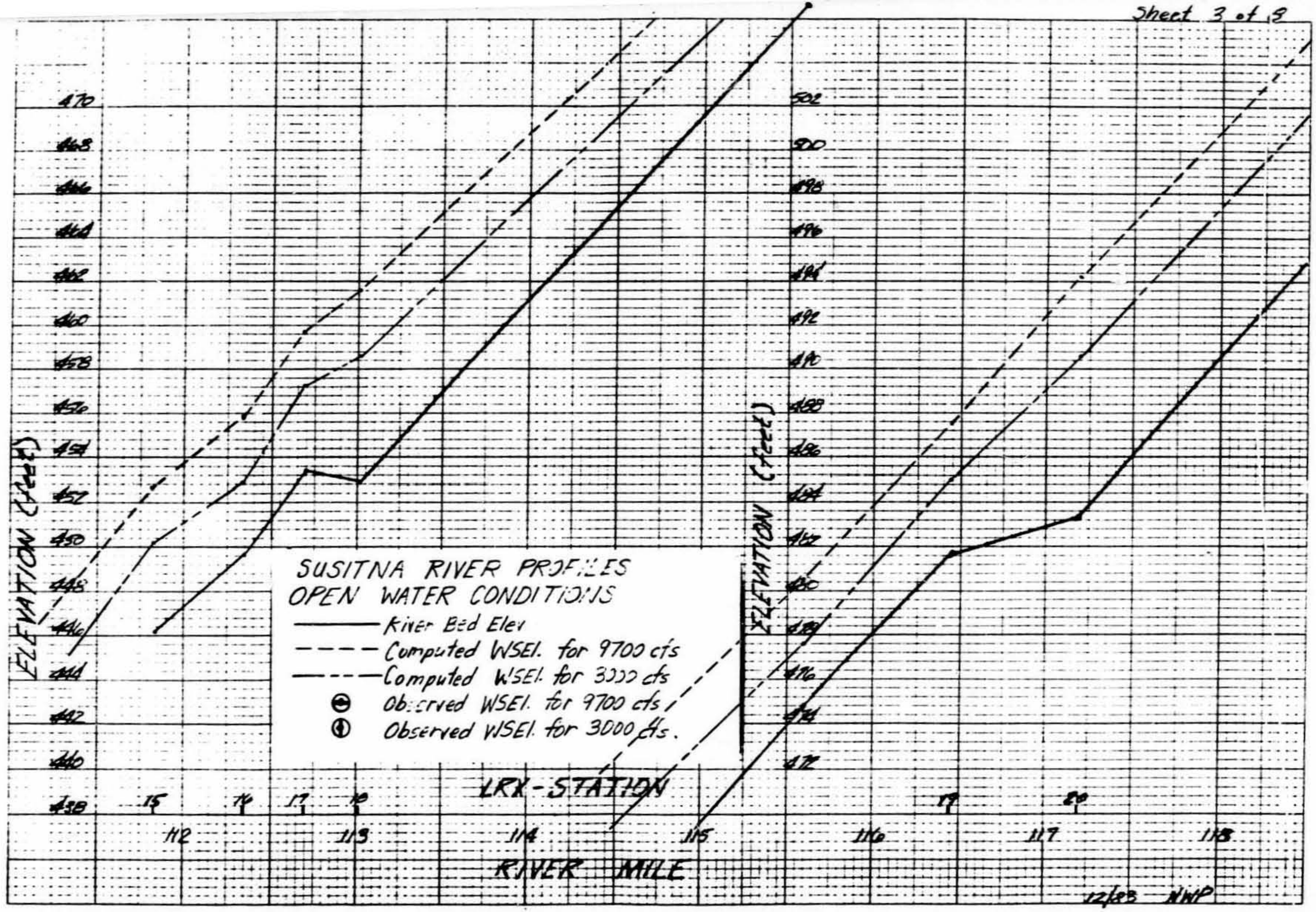
EXHIBIT 2.

