ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT

TASK 3 - HYDROLOGY

HYDRAULIC AND ICE STUDIES

Chapters 5 and 6 and Attachment A

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5 - ICE PROCESS ANALYSES

Geographically, the Susitna River upstream from Talkeetna can be divided into three major segments. The upper segment above the Oshetna confluence, the middle segment reaching to just below Devil Canyon, and the lower segment from near Indian River to Talkeetna.

The upper segment flows southward from its various glacial origins near latitude 63°30'N for some 90 miles to latitude 62°40'N. The elevation in this segment decreases from about 2,600 feet at the toes of the glaciers (which rise to above 10,000 feet) to 2,150 feet. This is a fall of sime 450 feet at an average slope of about 5 ft/mile. No notable concentration of fall occurs in this segment.

The middle segment flows westward with a slight northward trend for about 90 miles from the Oshetna River confluence near longitude 147°25'W to the downstream end of Devil Canyon (Indian River confluence) at 140°25'W and 62°50'N. The fall in this segment is about 1,350 feet to elevation 800 feet, providing an average slope of 15 ft/mile. Concentrations of the fall in the middle segment occur in four reaches: at the Oshetna River, at Vee Canyon, just below Devil Creek, and in particular, at Devil Canyon.

The lower segment flows in a south-southwesterly direction for about 40 miles from Indian River to near the town of Talkeetna at 150°05'W and 62°20'N. The fall in this segment is about 450 feet to elevation 350 feet at an average slope of about 11 ft/mile. No notable concentration of fall occurs in this segment.

Downstream to Talkeetna where the Susitna flow conjoins with those of the Chulitna and Talkeetna Rivers, the Susitna's course is southward for 75 miles to sea level at Cook inlet at 61°20'N with an average slope of 5 ft/mile. No concentration of fall occurs in this southern segment of the river.

5.1 - Field Observations

The geographic orientation of the river on the south slope of the Alaska Range results in air temperatures increasing along its course from the headwaters to the lower reaches. Whereas this temperature gradient may be due in part to the 2-degree latitudinal span of the river, it is probably due primarily to the 3,300-foot altitudinal difference from the lower to the upper reaches, as well as to the proximity of climate-moderating ocean waters to the lower reaches. In any case, the gradient gives rise to a period of time in the early stages of freezeup (late October-early November) in which the lower basin temperatures are above the freezing point while the upper basin is at subfreezing temperatures. This was the situation observed on October 17, 1980, with late afternoon temperatures (4:30 p.m. ADT) above Watana being 30°F or lower while the temperature at Talkeetna was at about 39°F. Presumably, a similar springtime period occurs with temperatures straddling the freezing point at some intermediate point in the basin. This point would move in an upstream direction with upward trending temperatures (i.e. springtime) and downstram with downward trending temperatures (i.e. autumn). In both cases, this pattern of temperature affects the sequence and timing of ice cover events.

As noted, on October 16 and 17, 1980, the foregoing autumn temperature situation was seen to prevail. Glacial melt from the headwaters cooled enough in its course through the relatively mild slope of the upper segment of the river to produce notable quantities of frazil flock and slush pans (15-25 percent surface coverage) under post-dawn air temperatures of 18°F to 14°F. In the fast-flowing rapids of the middle segment, relatively large quantities of frazil were being produced, which augmented the inflow of ice from upstream loading, to surface coverage of the river as high as 75-85 percent. As inflows from major tributaries along the source of the upper and middle segments had little, if any, ice content, the near-freezing temperature of the glacial melt is judged to be a significant determinant of the origin of ice from which a cover will develop and, therefore, of the timing of that development. Thus, the summer collection and storage of heat in the proposed reservoirs in the upper reaches of the river will produce significant changes in the autumn temperature regime in the downstream reaches and, therefore, in the timing and rate of cover development.

Details of the observations made during the river freeze-up (1980) and breakup (1981) may be found in the Ice Observations report (R&M, 1981b).

5.2 - Modeling of Ice Processes

(a) Description of the Computer Models

Acres' in-house computer models HEATSIM and ICESIM were used to simulate the ice processes in the river reach above Talkeetna. HEATSIM simulates a daily heat balance in the river reach to determine water temperature progressively downstream. Details of the model and its calibration to simulate Susitna river reaches are presented in Appendix A4 to the main Feasibility Report. The model is used to predict water temperature in the river and to determine the approximate location and time when water temperature reaches 32°F. This location is used as input to the ICESIM model which simulates the formation and progression of an ice cover and the water levels associated with the processes. The following paragraphs describe the ICESIM model in some detail.

ICESIM Model Input

Input data to the ICESIM model include streamflow, river cross-sectional details, and an estimate of ice flow into the study reach. Physical coefficients such as ice density, cohesion, and ice cover friction (Manning's n) are also input to the program. Standard values available in the literature are used in the model. Aspects of flow characteristics such as ice erosion velocity and critical Froude number for ice cover progression should also be defined. Based on the literature and field observations made in 1980-81, values were estimated for these parameters and are listed in Table 5.1.

Model Backwater Calculations

The ICESIM model includes a subroutine which calculates backwater profiles in the river reach to assess water levels at different cross-sections. The routine is similar to the HEC-2 model described in Section 4 but is less sophisticated with respect to hydraulic computations in order to accommodate the complexities of the ice process simulation. Effectively, this simplicity translates to less precise water level calculations (±1 to 2 feet), as compared to HEC-2 modeling accuracy which is to better than ±1', but it is considered adequate to provide representative results. This model was calibrated against the HEC-2 model results for a single river discharge as discussed below.

Historically, freezeup has started at a river discharge of around 4,000 cfs at Gold Creek in the end of October and progressed above Talkeetna until late November/ early December when the discharge dropped below 3,000 cfs. Calibrating the backwater routine with observed water levels for a river discharge of around 3,000 cfs at Gold Creek proved exceedingly difficult due to critical or near-critical flow conditions encountered in the river reach analyzed. Post-project winter discharges will be considerably higher (around 10,000 cfs) as discussed in Appendix A1 to the main Feasibility Report. It was therefore decided that the backwater routine should be calibrated against the HEC-2 model results for a discharge close to the 10,000 cfs. Field measurements of water levels in the river reach had been made for a natural streamflow of 9,700 cfs (at Gold Creek) and have been used in the calibration of the HEC-2 model (Section 4). It was considered appropriate to use this discharge to calibrate the backwater routine of the ICESIM model as well. A comparison of the HEC-2 and ICESIM routine calculations is presented in Table 5.2 which indicates a reasonable agreement between the two model results.

Modeling of Ice Cover Formation and Progression

The model simulates the formation and progression upstream of the ice cover given the location of the leading edge of ice cover and the time of its occurrence. The model checks the stability of ice cover and adjusts its thickness consistent with ice supply, river goemetry, and hydraulics of the flow. The ice thickness is adjusted either by telescoping of the cover or by thickening, and the model proceeds to the next section upstream. Except for occasional minor bridging, the steep river slope in the reach does not permit ice progression by bridging. This is also generally confirmed by the river observations in 1980-81.

Model Calibration

An attempt was made to calibrate the ice process simulation model with the field data collected during the 1980 river freezeup period. It became apparent that the model could not simulate numerous critical or near-critical flows that occur in the river, due to the relatively large lengths of subreaches modeled. Several intermediate river cross-sections were synthesized between surveyed sections to reduce these subreach lengths. Nevertheless, the model has been used to simulate ice formation and progression at average post-project winter flows. Several qualitative checks have been made to assess the accuracy of this simulation. These include general heat balance of the river waters, river hydraulic characteristics as observed in the field, and comparisons with similar studies elsewhere in the northern climate.

It must be emphasized that precision of predicted water levels in the river under post-project ice conditions is rather limited (±1 to 2 feet). However, the width of the uncertainty band in the modeling does not have a significant impact on the simulation of the ice regime of the river above the Talkeetna confluence, due to limited progression (see Section 5.3).

5.3 - Results of Simulation Studies

Studies were conducted for the following stages of project developments:

- During construction of the Watana dam.
- Only Watana development operational.
- Both Watana and Devil Canyon developments operational.

(a) Watana Construction Stage

During this stage, no significant change in the river regime is expected since natural flows in the river below the damsite will be maintained with the proposed diversion facilities. No simulation of this condition was carried out.

(b) Operation with Watana Development Only

Heat balance analyses were made using the HEATSIM model in the 35-mile river stretch between Watana and Devil Canyon damsites. The analyses indicated that the temperature of the power flow from Watana would reach close to 32°F below Devil Canyon by about the third week of November under average climatic conditions. This is about a month later than under natural conditions and would delay the ice progression above Talkeetna by a similar interval. It was determined that an ice cover will be formed above the Chulitna confluence around the end of November with ice generated from the reach below Watana damsite. Ice simulation studies indicated that the ice front progressed upstream at roughly 0.3 miles/day, a rate less than one-eighth of that observed in 1980 (Table 5.3). The front reached some 15 miles upstream by the end of January, after which a thermal decay of the ice cover is expected due to increased air temperature and reduced cooling of the power flow from Watana. The ice cover formed in the reach above Talkeetna is expected to melt in place by the end of March, and the decay will proceed further downstream thereafter. It is unlikely that any ice jam of significance will occur above the Chulitna confluence.

Below the confluence, it is speculated that ice cover formation will be delayed by one to three weeks due to lower and delayed supply of ice from the Susitna, but progression of the ice front would not significantly differ from that under natural conditions. However, the decay of the ice cover is expected to start earlier, by the end of March, due to warmer waters from the power development. Significant increase in water temperature from that under natural conditions is not expected near the river mouth.

