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STREAM FLOW AND TEMPERATURE MODELING IN THE SUSITNA BASIN, ALASKA

DRAFT REPORT

ARCTIC ENVIRONMENTAL INFORMATION AND DATA CENTER

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INTRODUCTION

The Alaska Power Authority, through Harza-Ebasco Joint Venture, contracted with the University of Alaska's Arctic Environmental Information and Data Center (AEIDC) to simulate postproject physical habitat conditions in the Susitna River drainage with a computerized model system. Water balance and stream temperature models permit the simulation of unmeasured water discharges and temperatures at various locations downstream from the proposed Watana or Devil Canyon dams (AEIDC 1983). These predictions are necessary for the analysis of project impacts on downstream fishery populations and habitats and will allow identification of appropriate streamflow regimes to minimize negative effects and aid mitigation efforts.

Determination of stream temperatures requires flow data at various mainstem and tributary locations. This is the main purpose of the Susitna water balance model. Water temperature is important because it has various effects on fish behavior, including habitat selection, migration, movement patterns, food selection, and the physiological functions associated with growth and metabolism. It has a direct effect on the time required for salmonid egg development. Many studies have illustrated the relationship between small temperature change over long periods of time and salmonid egg incubation (Reiser and Bjornn 1979). Temperature has also been implicated as a factor affecting the timing of outmigration of smolts and inmigration by adult spawners (Brett 1971; Coutant 1970; Cherry, et al. 1975; Reiser and Bjornn 1979). These physiological and behavioral functions may be altered by temperature changes of as little as 0.5 to 1.0 C.

For these reasons, it is important to predict downstream temperatures accurately and at the specific locations where fishery habitat may be affected. Tributary flows and temperatures also should be simulated so that the dilution or buffering effect of tributaries on the mainstem can be understood. Water balance and temperature predictions will also be critical to the river ice modeling efforts of Harza-Ebasco.

This report is organized into three major sections. The first section describes the water balance model and hydrologic data synthesis. The second section provides a description of the stream temperature model and how it was modified to more accurately reflect Alaska environmental conditions. It also includes an analysis of the temperature model's performance to date. The last section is a discussion of the future applications and enhancements of both the water balance and stream temperature models, including how they will be applied for estimating project effects. This report does not include actual estimates of project impacts.

WATER BALANCE ACCOUNTING FOR THE SUSITNA BASIN

INTRODUCTION

The task of water balance accounting in the Susitna Basin is one of defining the methodology to assign inflows between known flows at mainstem gage stations. The lack of hydrometeorologic data in this region makes this a difficult task, subject to a number of gross assumptions. Three basin water apportionment methods have been explored and are discussed in this section. AEIDC developed a computer program to employ these apportionment methods, generating time series of flows at a number of mainstem and tributary locations within the Susitna Basin. Output files containing these flows are directly usable as input to the stream network temperature model (SNTEMP).

DESCRIPTION OF THE WATER BALANCE MODEL

The water balance accounting program, H2OBAL, was designed to operate on the Susitna Basin between the USGS gages at Cantwell (Vee Canyon) and Susitna Station. AEIDC's initial modeling efforts focus on the reach from the Watana dam site to the USGS gaging station near the Parks Highway bridge at Sunshine. The Chulitna and Talkeetna river flows are incorporated into the system at the gage station on each river near Talkeetna.

The basin between Cantwell and Sunshine Station was divided into 16 sub-basins (excluding the Chulitna and Talkeetna basins above their respective USGS gages) for the purpose of water apportionment. These basins center around the larger tributaries and are defined by drainage divides (Figure 1). They do not necessarily follow the watershed boundaries of any single stream, often including drainages of three or more streams. In most of the sub-basins, a node location on the mainstem river was chosen, representing the point source for all inflow to the mainstem. For the few sub-basins without a dominant tributary, inflow is linearly distributed along the adjacent mainstem reach.

The accuracy associated with assigning flow within a basin between gage stations increases as the distance between gage stations decreases. Thus, it is advantageous to use as many data stations within the basin as are available. Gaps in historical data records exist at some

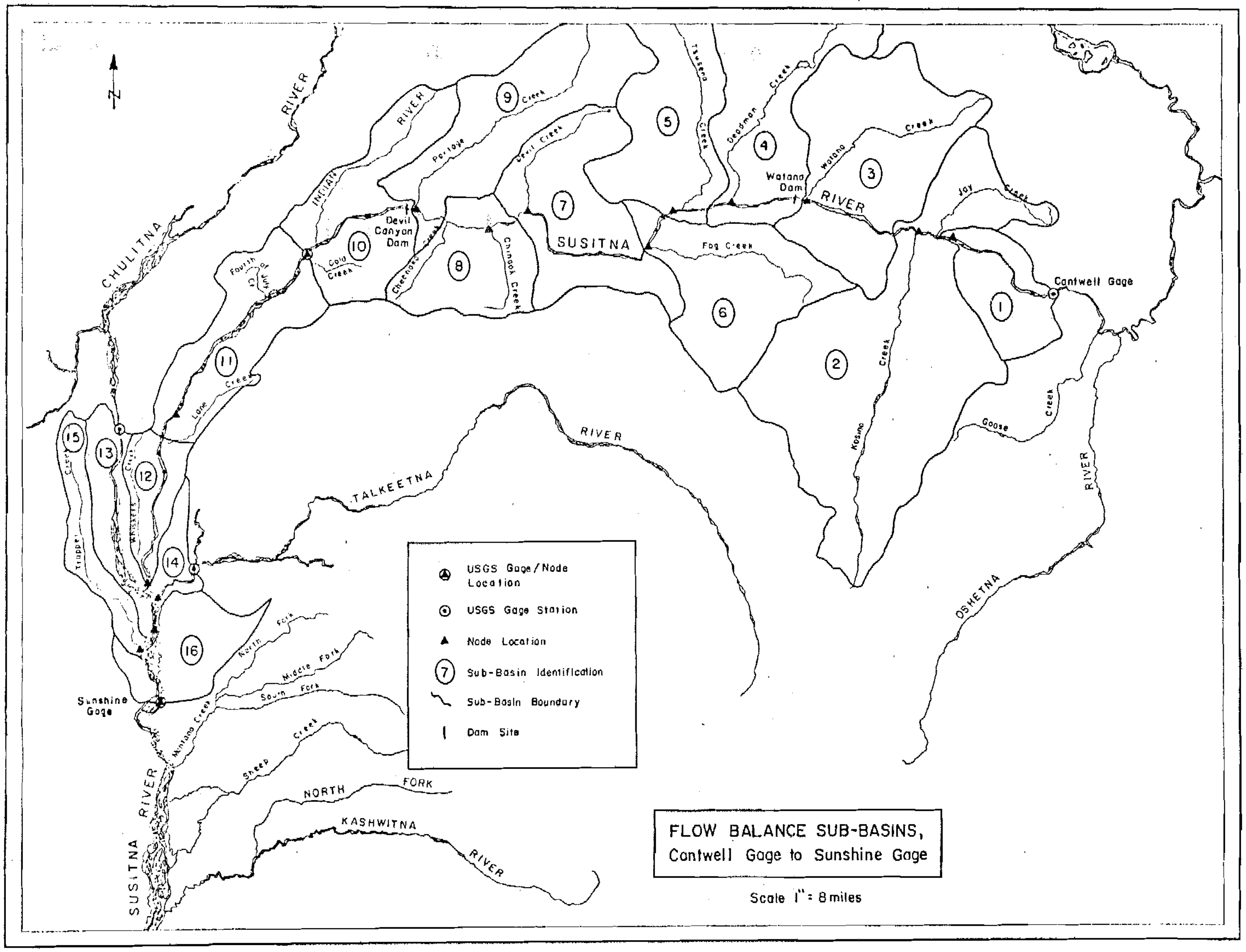


Figure 1. Flow balance sub-basins, Cantwell gage to Sunshine gage.

where:

Q is the mean flow for the given period (L^3/t),

C is a fractional constant determined from some combination of watershed area, areal precipitation, and water yield estimates (decimal),

s, s - 1 are subscripts referring to mainstem locations, numerically increasing for each sub-basin downstream,

1, 2 are subscripts referring to mainstem gage locations, numerically increasing downstream,

and

L, t refer to dimensions of length and time respectively

The node structure defining the network of sub-basins is fixed (nonvariable) within the water balance model. The different values of the C coefficients are selected as input options. We developed three different methods for determining values of the C coefficients.

Method I. Linear Watershed Area Contribution--Acres (1982) used this method to determine flow series at proposed dam sites between the USGS gages at Cantwell (Vee Canyon) and Gold Creek. A sub-basin that drains 10 percent of the basin area between gage stations is consistently assigned 10 percent of the difference in flow between these two sites. The C coefficients are defined by:

$$C_s = \frac{A_s}{A_b} \tag{2}$$

where:

A is the planimetered area (L^2), and subscripts refer to sub-basin, s, and the total basin, b.

Method II. Areal Precipitation Weighting--The purpose of this method is to incorporate the weight of relative sub-basin precipitation into the C coefficients. These coefficients are now defined by:

stations within the basin (see Figure 2 for historical flow data periods). Rather than discarding all data at a gage with occasional gaps, we used linear regression to fill them.

The H2OBAL program requires input data for the following USGS gage stations:

Susitna River near Cantwell (Vee Canyon)
Susitna River at Gold Creek
Susitna River at Susitna Station
Chulitna River near Talkeetna
Talkeetna River near Talkeetna

We used flows at the Yentna River gage for the period that they are available. For the present extent of simulation, flow data at Watana are preferable to those at Cantwell, and flows at Sunshine are used instead of those at Susitna Station. These additional stations provide for greater accuracy by effectively reducing the size of the basin under consideration. Usable statistically-filled 32-year data sets are available for the Cantwell, Watana, Devil Canyon, Chulitna, Talkeetna and Susitna Station sites (Acres 1983a).

A filled data record is also available for Sunshine gage but was not used in H2OBAL because of resulting flow deficits in the Gold Creek to Sunshine reach. These deficits occur when the sum of flows at the Gold Creek, Chulitna, and Talkeetna gages exceed the synthesized flow at Sunshine Station. The alternate method used to assign flows at Sunshine was to assume that the flow-per-unit-drainage-area contribution to the mainstem was the same for the Gold Creek to Sunshine basin as it was for the summed Gold Creek, Chulitna, and Talkeetna drainages. The limited accuracy of this method is acceptable considering this sub-basin comprises only 3.3 percent of the total drainage area defined at Sunshine.

METHODS TO APPORTION SUB-BASIN WATER

Once data records are collected or filled for the skeletal gage station network, interstation flows incrementally increase downstream by the following relationship:

$$Q_s = Q_{s-1} + C_s \ (Q_2 - Q_1) \qquad (1)$$

$$C_s = \frac{P_s A_s}{P_b A_b} \qquad (3)$$

where:

P is the mean annual precipitation (L), and the subscripts and other variables remain as previously defined.

The methods employed to determine the mean annual precipitation for each sub-basin are important to note, since a great amount of subjectiveness is involved. The primary data source for the precipitation distribution was a statewide, annual precipitation isohyetal map prepared by James Wise (1977), Alaska state climatologist. This map is contoured in 10-in intervals for the 10- to 40-in annual precipitation range, and 20-in intervals above 40-in annual precipitation. These isohyetals were redrawn on a 1:250,000-scale map of the Susitna Basin. Additional isohyetals were interpolated between each of the existing ones, resulting in 5-in contour intervals in the 10- to 40-in range, and 10-in intervals in areas with over 40-in of annual precipitation.

To find average precipitation for each basin, we assumed that the total precipitation between two isohyetals could be estimated as the product of the area between the isohyetals (found by polar planimetry) and the average of the two isohyetal values. These products were summed for all of the intercontour areas within a sub-basin and then divided by the sub-basin area to determine the average annual precipitation. The same process was used to find the mean annual precipitation for the entire basin (Figure 3).

Figure 2. Period of record for gage stations used in H2OBAL.

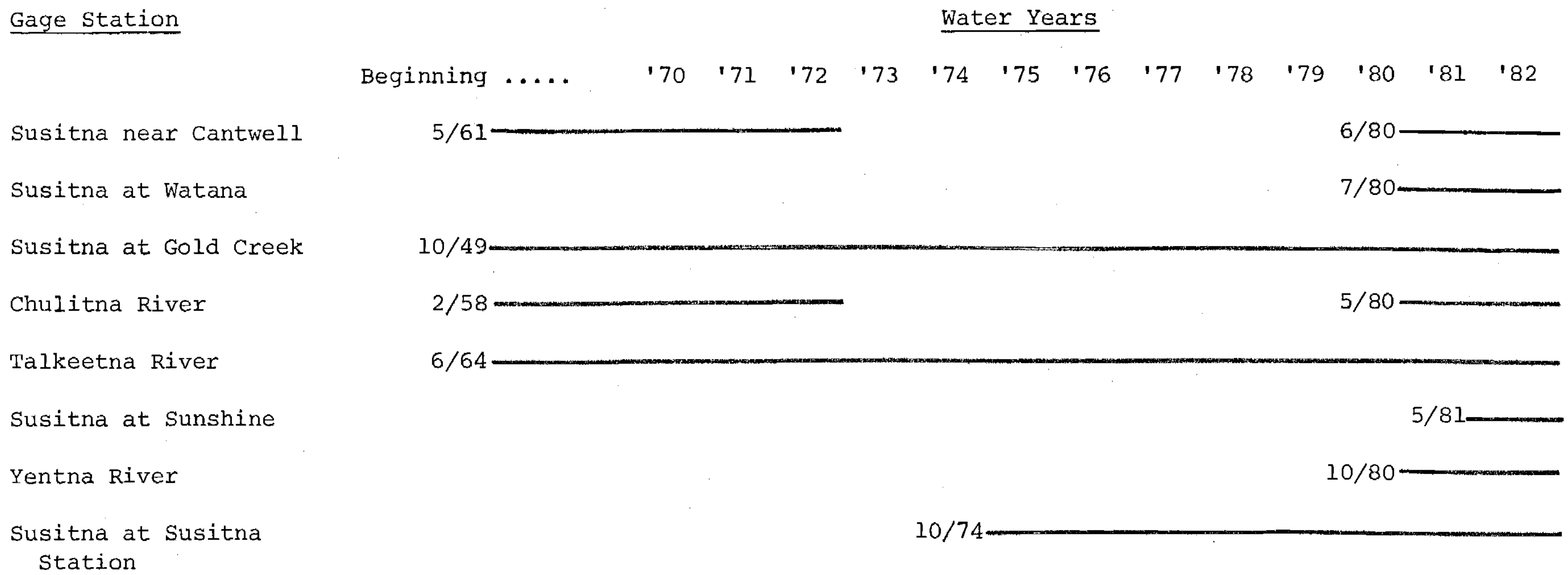


Figure 3. Calculated mean annual precipitation and water-yield values, Cantwell to Sunshine Basin.

Sub-Basin Name	Mean Annual Precipitation (in.)	Mean Annual Water Yield (in.)
Clarence	49.0	10.1
Kosina	50.4	19.1
Watana	51.8	18.9
Deadman	35.8	23.4
Tsusena	26.0	26.8
Fog	33.7	22.3
Devil	20.1	22.0
Chin-Chee	17.0	18.0
Portage	18.0	26.8
Indian	24.8	22.1
Curry	31.8	25.0
Whiskers	30.3	22.8
Chulitna	30.7	24.0
Talkeetna	24.7	14.4
Trapper	30.5	20.3
Sunshine	17.5	12.7

Method III. Water-Yield Weighting--A report by Evan Merrell of the U.S. Soil Conservation Service (1982) suggests a third method for determining the C coefficients. In this report Merrell uses precipitation and evapotranspiration estimates to develop a mean annual water-yield map of the Susitna Basin. To incorporate the relative weights of sub-basin water yield estimates, the C coefficients are defined as:

$$C_s = \frac{Y_s A_s}{Y_b A_b} \tag{4}$$

where:

Y refers to the mean annual water yield (L), and the remaining variables are as defined previously.