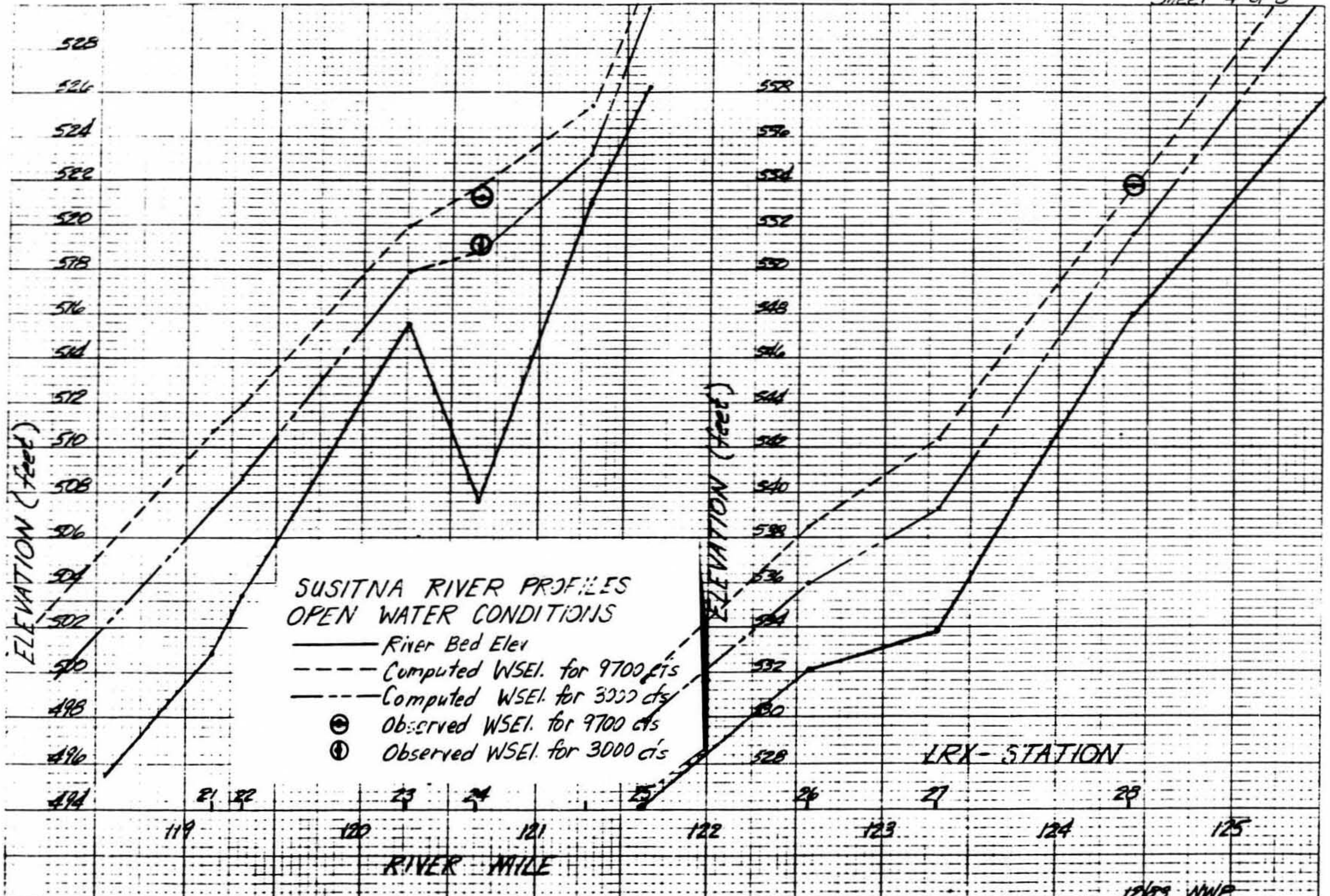
Exhibit 3

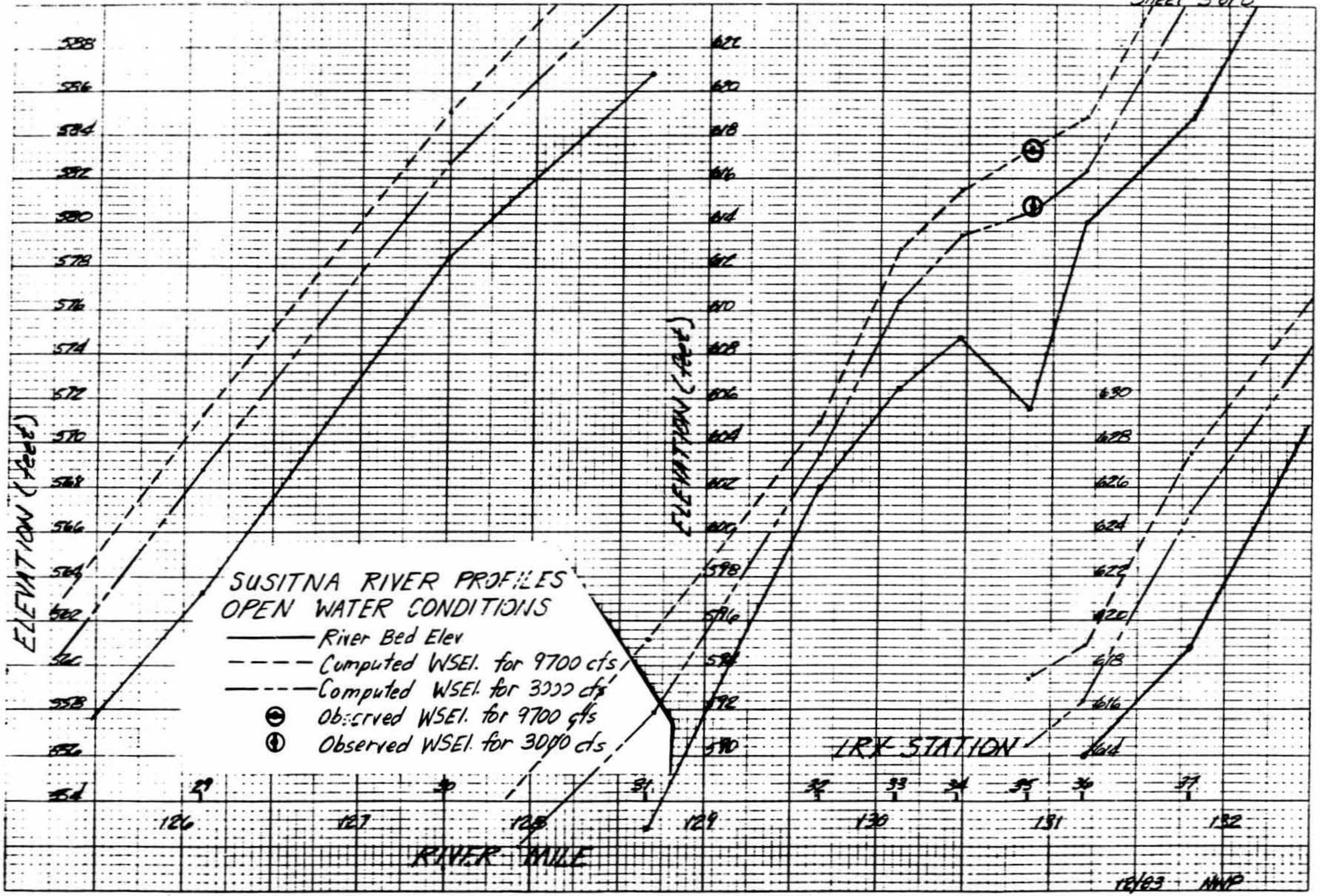


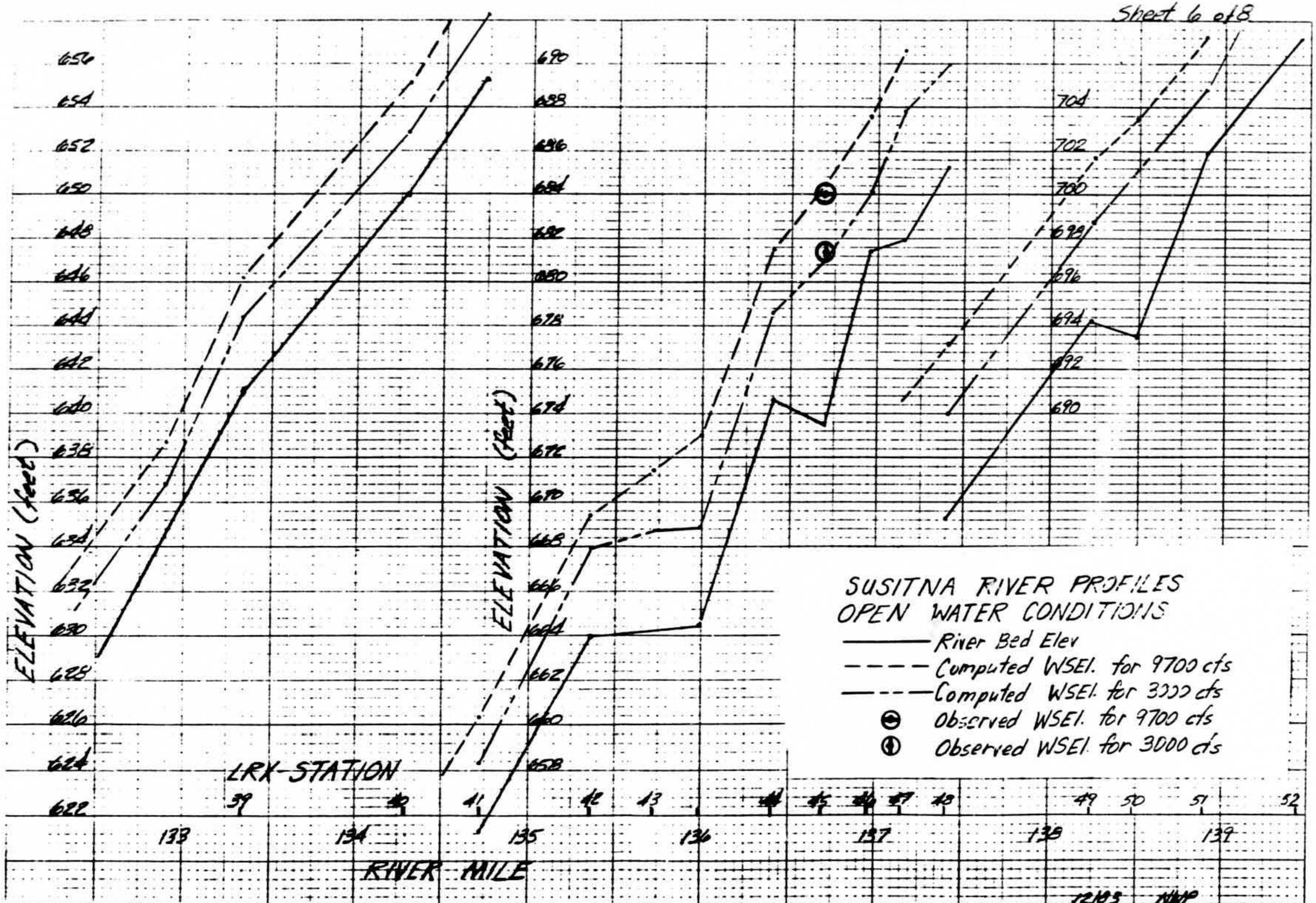
SUSITNA RIVER PROFILES
OPEN WATER CONDITIONS
River Bed Elev.
Computed WSEl. for 9700 cfs
Computed WSEl. for 3000 cfs
Observed WSEl. for 9700 cfs
Observed WSEl. for 3000 cfs
ELEVATION (feet)
RIVER MILE
LRX-3
LRX-4
LRX-5
LRX-6
LRX-7
LRX-8
LRX-9
98
99
100
101
102
103
104
320
322
324
326
328
330
332
334
336
338
340
342
344
346
348
350
352
354
356
358
360
362
364
366
368
370
372
374
376
378
380
382
384
12/83


SUSITNA RIVER PROFILES
OPEN WATER CONDITIONS
River Bed Elev.
Computed WSEl. for 9700 cfs
Computed WSEl. for 3000 cfs
Observed WSEl. for 9700 cfs
Observed WSEl. for 3000 cfs
ELEVATION (feet)
412
410
408
406
404
402
400
398
396
394
392
390
388
386
384
382
380
378
ELEVATION (feet)
444
442
440
438
436
434
432
430
428
426
424
422
420
418
416
414
LRX-10
LRX-11
LRX-12
LRX-13
LRX-14
105
106
107
108
109
110
111
RIVER MILE
12/83 NWP

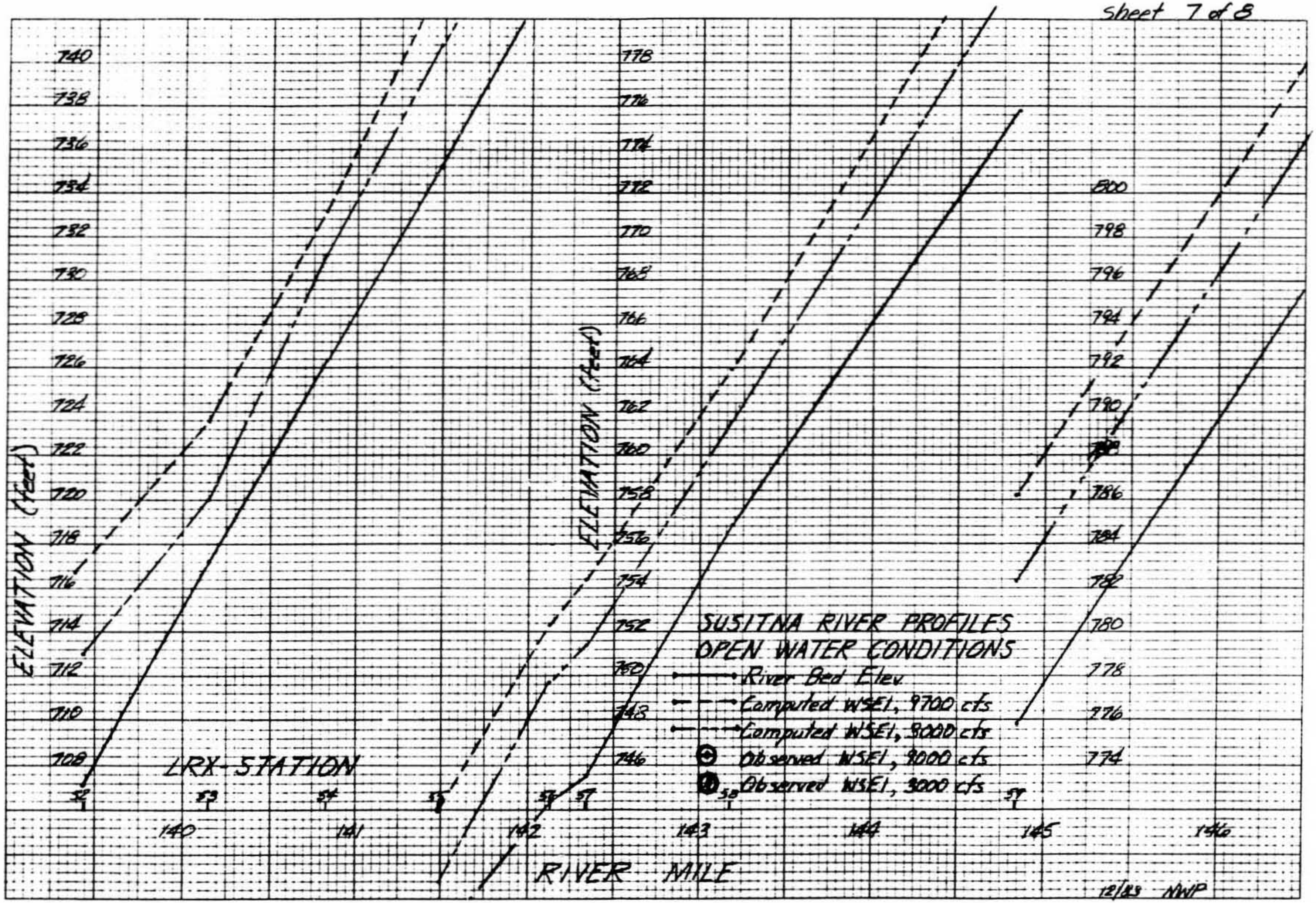

SUSITNA RIVER PROFILES
OPEN WATER CONDITIONS
River Bed Elev
Computed WSEl. for 9700 cfs
Computed WSEl. for 3000 cfs
Observed WSEl. for 9700 cfs
Observed WSEl. for 3000 cfs.
ELEVATION (Feet)
LRX-STATION
RIVER MILE
12/83 NWP


SUSITNA RIVER PROFILES
OPEN WATER CONDITIONS
River Bed Elev
Computed WSEl. for 9700 cfs
Computed WSEl. for 3000 cfs
Observed WSEl. for 9700 cfs
Observed WSEl. for 3000 cfs
ELEVATION (Feet)
RIVER MILE
LRX-STATION
494
496
498
500
502
504
506
508
510
512
514
516
518
520
522
524
526
528
530
532
534
536
538
540
542
544
546
548
550
552
554
556
558
21
22
23
24
25
26
27
28
119
120
121
122
123
124
125
12/83 WWP

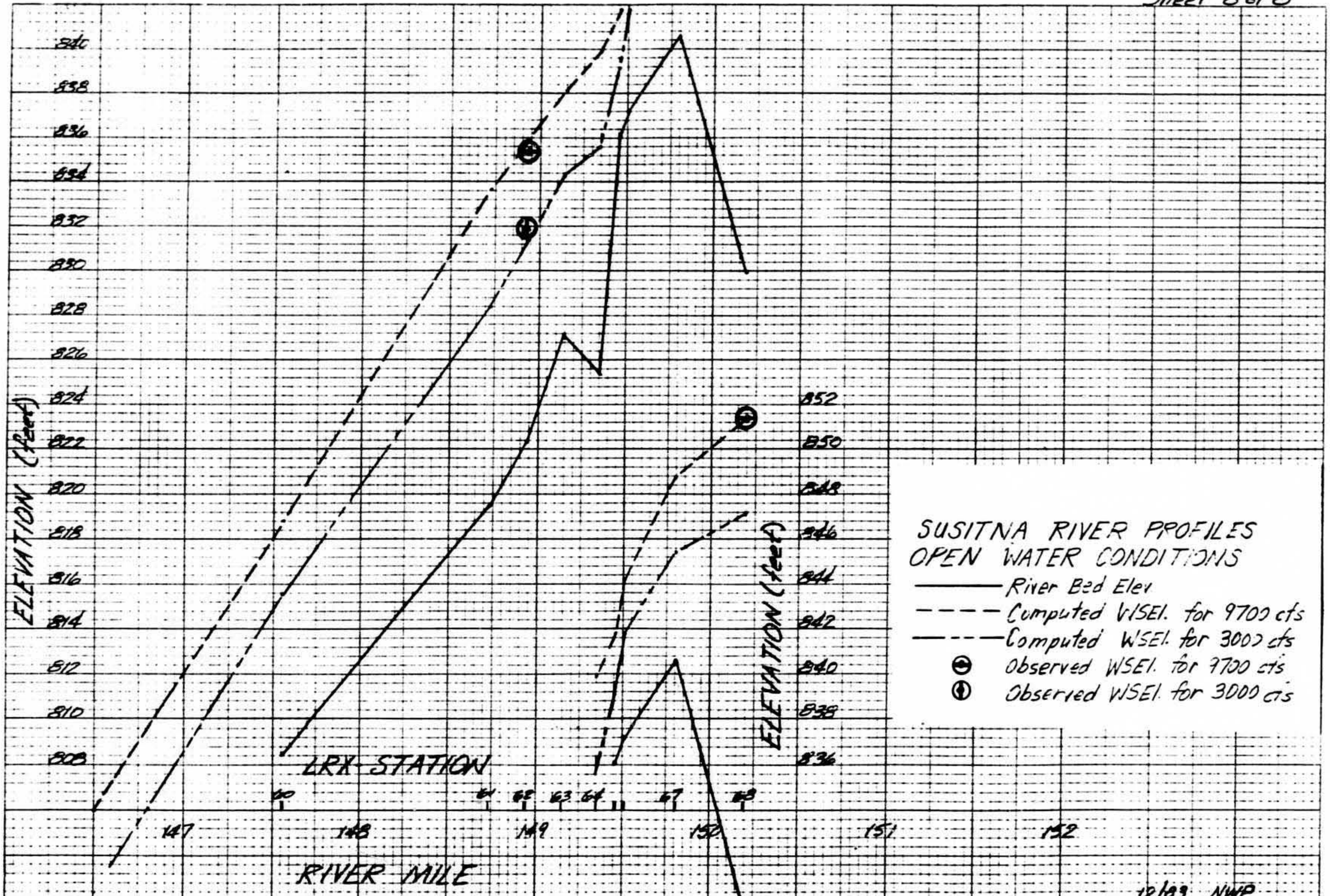

SUSITNA RIVER PROFILES
OPEN WATER CONDITIONS
River Bed Elev
Computed WSEl. for 9700 cfs
Computed WSEl. for 3000 cfs
Observed WSEl. for 9700 cfs
Observed WSEl. for 3000 cfs
ELEVATION (feet)
ELEVATION (feet)
LRX STATION
RIVER MILE
126
127
128
129
130
131
132
12/83 NWP



SUSITNA RIVER PROFILES
OPEN WATER CONDITIONS
River Bed Elev
Computed WSEl. for 9700 cfs
Computed WSEl. for 3000 cfs
Observed WSEl. for 9700 cfs
Observed WSEl. for 3000 cfs
ELEVATION (feet)
LRX-STATION
RIVER MILE
133
134
135
136
137
138
139
39
40
41
42
43
44
45
46
47
48
49
50
51
52
12/83



SUSITNA RIVER PROFILES
OPEN WATER CONDITIONS
River Bed Elev.
Computed WSEl, 9700 cfs
Computed WSEl, 3000 cfs
Observed WSEl, 9000 cfs
Observed WSEl, 3000 cfs
ELEVATION (Feet)
RIVER MILE
LRX-STATION
140
141
142
143
144
145
146
12/83 NWP


SUSITNA RIVER PROFILES
OPEN WATER CONDITIONS
River Bed Elev
Computed WSEl. for 9700 cfs
Computed WSEl. for 3000 cfs
Observed WSEl. for 9700 cfs
Observed WSEl. for 3000 cfs
ELEVATION (feet)
840
838
836
834
832
830
828
826
824
822
820
818
816
814
812
810
808
ELEVATION (feet)
852
850
848
846
844
842
840
838
836
LRX STATION
60
61
62
63
64
67
68
147
148
149
150
151
152
RIVER MILE
12/83 NWP