(c) Operation with Watana and Devil Canyon

When both developments are operational, the temperature of power outflows from Devil Canyon is expected to be close to 39°F during the winter months (see Appendix A4 to the main Feasibility Report). As it progresses downstream, water becomes cooler from heat exchange with the atmosphere. By early January, it is expected that this water will cool to about 32°F near Talkeenta (see Figure 5.1). It is expected that very little ice cover will be formed in the river reach above Talkeetna under average weather conditions.

Due to the warmer water temperatures above the confluence, ice cover formation and progress in the lower river will also be delayed. It is expected that ice contribution from the Chulitna, Talkeetna, and Yentna Rivers will cause an ice cover to be formed in the lower river, but this cannot be quantified at this time without field data on such ice contributions and further observations of river freezeup phenomena.

(d) River Water Levels Under Ice Cover Conditions

Under natural conditions, significant staging occurs at several points in the river during ice cover formation. Table 5.4 presents staging observations made during the 1980 freezeup period for selected locations in the river. With increased flows in the winter under post-project conditions, a significant rise in water level during ice cover formation can be expected near Talkeetna. Table 5.5 presents estimated water levels under pre- and post-project conditions. Below the confluence, the rise in water levels during ice cover formation under post-project conditions will progressively decrease downstream. More detailed river cross-section surveys and river freezeup observations will be necessary to confirm these estimates and speculations.

5.4 - Reservoir Ice Cover

Ice cover formation and growth in the Watana and Devil Canyon reservoirs will be substantially different from that in the corresponding river reach under natural conditions. An assessment of the formation, growth, bank-ice deposition, and eventual decay of the reservoir ice is presented below.

The initial ice cover on the reservoirs is expected to be formed with some 100 freezing degree-days (°F) after the surface water reaches 32°F. Based on available climatic data and the reservoir thermal modeling (see Appendix A4 to the main Feasibility Report), the initial ice cover will be formed toward the end of October under average weather conditions. Once a stable cover is formed, its growth is accomplished chiefly by conductive heat loss to the atmosphere. Figure 5.2 presents estimated ice cover growth in the Watana reservoir over an average winter season. Devil Canyon reservoir ice cover would progress similarly. The only difference would be that several miles of this reservoir immediately below Watana dam may have open water year-round due to outflow temperatures from Watana of 39°F or higher. Near the power intakes at each development, open water stretches will be present because of larger velocities, as well as significant mixing with warmer (39°F) waters in the lower layers.

Under normal operation, the Watana and Devil Canyon reservoirs will be drawn down by about 90 and 50 feet, respectively, toward the end of winter. Thus, the ice cover formed on the surface would be deposited on the banks as blocks, with sizes varying from a few inches to about three feet. The deposits will be generally irregular and cracked due to irregular bank slopes and drawdown rates. Most of this bank ice is unlikely to melt until about the end of June, or earlier if the reservoir level is raised with spring floods.

The ice cover in the reservoir itself will essentially melt in place. By late February or early March, the ice cover will slowly start to disintegrate with higher air temperatures and increased solar radiation on the surface. Operation of the power intakes may slightly alter the disintegration of ice cover close to the intake with convection mixing underneath the cover. It is expected that the ice cover in the reservoirs will completely dissipate by the end of May or early June, with warmer inflow waters and the onset of spring. During the period between March and May, the ice cover may become structurally weak due to the disintegration process, though its thickness may still be two to three feet.

TABLE 5.1

CALIBRATION COEFFICIENTS USED IN ICESIM

Manning's 'n' of Ice	0.050
Critical Froude No. at Ice Front	0.120
Erosion Velocity	6.5 ft/sec
Density of Ice	47.0 lb/ft^3
Cohesion of Ice	0.145 psi

TABLE 5.2

COMPARISON OF HEC-2 AND ICESIM
BACKWATER ROUTINE RESULTS

Cross-Section No.	Computed Water Surface Elevation (ft, msl)* HEC-2	ICESIM
LRX - 3	344.0	--
LRX - 9	378.1	379.0
LRX - 15	452.5	453.5
LRX - 21	510.0	511.7
LRX - 27	542.9	544.4
LRX - 34	616.0	615.8
LRX - 41	659.9	659.8
LRX - 47	690.6	690.3
LRX - 54	733.2	733.8
LRX - 61	832.9	834.2
LRX - 68	850.6	--

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* For Gold Creek discharge of 9700 cfs.

TABLE 5.3

ESTIMATED ICE COVER PROGRESSION ABOVE TALKEETNA
Post-Project Conditions - Average Year

Date	Location of Leading Edge*	
	Rivermiles	Section
December 1	No Ice Cover	
December 15	102	LRX-7
December 25	105	LRX-10
January 10	109	LRX-12
January 20	112	LRX-15

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* With Watana only operational.

TABLE 5.4

OBSERVED RIVER STAGING DURING
ICE COVER FORMATION - 1980

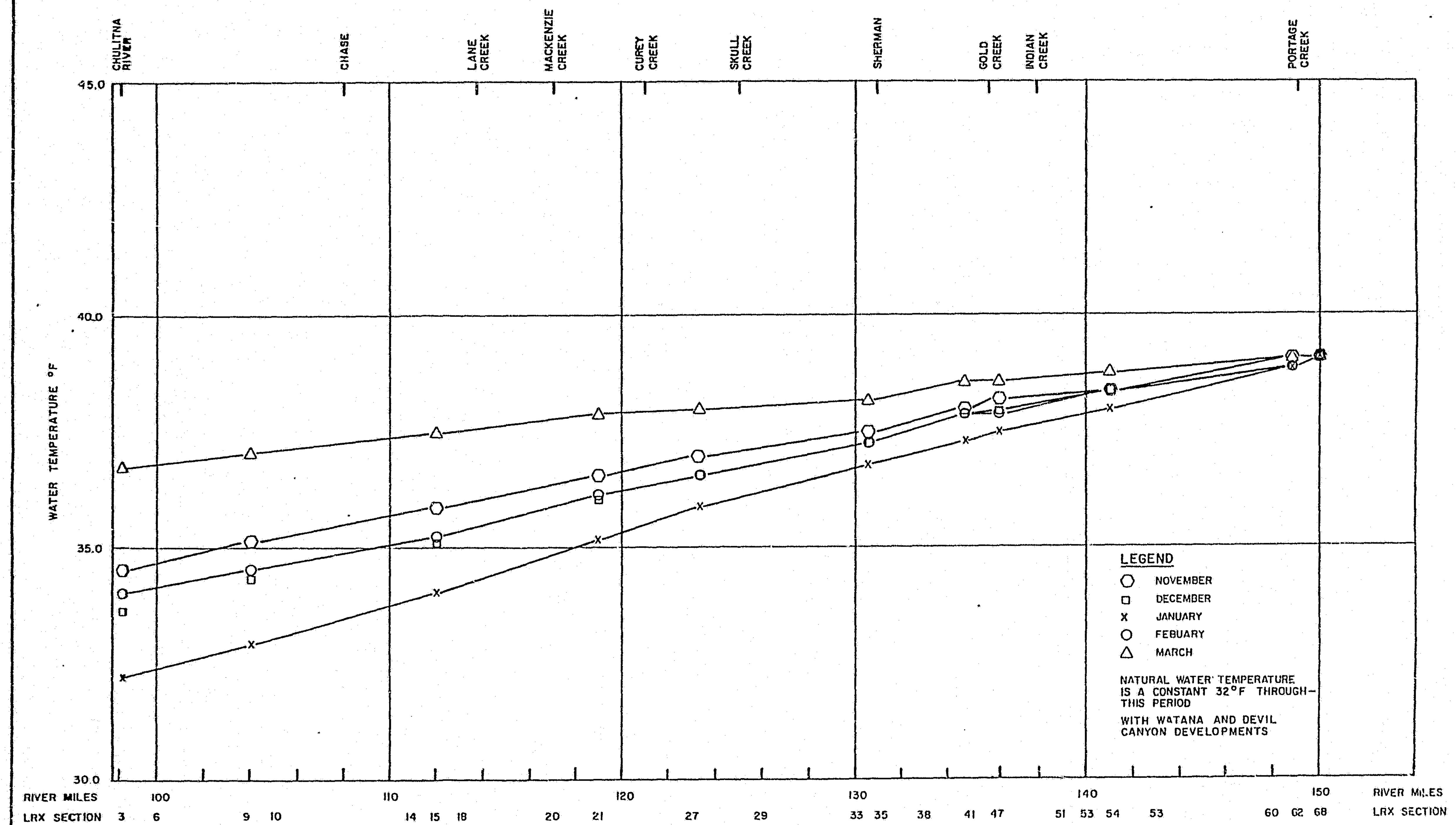
Location	Approximate Maximum Observed Staging Above 10/17/80 Open Water Level
Talkeetna (LRX-3)	3 - 4 ft.
Gold Creek	5 - 6 ft.
Downstream end of Devil Canyon	12 - 15 ft.
Devil Canyon Dam Site (Devil's Elbow)	10 - 12 ft.
Immediately upstream of Devil's Elbow	3 - 15 ft.