The mean annual water-yield values for each sub-basin were determined in the same manner as the mean annual precipitation values. The water yield isopleths were redrawn on a base map of the basin, along with the sub-basin outline. The exception to note is that no isopleths were interpolated between those given by Merrell. Once again, polar planimetry was used to determine the areally-weighted basin water-yield values (refer to Figure 3).

TESTING THE C COEFFICIENTS

The C coefficients determined for any of the methods will sum to the value 1.0 over the basin defined by two gage stations. A variety of basins can be defined within the area of concern by using different pairs of gaging stations. As previously discussed, increased accuracy results from using data at all available gage stations.

The applicability of each method was tested by determining the three sets of C coefficients for the Cantwell to Gold Creek basin and applying these methods to the period for which historical records are available at the Watana dam site. The predicted values were then compared to the historical record at Watana. Figure 4 gives the C coefficients for the Cantwell to Gold Creek basin. Predicted flow at Watana is given by:

$$Q_w = Q_c + C_w (Q_g - Q_c) \quad (5)$$

where:

subscripts w, c and g refer to Watana, Cantwell and Gold Creek respectively, and Q and C are as previously defined.

The calculated C_w for each of the three methods is:

Method I	Method II	Method III
0.5104	0.6759	0.4636

Figure 4. C coefficients, Cantwell to Gold Creek Basin.

Sub-Basin Name	Area (mi^2)	$\frac{P_s}{P_b}$	$\frac{Y_s}{Y_b}$	C Coefficients Meth I $\frac{A_s}{A_b}$	Meth II $\frac{P_s A_s}{P_b A_b}$	Meth III $\frac{Y_s A_s}{Y_b A_b}$
Clarence	76.8	1.3660	.4741	.0383	.0524	.0181
Kosina	485.1	1.4049	.8954	.2421	.3401	.2153
Watana	242.4	1.4439	.8837	.1210	.1747	.1090
Deadman	218.4	.9979	1.0971	.1090	.1087	.1212
Tsusena	191.5	.7248	1.2529	.0996	.0693	.1175
Fog	175.0	.9394	1.0428	.0873	.0820	.0891
Devil	174.5	.5603	1.0310	.0871	.0488	.0896
Chin-Chee	94.2	.4739	.8425	.0470	.0223	.0399
Portage	186.4	.5018	1.2548	.0930	.0467	.1150
Indian	159.4	.6913	1.0358	.0796	.0550	.0852

The mean observed value of C_w for the 13 months of record when data were collected at all three stations (Cantwell, Watana, and Gold Creek) was 0.6034, with a standard deviation of 0.1119. It is important to note that these data were collected during the June through November period, and may not be representative for the entire year. However, since approximately 82 percent of the annual flow occurs during this period (based on the 1950 through 1979 flow record at Gold Creek), this period of record appears adequate.

C COEFFICIENTS TEST RESULTS

One conclusion that can be drawn from this simple test is that none of the three methods show clear superiority. Based on the estimates of C_w, we preferred Method II, the relative precipitation weighting scheme, for determining C coefficients; however, a couple of points concerning these three methods should be mentioned. One concerns the differences resulting from use of the linear drainage area method and the observed flows at Watana. Acres (1982), using a drainage area-based C_w value of 0.515, calculated a synthesized mean annual flow at Watana of 8023 cfs (Acres 1983a). The observed C_w value of 0.6034 applied to the same 32-year period results in an annual flow of 8338 cfs. This constitutes a 3.9 percent increase in available water for the Watana reservoir. Though the magnitude of this increase seems insignificant, it indicates that any error would probably be on the side of underestimating water supply at Watana. Second, the water-yield map used for Method III was developed to consider the smaller topographic features of the Susitna Basin, while the precipitation map used for Method II has considerably less topographic resolution. Consequently, greater utility would be expected from the increased sophistication of Method III. The water-yield map, however, apparently underestimates the contributions of the upper basin (Cantwell to Watana) substantially. In calibrating the map, Merrell was restricted to the available gage data at Cantwell and Gold Creek.

If used on a small scale sub-basin such as Cantwell to Watana, Method III might prove to be much more accurate than Method II. However, the lack of flow data for the smaller tributaries presently makes this assumption untenable.

USE OF RELATIVE PRECIPITATION WEIGHTING

Method II accepts the premise that the sub-basin watersheds contribute to mainstem flow in amounts relative to the distribution of mean annual precipitation. However, actual watershed conditions exhibit strong seasonal influences which must be considered. Consequently, the year was divided into two periods for application of this method.

May through September. Flow in the early part of this period (May through June) is dominated by the melt of winter precipitation. During July through September, when storm events contribute a large amount to tributary flow, the accuracy of this method depends on the matching of storm precipitation with average annual precipitation patterns.

October through April. Most tributary flow during this period is generated by groundwater baseflow; very little is a direct result of precipitation or of snowpack melting. Consequently, annual precipitation patterns are not used to weight relative basin contributions. For this period we have continued to use linear drainage area weighting (Method I).

RESULTS AND DISCUSSION

The water balance accounting model is largely a support program, providing input flows to other component models. As such, it operates on a specific scenario, generating an output flow time series for each nodal location in the system.

To generate the postproject flow time series, H2OBAL runs through two cycles. A time series at each node is first determined based on the natural input flows. Tributary contributions are determined in this step. The next cycle reassigns postproject output flows to the dam node and flows at the remaining mainstem nodes are re-adjusted.

Figure 5, longitudinal profiles of the pre- and postproject mean June flow regimes, provides graphic representation of H2OBAL output. Figure 6 gives tabular comparison of the three apportionment methods for the same preproject mean June flows.

Since filled flow records for the 32-year period of simulation exist for the Talkeetna and Chulitna rivers, flow from these systems can be treated as point source inputs to the mainstem basin. The Yentna River, however, cannot be treated in this way, except when simulating the period covered by the two-year gage record. When extending the water accounting system downstream from Sunshine, Yentna River flow must be apportioned as a fraction of the difference between Susitna Station and Sunshine Station gage flows.

The decision to use the area weighting procedure in the lower basin, regardless of the method used in the upper basin (i.e., upstream from Sunshine Station), was based on the following considerations:

1. The large size of the Yentna Basin (6180 mi^2) makes the task of developing C coefficients for water-yield or precipitation weighting formidable.

Figure 5. Mean pre- and postproject June flow profiles, Watana to Sunshine Station, using precipitation-weighting water balance method.

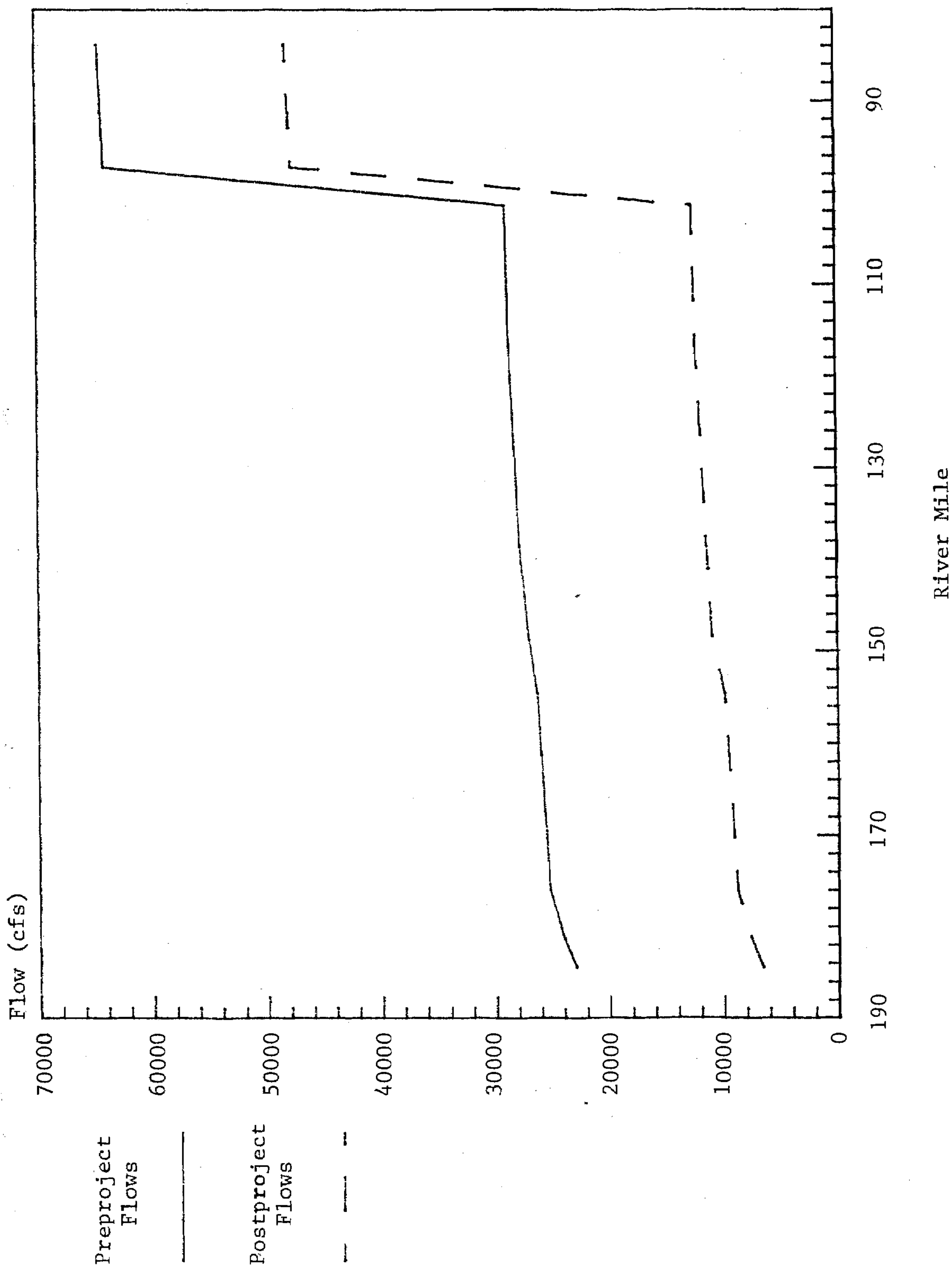


Figure 6. Mean preproject June flows, Watana to Sunshine Station, using three weighting methods.

Location Name	River Mile	Preproject Flows (cfs) Area Weighting	Precip. Weighting	Water-Yield Weighting
Watana	184.4	23034	23034	23034
Tsusena	181.3	23999	24056	24081
Fog	176.0	24844	25266	24876
Devil Canyon	161.3	25688	25986	25675
Chinchee	154.6	26143	26314	26031
Portage	148.8	27044	27003	27056
Indian	138.6	27815	27815	27815
Mckenzie	116.8	28543	28655	28687
Whiskers	101.4	28787	28917	28952
Chulitna	98.6	52359	52526	52589
Talkeetna	97.2	63916	64064	64103
Trapper	91.2	64117	64280	64291
Sunshine	83.8	64555	64555	64555

2. The lack of gage data for the Yentna River with which to calibrate makes any selection of a weighting scheme somewhat arbitrary.
3. The confluence of the Yentna River is at the downstream end of the Susitna Basin, far from the dam sites. Consequently, this is the region least sensitive to differences in flow apportionment methods.

Enhancement of the apportionment methodologies might be undertaken in a number of ways. The relative precipitation weighting method could be improved by using monthly or seasonal precipitation distribution maps. Presently, however, these maps are not available. Kilday (1974) developed mean monthly precipitation maps for the State, but they do not have the resolution necessary to be used on the Susitna Basin.

Sub-basin water yield would be determined most directly using Method III, relative water-yield weighting. Improvement of the present water-yield map is possible as additional precipitation and streamflow data become available. Continued enhancement could lead to monthly or seasonal water-yield estimates.

B = stream top width, L

ΣH = net heat flux, $(E/L^2)/t$

ρ = water density, M/L^3

c_p = specific heat of water, $(E/M)/T$

and dimensions are:

M - mass

T - temperature

L - length

t - time

E - energy

The assumption of steady state ($\partial T/\partial t = 0$) can be used to reduce the order of Equation (6) when 24-hour average temperature predictions are sufficient, resulting in:

$$dT/dx = [(q_d/Q)\ (T_d - T)] + [(B\Sigma H)/(Q\rho c_p)] \tag{7}$$

It is significant that this equation does not contain a stream velocity term. SNTEMP does not require stream velocities for prediction of average daily temperatures downstream from a known temperature.

Dynamic temperature predictions are possible if steady state is not assumed. Equation (6) can also be solved by the method of characteristics (Theurer et al. 1983) which results in a solution identical in form to Equation (7). Dynamic temperature predictions require Equation (7) to be solved along the characteristic line equation as follows:

$$dx = (Q/A)\ dt \tag{8}$$

The factor Q/A is stream velocity. Dynamic temperature predictions require an estimate of stream velocity which SNTEMP computes using Manning's equation. Closed form solutions of Equation (7) are obtained by assuming that 1) the flow is uniform within a reach and 2) a second order approximation of the heat flux is valid. This heat flux approximation can be expressed mathematically:

$$\Sigma H = K_1(T_e - T) + K_2(T_e - T)^2 \quad (9)$$

where:

T_e = equilibrium temperature, T

K_1 = first order thermal exchange coefficient, $[((E/L^2)/t)/T]$

K_2 = second order thermal exchange coefficient, $[((E/L^2)/t)/T^2]$

The equilibrium temperature is the theoretical temperature the stream would approach if all heat transfer processes were held constant with time. If the water reached equilibrium temperature, the rate of heat input to the water would equal the rate of heat loss ($\Sigma H = 0$).

Equilibrium temperature and steady flow assumptions constrain the methods used to average input data. The input hydrologic and meteorologic conditions must be representative throughout the travel time from the initial to final points of the model network. If the travel time from the most upstream point to the downstream end of the network becomes significant compared to the data averaging time, then model prediction becomes less reliable. For example, assume that a 30-day meteorologic data averaging period has been selected and that it takes 30 days for water to travel from point A to point B. Water passing point B on the first day of this 30-day period left point A 30 days earlier. Therefore, the meteorologic conditions which determine the daily average water temperature at point B on the first day are not included in the time period averages. Only the last day's water column can be considered to have been influenced by the 30-day average meteorologic conditions.

This data averaging versus travel time dilemma can be overcome either by 1) selecting averaging periods greater than the network travel time or 2) dividing the network into serially connected subnetworks, or reaches, and using moving average input conditions. The first technique is the standard way of operating SNTEMP. If short-term average water temperature predictions are necessary, the second technique can be accomplished with SNTEMP by simulating an upstream reach with appropriate average input data, and using this simulation's output as input to the next downstream reach.

MODIFICATIONS

AEIDC modified SNTEMP to more accurately simulate conditions specific to Alaska and the Susitna Basin, including techniques to approximate the seasonal variation in canyon wall shading and winter air temperature inversions which normally occur in the Susitna River basin. The original design of SNTEMP assumed topographic shading to be constant. Since solar altitude angles are so acute in Alaska, resulting in extreme shading during the winter months, SNTEMP was modified to accept a monthly topographic shading parameter.