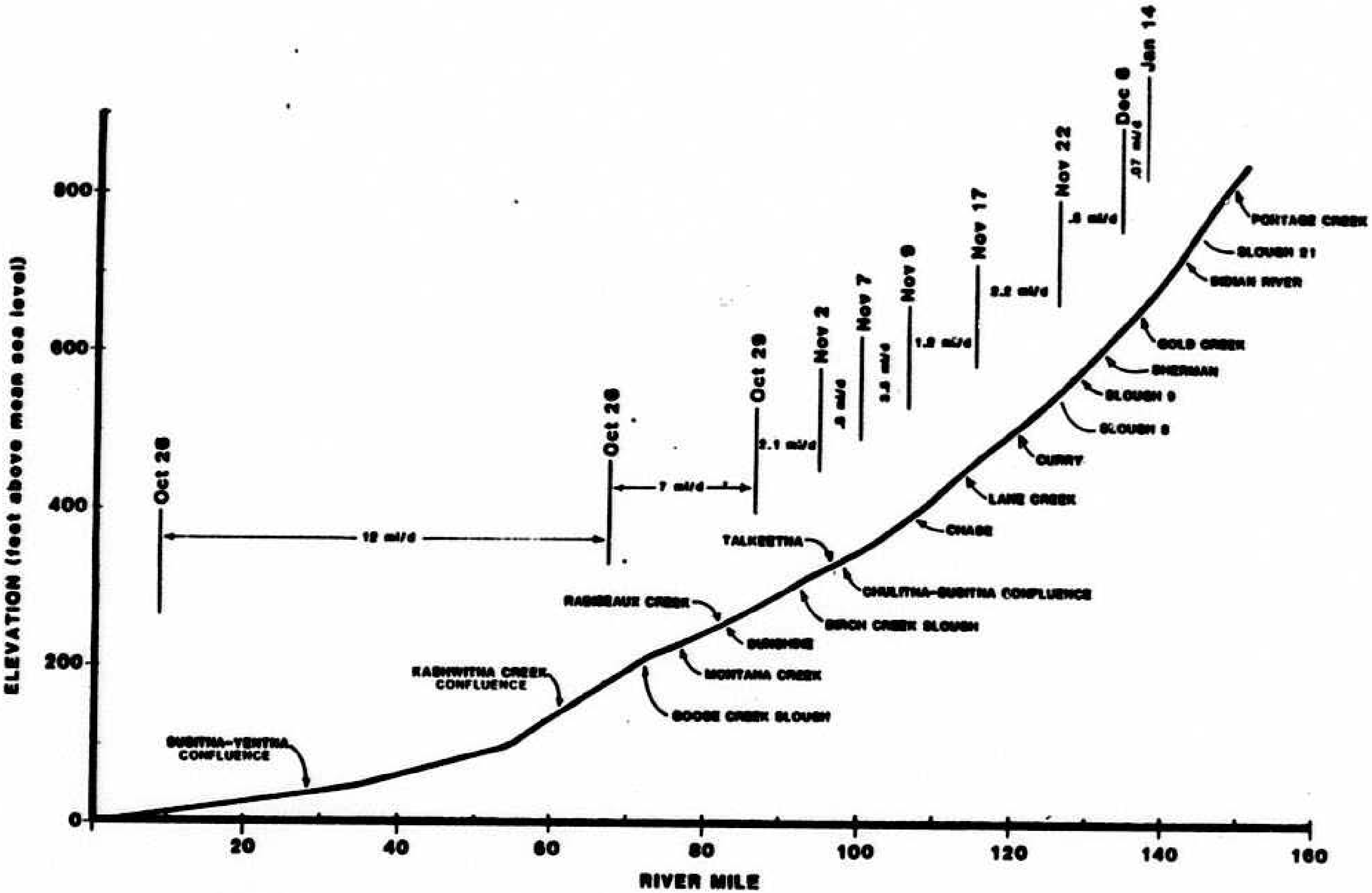
R&M CONSULTANTS, INC.

Figure 4.3

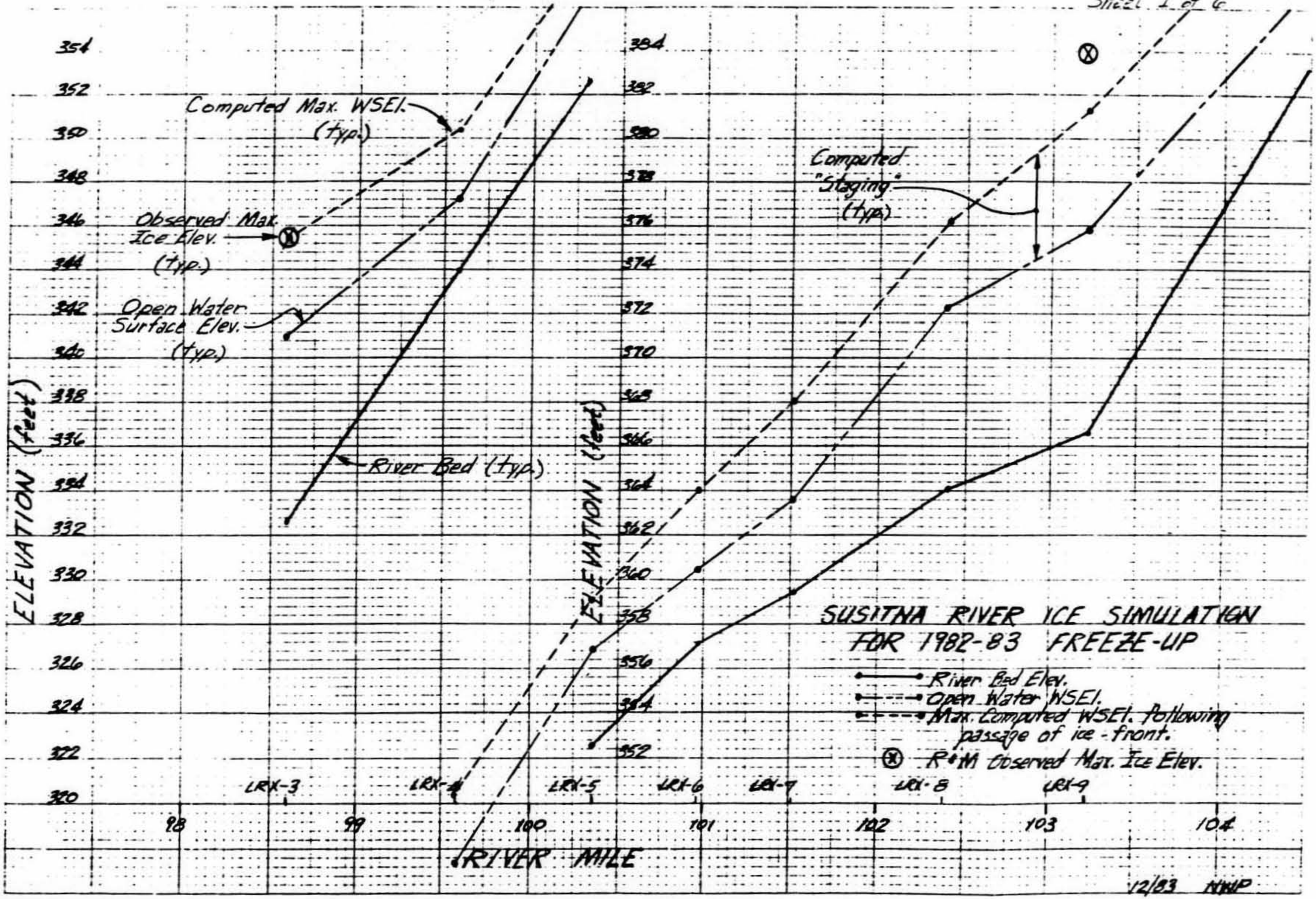
HARZA-EBASCO

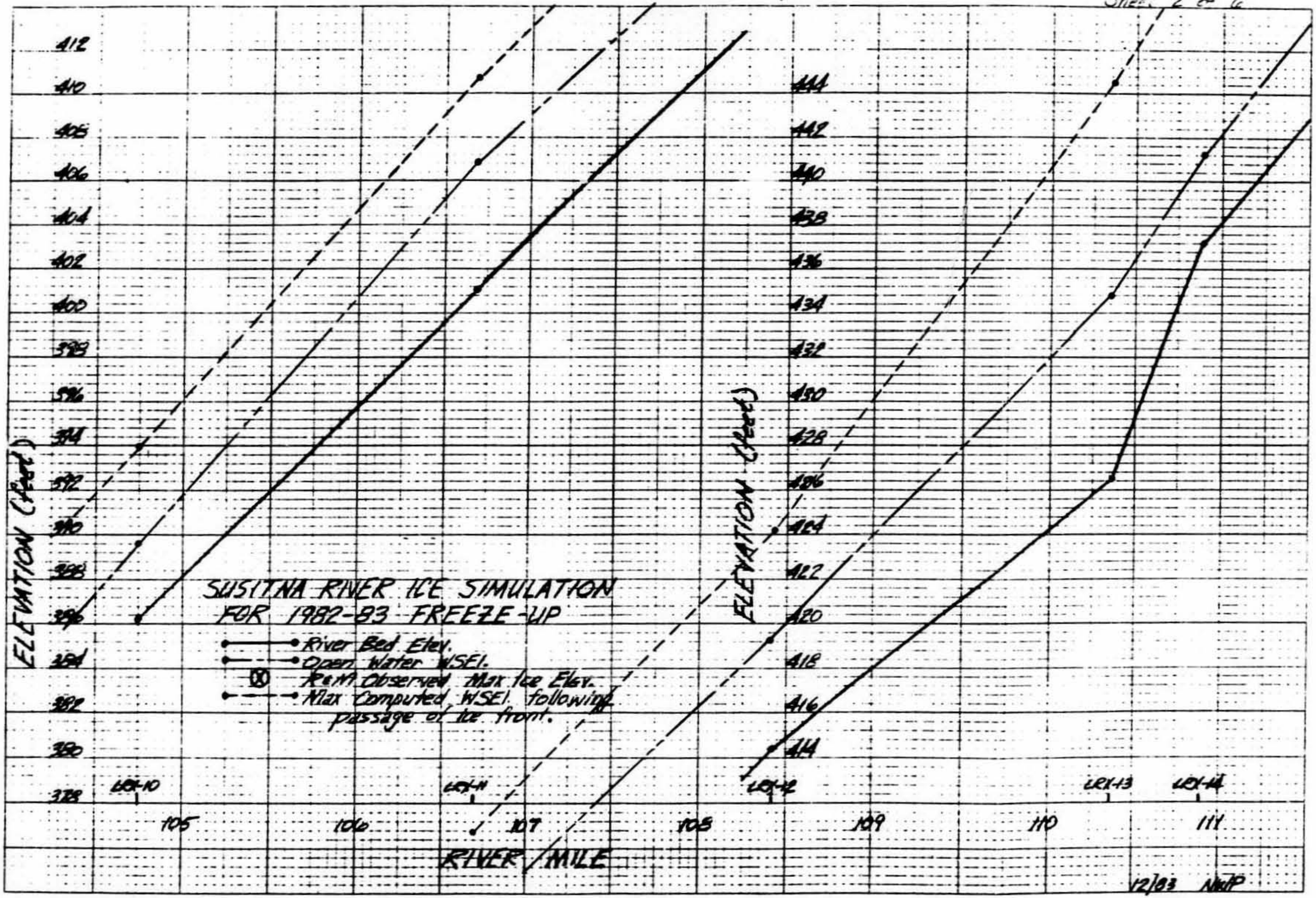
From R&M Report: Susitna River Ice Study 1982-83