TABLE 5.5

ESTIMATED WATER LEVELS AT SELECTED RIVER SECTIONS

River Cross-Section Number	Water Surface Elevations (feet)		
	Natural Ice-Cover Condition[1]	Post Project Conditions[2]	
		Open Water[3]	With Ice Cover[4]
LRX - 3	349.0	345.0	352.7
LRX - 5	N/A	358.0	362.4
LRX - 6	N/A	362.9	366.5
LRX - 7	N/A	366.9	370.8
LRX - 8	N/A	373.8	378.1
LRX - 9	381.0	379.0	389.8
LRX - 10	395.0	391.6	405.4
LRX - 12	421.0	421.9	430.4
LRX - 13	437.0	437.4	445.4
LRX - 15	450.0	453.5	455.8
LRX - 16	457.0	456.1	457.2
LRX - 19	N/A	486.9	no ice

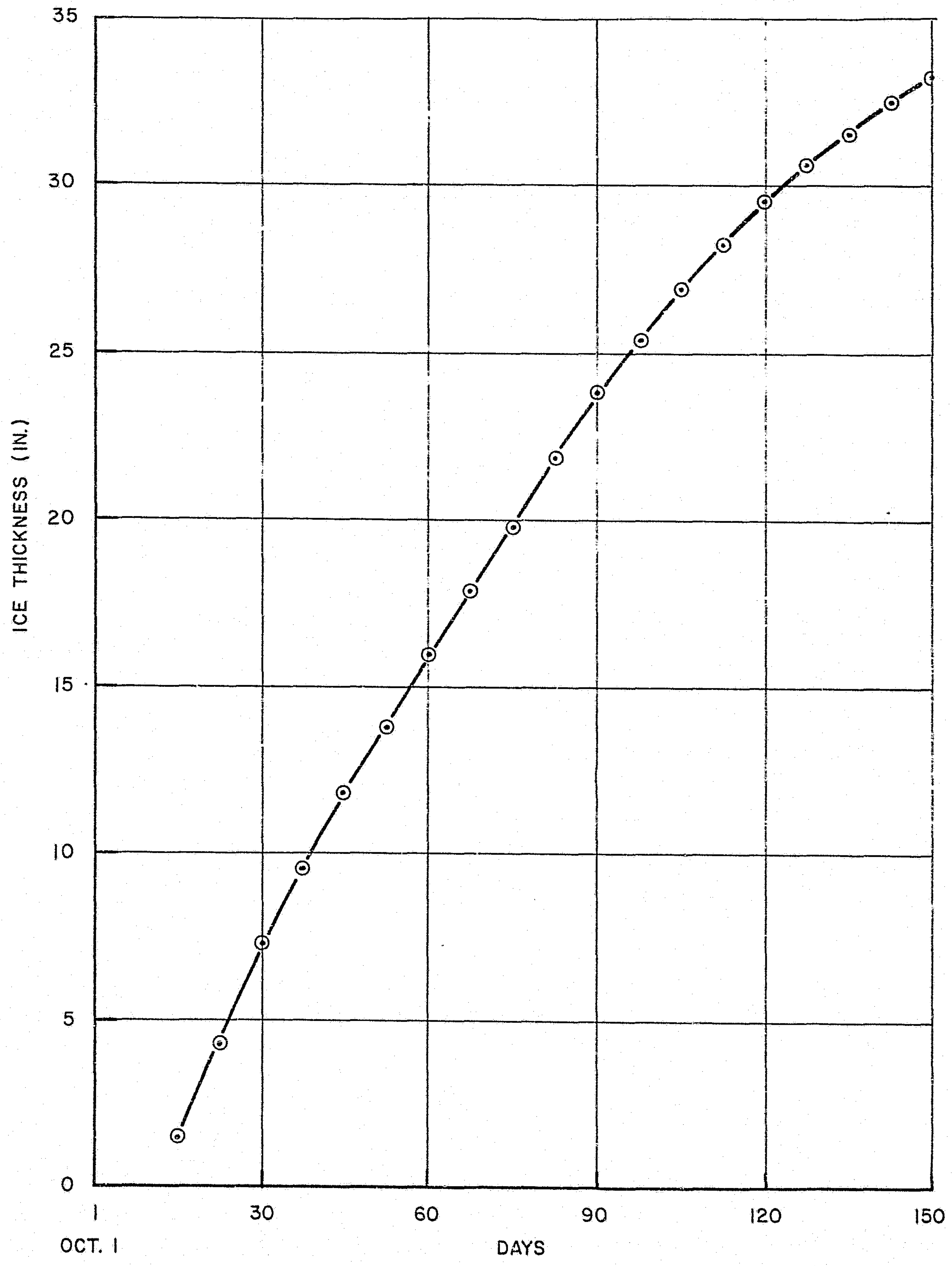
1 1980 Freeze-up data.
2 Average discharge 9,700 cfs at Gold Creek.
3 With Watana and Devil Canyon both operational.
4 With Watana only operational.
N/A Not Available.



LONGITUDINAL THERMAL PROFILES
POST PROJECT AND NATURAL CONDITIONS

ACRES

FIGURE 5.1



ESTIMATED ICE COVER DEVELOPMENT IN
WATANA RESERVOIR

ACRES

FIGURE 5.2

6 - REFERENCES

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ATTACHMENT A

STAGE-DISCHARGE RATING CURVES, STUDY REACH OBSERVATION SITES

NOTES ON RATING CURVES

1. Rating curves are provided for the following water level observation sites:

URX-101	Susitna River near Deadman Creek CSR*
URX-106.3	Susitna River at Watana Damsite CSR
URX-111	Susitna River near Watana Damsite Streamgage
URX-121	Susitna River near Devil Creek CSR
LRX-68	Susitna River at Devil Canyon Staff Gage
LRX-62	Susitna River at Portage Creek CSR
LRX-45	Susitna River at Gold Creek Streamgage
LRX-35	Susitna River at Sherman CSR
LRX-28	Susitna River at Section 25 CSR
LRX-24	Susitna River at Curry CSR
LRX-9	Susitna River at Chase CSR
LRX-4	Susitna River at Chulitna River Confluence CSR

2. The sites are in order by upstream-to-downstream sequence, with a space separating the Upper Susitna Study Reach from the Middle Susitna Study Reach.

3. Streamflows plotted on the curves were determined by adjusting the recorded flow at the nearest streamgage by a factor based on drainage area. The two streamgages used were the USGS gage at Gold Creek and the R&M gage near the Watana Damsite. Adjustment factors are given on each rating curve.

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* "CSR" = crest-stage recorder.