SNTEMP originally featured a constant lapse rate to simulate air temperature and humidity change at elevations other than those where data were recorded. Radiosonde data from Fairbanks and Anchorage indicated this approximation to be a poor predictor of actual conditions, especially in the colder months (U.S. National Weather Service 1968, 1969, 1970, 1980; World Meteorological Organization 1981, 1982). AEIDC modified SNTEMP to accept monthly, nonconstant lapse rates. Local monthly temperature lapse rates were determined by regressing temperature on elevation using data recorded above Anchorage and Fairbanks (1968 through 1970; 1980 through 1982) by U.S. National Weather Service balloons. The temperature lapse rate curves for June, July, August, and September are shown in Figure 7. Piece-wise linear humidity lapse rate curves were also determined from the balloon data and are presented in Figure 8.

In addition, we also adjusted the normal SNTEMP operating method to accommodate the limited water temperature data available throughout the study area. Typically, a built-in regression model provides missing water temperature data and smooths the data but we had to bypass this feature since it required more data than were available at any of the water temperature collection sites. This will be discussed further in the section entitled "Synthetic Temperatures."

STREAM NETWORK

The stream network as defined for SNTEMP is designed to allow easy manipulation of flows and water temperatures at specific locations. This network can be used for simulations with either or both Watana and Devil Canyon reservoirs. Using expected water temperatures and outflows

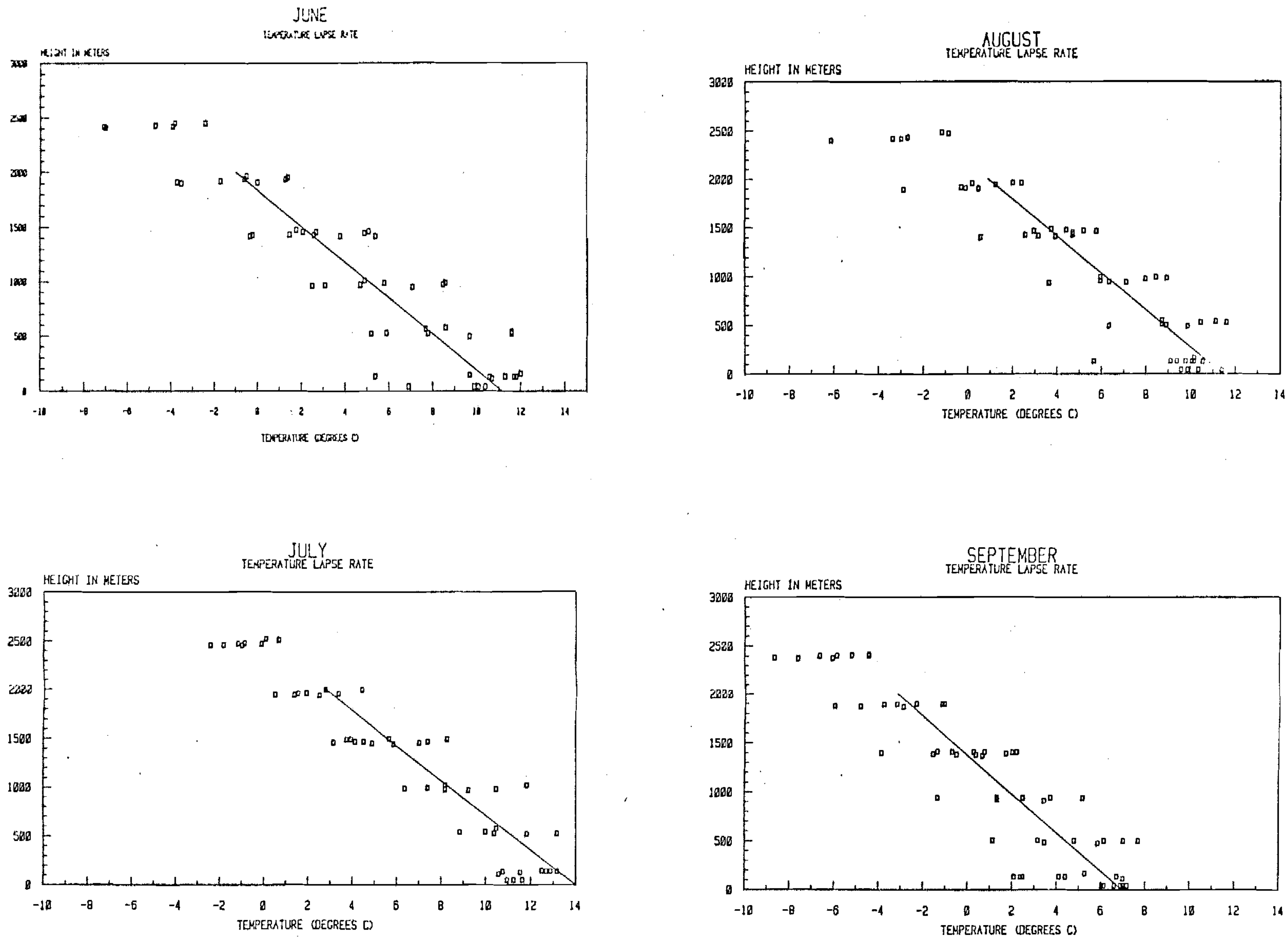
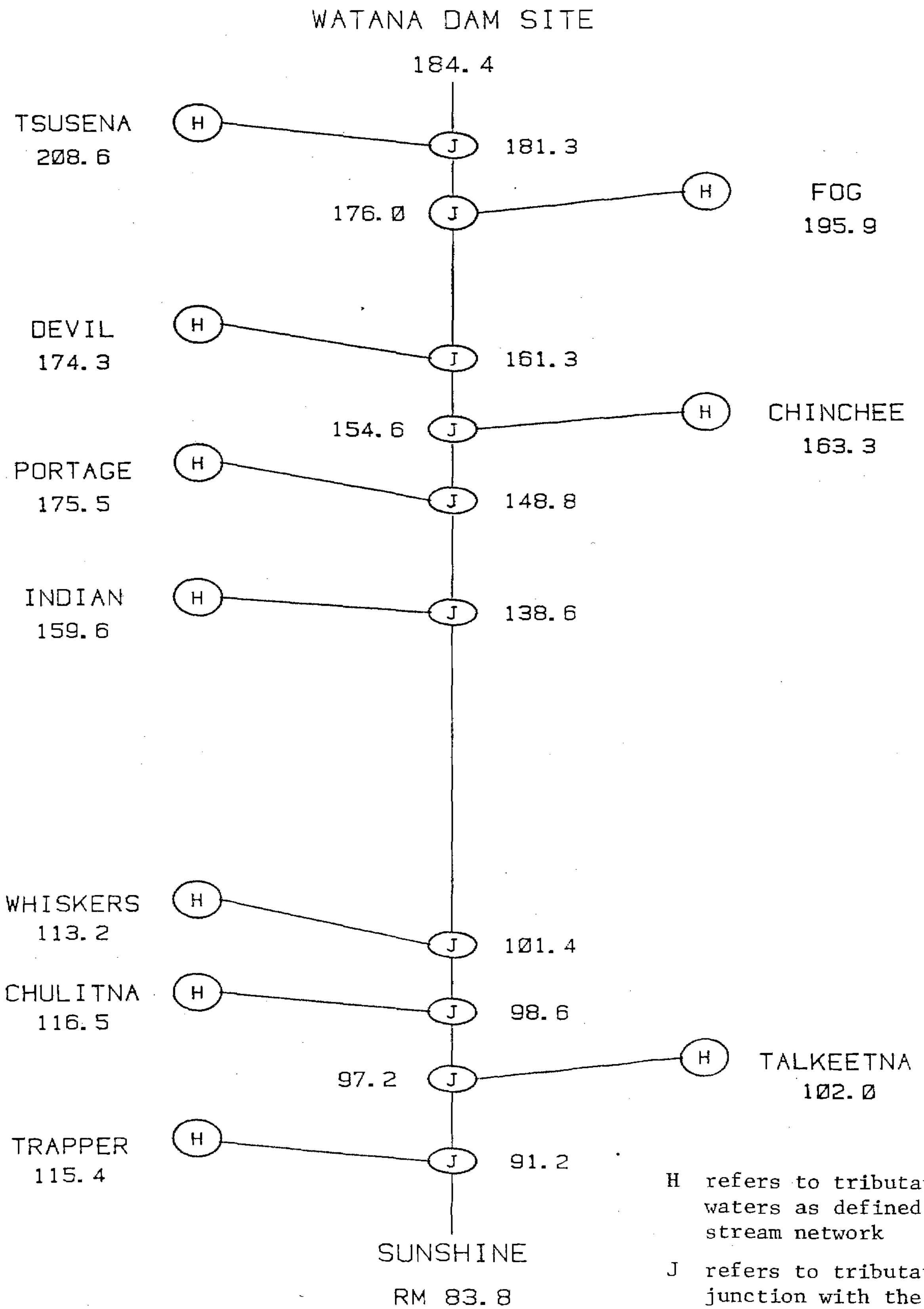


Figure 7. Vertical air temperature distribution. Anchorage and Fairbanks 1968, 1969, 1970, 1980, 1981, 1982.

Figure 9. Stream network from Watana to Sunshine.

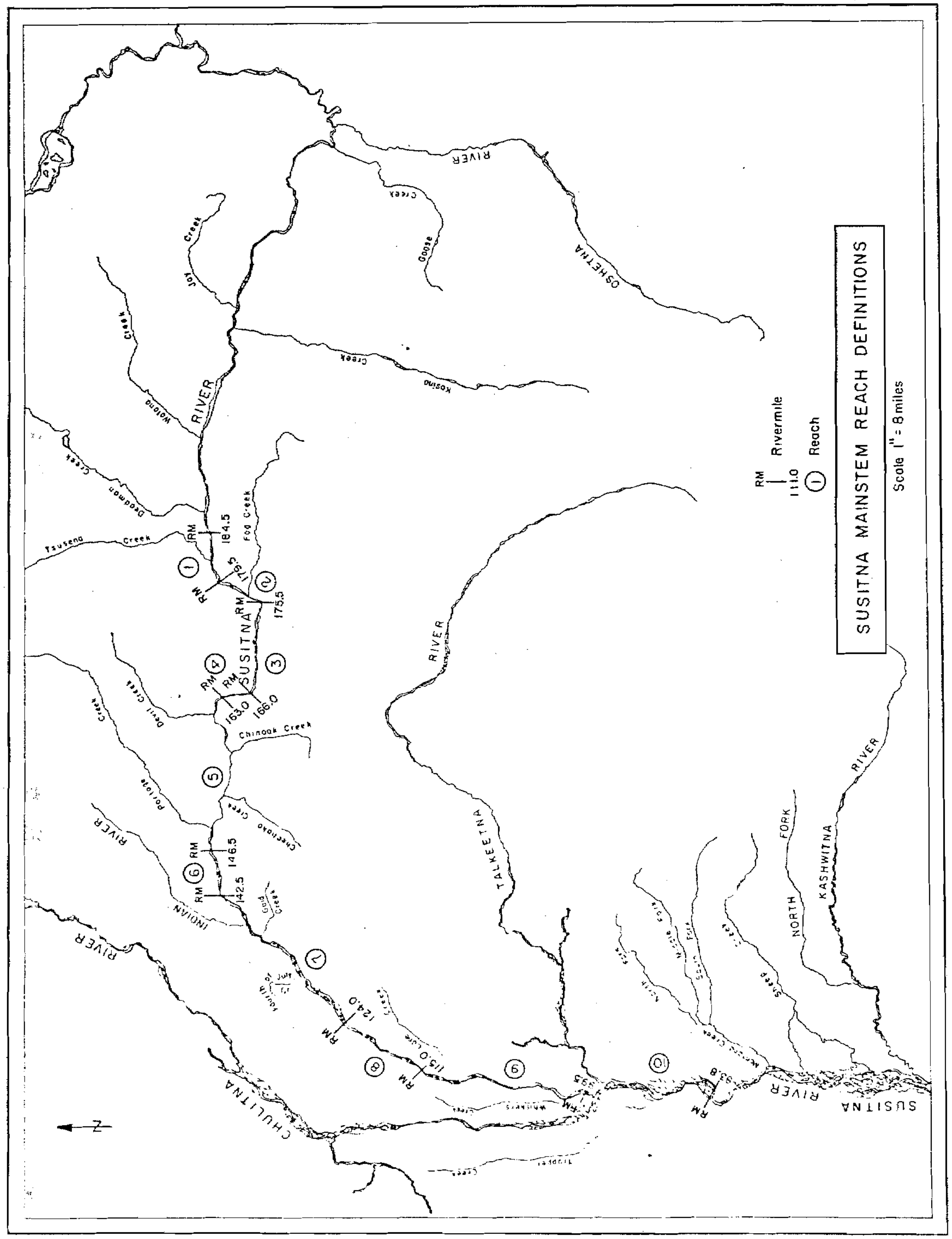


H refers to tributary headwaters as defined in the stream network

J refers to tributary junction with the mainstem

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

Figure 10. Susitna mainstem reach definitions.



terrain altitude angles were determined from each of these transects and then transferred to solar altitude versus bearing angle plots (Siefert 1981). We computed the average sunrise/sunset altitude angles for each month from these plots (Appendix A).

Stream Widths

The quantity of radiative energy entering or leaving the stream is a function of the stream surface area. An estimate of the stream width is necessary for surface area determination. Mainstem wetted widths used in SNTEMP from the Talkeetna River confluence to Watana were determined from the R&M HEC-2 cross sections and simulations (R&M 1982d). The stage-discharge relationships developed by ADF&G (1983) were not available when our width analysis was being performed. However, since the stage discrepancies noted between the R&M simulations and ADF&G observations would not result in significant width differences, we do not propose to modify the width functions at this time.

Water surface widths simulated by R&M were measured from the cross section diagrams (R&M 1982d) and plotted as a function of flow. We calculated width/flow functions from these plots.

Other methods were used to estimate top width for other mainstem reaches and tributaries. USGS (1980, 1981) observations at Cantwell, Chulitna, and Talkeetna provided some stream width and flow data. Width data at the Chulitna and Talkeetna gages were available for several flows. Several width measurements within a narrow range of flows provided a constant width estimate for the Susitna River between Cantwell gage and the Watana dam site. The width of the reach below the Chulitna junction to Sunshine Station was determined from transects collected by R&M (Coffin 1983). This width was also assumed constant with flow. Field personnel estimated widths of the tributaries (Sauntner 1983; Schoch 1983; Quane 1983) which were assumed constant with flow.

Figure 11 presents width/flow functions in tabular form with graphic presentations in Appendix B. The plots present data points connected by line segments and the computed function.

Figure 11. Tabular values of width function parameters.

Stream	Reach #	Start (mile)	End (mile)	a	b
Susitna	1	184.5	179.5	98.26	0.1577
Susitna	2	179.5	175.5	105.40	0.1708
Susitna	3	175.5	166.0	98.13	0.1820
Susitna	4	166.0	163.0	189.96	0.0774
Susitna	5	163.0	146.5	144.88	0.1005
Susitna	6	146.5	142.5	98.15	0.1845
Susitna	7	142.5	124.0	13.16	0.4078
Susitna	8	124.0	115.0	33.95	0.3117
Susitna	9	115.0	99.5	29.77	0.3390
Susitna	10	99.5	83.8	1256	-
Tsusena	1	208.6	181.3	80	-
Fog	1	195.9	176.0	50	-
Devil	1	174.3	161.3	35	-
Chinchee*	1	163.3	154.6	25	-
Portage	1	175.5	148.8	60	-
Indian	1	159.6	138.6	50	-
Whiskers	1	113.2	101.4	20	-
Chulitna	1	116.5	98.6	60.70	0.2086
Talkeetna	1	102.0	97.2	97.92	0.1761
Trapper	1	115.4	91.2	18	-

Values for "a" and "b" in the function width (feet) = a · flow (cfs)^b. If "b" is undefined, "a" represents a constant width (feet).