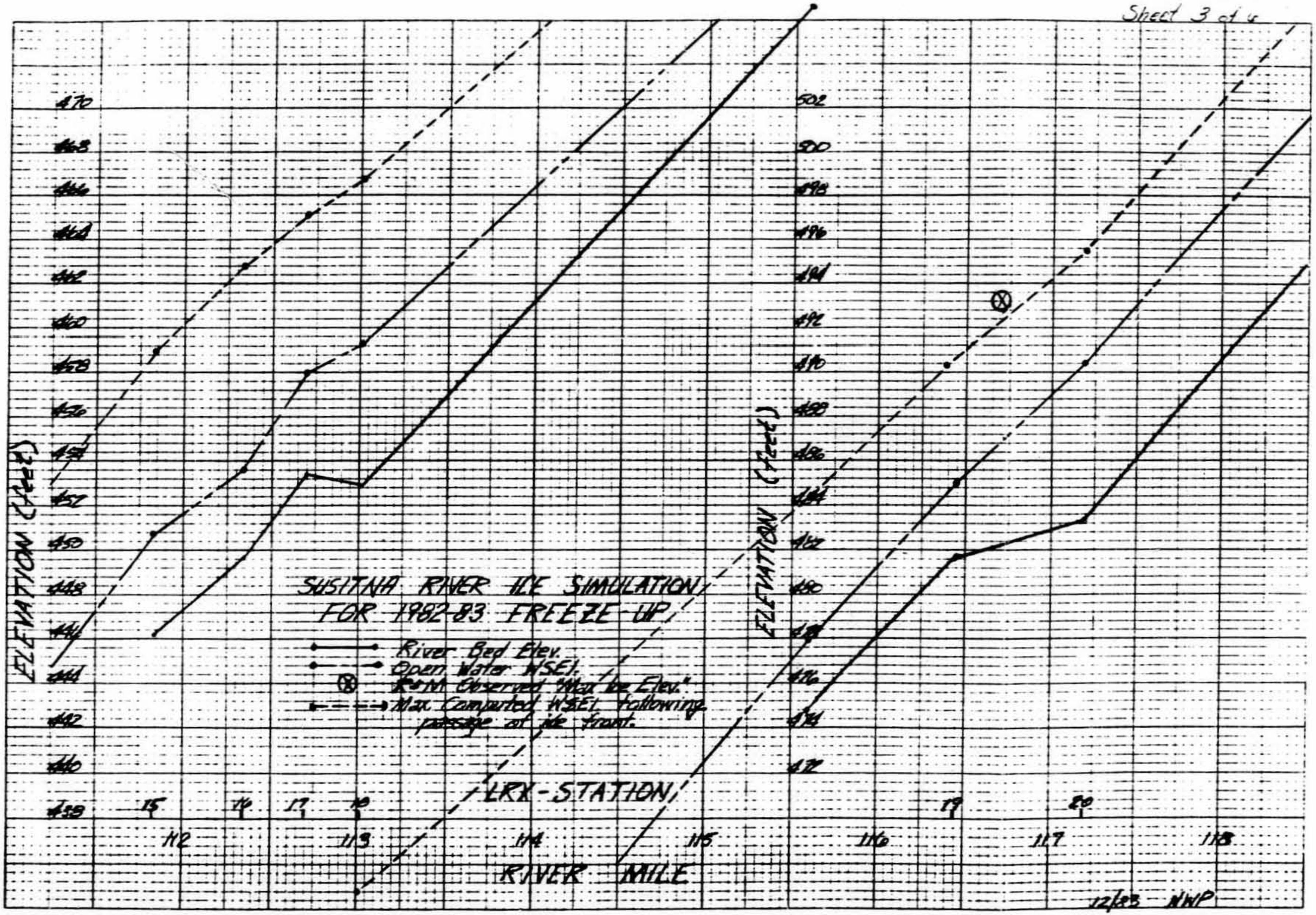
Exhibit 4.

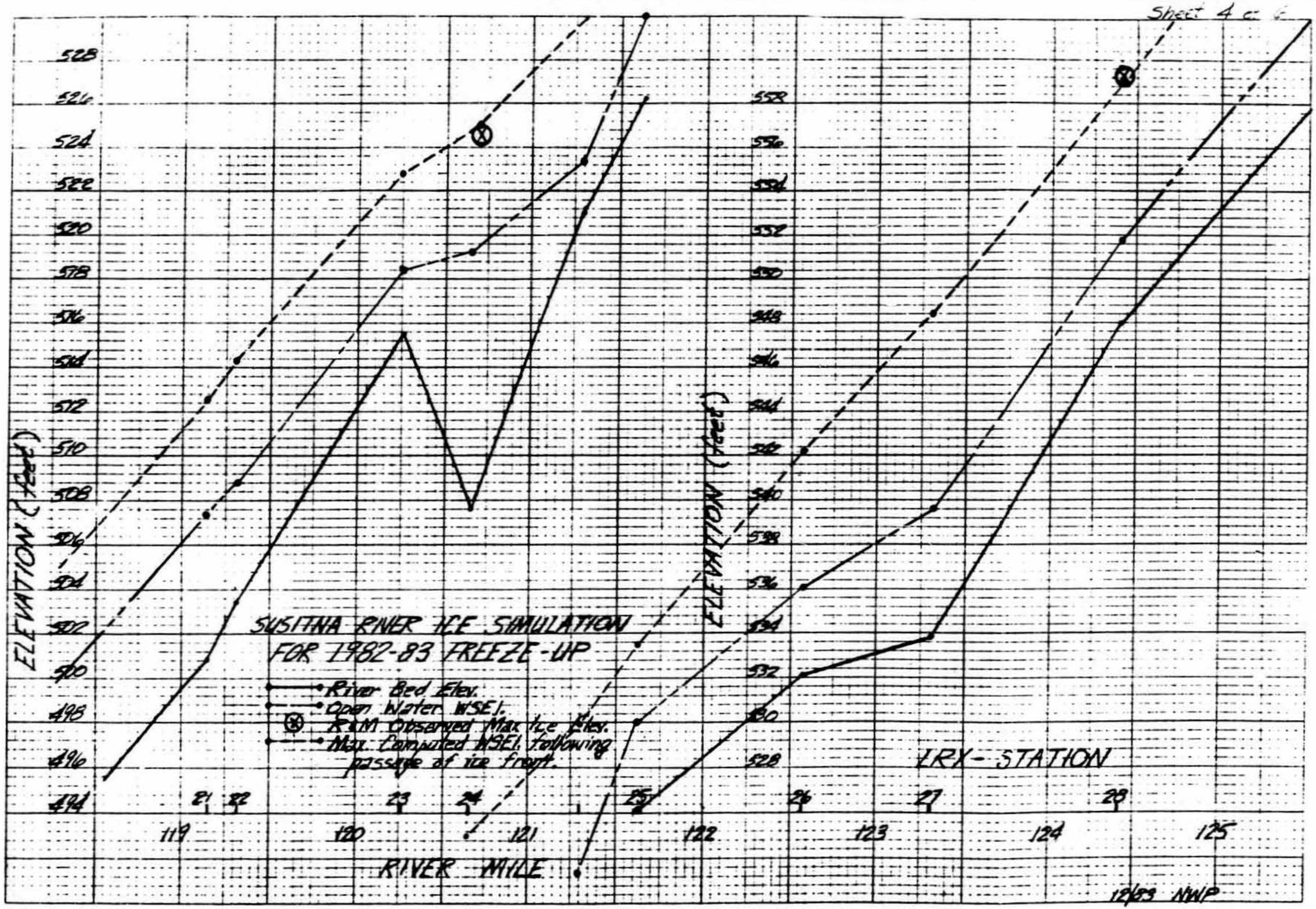


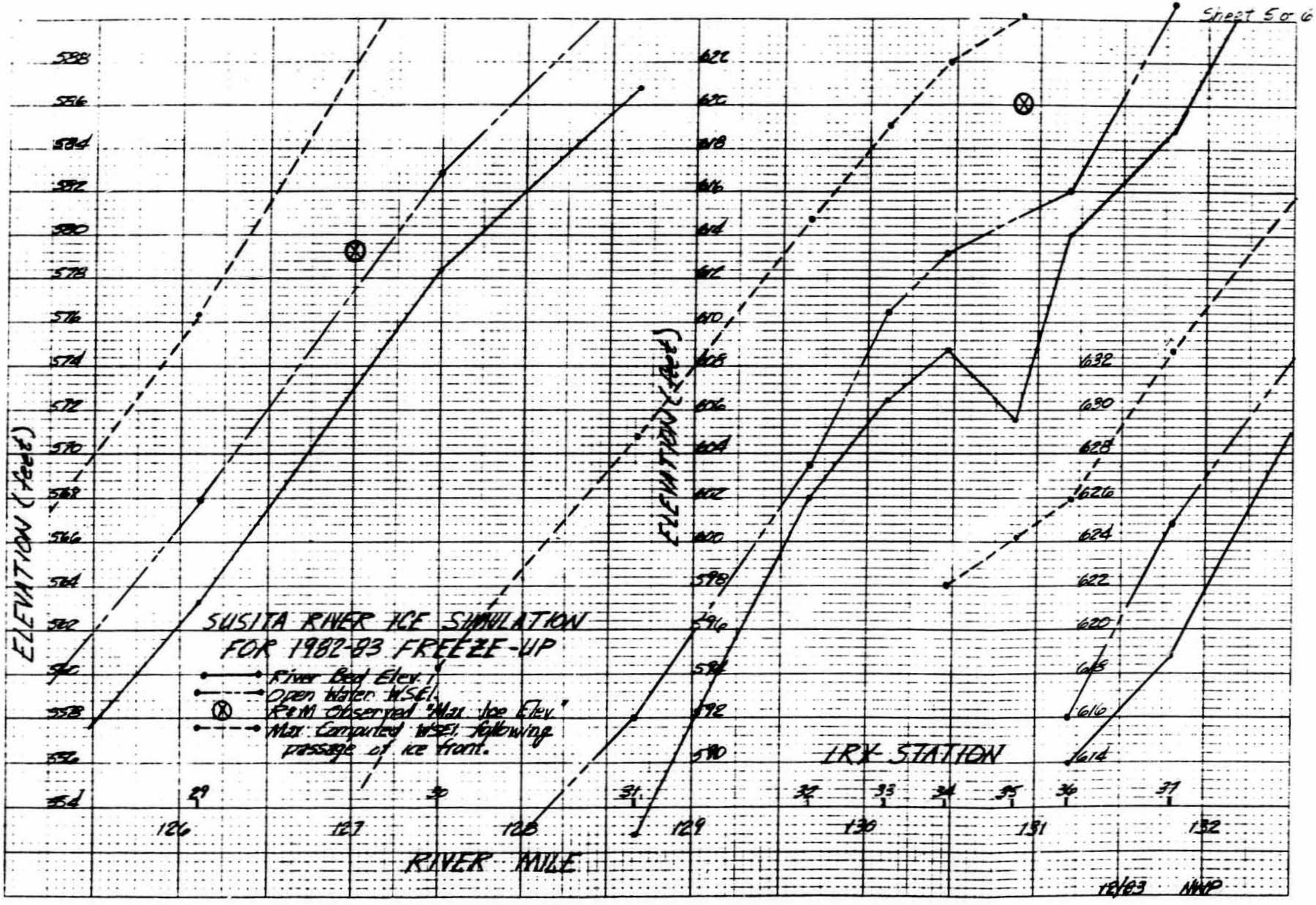
SUSITNA RIVER ICE LEADING EDGE PROGRESSION RATES (miles/day) RELATIVE TO THE THALWEG PROFILE FROM RIVER MILE 0 (Cook Inlet) TO RIVER MILE 155


Computed Max. WSEl. (typ.)
Observed Max. Ice Elev. (typ.)
Open Water Surface Elev. (typ.)
River Bed (typ.)
Computed "Staging" (typ.)
ELEVATION (feet)
RIVER MILE
LRX-3
LRX-4
LRX-5
LRX-6
LRX-7
LRX-8
LRX-9
98
99
100
101
102
103
104
SUSITNA RIVER ICE SIMULATION FOR 1982-83 FREEZE-UP
River Bed Elev.
Open Water WSEl.
Max. Computed WSEl. following passage of ice-front.
R&M Observed Max. Ice Elev.
12/83 NWP

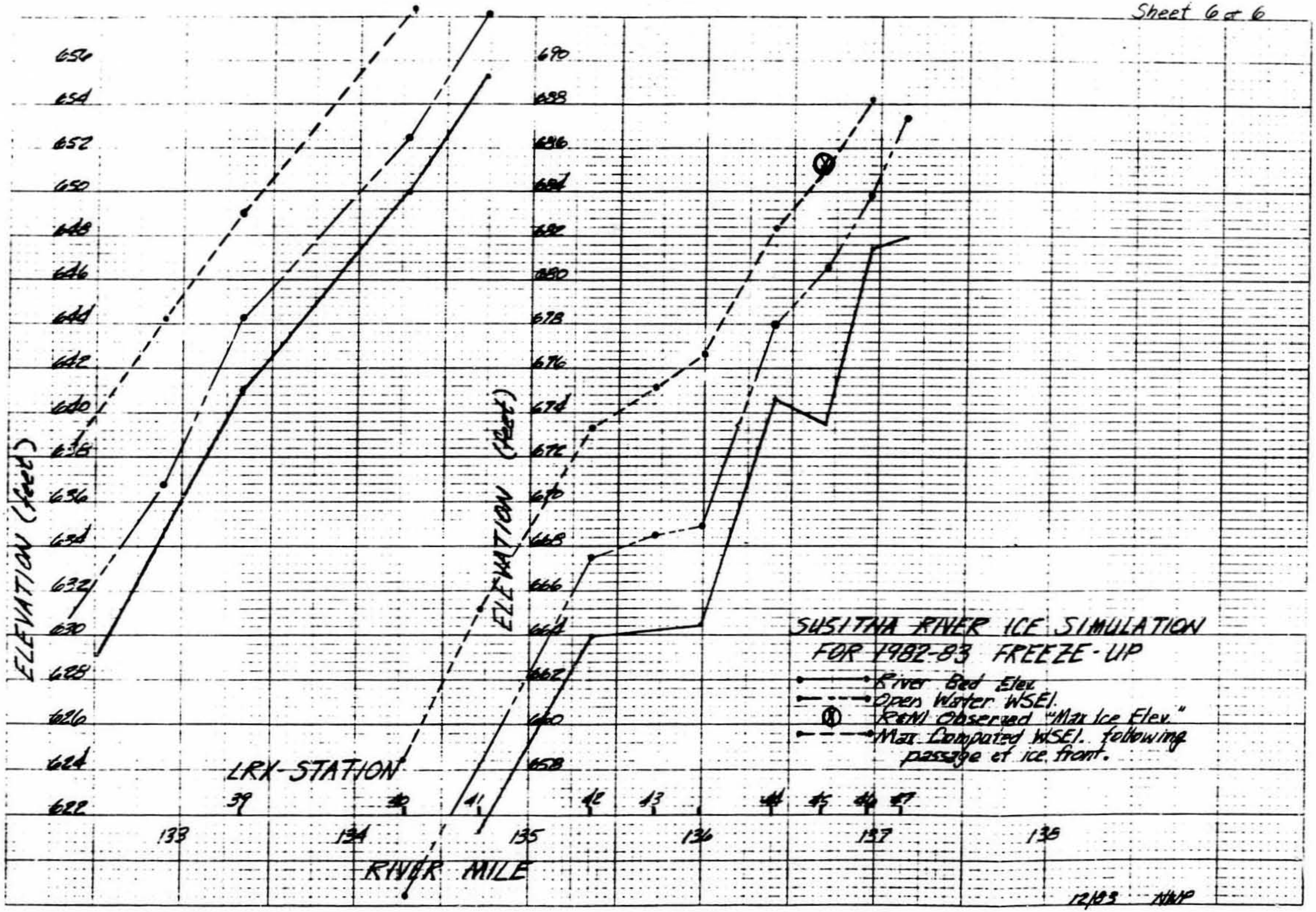

SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
Open Water WSEl.
R&M Observed Max Ice Elev.
Max Computed WSEl following passage of ice front.
ELEVATION (Feet)
RIVER MILE
LRX-10
LRX-11
LRX-12
LRX-13
LRX-14
105
106
107
108
109
110
111
12/83 NWP


SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
Open Water WSEL
Observed "Max Ice Elev."
Max Computed WSEL following passage of ice front.
ELEVATION (Feet)
470
468
466
464
462
460
458
456
454
452
450
448
446
444
442
440
438
502
500
498
496
494
492
490
488
486
484
482
480
478
476
474
472
LRX-STATION
15
16
17
18
19
20
112
113
114
115
116
117
118
RIVER MILE
12/83 NWP


Sheet 4 of 6
SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
Open Water WSEl.
R&M Observed Max Ice Elev.
Max. Computed WSEl. following passage of ice front.
ELEVATION (feet)
528
526
524
522
520
518
516
514
512
510
508
506
504
502
500
498
496
494
ELEVATION (feet)
558
556
554
552
550
548
546
544
542
540
538
536
534
532
530
528
LRX - STATION
21
22
23
24
25
26
27
28
119
120
121
122
123
124
125
RIVER MILE
12/83 NWP

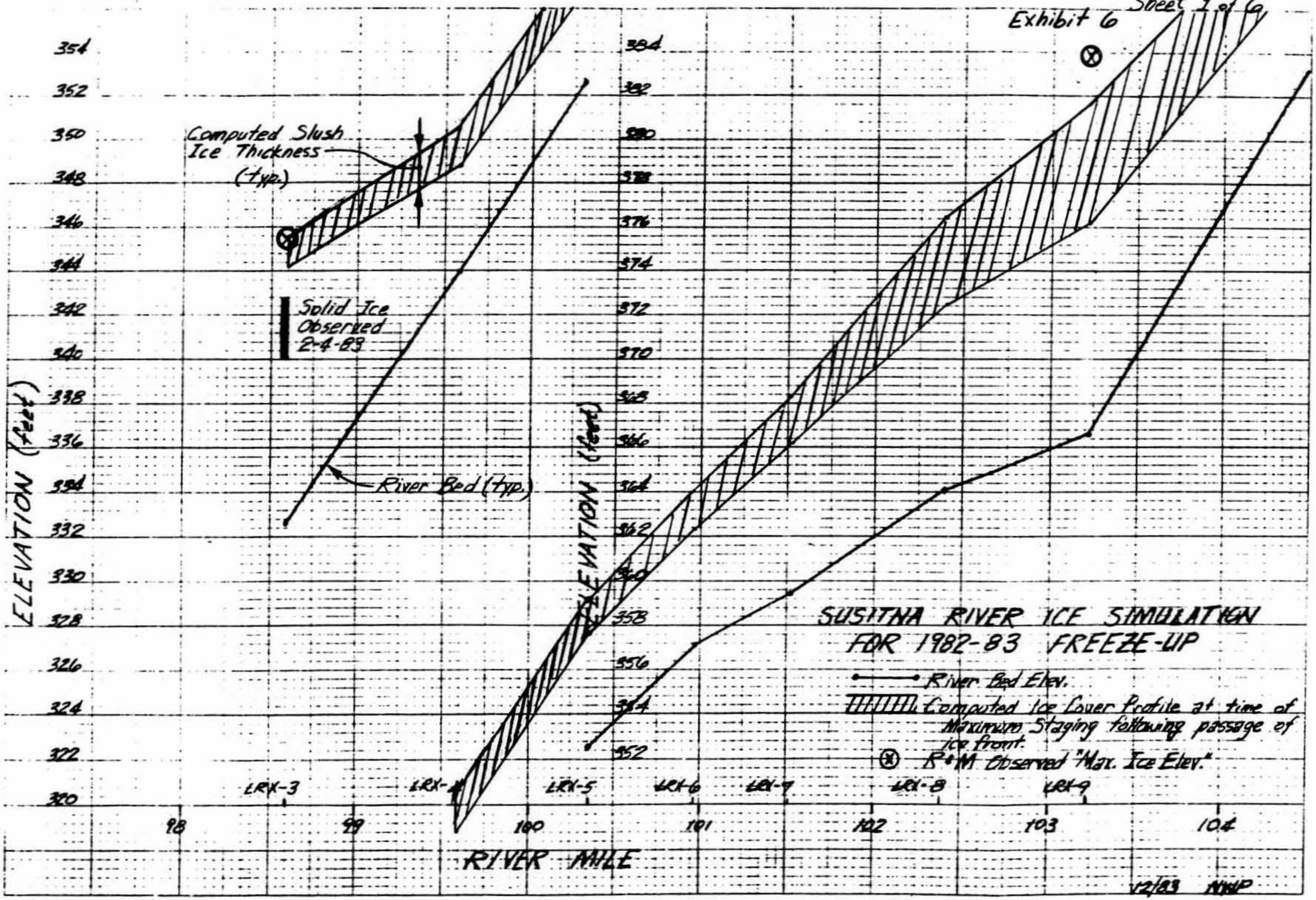


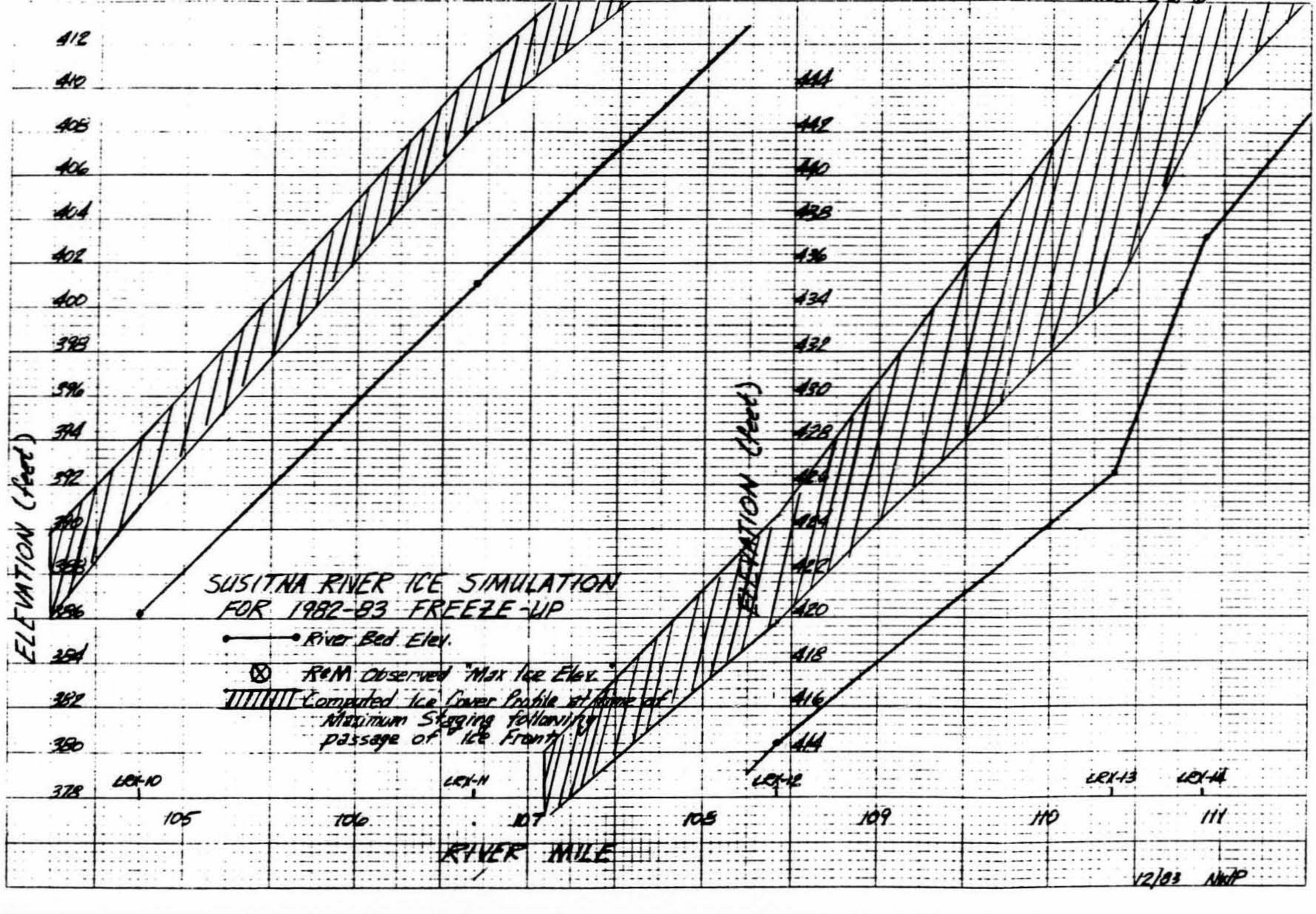
Sheet 5 of 6
SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
Open Water WSEL
R&M Observed "Max Ice Elev."
Max. Computed WSEL following passage of ice front.
ELEVATION (feet)
RIVER MILE
LRX STATION
126
127
128
129
130
131
132
29
30
31
32
33
34
35
36
37
12/83