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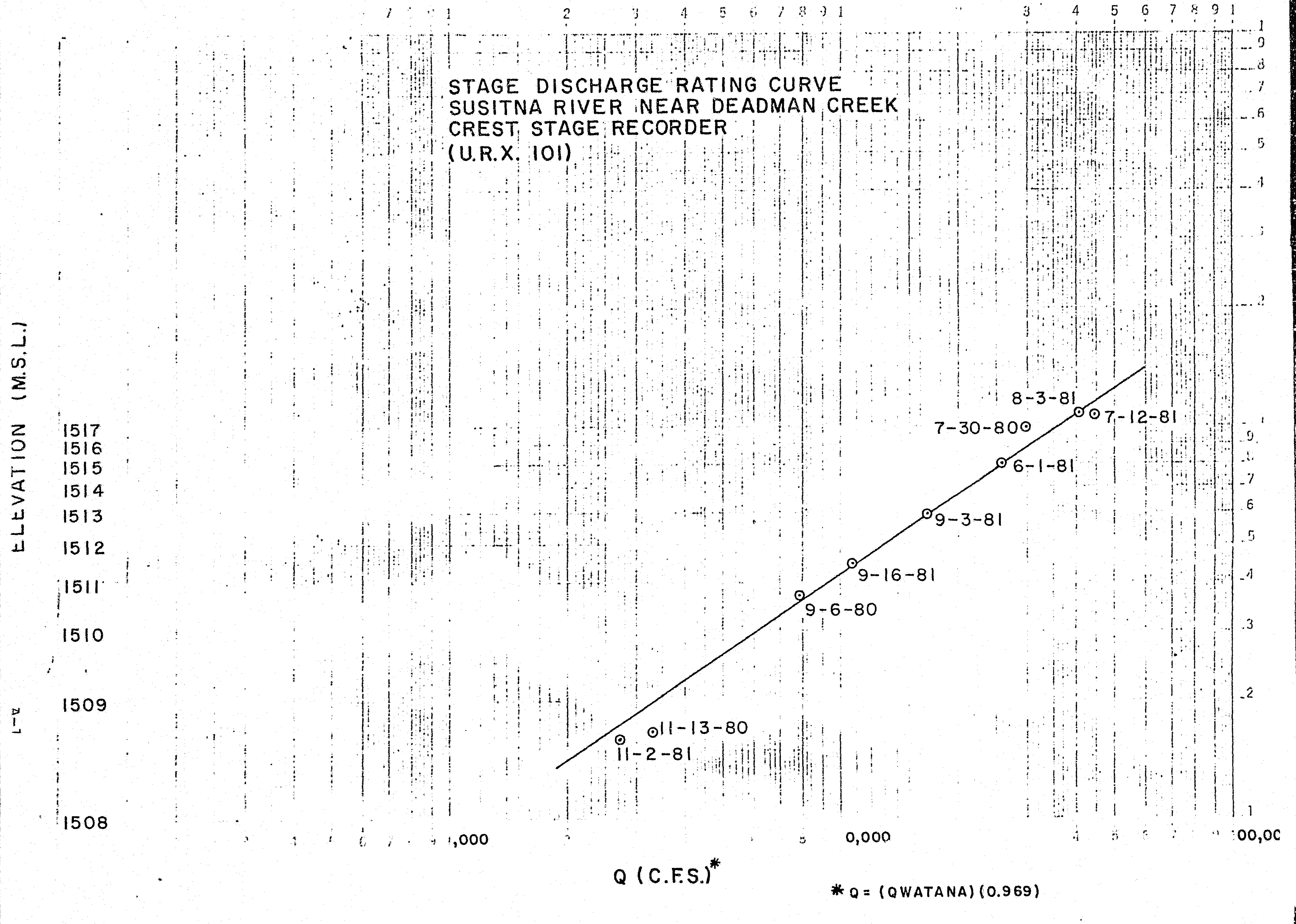
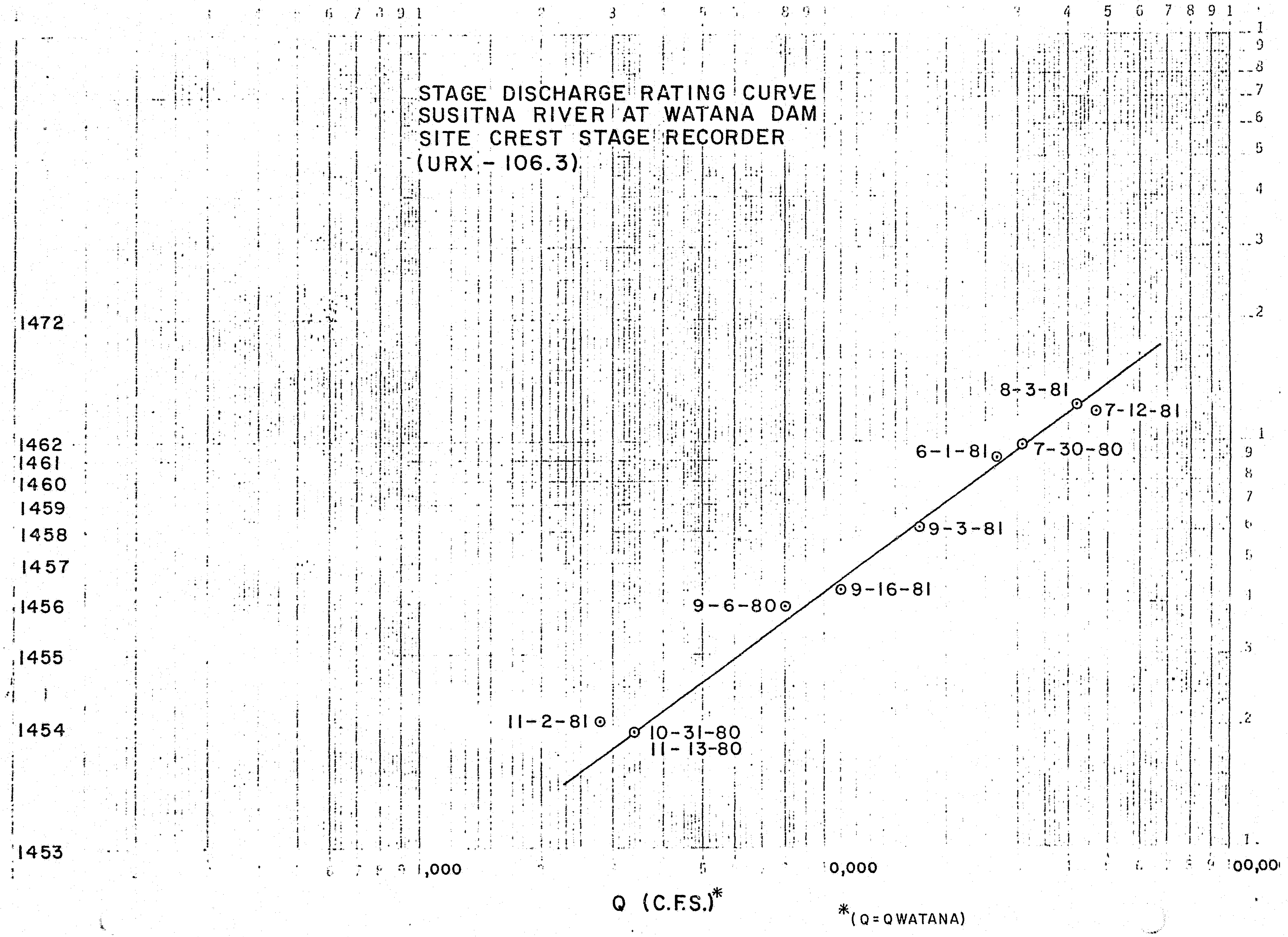

STAGE DISCHARGE RATING CURVE
SUSITNA RIVER NEAR DEADMAN CREEK
CREST STAGE RECORDER
(U.R.X. 101)
ELEVATION (M.S.L.)
1517
1516
1515
1514
1513
1512
1511
1510
1509
1508
8-3-81
7-12-81
7-30-80
6-1-81
9-3-81
9-16-81
9-6-80
11-13-80
11-2-81
1,000
10,000
100,000
Q (C.F.S.)*
* Q = (QWATANA) (0.969)


STAGE DISCHARGE RATING CURVE
SUSITNA RIVER AT WATANA DAM
SITE CREST STAGE RECORDER
(URX - 106.3)
1472
1462
1461
1460
1459
1458
1457
1456
1455
1454
1453
8-3-81
7-12-81
6-1-81
7-30-80
9-3-81
9-16-81
9-6-80
11-2-81
10-31-80
11-13-80
1,000
10,000
100,000
Q (C.F.S.)*
*(Q = Q WATANA)