*A synthetic stream representing the combined Chinook and Chechako tributaries.

Hydraulic Retardance

SNTEMP does not require stream velocity estimates to predict average daily downstream water temperatures (see "Description of the Stream Temperature Model"). On the other hand, daily minimum and maximum temperature predictions do require estimates of stream velocities. If daily maximum and minimum temperature estimates are desired later, it will become necessary to obtain the Manning's n values to compute stream velocities.

Tributary Assumptions

Except for the Chulitna and Talkeetna rivers, all Susitna tributaries simulated by SNTEMP are essentially self-starting. Simulation of these tributaries starts from their estimated headwaters where a constant headwater temperature of 0 C is assumed. Since the headwater flow is assumed to be zero, this seasonally constant initial water temperature is not critical (the heat content of zero mass would be zero, exclusive of the temperature assigned). Flow is added to these tributaries based on the flow balance schemes discussed in the section "Water Balance Accounting for the Susitna Basin." Predicted tributary temperatures are highly sensitive to the temperature assumed for distributed flow. Techniques for estimating these temperatures will be discussed in the section "Temperatures of Distributed Flow." Tributary widths were based on field estimates and lengths were measured from topographic maps with an opisometer. Each tributary in the model is assumed to be a single stream. For branched tributaries we estimated a sub-basin area-weighted average length. Tributary reaches were defined based on 300 m elevation drops.

HYDROLOGY

Flows

As described in the section "Water Balance Accounting for the Susitna Basin," we investigated three types of flow balancing techniques for supplying flow estimates to the temperature model. These techniques are used both with historical flows and for gaming with reservoir releases.

Stream Temperatures

Observed Temperatures. SNTEMP uses observed water temperature data of two types--initial water temperatures necessary for starting the model and validation/calibration water temperatures. Only three initial temperatures are required for the Watana (or Cantwell) to Sunshine Station simulations. These are Susitna River at Watana (or Cantwell), Chulitna River at the USGS Gage, and Talkeetna River at the USGS gage. The remaining observed water temperatures are essential in determining how well the mainstream and tributary temperatures are being simulated and in serving as a calibration target.

Most of the validation/calibration temperatures for this study are being collected by ADF&G (1981, 1983); USGS (USGS 1980, 1981; Bigelow 1983) collected the three initial water temperatures. Unfortunately, most of these initial temperatures are unusable as a result of incomplete records or discrete sampling. Usable data are defined as those data which are complete for the month or, if not complete, symmetric around the middle of the month. Data which cluster evenly around the middle of the month should result in an unbiased measure of the monthly mean. Figure 12 presents the available data, and Figure 13 presents usable data collected for the June to September periods of 1980 through 1982. Data collected by USGS at Gold Creek were not used in this study since it had been observed that the temperature recorder was in the plume of the Gold Creek tributary (Trihey 1983) and thus not representative of mainstem flow. USGS recently relocated this temperature recorder, and future data provided by USGS and ADF&G should allow adjustment of the historical USGS data to be representative of the mainstream temperatures.

Synthetic Temperatures. USGS Cantwell gage on the Susitna River (RM 223.7). Stream temperature data were recorded at the Cantwell gage during the 1980 and 1982 June through September periods. To verify downstream temperature predictions with stream temperatures observed by ADF&G (1981) and R&M (1982b), we estimated water temperatures at Cantwell for 1981. SNTEMP incorporates a regression technique for data filling, but, as discussed previously, more data than are available are necessary for this technique to produce physically reasonable results.

Figure 12. Monthly stream temperatures, available data June to Sept. 1980, 1981, 1982.

Mainstem/Tributary River Mile	River name / description	1980				1981				1982			
		Number of Days											
		J	J	A	S	J	J	A	S	J	J	A	S
10.1/0.5	Alexander Cr.					25	31	31	30				
10.1	Susitna above Alexander Cr.					25	31	31	1				
25.8	Susitna R., Su Station	30	31	31	30					10	—	—	—
28.0/2.0	Yentna R.					26	31	31	14				
28.0/4.0	Yentna R.									23	31	31	27
29.5	Susitna R. above Yentna R.									20	31	31	30
32.3	Susitna R. above Yentna R.					25	31	31	12				
40.6/1.2	Deshka R.					21	31	31	30				
49.8/4.9	**Deception Cr. near Willow	5	8	—	8								
49.8/11.6	**Willow Cr. near Willow	5	18	—	22								
50.5/1.0	Little Willow Cr.					7	31	31	30				
50.5	Susitna R. above Little Willow Cr.					7	31	31	24				
61.2	Susitna R. above Kashwitna R.					—	—	2	27				
77.2/0.0	Montana Creek					19	24	—	1				
77.5	Susitna R. above Montana Cr.					19	3	2	30				
83.8	Susitna R., east shore—Parks Hwy.					20	14	—	—	—	—	—	30
83.9	Susitna R., west shore—Parks Hwy.									23	9	10	30
97.0	Susitna R.—LRX 1									17	—	—	—
97.2/5.0	**Talkeetna R. near Talkeetna	—	1	—	—								
97.0/1.0	Talkeetna R.					10	31	31	30				
97.2/1.5	Talkeetna R.									17	1	31	30
98.5/18.0	**Chulitna R. near Talkeetna	1	1	1	—					27	30	3	20
98.6/0.5	Chulitna R.					11	17	—	20				
98.6/0.6	Chulitna R.									17	—	10	25
103.0	Susitna R.—TKA fishwheel					11	10	19	22	7	28	31	25
113.0	Susitna R.—LRX 18									—	25	31	30
120.7	Susitna R.—Curry									—	25	31	30
126.0	Susitna R.—Slough 8A									—	4	31	30
126.1	Susitna R.—LRX 29									—	22	31	30
129.2	Susitna R.—Slough 9									—	4	31	24
130.8	Susitna R.—LRX 35									—	23	4	17
131.3	Susitna R. above 4th of July Cr.					15	31	30	26				
136.5	**Susitna R. near Gold Cr.	30	31	31	30	—	8	25	29	—	—	12	30
136.8/0.0	Gold Creek					—	7	3	—				
138.6/1.0	Indian R.									23	31	4	28
138.6/0.1	Indian R.					—	10	25	14				
138.7	Susitna R. above Indian R.					—	11	29	16				
140.0	Susitna R.—Slough 19					—	—	5	13				
140.1	Susitna R.—LRX 53									—	—	23	—
142.0	Susitna R.—Slough 21					—	—	4	29	—	4	31	30
148.8	Susitna R. above Portage Cr.					—	13	31	29				
148.8/0.1	Portage Cr.									13	26	28	—
181.3/0.0	Tsusena Cr.									12	7	31	30
184.4	*Susitna R. at Watana dam site					30	—	31	30				
194.1/0.0	Watana Cr.									11	31	15	16
206.8/0.0	Kosina Cr									4	31	17	12
223.7	**Susitna R. near Cantwell	—	—	—	—					27	31	31	22
231.3/0.0	Goose Creek									—	31	31	30
233.4/0.0	Oshetna Creek									—	31	31	30

*R&M gages

**USGS gages

All others are ADF&G gages.

Figure 13. Monthly stream temperatures, usable data June to Sept. 1980, 1981, 1982.

Mainstem/Tributary River Mile	River name / description	Number of Days 1980				1981				1982			
		J	J	A	S	J	J	A	S	J	J	A	S
10.1/0.5	Alexander Cr.					18	31	31	26				
10.1	Susitna above Alexander Cr.					18	31	27	—				
25.8	Susitna R., Su Station	30	31	31	30					—	—	—	—
28.0/2.0	Yentna R.					20	31	31	—				
28.0/4.0	Yentna R.									14	31	31	24
29.5	Susitna R. above Yentna R.									10	31	31	30
32.3	Susitna R. above Yentna R.					18	31	29	6				
40.6/1.2	Deshka R.					10	31	31	30				
49.8/4.9	**Deception Cr. near Willow	—	—	—	2								
49.8/11.6	**Willow Cr. near Willow	—	13	—	4								
50.5/1.0	Little Willow Cr.					—	31	31	28				
50.5	Susitna R. above Little Willow Cr.					—	31	31	10				
61.2	Susitna R. above Kashwitna R.					—	—	—	22				
77.2/0.0	Montana Creek					6	17	—	—				
77.5	Susitna R. above Montana Cr.					8	—	—	30				
83.8	Susitna R., east shore—Parks Hwy.					8	—	—	—	—	—	—	30
83.9	Susitna R., west shore—Parks Hwy.									14	—	—	30
97.0	Susitna R.—LRX 1									14	—	—	—
97.2/5.0	**Talkeetna R. near Talkeetna	—	—	—	—								
97.0/1.0	Talkeetna R.					—	31	31	30				
97.2/1.5	Talkeetna R.									14	—	31	30
98.5/18.0	**Chulitna R. near Talkeetna	—	—	—	—					24	30	—	10
98.6/0.5	Chulitna R.					—	3	—	12				
98.6/0.6	Chulitna R.									14	—	—	18
103.0	Susitna R.—TKA fishwheel					—	—	17	13	—	21	31	16
113.0	Susitna R.—LRX 18									—	17	31	30
120.7	Susitna R.—Curry									—	17	31	30
126.0	Susitna R.—Slough 8A									—	—	29	30
126.1	Susitna R.—LRX 29									—	13	31	30
129.2	Susitna R.—Slough 9									—	—	31	20
130.8	Susitna R.—LRX 35									—	—	—	6
131.3	Susitna R. above 4th of July Cr.					—	31	26	22				
136.5	**Susitna R. above Gold Cr.	30	31	31	30	—	—	24	24	—	—	—	30
136.8/0.0	Gold Creek					—	—	—	—				
138.6/1.0	Indian R.									16	31	—	—
138.6/0.1	Indian R.					—	—	17	8				
138.7	Susitna R. above Indian R.					—	—	21	10				
140.0	Susitna R.—Slough 19					—	—	—	—				
140.1	Susitna R.—LRX 53									—	—	23	—
142.0	Susitna R.—Slough 21					—	—	—	28	—	—	31	30
148.8	Susitna R. above Portage Cr.					—	—	31	28				
148.8/0.1	Portage Cr.									—	15	25	—
181.3/0.0	Tsusena Cr.									—	31	31	30
184.4	*Susitna R. at Watana dam site					30	—	31	30				
194.1/0.0	Watana Cr.									—	31	—	6
206.8/0.0	Kosina Cr									—	31	3	—
223.7	**Susitna R. near Cantwell	—	—	—	—					24	31	31	15
231.3/0.0	Goose Creek									—	31	31	30
233.4/0.0	Oshetna Creek									—	15	31	24

*R&M gages
**USGS gages
All others are ADF&G gages.

To fill this missing year, we simplified, but retained, the logic of the SNTEMP regression technique.

SNTEMP uses what may be termed a "physical process" regression model for data filling and smoothing. The regression model is based on a simplified version of the heat transport model used to predict downstream water temperatures. These models employ an equilibrium stream temperature assumption where the calculated equilibrium temperature (T_e) represents the value the stream is asymptotically approaching. The standard regression model of SNTEMP uses the calculated T_e and the rate of approach to T_e as independent variables. For the Susitna River application, this model was simplified to use only the equilibrium temperature (Figure 14).

USGS gage data collected on the Chulitna and Talkeetna rivers. Only three usable water temperatures were available for the Talkeetna and Chulitna rivers during the June to September periods. These temperatures were recorded on the Chulitna River during June, July, and September of 1982 (Bigelow 1983). Because of the limited data at these stations, regressions similar to those used for the Cantwell gage were of little value (Figures 15 and 16). However, the values predicted by these regressions were used to fill in the missing data and to smooth those observed data points with only one observation per month. Where available, ADF&G temperature data were used to adjust the temperatures at the gages so that simulated temperatures matched the observed data at the ADF&G sites. Figures 15 and 16 list the values assumed by the model, but the reader should note the low confidence associated with these values.

Temperatures of Distributed Flow. Flow accretions from groundwater or surface inflow are included in the network as continuous additions to the stream flow, referred to as distributed flows. This is the primary mechanism for simulating Susitna tributary flows. Water temperature predictions for smaller tributaries depend on the water temperatures assigned to tributary distributed flows. Thus, the accuracy of temperatures assigned to distributed flow is critical to the simulation. Contribution from surface or groundwater flows have not been quantified

Figure 14. Temperature regression for Susitna River at Cantwell gage.

Month	Regression Prediction (C)	Regression 95 Percent Confidence Intervals (C)
June 81	8.82	± 0.94
July 81	8.96	± 0.98
August 81	8.20	± 0.87
September 81	5.29	± 1.70

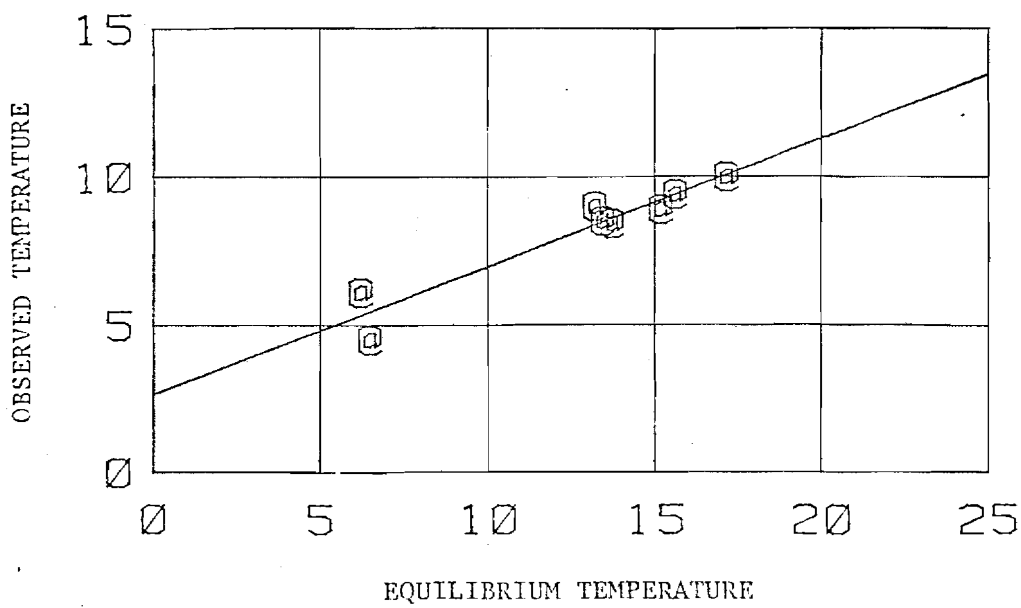


Figure 15. Temperature regression for Chulitna River at USGS gage.

Month	Observed (C)/ Sample Size	Regression Prediction (C)	Regression 95 Percent Confidence Intervals (C)	Value Used (C)
June 81	7.4/1	6.68	± 0.98	6.68
July 81	-/0	6.90	± 1.09	7.10*
August 81	7.2/1	6.64	± 0.97	6.64
September 81	-/0	4.95	± 2.67	5.25*
June 82	7.3/24	6.53	± 0.97	5.45*
July 82	5.7/31	7.01	± 1.17	5.7
August 82	-/0	7.01	± 1.17	7.01
September 82	4.6/10	5.22	± 2.30	4.6

*Temperature at gage was adjusted so downstream simulation matched data collected by ADF&G.