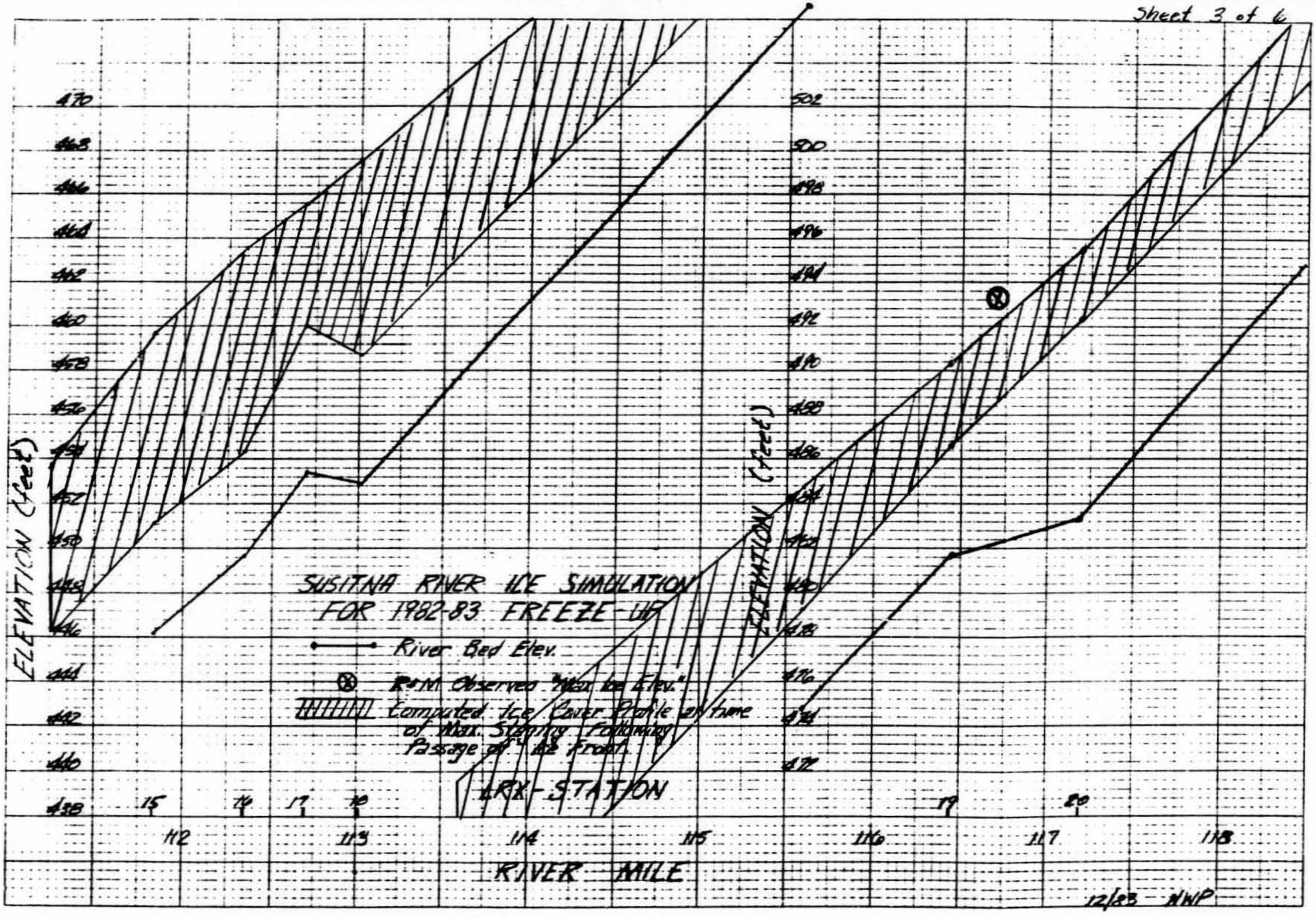


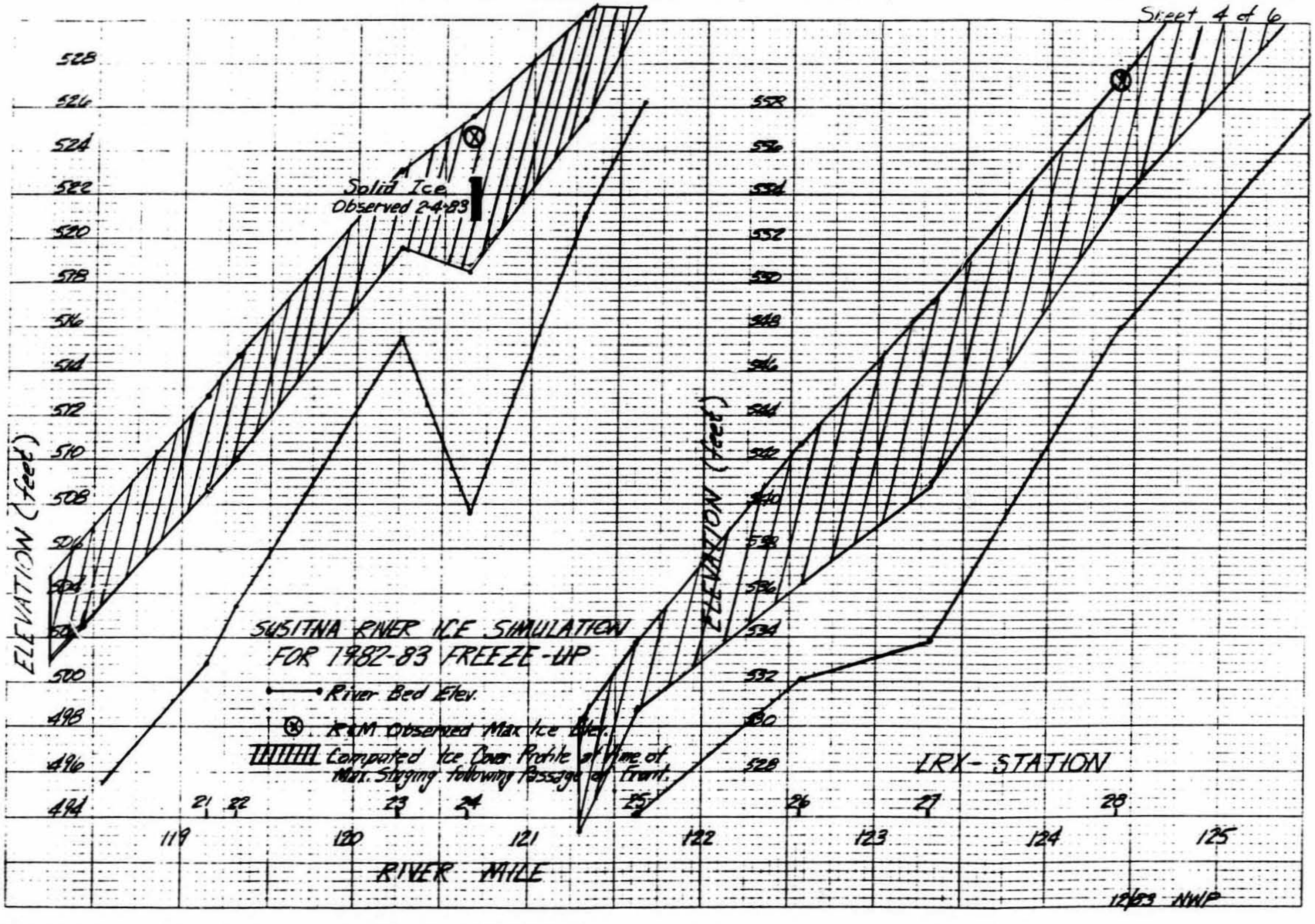
SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
Open Water WSEl.
R&M Observed "Max Ice Elev."
Max Computed WSEl. following passage of ice front.
ELEVATION (feet)
RIVER MILE
LRX-STATION
39
40
41
42
43
44
45
46
47
133
134
135
136
137
138
622
624
626
628
630
632
634
636
638
640
642
644
646
648
650
652
654
656
658
660
662
664
666
668
670
672
674
676
678
680
682
684
686
688
690
12/83 NMP

Exhibit 6

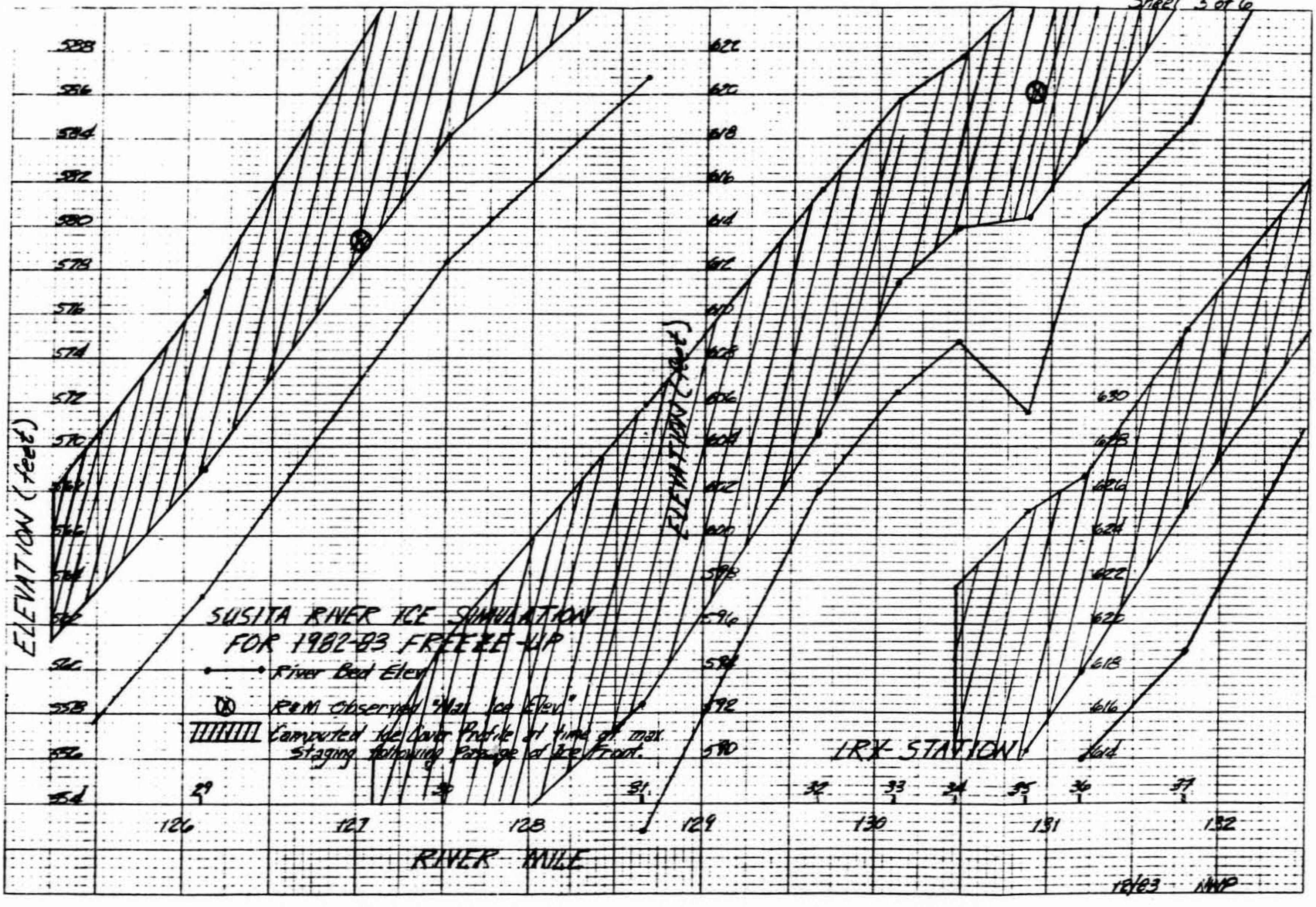

SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
Computed Ice Cover Profile at time of Maximum Staging following passage of ice front.
R&M Observed "Max. Ice Elev."
Computed Slush Ice Thickness (typ.)
Solid Ice Observed 2-4-83
River Bed (typ.)
ELEVATION (feet)
RIVER MILE
LRX-3
LRX-4
LRX-5
LRX-6
LRX-7
LRX-8
LRX-9
98
99
100
101
102
103
104
354
352
350
348
346
344
342
340
338
336
334
332
330
328
326
324
322
320
384
382
380
378
376
374
372
370
368
366
364
362
360
358
356
354
352
1/2/83 NWP

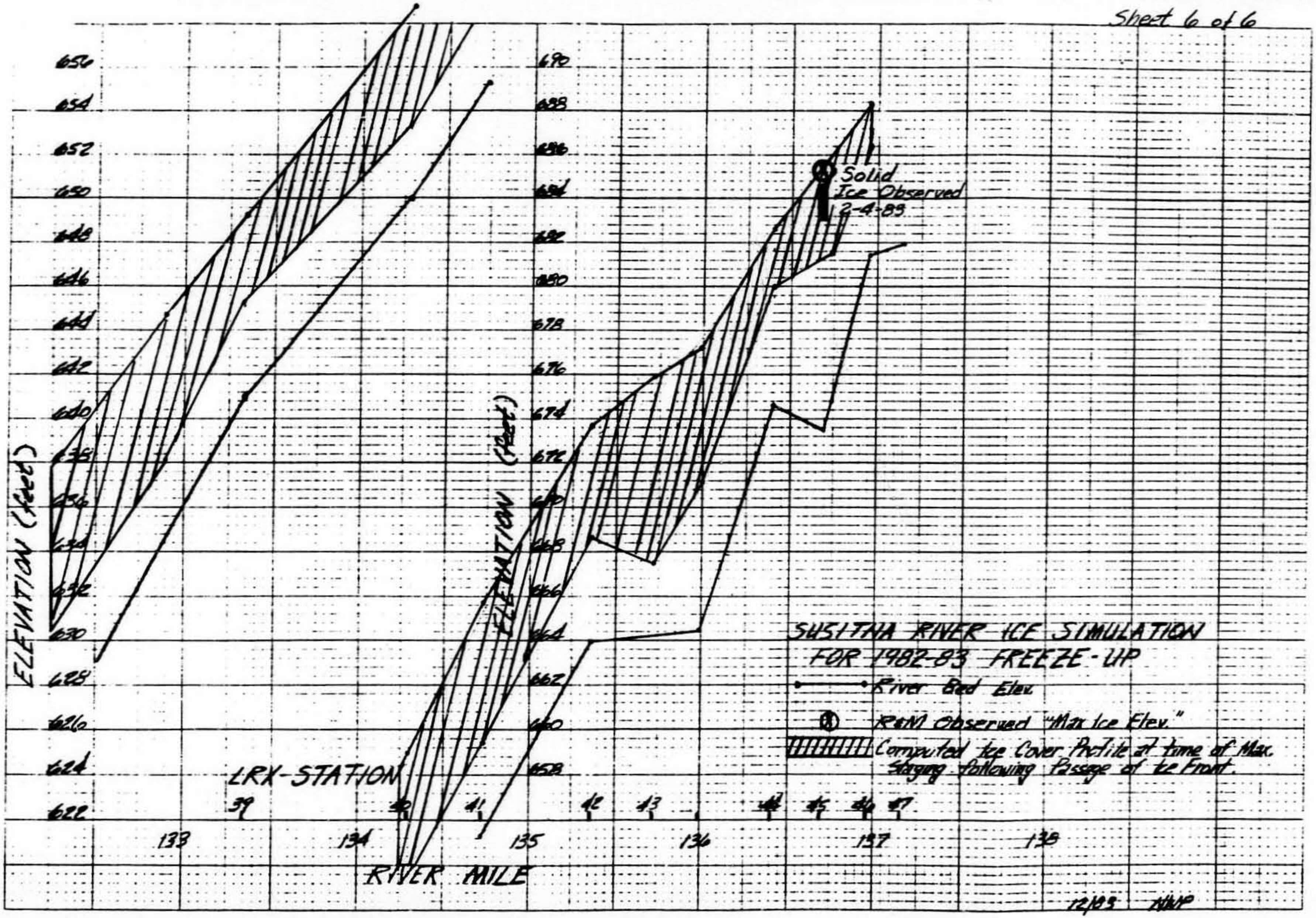

SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
R&M Observed "Max Ice Elev."
Computed Ice Cover Profile at time of Maximum Staging following passage of Ice Front
ELEVATION (feet)
RIVER MILE
412
410
408
406
404
402
400
398
396
394
392
390
388
386
384
382
380
378
444
442
440
438
436
434
432
430
428
426
424
422
420
418
416
414
LRX-10
LRX-11
LRX-12
LRX-13
LRX-14
105
106
107
108
109
110
111
12/83 NWP


SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
R&M Observed "Max Ice Elev."
Computed Ice Cover Profile at time of Max. Staging Following Passage of Ice Front
LRX-STATION
ELEVATION (feet)
RIVER MILE
112
113
114
115
116
117
118
15
16
17
18
19
20
470
468
466
464
462
460
458
456
454
452
450
448
446
444
442
440
438
502
500
498
496
494
492
490
488
486
484
482
480
478
476
474
472
12/83 NWP



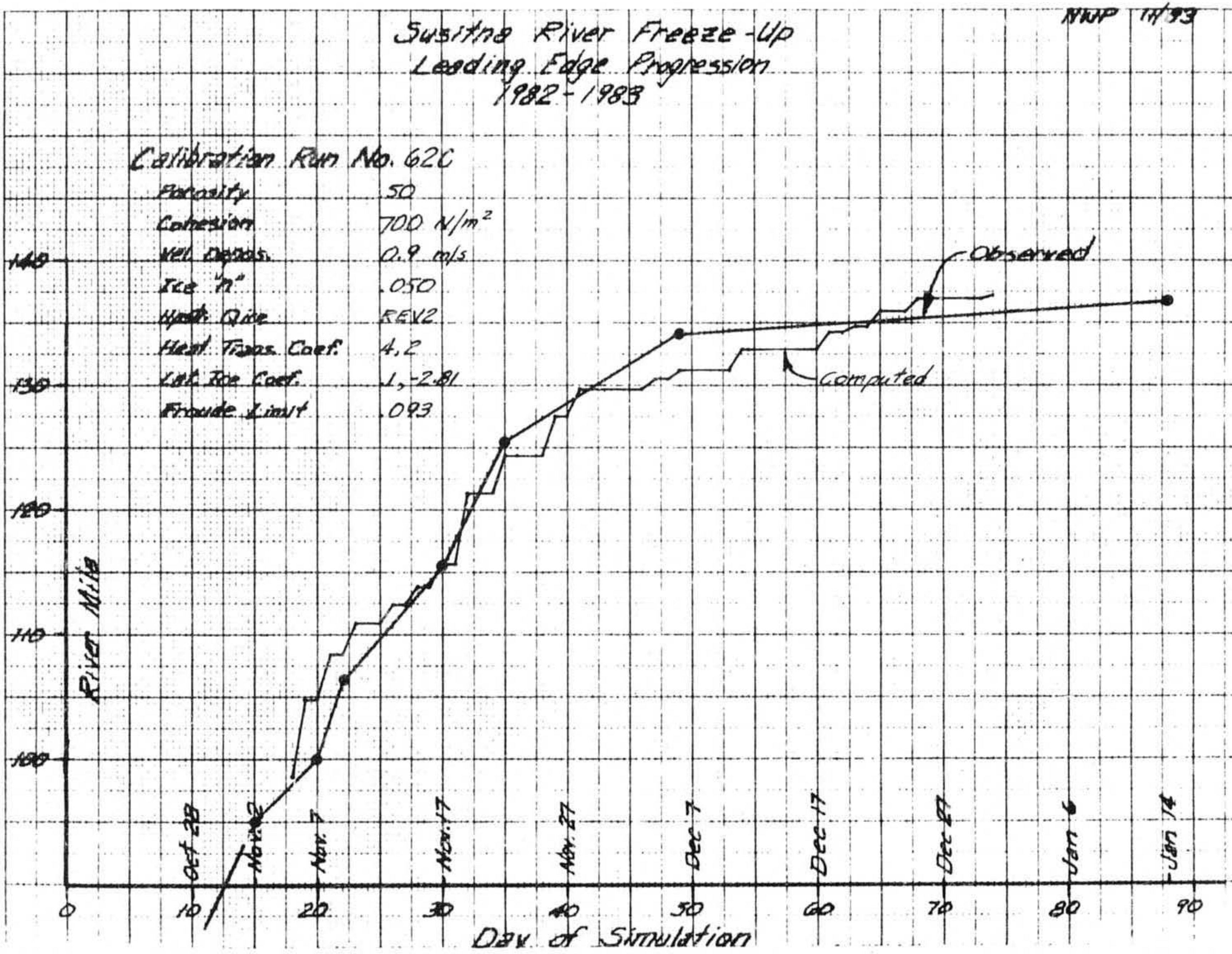
Solid Ice Observed 2-4-83
SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
R&M Observed Max Ice Elev.
Computed Ice Cover Profile at time of Max. Staging following Passage of Front.
ELEVATION (feet)
LRX-STATION
RIVER MILE
119
120
121
122
123
124
125
12/83 NWP


SUSITA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev
R&M Observed "Max Ice Elev"
Computed Ice Cover Profile at time of max. Staging following Passage of Ice Front.
ELEVATION (feet)
RIVER MILE
LRX STATION
126
127
128
129
130
131
132
29
30
31
32
33
34
35
36
37
12/83 NWP



ELEVATION (feet)
RIVER MILE
LRX-STATION
SUSITNA RIVER ICE SIMULATION
FOR 1982-83 FREEZE-UP
River Bed Elev.
R&M Observed "Max Ice Elev."
Computed Ice Cover Profile at time of Max. Staging following Passage of Ice Front.
Solid Ice Observed 2-4-83
133
134
135
136
137
138
12/83 NWP

Exhibit 7



NWP 11/83
Susitna River Freeze-Up
Leading Edge Progression
1982-1983
Calibration Run No. 62C
Porosity .50
Cohesion 700 N/m²
Vel. Depos. 0.9 m/s
Ice "n" .050
Hyd. Qice REV2
Heat Trans. Coef. 4.2
Lat. Ice Coef. 1, -2.81
Froude Limit .093
Observed
Computed
River Mile
140
130
120
110
100
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
Day of Simulation

APPENDIX A

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)

e) Heat transfer slope $\frac{W\text{-sec}}{M^3\text{-}^oC}$

} $a + bV_w$

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 velccity 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) Shoving 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.

NWP 1/5/84

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	V_c
0° to $-7^\circ C$	0.9 m/s
-7 to $-19^\circ C$	0.9/0.95 m/s
-18 to $-30^\circ C$	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 $0^\circ C$)

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°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/m²-°C.

e = porosity of ice cover

λ = heat of fusion of ice, J/kg.

ρ = density of ice, kg/m³.

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

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 = $\frac{Vuh}{2\nu}$ (reach)

f = Darcys friction factor for the ice cover (reach)

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):

$$T_{w1} = (T_{wo} - T_a) * \exp (h_\omega^* \Delta X / \rho C_p V H) + Ta$$

T_a = reach average air temperature

T_{wo} = water temperature at upstream section

T_{w1} = water temperature at downstream section

h_ω = reach average heat transfer coefficient

ΔX = distance between cross sections

ρ = density of water

C_p = specific heat capacity of water

H, V = reach average depth, velocity

$h_\omega = a + bV_w$

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

Darryl J. Calkins

Research Hydraulic Engineer

USACRREL-Hanover, NH

Class notes: Ice Engineering for Rivers and Lakes
Feb. 1-2, 1982, Univ. of Wisconsin, Madison, WI
REVISED JAN 83

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.

Conditions Leading to Ice Bridging

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

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

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

$$\frac{V_2}{V_1} = 0.63 \frac{n_b}{n_c} \left[1.0 - \frac{\rho_i}{\rho} \frac{t}{y_1}\right] \qquad [9]$$

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.

<u>Ice Cover Progression and Thickening</u>

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)

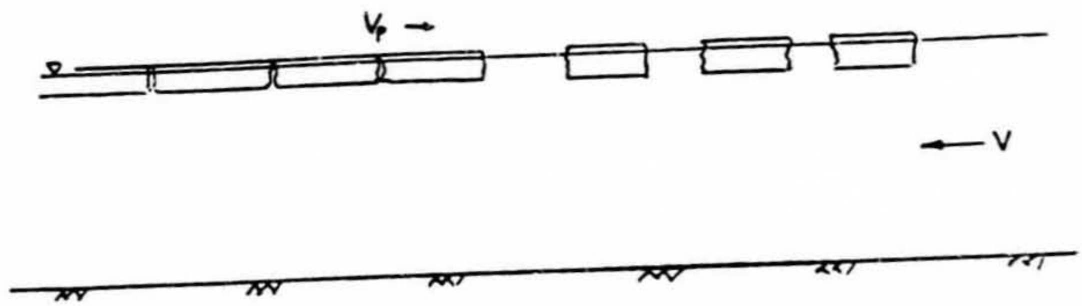
B_1 = open water width (m)

t_s = equivalent thickness of the floating ice (m)

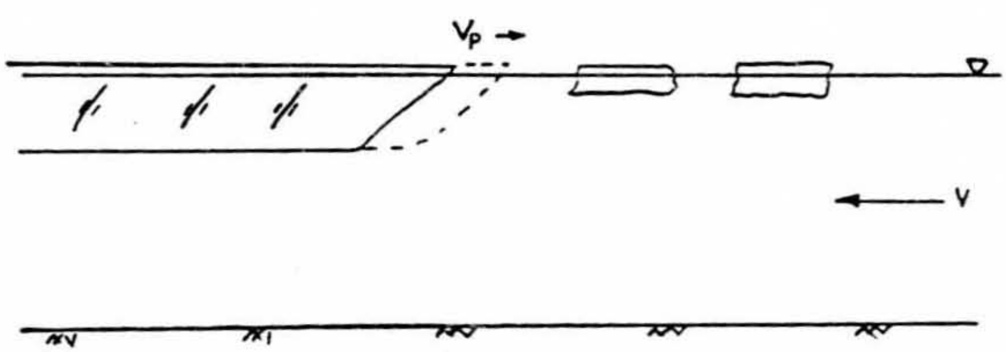
ε_s = porosity of the floating slush.

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.

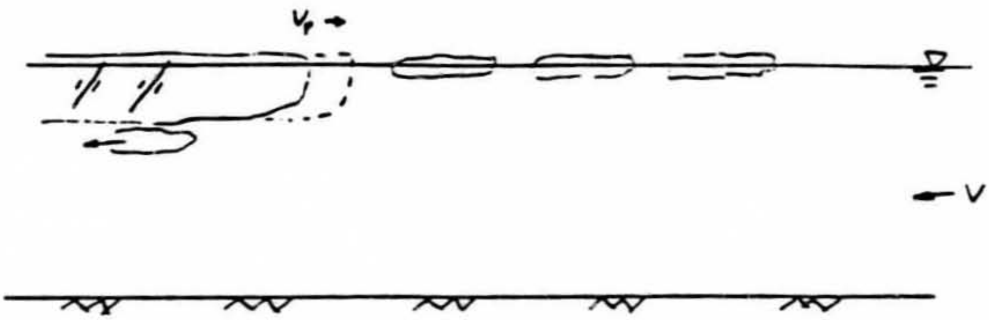
1. Progression by simple juxtaposition of the arriving floes with no thickening.



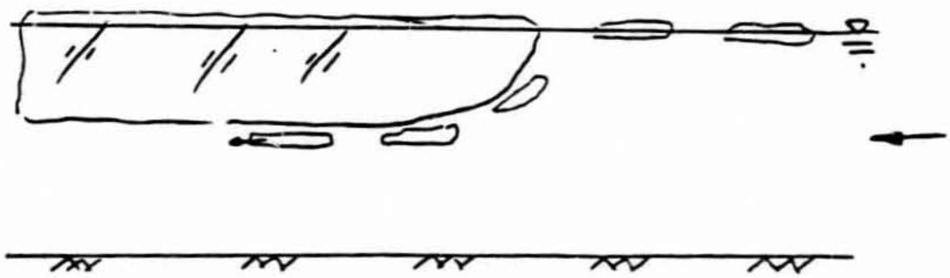
2. Progression, but the arriving floes thicken to values greater than the initial thickness of the arriving ice, $t_j/H < 0.33$, or $t_j/H > .33$.



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.

RESUME

NAME: Darryl J. Calkins

DATE PREPARED: 16 November 1982

DATE OF BIRTH: 16 November 1946
St. Johnsbury, VT

EDUCATION:

Danville High School
Danville, VT, 1964

University of Maine, Orono, Me.
BS in Civil Engineering, 1969
Major in Sanitary Engineering

University of New Brunswick, Fredericton, NB
MS in Civil Engineering, 1970
Major Field: Hydraulic and Water Resources Engineering

University of Iowa, Iowa City, Iowa
Department of Mechanics and Hydraulics
Energy Engineering Division
August 1976 - August 1977

POSITION:

1. Research Hydraulic Engineer, Ice Engineering Research Branch, Experimental Engineering Division, U. S. Army Cold Regions Research and Engineering Laborabory, Hanover, NH.

2. Instructor for course "Ice Engineering for Rivers and Lakes," Univ. of Wisconsin, 1980, 81, 82. Subject - Hydraulics of Ice Covered Rivers.