A-2

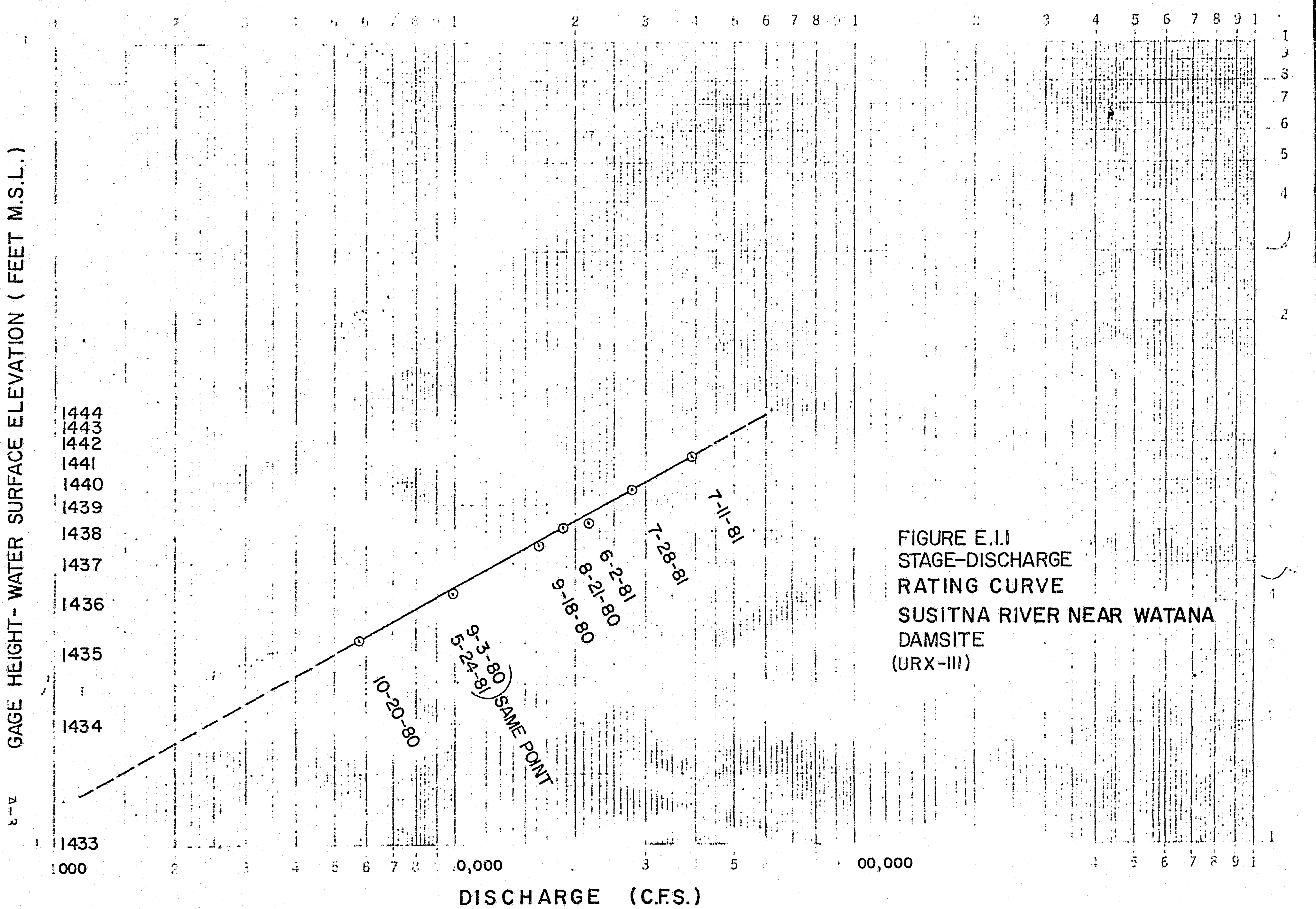
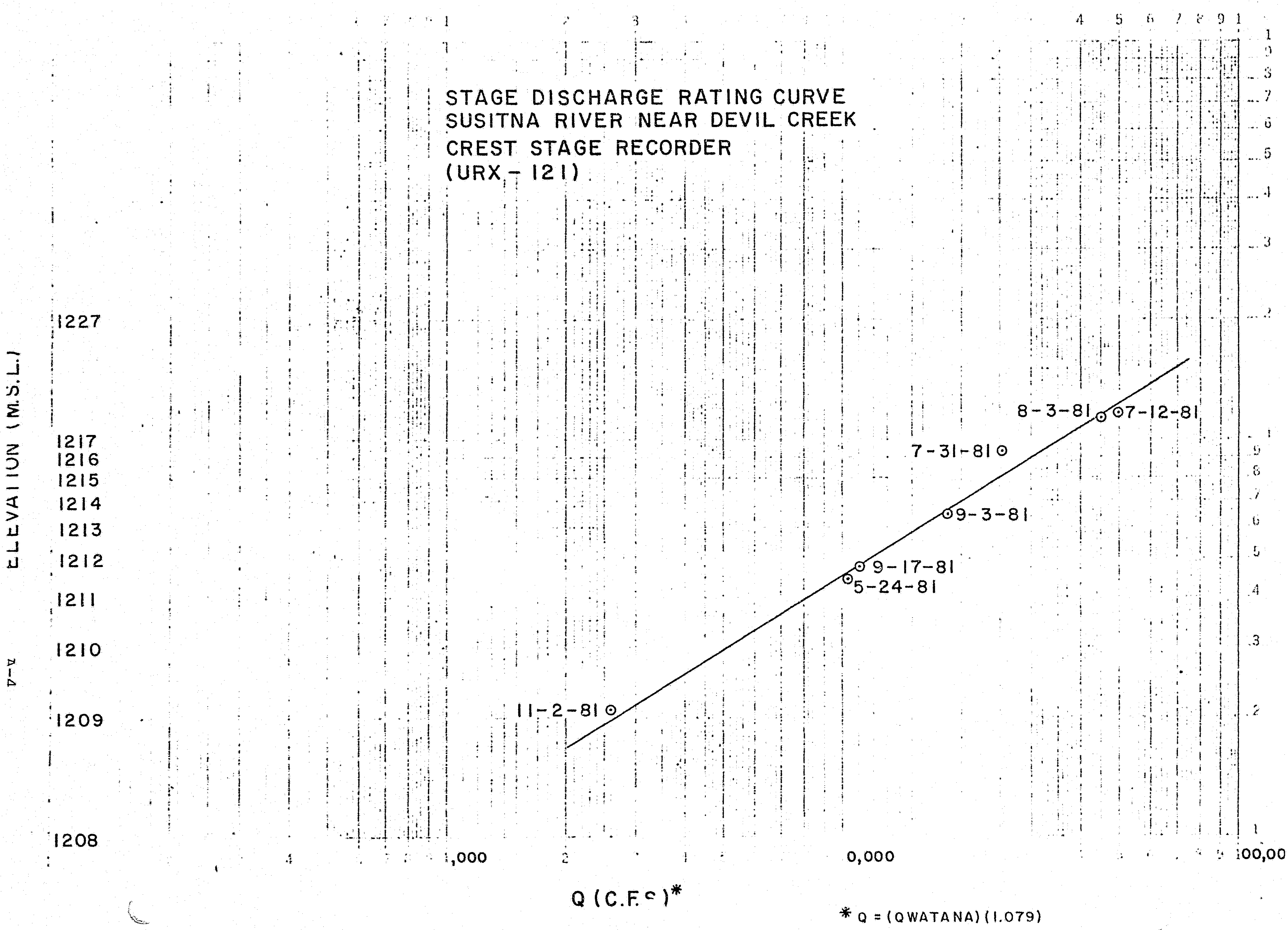
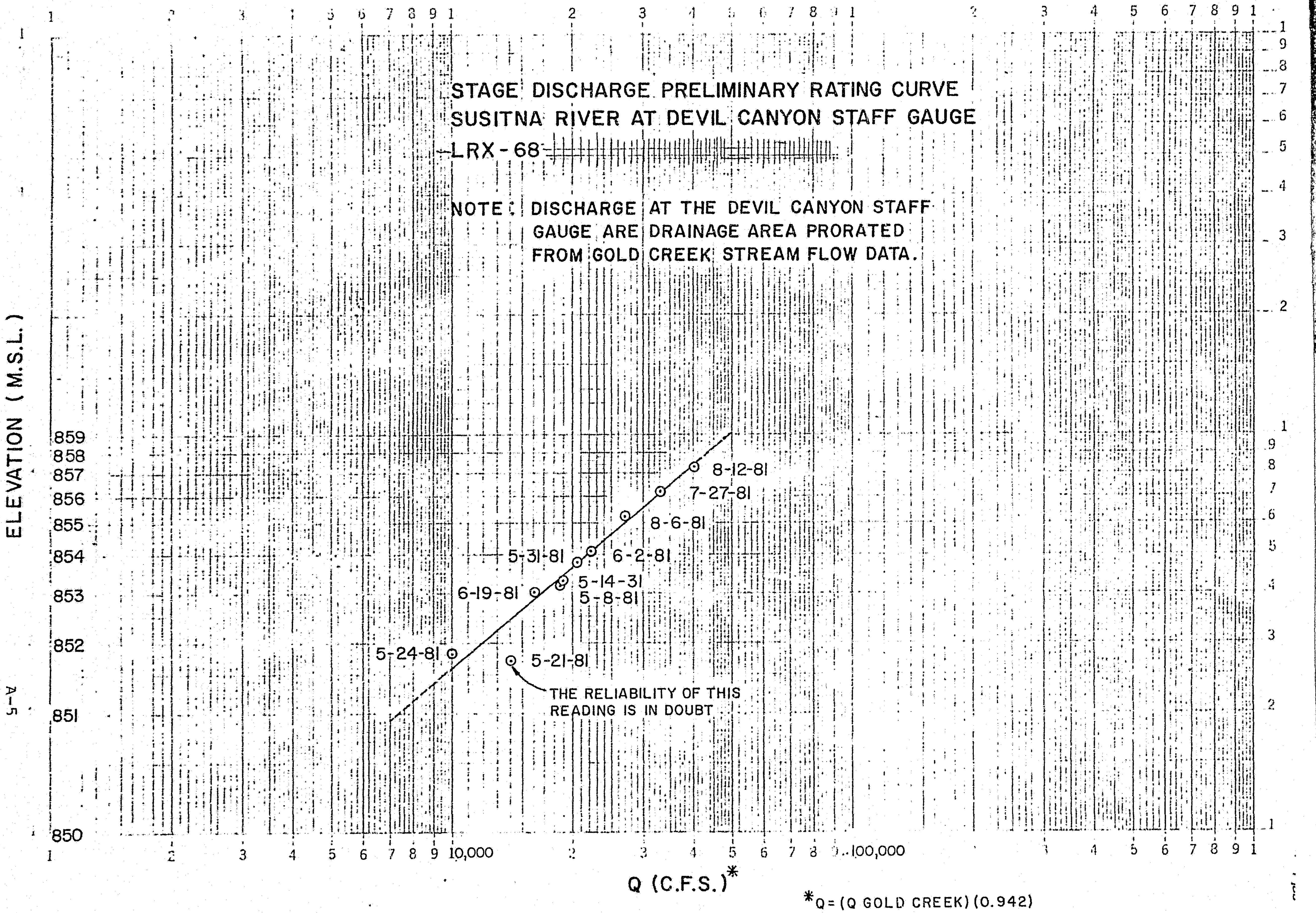


FIGURE E.1.1
STAGE-DISCHARGE
RATING CURVE
SUSITNA RIVER NEAR WATANA
DAMSITE
(URX-III)