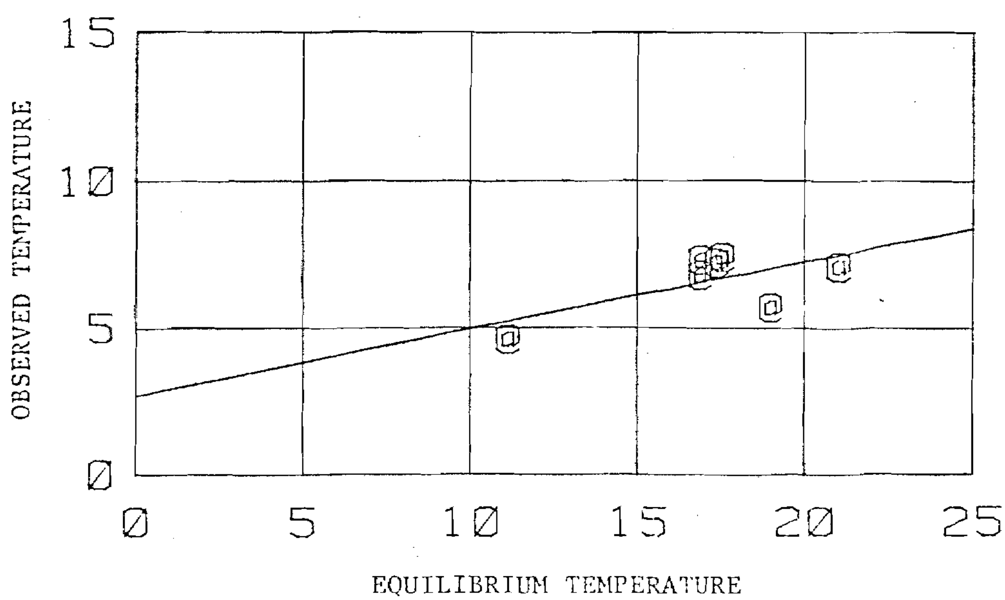
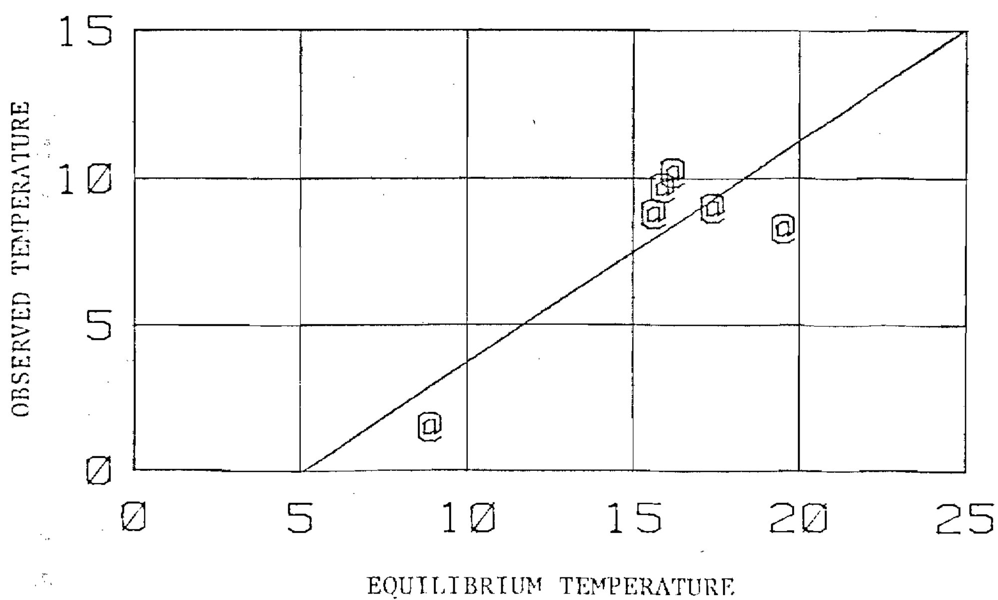


Figure 16. Temperature regression for Talkeetna River at USGS gage.

Month	Observed (C)/ Sample Size	Regression Prediction (C)	Regression 95 Percent Confidence Intervals (C)	Value Used (C)
June 81	10.2/1	8.37	± 1.15	8.37
July 81	9.0/1	9.28	± 1.30	8.60*
August 81	9.7/1	8.14	± 1.14	8.40*
September 81	1.5/1	2.86	± 2.58	5.70*
June 82	-/0	8.54	± 1.17	7.00*
July 82	-/0	9.67	± 1.39	9.67
August 82	-/0	9.52	± 1.35	9.20*
September 82	-/0	2.74	± 2.63	5.50*

*Temperature at gage was adjusted so downstream simulation matched data collected by ADF&G.



in Susitna tributaries; therefore, they must be estimated. Presently, two techniques can be used to estimate these temperatures. The first is to assume groundwater inflow at a constant temperature for all time periods and all locations. G. Nelson (1983) of the USGS suggested a value of 3 C as representative of a wide range of conditions encountered by that organization in adjacent drainages. This assumption does not allow for 1) seasonal ground temperature variation, 2) ground temperature variation with site elevation, or 3) the possibility of surface runoff.

Rather than assuming a constant temperature for distributed flows, an alternative technique is to vary temperature by location and depth. AEIDC modified the ground temperature function presented by Williams and Gold (1976):

$$T_g(x,t) = \bar{T}_g + (\Delta T_g/2) \cos [(2\pi t/t_o) - x\sqrt{\pi/\alpha t_o}] \exp(-x\sqrt{\pi/\alpha t_o}) \qquad (10)$$

where:

$\bar{T}_g$ = average annual ground surface temperature (C)

ΔT_g = annual range of ground surface temperature variation (C)

t = time from occurrence of peak temperature (days)

t_o = time for one cycle of temperature variation (365 days)

x = depth (m)

α = thermal diffusivity (m^2/day) = thermal conductivity/volumetric heat capacity

This formula can be used to predict ground temperatures at variable depths and times if the average annual ground surface temperature ($\bar{T}_g$) and annual range of ground surface temperature variation (ΔT_g) are known. The annual range of ground temperature can be assumed to be the same as the annual range of air temperature variation (Williams and Gold 1976) which is 28.2 C at Talkeetna. Data presented in Williams and Gold (1976) indicates that the average annual ground temperature is approximately 1 to 7 C warmer than the average annual air temperature in regions with persistent snow cover. If, for notational purposes, we designate this 1 to 7 C offset by T_{off} and define $A = 2\pi/t_o$, $B = \sqrt{\pi/\alpha t_o}$, the formula becomes:

$$T_g(x,t) = \bar{T}_{air} + T_{off} + 14.1 \cos (At-Bx) \exp(-Bx) \qquad (11)$$

Air and ground temperature data collected at Gulkana, Alaska (Aitken 1964b) and Big Delta, Alaska (Aitken 1964a) suggest that this offset temperature is in the range of 4.3 to 4.9 C. For purposes of further discussion in this paper a value of 4.6 C will be assumed, although in the SNTEMP implementation of this ground temperature model T_{off} will be used as a calibration variable.

The mean annual air temperature of an arbitrary location at elevation Z can be computed from the mean annual air temperature at Talkeetna (0.3 C) using the lapse rate equations discussed in the modifications section:

$$T_Z = T_0 - \gamma(Z-Z_0) \qquad (12)$$

where:

T_Z = air temperature at elevation Z (C)
T_0 = observed air temperature at elevation Z_0 (C)
Z_0 = elevation of site where air temperature is known (Z_0 = 105 m for Talkeetna)
Z = elevation of site where air temperature is desired (m)
γ = air temperature lapse rate (C/m)

By substituting the air temperature lapse rate expression for air temperature at elevation Z, the ground temperature formula can be rewritten as:

$$T_g(x,t,Z) = 4.9 - \gamma(Z-105) + 14.1 \cos(At-Bx) \exp(-Bx) \qquad (13)$$

If a value is assumed for the thermal diffusivity, the only undefined variable for any location and time period is the depth of the ground temperature. There are two depths of interest which correspond to two separate forms of heat flux--conduction to and from the streambed and mass transfer of heat (distributed flow). Streambed conduction is a function of the depth at which the ground temperature variation is essentially zero for the simulation time period. Given an estimate of α, a depth can be computed where daily temperature fluctuations are essentially zero. Williams and Gold (1976) give an α-value for wet sand of 0.01 cm^2/sec. This value is also used to represent the thermal diffusivity of sand, gravel, cobbles, and boulders in the Susitna slough hydrogeology study (Acres 1983b). Using this value, daily temperature fluctuations penetrate to a depth of approximately 0.8 m. Substituting 0.01 cm^2/sec for α and 0.8 m for depth, the above formula reduces to:

$$T_g(t,Z) = 4.9 - \gamma(Z-105) + 10.3 \cos(At-0.316) \qquad (14)$$

The distributed flow heat flux is a function of the average depth from which the water flows. Rather than assume a value, this depth has been retained as a variable for calibration purposes.

This ground temperature model must be considered provisional as the assumptions made cannot be tested or validated without further data collection. Temperature at depth data at several locations within the Susitna Basin would be required for validation of this model and improving estimates of assumed values. AEIDC is continuing a literature search for techniques to improve the resolution of the model.

Gaming Flows and Temperatures

Flows ranging from the historical summer flows to the proposed filling and operational summer Watana dam releases (Acres 1983a) are available for simulation. Reservoir temperature simulations using 1981 data and 15-minute timesteps suggest that summer release temperatures from Watana will range between 4.5 and 10.5 C (Acres 1983a). Simulated monthly mean temperatures for the same period range from 7.7 to 9.5 C (Figure 17).

Figure 17. Simulated monthly mean temperatures of Watana Dam outflow.

	June	July	Aug	Sept
Water Temp. C	7.7	9.5	8.7	8.3

These instantaneous and mean monthly temperatures are currently being used to estimate mean and extreme release temperature values until more data become available.

METEOROLOGY

Selection of Meteorologic Data

The SNTEMP model is designed for climatic data input from only one representative meteorologic data station per stream network. The only long-term meteorologic data station within the Susitna Basin is the U.S. National Weather Service station located in Talkeetna. This station has summarized monthly data (air temperature, wind speed, relative humidity, and percent cloud cover)--the data required by SNTEMP--for the period 1968 to 1982. In addition, unreduced data are available from 1950 to 1968 on computer tape from the National Climatic Data Center. This period of record allows stream temperature simulations under extreme and normal meteorologic conditions. We used meteorologic data collected specifically for the Susitna study (R&M 1980, 1982a, 1982b, 1982c, 1982e, 1982f) to validate the meteorologic predictions of SNTEMP.

Ground Reflectivity and Atmospheric Dust

The stream temperature model predicts solar radiation based on site latitude, period of the year, cloud cover, ground reflectivity, and atmospheric dust. AEIDC determined monthly ground reflectivity values for the Susitna Basin using the percent area groundcover vegetation types presented in McKendrick (1982) and Bredthauer and Drage (1982). The remaining component necessary to predict solar radiation is an estimate of atmospheric dust. Dust was estimated by calibrating monthly average predicted solar radiation to observed values using the published solar radiation and percent possible sunshine data collected at the Palmer Agricultural Experiment Station (Matanuska Station as recorded in Wise 1979). Figure 18 presents these coefficient values.

Meteorologic Predictions

Conditions observed at Talkeetna are not necessarily representative of the entire basin. SNTEMP adjusts most of the recorded variables to better represent the local conditions within the basin. For example, the predicted solar radiation considers local topographic shading. The following discussion compares Susitna Basin meteorologic predictions with data collected by R&M.

As was previously discussed, SNTEMP has been modified to accept monthly air temperature/elevation and humidity/elevation functions. The air temperatures and humidities predicted by these equations are compared to the data collected by R&M (Figures 19 and 20). From these plots it appears that the humidity lapse model is a poor predictor of basinwide conditions; however, we retained it in SNTEMP for three reasons: 1) Talkeetna humidity data are based on wet/dry bulb measurements which are inherently more accurate than ceramic plate recorders (Wise 1983); 2) balloon-carried radiosondes are calibrated at the time of release and resultant data are the means of twice-daily observations; and 3) erratic behavior (e.g., daily 0 to 100 percent oscillations) was noted in several of the R&M humidity recordings.

The wind speeds at Talkeetna are not currently adjusted in any way to better represent winds within other parts of the Susitna River basin. Wind speeds recorded at Talkeetna were compared to wind speeds recorded by R&M at various locations within the basin (Figure 21). It would be relatively simple to incorporate a linear adjustment equation to translocate observed Talkeetna wind speed data to locations which would be better represented by the observed R&M data. However, the wind speed data collected by R&M does not necessarily represent the wind speeds which occurred directly above the water surface and are responsible for the rates of convective and evaporative heat flux. R&M (Coffin 1983) has proposed a water surface wind speed collection effort for 1983.

Figure 18. Ground reflectivity and atmospheric dust coefficients, Matanuska Agricultural Experiment Station, Palmer.