3. Instructor for course "River Ice Hydraulics" Environment Canada-Inland Waters Directorate Ottawa, Ontario, June 1982.

4. Adjunct Professor, Antioch College-New England, Keene, NH. Instructor in Environmental Science Program-Fundamentals of Meteorology and Hydrology, 3 credit course, Spring 1979.

PROFESSIONAL ACTIVITIES:

1. Secretary, Executive Committee ASCE Hydraulics Division, 1981-83.

2. Member, ASCE Upper Valley Branch.

3. Newsletter Editor, ASCE Hydraulics Division, 1979-1981.

4. Registered Professional Engineer.

5. Member, New England Junior Science and Humanities Symposium Executive Committee.

EXPERIENCE:

July 1980 - Present
Project engineer conducting hydraulic modeling studies, investigating the basic mechanics of ice jam formation, and conducting field studies of ice/hydraulics, frazil ice formation and ice jams. The modeling work has evolved around laboratory tests in which the basic understanding of ice jam formation is being formulated. To complement the laboratory work an extensive in-depth field observation program on ice jams has been implemented and instrumentation has been installed to help gather the necessary field data that is being used in the refrigerated physical model simulations. Several preliminary studies have been completed on ice jam conditions in the field.

September 1978 - June 1980
Project engineer responsible for the Port Huron Ice Control Model Study conducted for the Detroit District COE under the Winter Navigation Demonstration Program. This project was the first time a hydraulic model has been designed to operated in a refrigerated room. I was responsible for the design, construction, calibration and testing of the physical model and shared the responsibility for the development of the wind stress modelling concept. I was responsible for all field data collected during the winter season to be used for model calibration, as well as for the background and supporting data on general ice conditions in the area. This involved coordination with the Detroit District COE for ground control and the U.S. Coast Guard Station, Detroit for transportation by helicopters to the ice sheet.

August 1976 - August 1977
Attended the University of Iowa under the Dept. of Army Long Term Training Program in the Department of Mechanics and Hydraulics and the Iowa Institute of Hydraulic Research. The year was devoted to taking such typical courses as fluid mechanics, advanced engineering mathematics, numerical methods, heat transfer and other hydraulic engineering courses. I had an excellent opportunity to observe and discuss the various hydraulic projects under study. These included sediment transport, fixed bed hydraulic models as well as the ice-hydraulic related studies.

November 1973 - August 1976
Project engineer conducting hydraulic modeling studies investigating the fundamental mechanics of ice jam formation. Field activities have included the gathering of channel cross section data, flow profiles and ice characteristics to complement the hydraulic model studies. A continuing study that has been under investigation is the simulation of drifting snow using the sand-water analog to replicate blowing snow conditions.

November 1975 - April 1976
Project supervisor on a small task of the lock-wall de-icing program devoted to water jet-cutting of ice off lock walls.

January 1971 - November 1973
Assistant Civil Engineer - active duty U.S. Army. Assisting project personnel on studies of lightweight snowfence materi s. Design and fabrication of full-scale models of missile cell covers for field tests on drifting snow in North Dakota.

Design, construction and calibration of a hydraulic sedimentation flume including the necessary laboratory equipment for conducting research in such a facility. The flume was designed to multi-purpose model experiments; (a) sediment transport (simulation of drifting snow), (b) ice jam mechanics at retention facilities, ice booms, bridge piers, etc., and other special projects where hydraulic phenomena can be simulated.

June 1969 - October 1970
Conducted and coordinated research involving sedimentation, water quality, soil moisture and surface runoff in an experimental watershed in central New Brunswick for the International Hydrologic Decade (IHD) program in Canada. Layout of hydraulic fluem facility for the Dept. of Civil Engineering.

Summer 1968
Assistant Civil Engineer, U.S. Dept. of Agriculture, Agriculture Research Service, Sleepers River Research Watershed in Danville, VT.

Developed a field procedure for measuring channel velocities in small streams using a portable pH meter using a sodium ion probe and injecting salt solutions upstream. Supervisor for all surveying activities and drilling operations in the watershed.

Summers 1967, 1966, 1965
USDA - ARS in Danville, VT.

Engineering Aide - Hydrographic and topographic surveying, assisting engineers and scientists in their field work on water quality, sedimentation and stream runoff projects.

PUBLICATIONS: Journal Articles and Conference Proceedings

1. Calkins, D.J., R. Hayes, S.F. Daly and A. Montalvo, "Application of HEC-2 for ice-covered waterways," Journal of Technical Councils of ASCE - Cold Regions Council, November 1982.

2. Calkins, D.J., "Ice Jams in Shallow Rivers with Floodplain Flow," Submitted to Canadian Journal of Civil Engineering, September 29, 1982.

3. Calkins, D.J. and G. Gooch, "Ottauquechee River - Analysis of Freeze-up Processes," presented at Workshop on Hydraulics of Ice Covered Rivers, Edmonton, Alberta, June 1-2, 1982.

4. Calkins, D.J., D.S. Deck and Carl R. Martinson," "Resistance coefficients from velocity profiles in ice covered shallow streams," Canadian Journal of Civil Engineering, Vol. 9, No. 2, June 1982, pp. 236-247.

5. Calkins, D.J., R. Hayes, S.F. Daly and A. Montalvo, "Determining water surface profiles in navigation channels under various ice conditions using HEC-2," present at ASCE National Conference, St. Louis, MO, 28 October 1981.

6. Calkins, D.J. D.S. Sodhi and D.S. Deck, "Port Huron ice control studies," IAHR International Symposium on Ice, Quebec, Canada, July 27-31, 1981.

7. Calkins, D.J., D.S. Deck and C.R. Martinson, "Analysis of velocity profiles under ice in shallow streams," Proceedings of Workshop on Hydraulic Resistance of River Ice, National Water Research Institute, Canada Center for Inland Waters, September 23-24, 1980, edited by G. Tsang and S. Beltaos.

8. Calkins, D.J., "Arching of Model Ice Floes at Bridge Piers," IAHR Symposium on Ice Problems, August 7-9, 1978, Lulea, Sweden.

9. Muller, A. and D.J. Calkins, "Frazil Ice Formation in Turbulent Flow," IAHR Symposium on Ice Problems, August 7-9, 1978, Lulea, Sweden.

10. Calkins, D.J. "Physical Measurements of Ice Jams," Water Resources Research, Vol. 14, No. 4, AGU, August 1978.

11. Calkins, D.J. and G.D. Ashton, "Passage of Ice at Hydraulic Structures," Rivers 76, Symposium on Inland Waterways for Navigation Flood Control and Water Diversions, Vol. II, August 10-12, 1976.

12. Calkins, D.J. and M. Mellor, "Investigation of Water Jets for Lock Wall Deicing," Paper presented at Third International Jet Cutting Symposium, May 1976, Chicago.

13. Calkins, D.J. and G.D. Ashton, "Arching of Fragmented Ice Cover," Canadian Journal of Civil Engineering, Vol. 2, No. 4, December 1975.

14. Calkins, D.J. and M. Mellor, "Cost Comparisons for Lock Wall Deicing," Third International Symposium on Ice Problems, International Association for Hydraulic Research, Hanover, NH, August 18-21, 1975.

15. Calkins, D.J. and G.D. Ashton, "Arching of Fragmented Ice Covers," presented at 2nd Canadian Geotechnical Conference, May 1975, Burlington, Ont.

16. Davar, K.S. and D.J. Calkins, "Evaluation of Soil Moisture Regime in a Watershed," A paper presented at the International Symosium on Water Resources Planning, Mexico City, Mexico, 4-8 Dec 1972.

17. Calkins, D.J. and T. Dunne, "A Salt Tracing Technique for Measuring Channel Velocities in Small Mountain Streams," Journal of Hydrology, Amsterdam, Vol. 11, No. 2, November 1970.

18. MS Thesis, "Evaluation of Soil Moisture in Watershed Response," University of New Brunswick, October 1970.

DISCUSSIONS:

1. Calkins, D.J. and G.D. Ashton, 1982, Discussion of paper on Resistance of Beauharnois Canal in Winter, ASCE J. of Hydraulics Division.

USACRREL REPORTS:

1. Calkins, D.J. D.S. Deck and D.S. Sodhi, "Hydraulic Model Study of Port Huron Ice Control Structure," CRREL Report 82-34, November 1982, 68 p.

2. Sodhi, D.S., D.J. Calkins and D.S. Deck, "Model Study of Port Huron Ice Control Structure - Wind Stress Simulation," CRREL Report 82-9, April 1982.

3. Calkins, D.J. and A. Mueller, "Measurement of the shear stress on the underside of simulated ice covers," CRREL Report 80-24, October 1980.

4. Calkins, D.J., "Accelerated Ice Growth in Rivers," CRREL 79-14, May 1979.

5. Calkins, D.J. and G.D. Ashton, "Arching of Model Ice Floes: Effect of Mixture Variation in Two Block Sizes," CRREL 76-42, November 1976.

6. Calkins, D.J., M. Hutton, and T. Marlar, "Analysis of Potential Ice Jam Sites on the Connecticut River at Windsor, VT," CRREL 76-31, Sept. 1976.

USACRREL SPECIAL REPORTS:

1. Brierly, W., D.J. Calkins, et a., "Lock Wall Deicing with Water Jets, Field Tests at Ship Locks in Montreal and Sault Ste. Marie," USACRREL Special Report.

2. Calkins, D.J., M. Hutton, and T. Marlar, "Analysis of Potential Ice Jam Sites - Connecticut River at Windsor, VT," report submitted to the New England Division, Corps of Engineers, Waltham, MA, Sept. 1975.

3. Calkins, D.J. and M. Mellor, "Preliminary Economic Analysis of Lock Wall Deicing Methods," USACRREL Internal Report 444, April 1975.

4. Calkins, D.J. and G.D. Ashton, "Arching of Fragmented Ice Covers," USACRREL Special Report 222, May 1975.

5. Calkins. D.J., "Simulated Snow Drift Patterns: Evaluation of Geometric Modeling Criteria for a Three-dimensional Structure," USACRREL Special Report 219, January 1975.

6. Calkins, D.J., "Model Studies of Drifting Snow Patterns at Safeguard Facilities in North Dakota," USACRREL Technical Report 256, Nov. 1974.

7. Calkins, D., "A Research Hydraulic Flume for Modeling Drifting Snow - Design, Construction and Calibration," USACRREL Technical Report 251, June 1974.

USACRREL TECHNICAL NOTES:

1. Calkins, D.J., "Field Measurements of the Hydraulic Transients during the Ice Cover Formation and Break-up: Ottauquechee River 1980-81," Technical Note, April 1981.

2. Calkins, D.J., "Ice Jam Flood Levels - Measurements on the Ottauquechee River 1977-1981," Technical Note, April 1981.

3. Calkins, D.J., "Growth of Brash Ice in Ship Tracks and River Ice Closure Rates," Technical Note, December 1980.

4. Calkins, D.J., "Frazil Production in Shallow Streams and Laboratory Modeling Concepts," Technical Note, October 1980.

5. Calkins, D.J., "Ice Jam Measurements and Undercover Roughness Calculations," Internal Report 629, March 1980.

6. Calkins, D.J., "Ice Jam Flood Levels - Measurements on the Ottauquechee River 1977-1981," April 1981.

7. Calkins, D.F., "Field Measurements of the Hydraulic Transient during the Ice Cover Formation and Break-up: Ottauquechee River 1980-1981," April 1981.

8. Calkins, D.J., "Methodology for Ice Jam Analysis," February 1981.

9. Calkins, D.J., "Growth of Brash Ice in Ship Tracks and River Ice Closure Rates," December 1980.

10. Calkins, D.J., "Frazil Production in Shallow Streams and Laboratory Modeling Concepts," October 1980.

11. Calkins, D.J., "Ice Jam Measurements and Undercover Roughness Calculations," March 1977.

12. Calkins, D.J., "Observation of Mid-winter Ice Jams - White, Ottauquechee and Connecticut Rivers," March 1976.

13. Calkins, D.J., "Water Surface Profiles - Connecticut River," USACRREL Internal Report 423, May 1975.

14. Calkins, D.J. and J. Ingersoll, "Laboratory Ice Adhesion Studies - Shearing Tests," March 1975.

15. Brierly, W., D.J. Calkins, S. DenHartog, M. Mellor and H. Ueda, "Ice Cutting Tests at Soo Locks," March 1975.

16. Brierly, W., D.J. Calkins, S. DenHartog, M. Mellor and H. Ueda, "Jet Cutting Tests at St. Lambert," December 1974.

17. Morse and D.J. Calkins, "Construction Techniques for Underwater Model Construction," December 1974.

18. Calkins, D.J., "Simulated Snow Drifts Around Three Proposed Air Transportable Buildings Using a Hydraulic Model Technique - Preliminary Study," June 1974.

19. Calkins, D.J., "Scale Models for Drifting Snow," May 1971.

AWARDS:

USACRREL Recognitions: Successful project completion of worlds first refrigerated hydraulic model study, 1980.

USACRREL Award for Outstanding Engineering Achievement for Enlisted Personnel, 1973.

Student paper presentation, ASCE New England Meeting, 2nd prize, 1969.

NRC Scholarship from the Canadian government for support of research in experimental watershed as published in M.S. Thesis, 1969.

CONTINUING EDUCATION:

Institute on Unsteady Flow Analysis in Open Channels, Colorado State University, June 1974, Awarded 4 quarter credits on pass fall grading system.