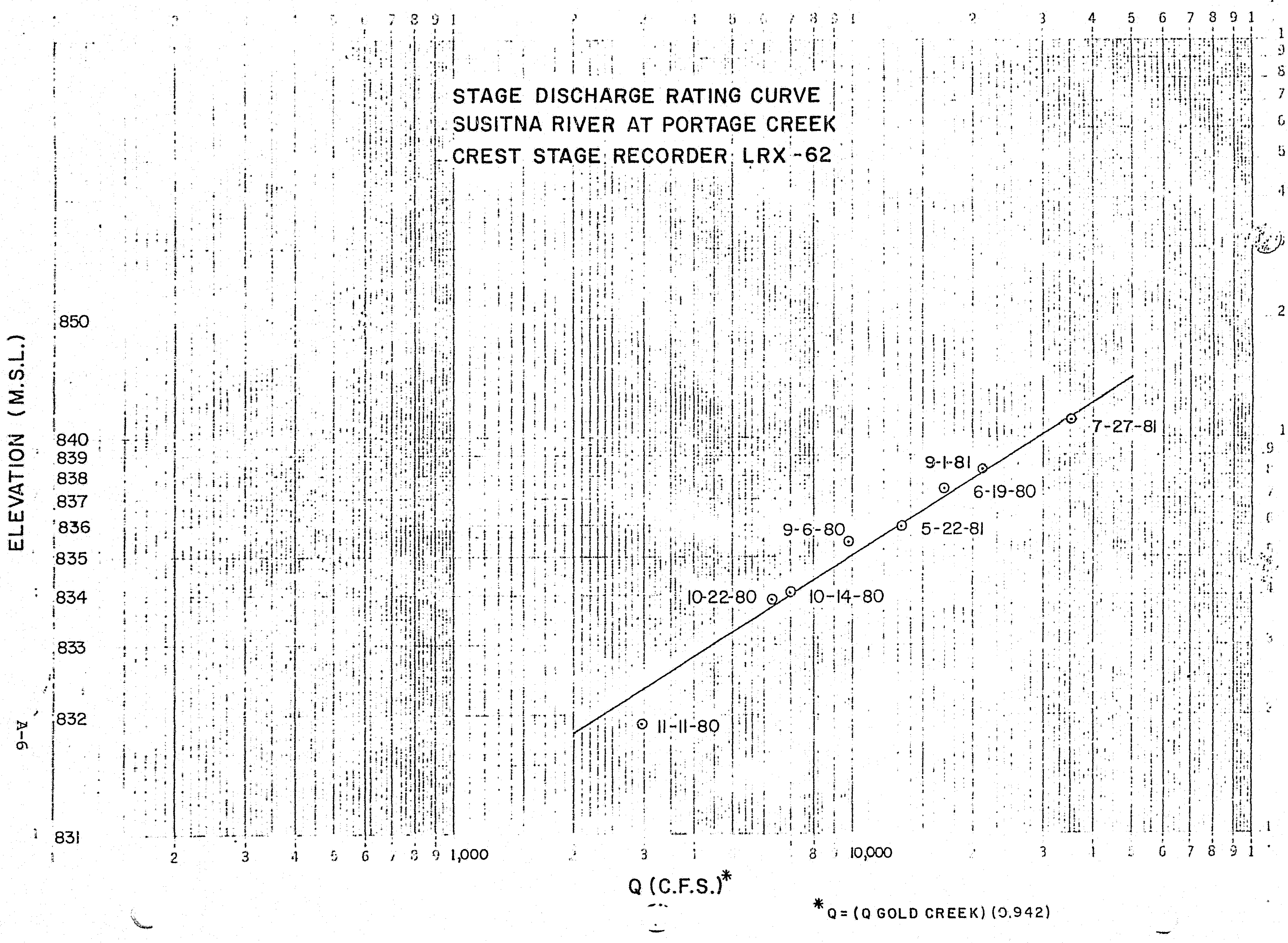


STAGE DISCHARGE RATING CURVE
SUSITNA RIVER NEAR DEVIL CREEK
CREST STAGE RECORDER
(URX - 121)
ELEVATION (M.S.L.)
1227
1217
1216
1215
1214
1213
1212
1211
1210
1209
1208
8-3-81
7-12-81
7-31-81
9-3-81
9-17-81
5-24-81
11-2-81
1,000
0,000
100,00
Q (C.F.S)*
* Q = (QWATANA)(1.079)

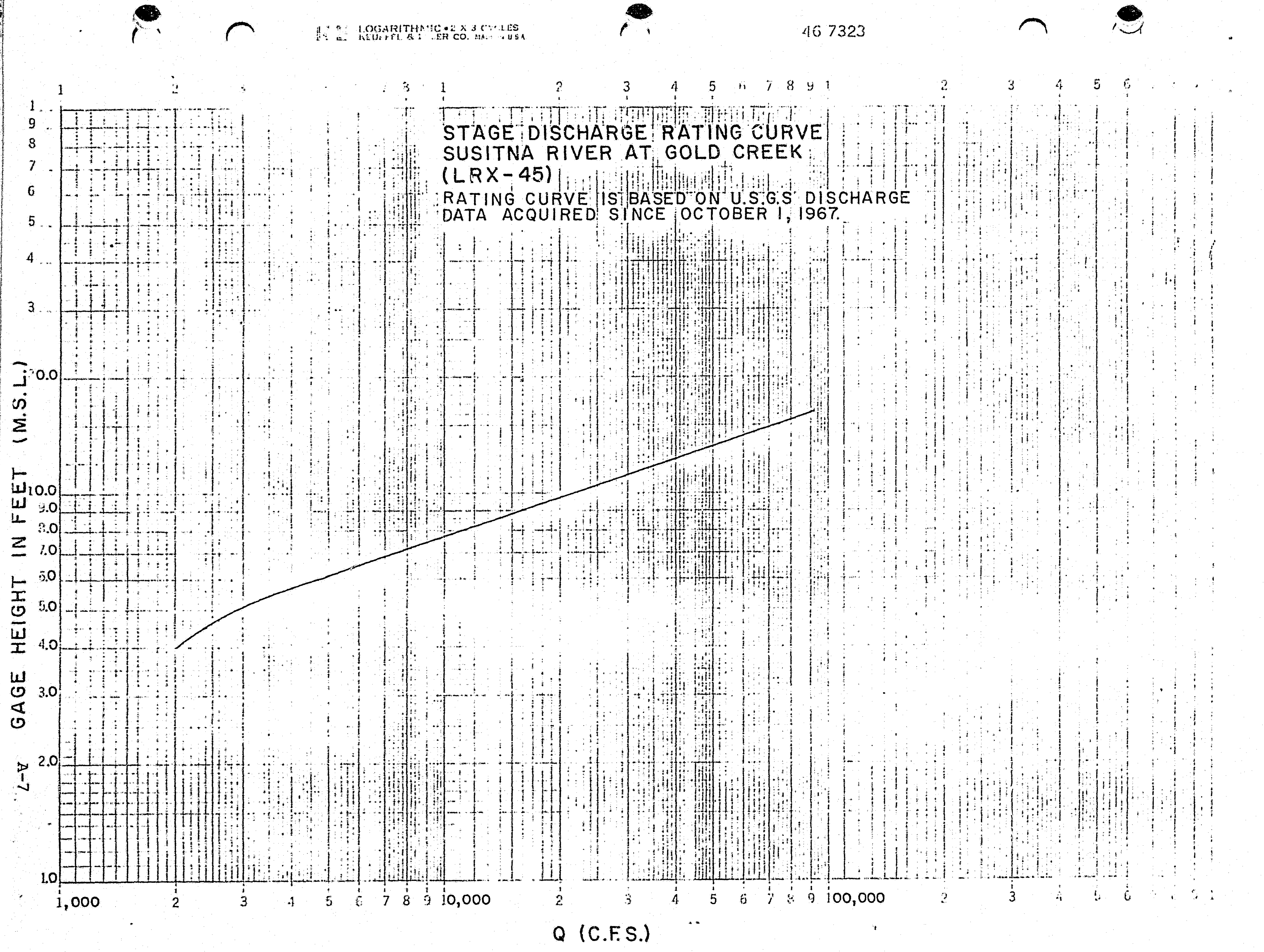


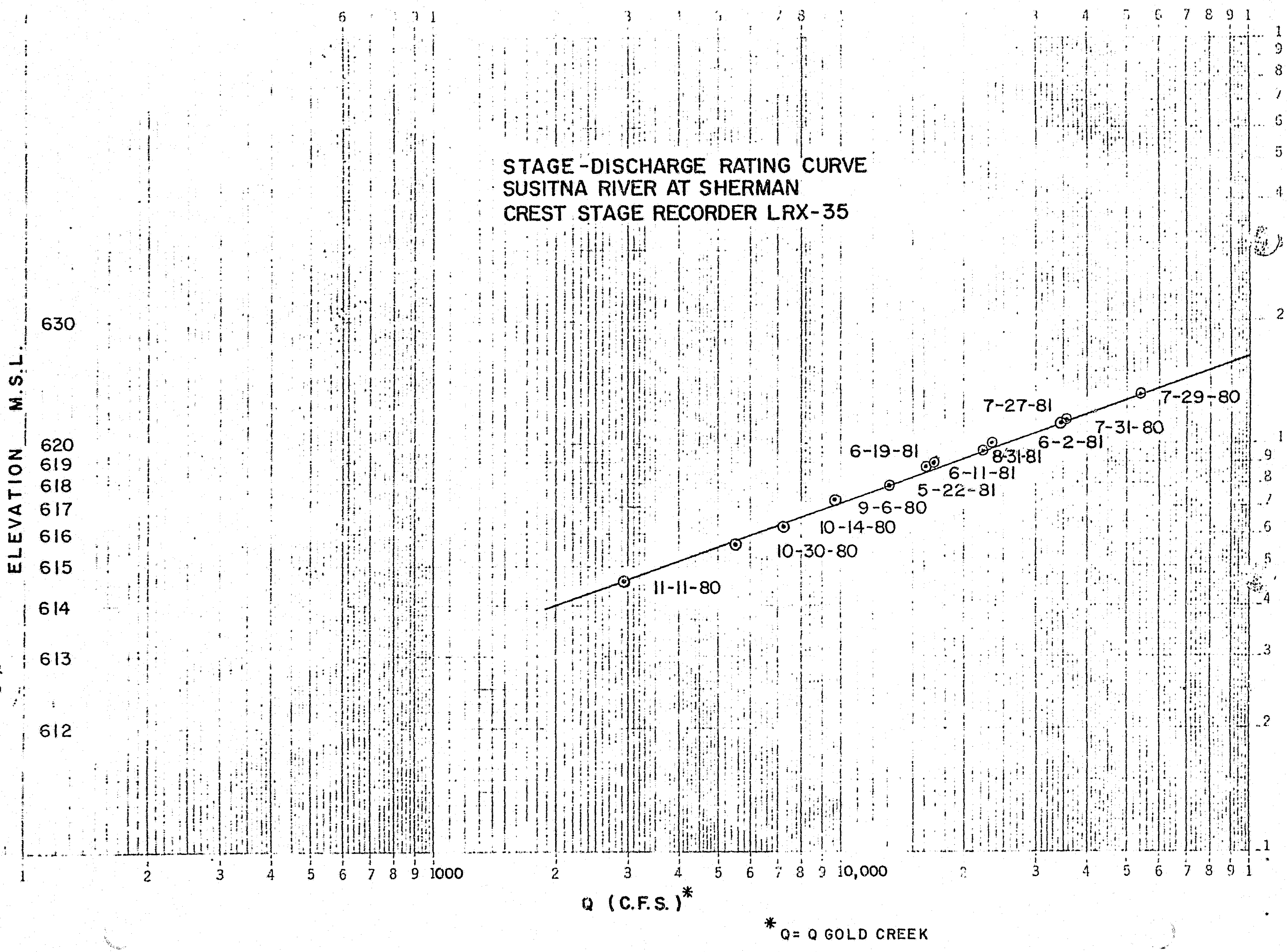
STAGE DISCHARGE PRELIMINARY RATING CURVE
SUSITNA RIVER AT DEVIL CANYON STAFF GAUGE
LRX - 68
NOTE: DISCHARGE AT THE DEVIL CANYON STAFF GAUGE ARE DRAINAGE AREA PRORATED FROM GOLD CREEK STREAM FLOW DATA.
ELEVATION (M.S.L.)
859
858
857
856
855
854
853
852
851
850
8-12-81
7-27-81
8-6-81
5-31-81
6-2-81
5-14-31
5-8-81
6-19-81
5-24-81
5-21-81
THE RELIABILITY OF THIS READING IS IN DOUBT
10,000
100,000
Q (C.F.S.)*
*Q = (Q GOLD CREEK) (0.942)