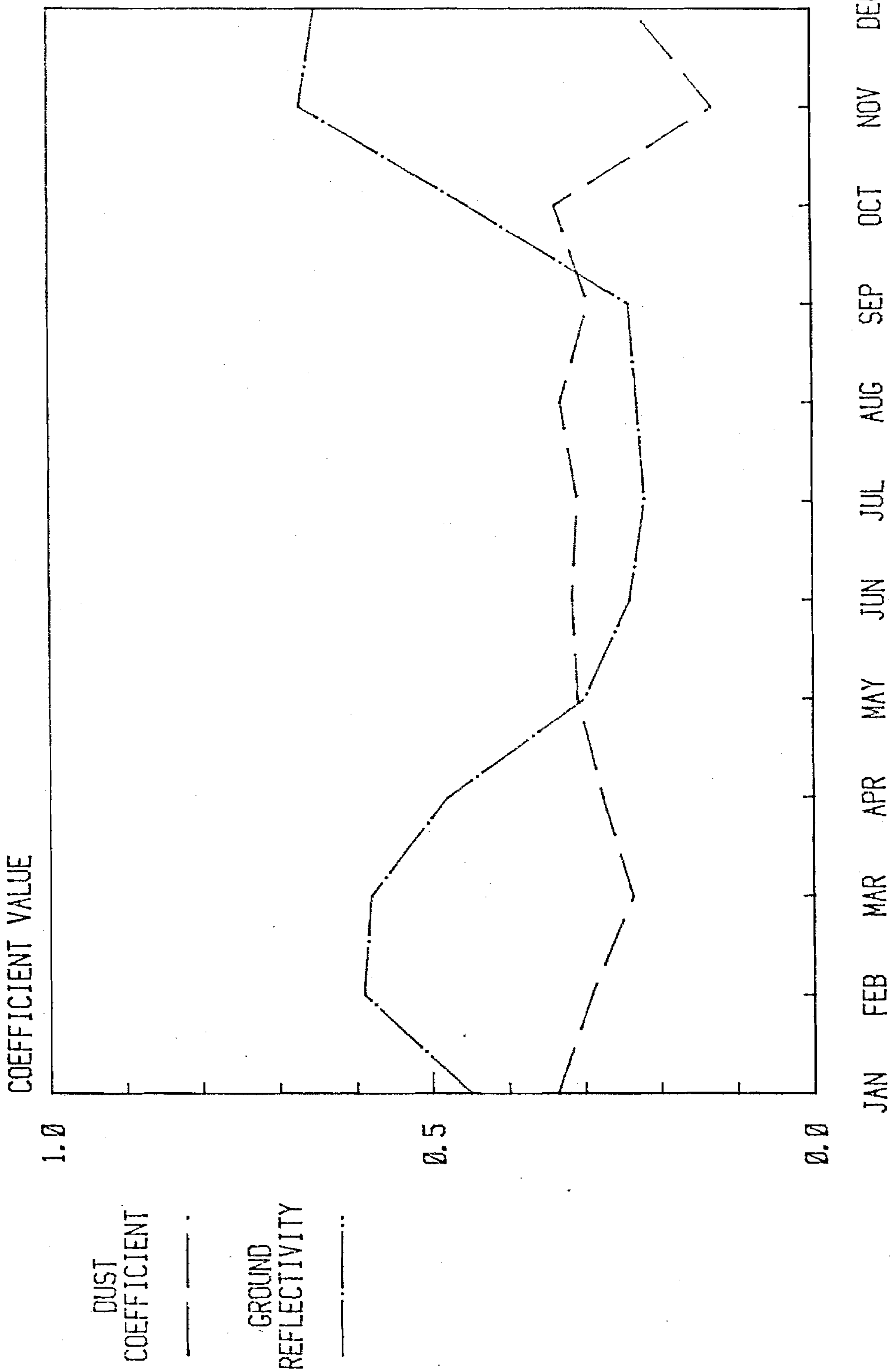
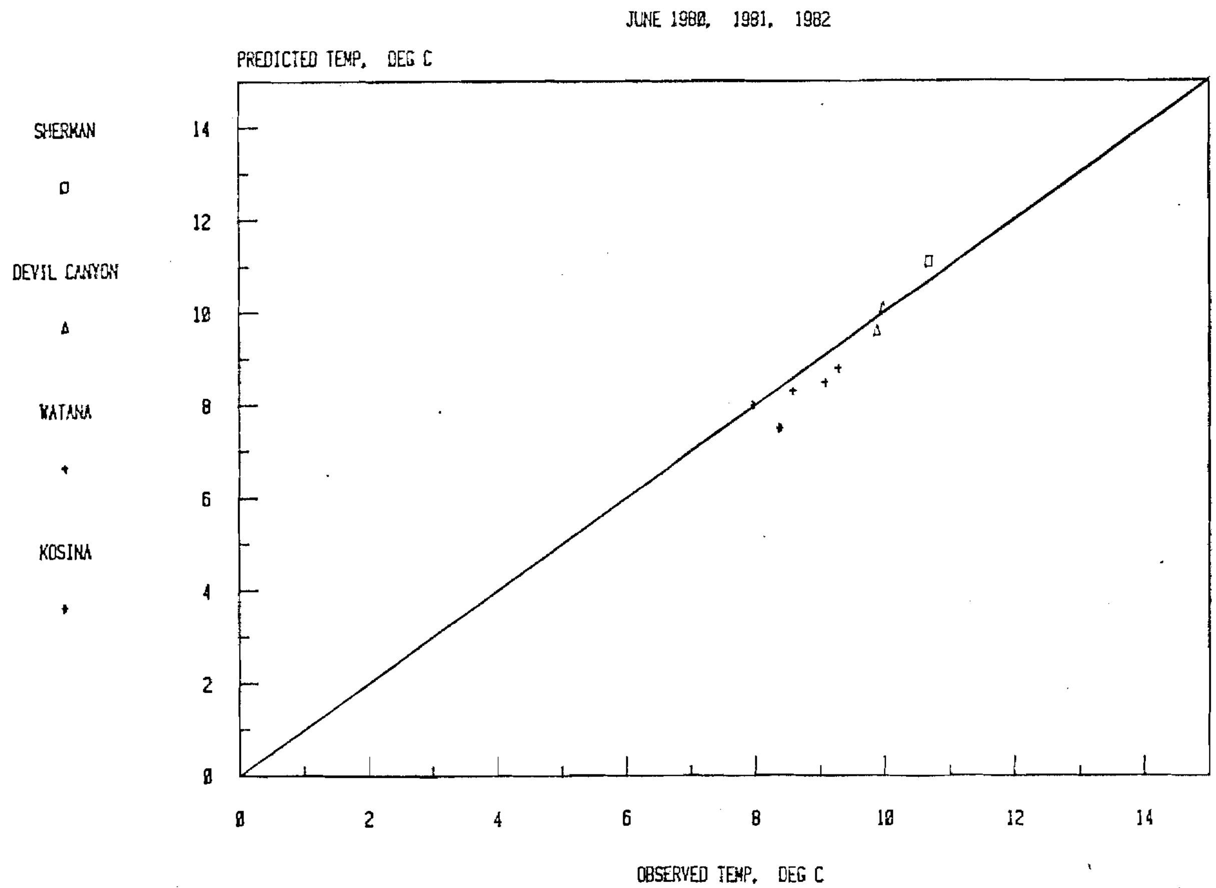


Figure 19. Observed vs. predicted air temperatures.



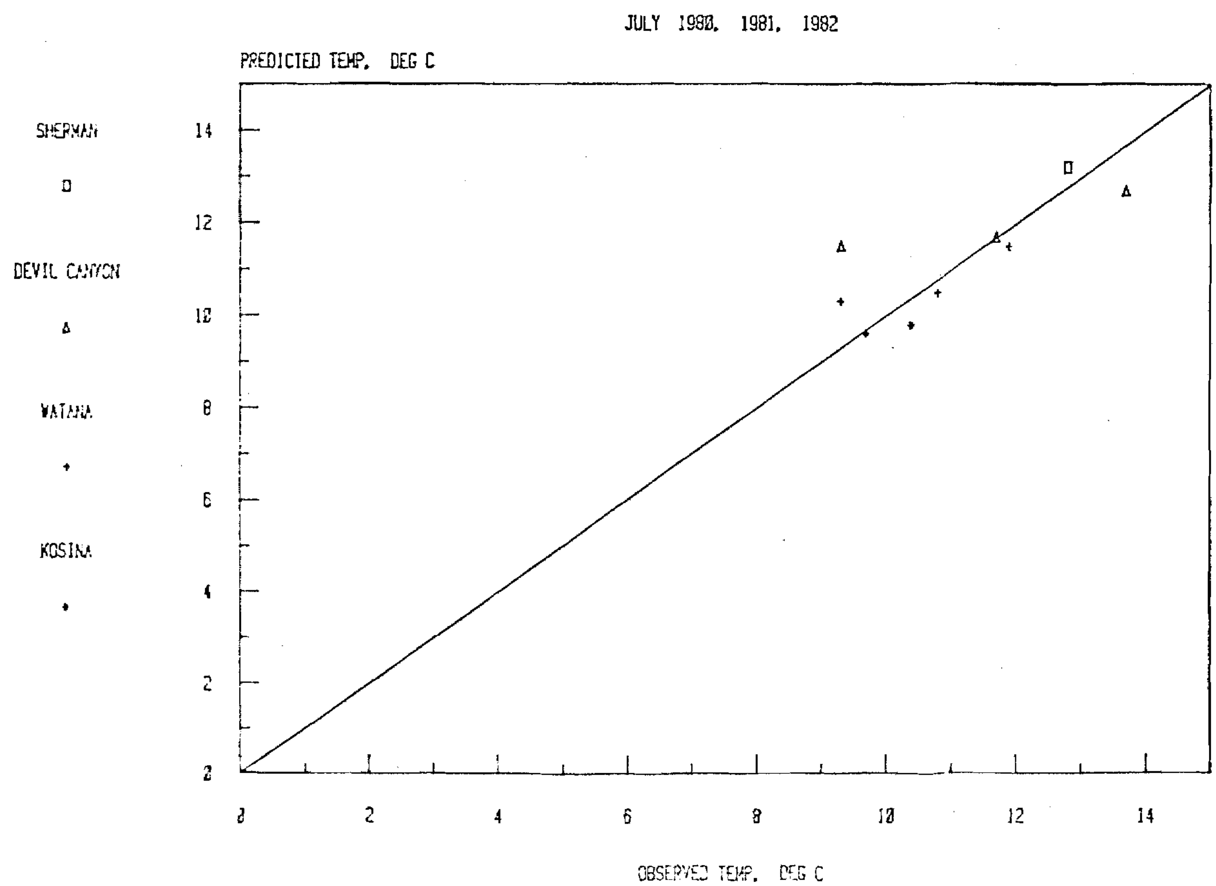
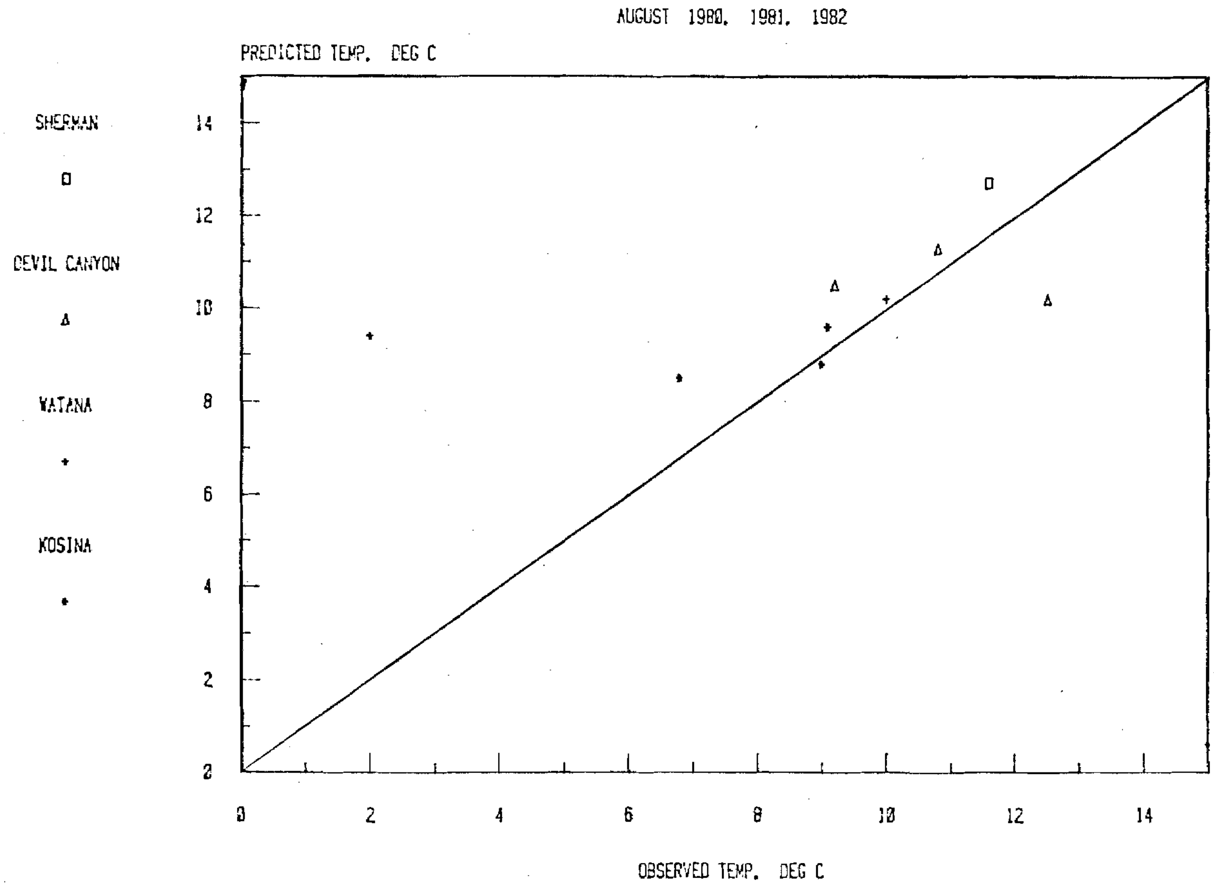


Figure 19 (Continued). Observed vs. predicted air temperatures.



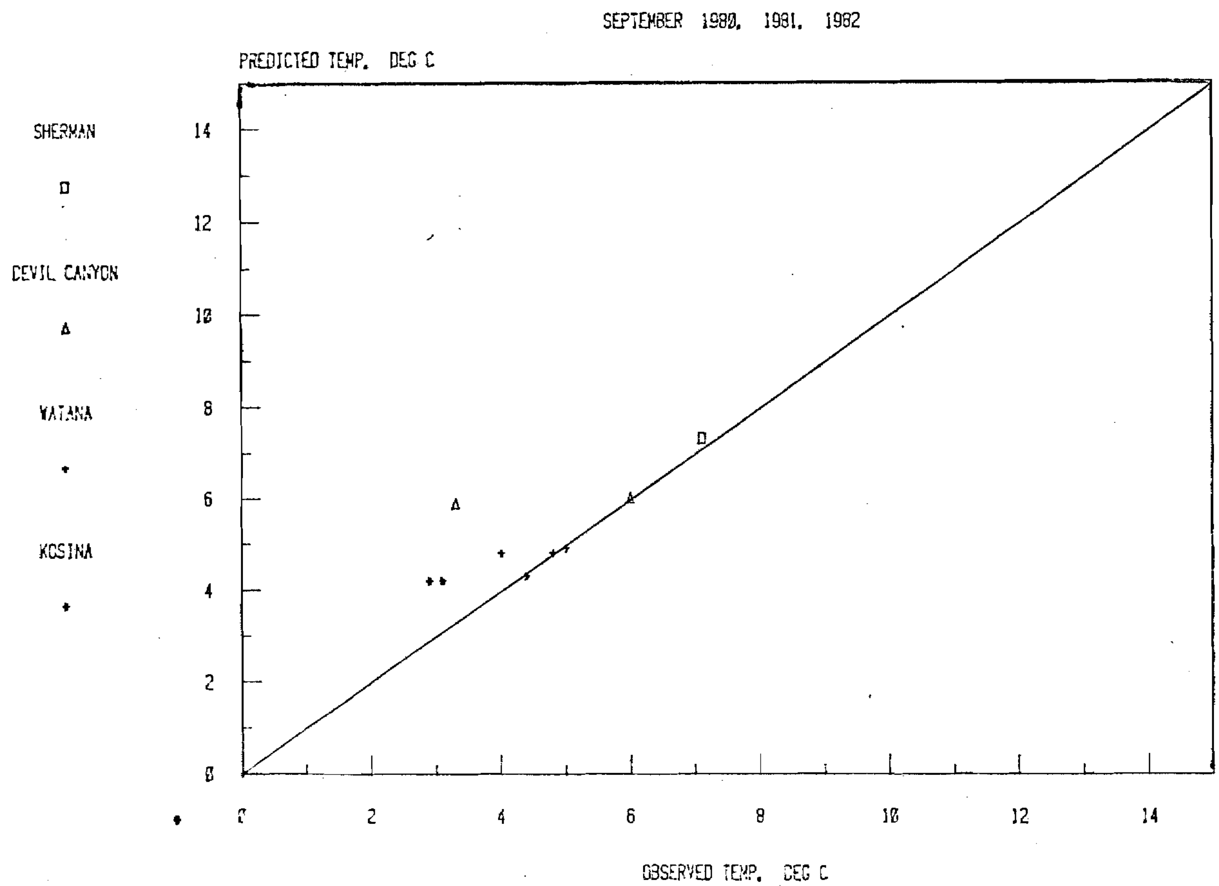
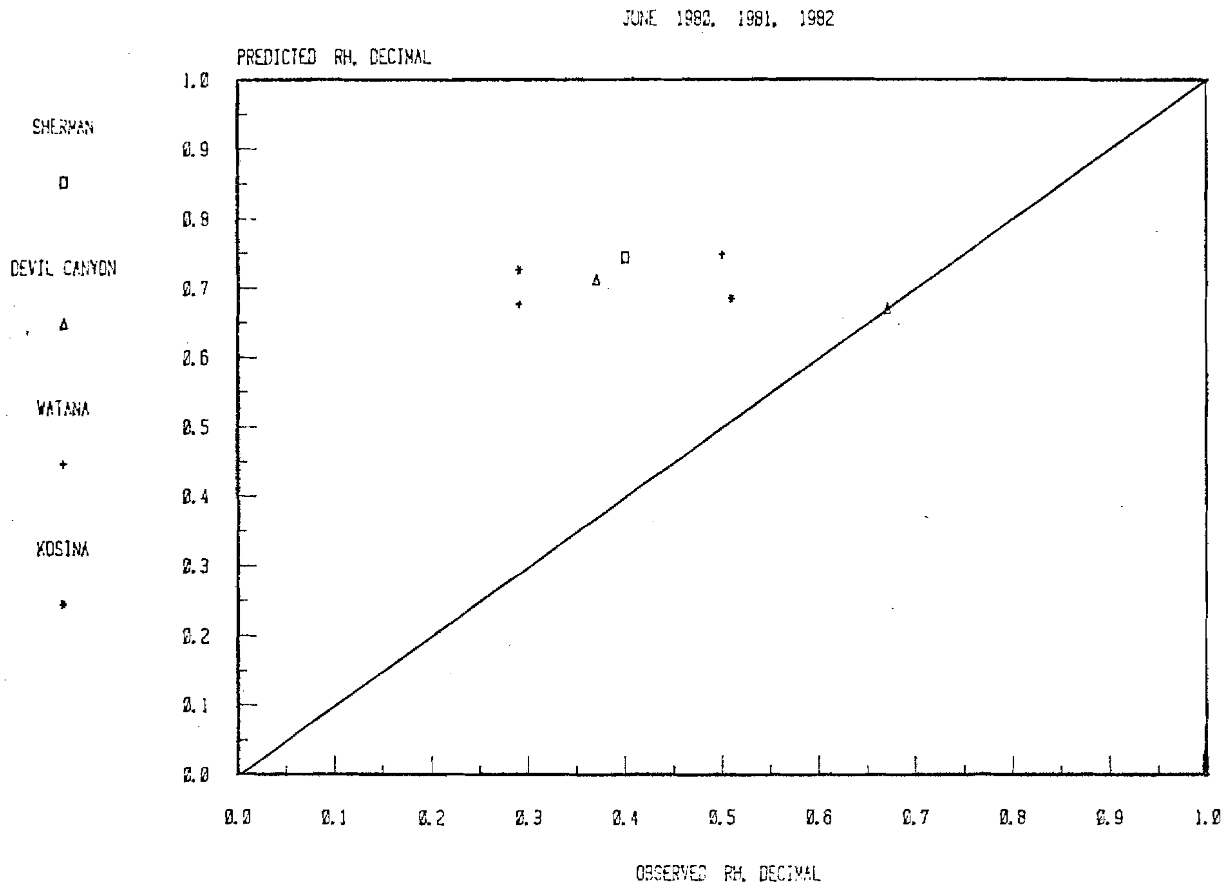