A-5



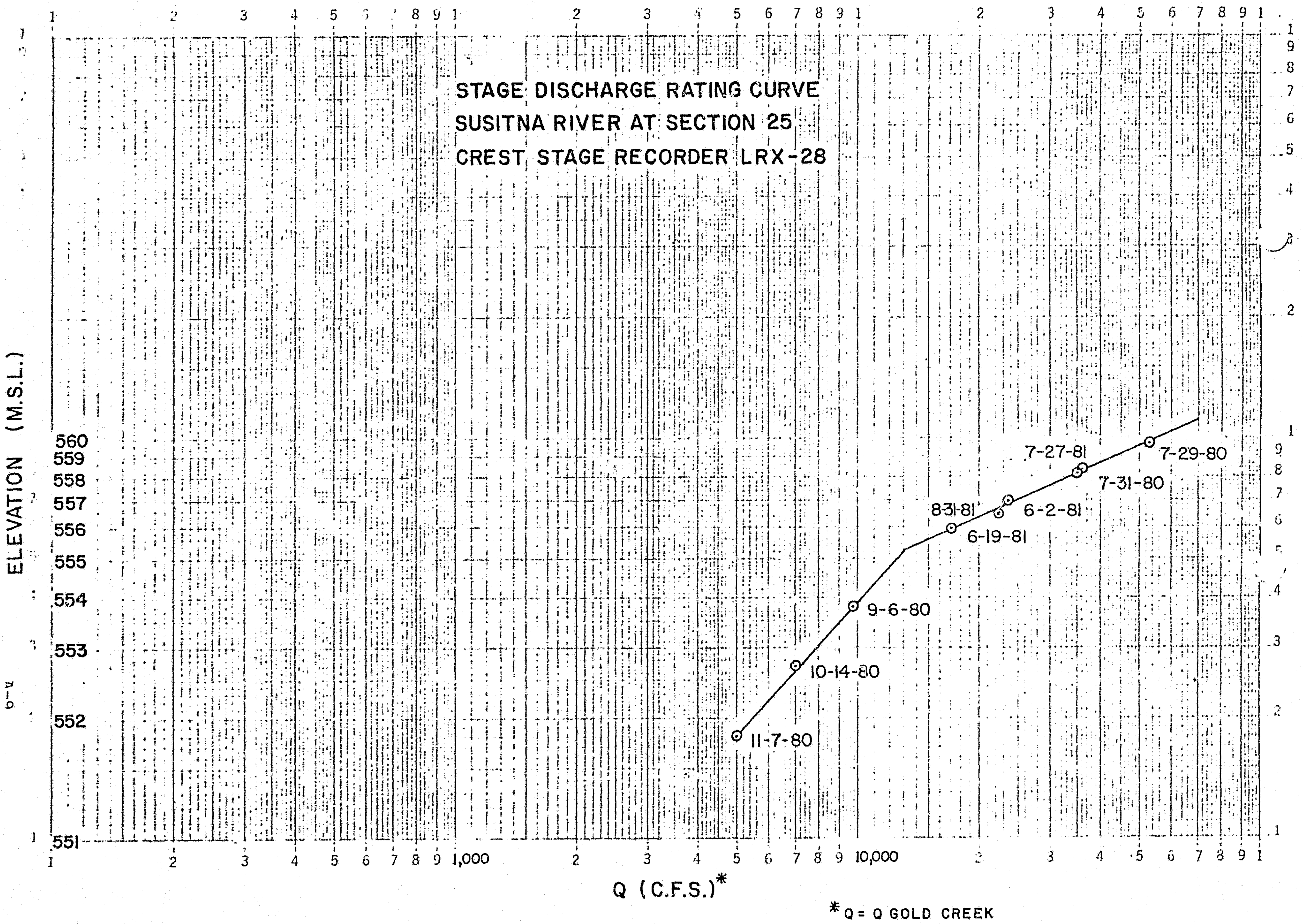
STAGE DISCHARGE RATING CURVE
SUSITNA RIVER AT PORTAGE CREEK
CREST STAGE RECORDER LRX-62
ELEVATION (M.S.L.)
850
840
839
838
837
836
835
834
833
832
831
7-27-81
9-1-81
6-19-80
5-22-81
9-6-80
10-22-80
10-14-80
11-11-80
1,000
10,000
Q (C.F.S.)*
*Q = (Q GOLD CREEK) (0.942)


STAGE DISCHARGE RATING CURVE
SUSITNA RIVER AT GOLD CREEK
(LRX-45)
RATING CURVE IS BASED ON U.S.G.S. DISCHARGE
DATA ACQUIRED SINCE OCTOBER 1, 1967.
GAGE HEIGHT IN FEET (M.S.L.)
Q (C.F.S.)
1,000
10,000
100,000
46 7323


STAGE-DISCHARGE RATING CURVE
SUSITNA RIVER AT SHERMAN
CREST STAGE RECORDER LRX-35
ELEVATION M.S.L.
630
620
619
618
617
616
615
614
613
612
7-29-80
7-27-81
7-31-80
6-2-81
8-31-81
6-19-81
6-11-81
5-22-81
9-6-80
10-14-80
10-30-80
11-11-80
1000
10,000
Q (C.F.S.)*
*Q= Q GOLD CREEK

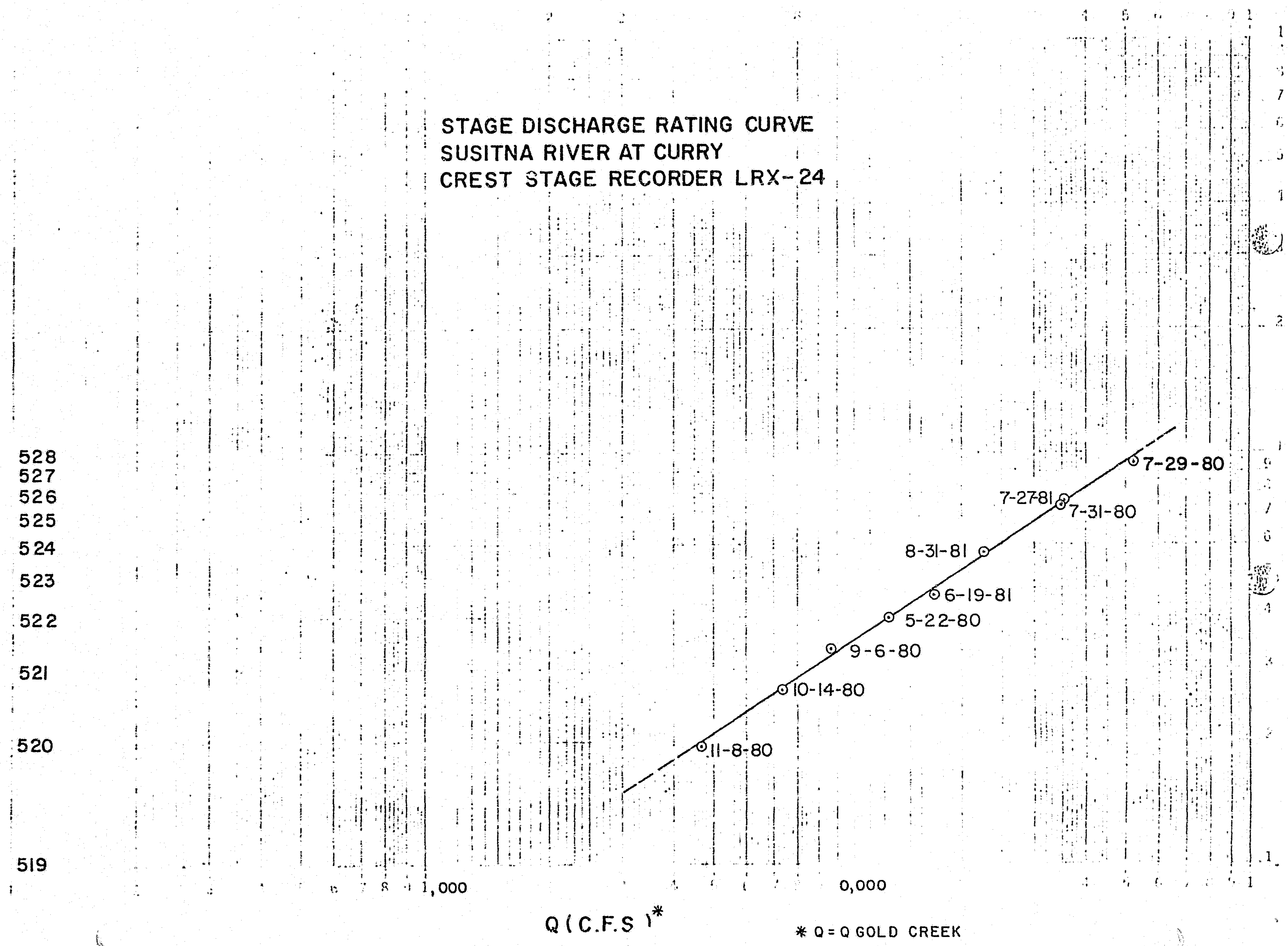
A-8

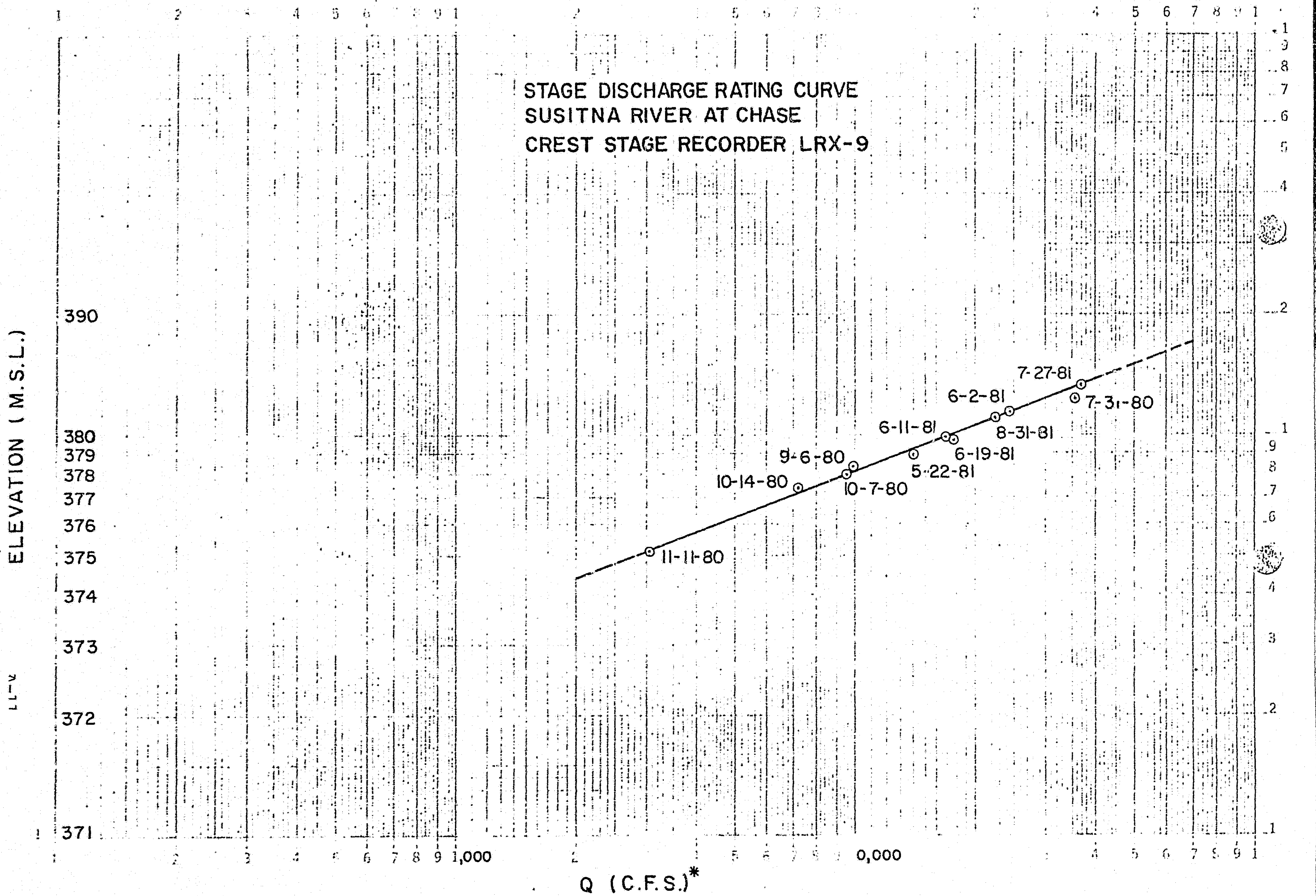
46 7323



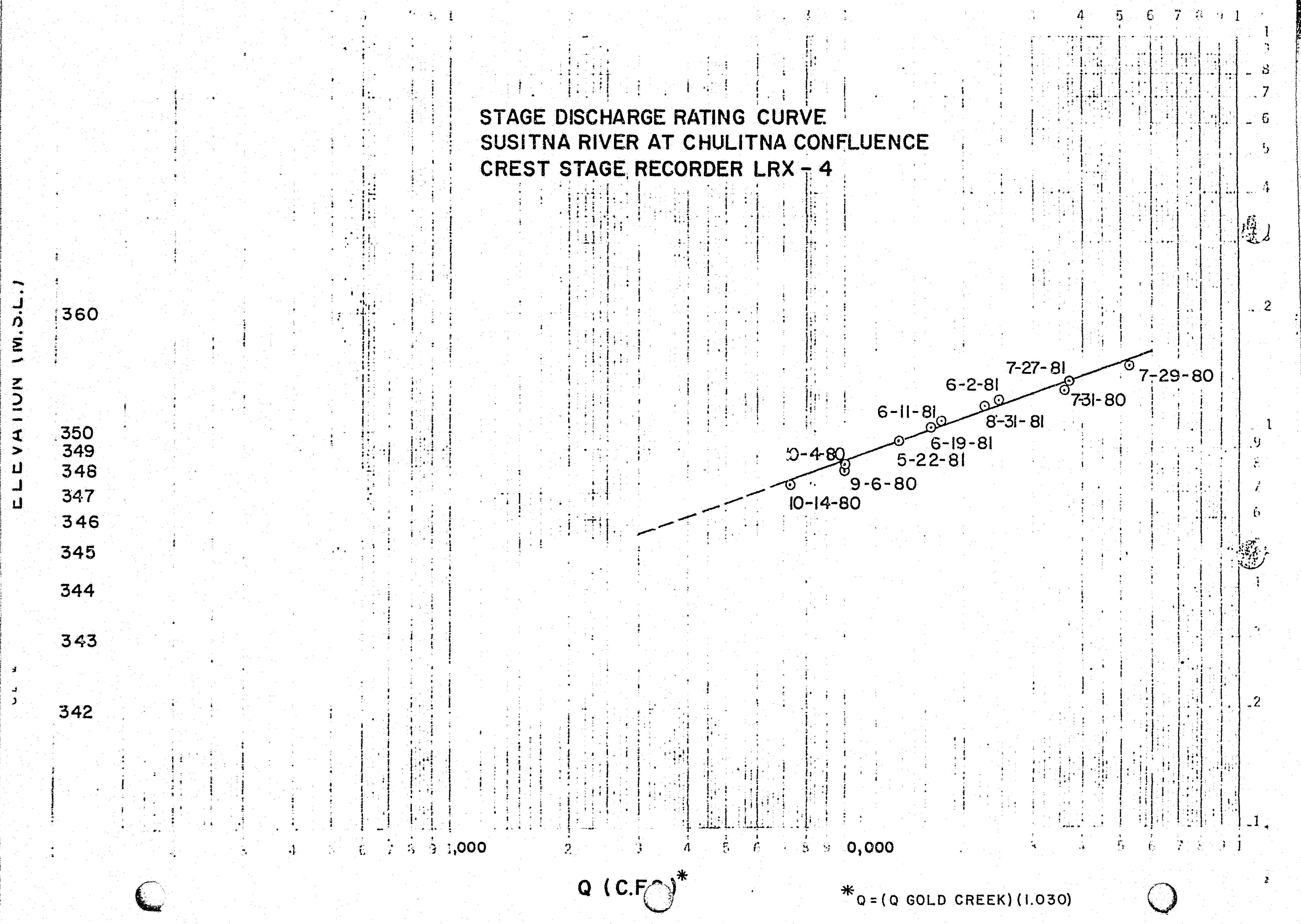
STAGE DISCHARGE RATING CURVE
SUSITNA RIVER AT SECTION 25
CREST STAGE RECORDER LRX-28
ELEVATION (M.S.L.)
560
559
558
557
556
555
554
553
552
551
1,000
10,000
Q (C.F.S.)*
7-29-80
7-27-81
7-31-80
8-31-81
6-2-81
6-19-81
9-6-80
10-14-80
11-7-80
*Q = Q GOLD CREEK

A-9


STAGE DISCHARGE RATING CURVE
SUSITNA RIVER AT CURRY
CREST STAGE RECORDER LRX-24
528
527
526
525
524
523
522
521
520
519
1,000
0,000
Q (C.F.S)*
* Q = Q GOLD CREEK
7-29-80
7-27-81
7-31-80
8-31-81
6-19-81
5-22-80
9-6-80
10-14-80
11-8-80



*Q = (Q GOLD CREEK) (1.030)


STAGE DISCHARGE RATING CURVE
SUSITNA RIVER AT CHULITNA CONFLUENCE
CREST STAGE RECORDER LRX - 4
ELEVATION (M.S.L.)
360
350
349
348
347
346
345
344
343
342
7-27-81
7-29-80
6-2-81
7-31-80
6-11-81
8-31-81
6-19-81
10-4-80
5-22-81
9-6-80
10-14-80
1,000
2
3
4
5
6
10,000
4
5
6
7
Q (C.F.S.)*
*Q = (Q GOLD CREEK) (1.030)