Figure 20. Observed vs. predicted relative humidities.



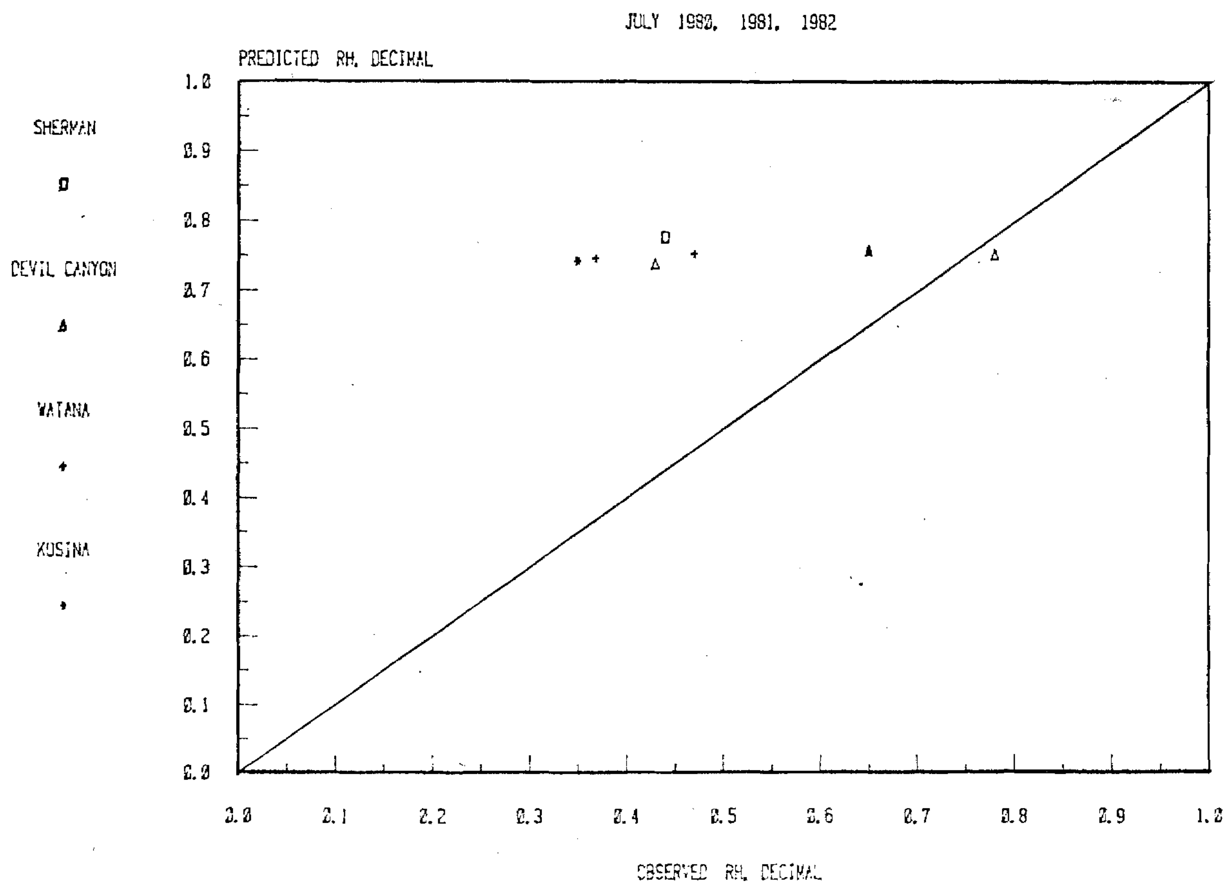
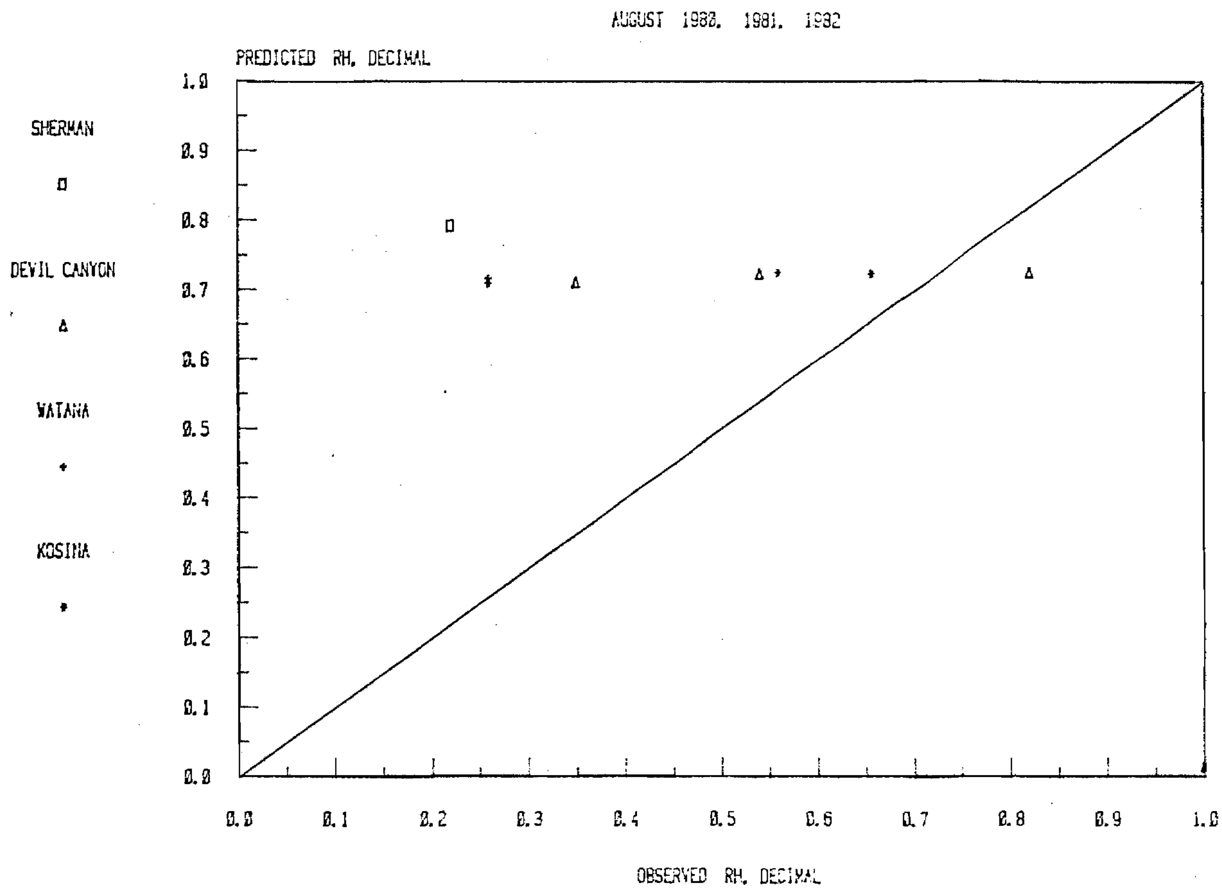


Figure 20 (Continued). Observed vs. predicted relative humidities.



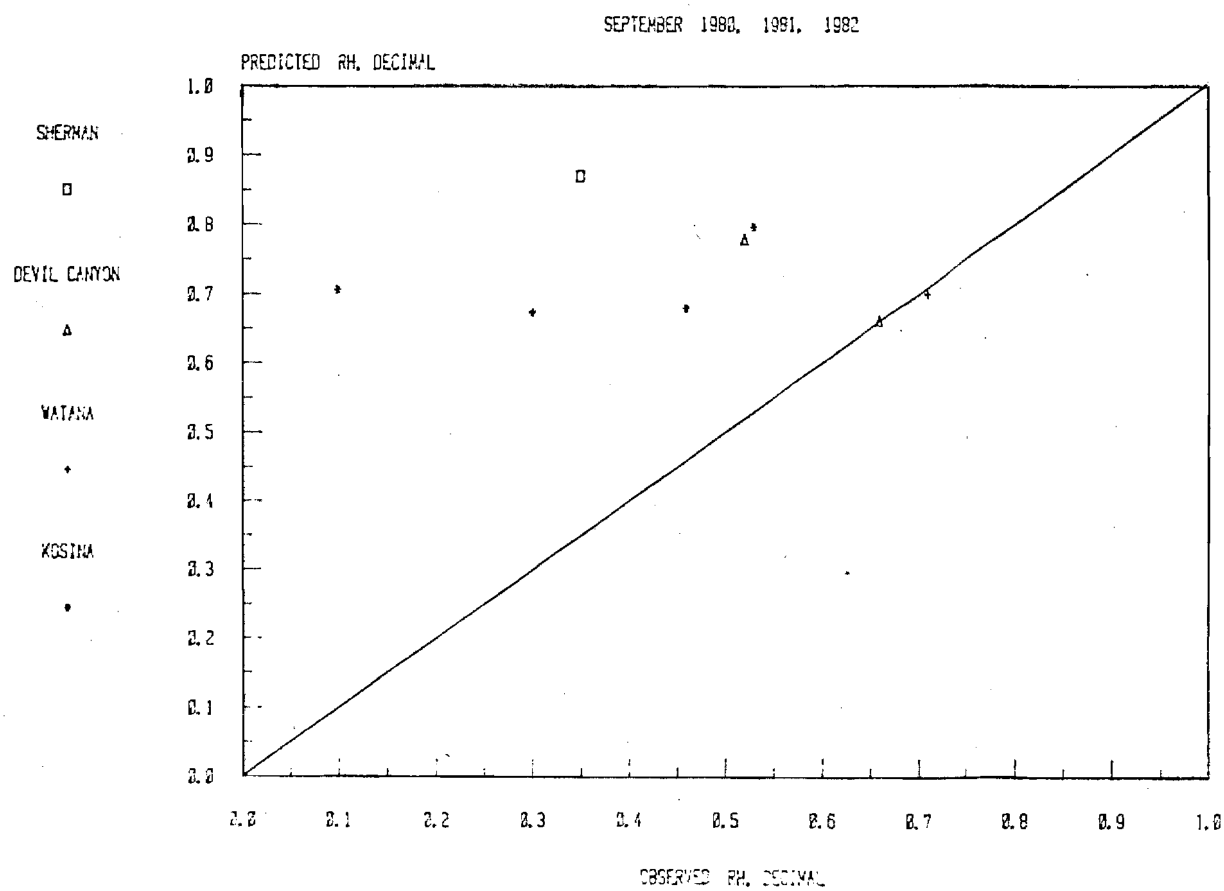


Figure 21. Average monthly wind speeds (M/S), 1980, 1981, 1982.

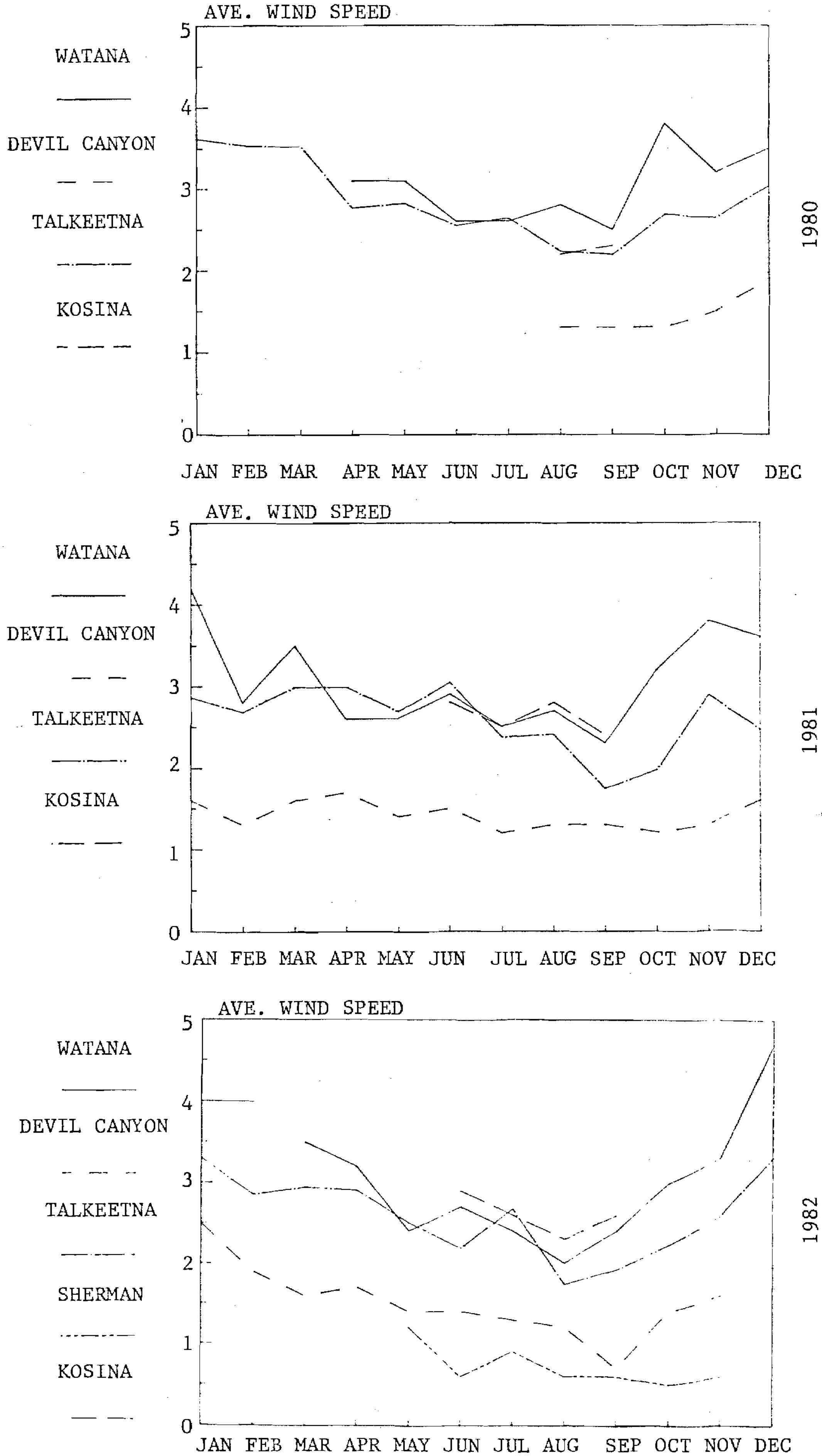


Figure 22 compares observed solar radiations to predicted solar radiation. The simulated data are a reasonable approximation of the field measurements.

VALIDATION

The purpose of model validation is to locate systematic prediction errors. Systematic errors result when observed or assumed data for a particular study do not represent actual conditions. Since the stream temperature model has been verified with previous applications (Theurer and Voos 1982; Theurer et al. 1983) and, since some adjustments have been made to SNTEMP to account for conditions particular to the Susitna application, it is assumed that any remaining systematic errors are the result of nonrepresentative input data.

An initial validation run of the Susitna-modified SNTEMP demonstrated a tendency to underpredict the upper tributary temperatures (Figure 23). Since most of the data defining these tributaries are assumed or estimated values, much uncertainty exists in the definition of each tributary. Several poorly defined variables which might be adjusted to improve model predictions are 1) stream flow, 2) initial stream temperature, 3) stream length, 4) stream width, and 5) distributed flow temperatures. An effort has been made to adjust other variables to better represent prevailing conditions (e.g., air temperature, relative humidity, and topographic shading).

Of the five poorly defined variables, most improvement could be gained from focusing on temperatures of distributed flows. This determination was based on the following logic.

1. Without the benefit of continuous tributary flow gaging, present stream flow estimates cannot be substantially enhanced.
2. With the subsequent necessary assumption of zero flow at the tributary headwaters, initial tributary temperatures have no influence on the predictions.
3. Tributary lengths were measured from maps.
4. Stream widths are based on field estimates and initial tests with SNTEMP demonstrated that this variable was not sensitive enough to remove the existing predictive bias.

Figure 22. Predicted vs. observed solar predictions, 1980, 1981, 1982.

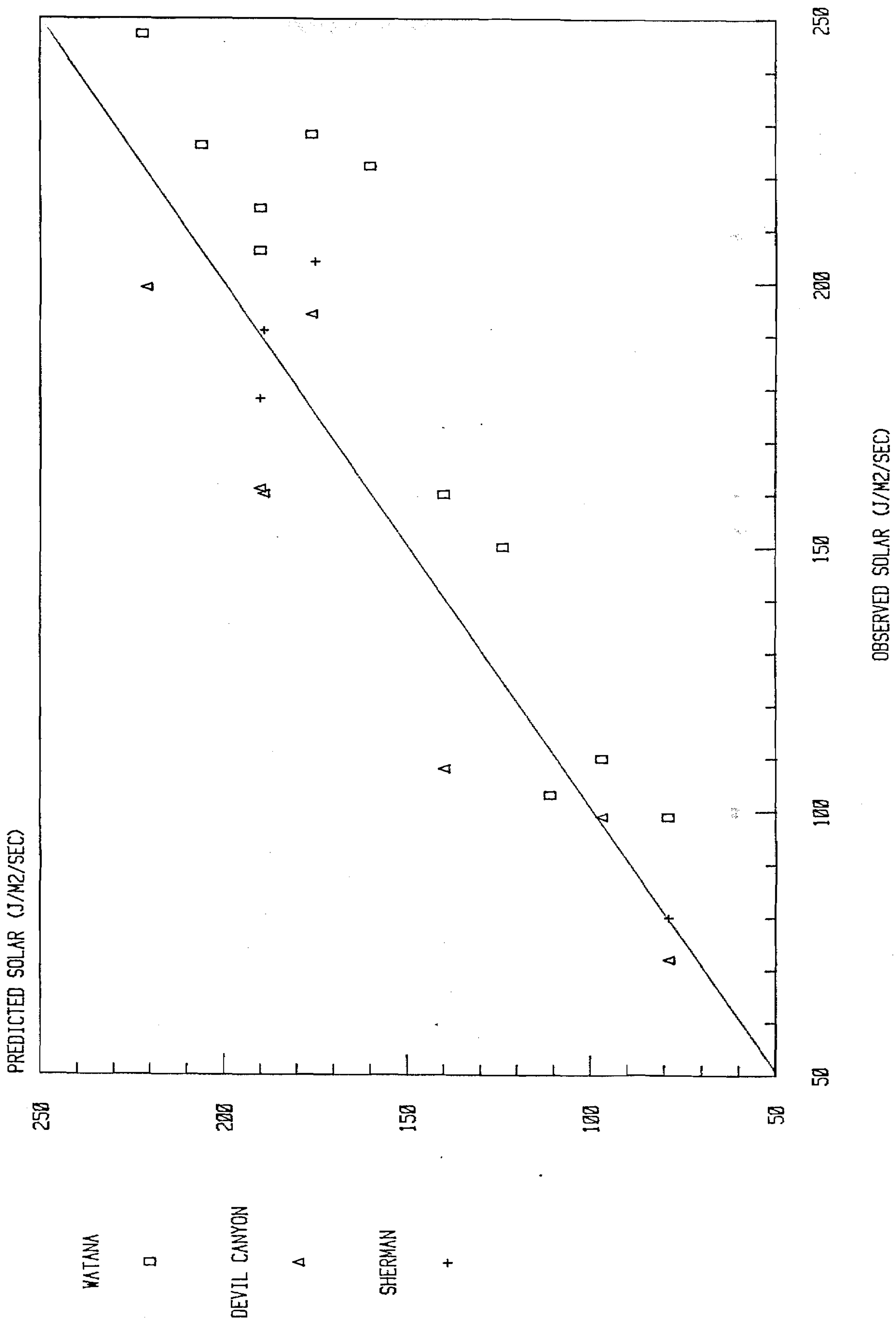
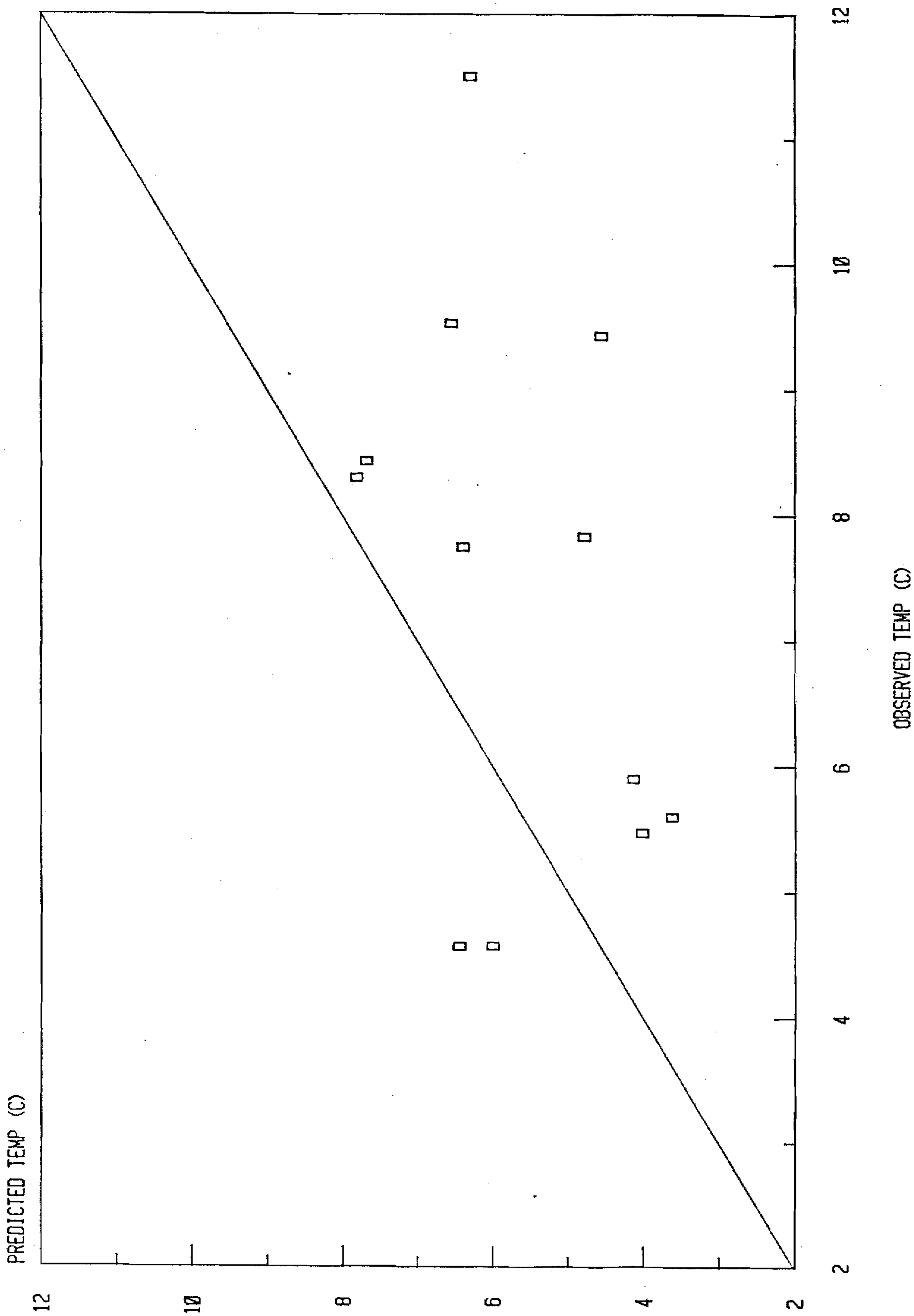


Figure 23. Tributary temperatures; 3 C groundwater inflow assumed.



Rather than arbitrarily modifying the constant 3 C estimate of groundwater temperature, the groundwater temperature model previously described was employed to generate physical process-based temperature estimates. This model introduced three variables which must be estimated--the average annual air/ground temperature offset (T_{off}), thermal diffusivity (α), and depth of inflow (x). AEIDC is currently seeking techniques and data for estimating values of these variables. Until solid estimates can be obtained, these variables will be adjusted to calibrate to observed water temperature data.

CALIBRATION

Tributary temperature predictions were improved by adjusting the three groundwater temperature parameters (Figure 24). The resulting values were: T_{off} = 1.0 C and α = 0.01 cm^2/sec for the entire basin, Z = 0.4 m for Kosina Creek, Z = 0.7 m for Watana Creek, and Z = 2.0 m for the mainstem and remaining tributaries. Further analysis is necessary to validate these values.

The goodness of fit was determined by using the following statistics:

$$\Delta = \Sigma(\hat{T}_i - T_i)/n \quad (15)$$

$$S_\Delta = \sqrt{\Sigma(\hat{T}_i - T_i)^2/[n(n-1)]} \quad (16)$$

where:

Δ = mean difference, C

T_i = i^{th} published temperature, C

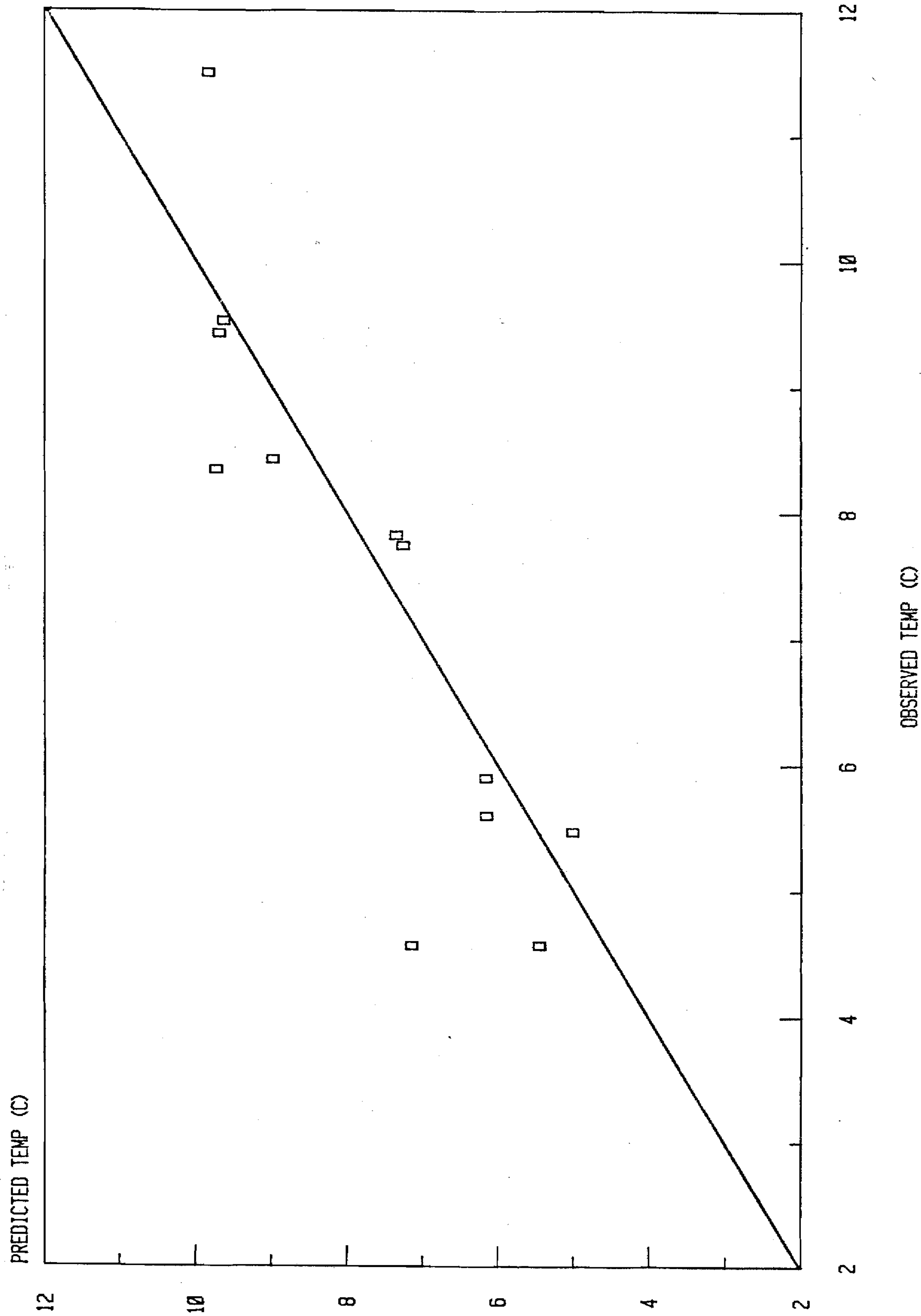
$\hat{T}_i$ = i^{th} temperature predicted by SNTEMP, C

n = number of observed temperatures

S_Δ = standard error estimate, C

These statistics can be combined with Student's t values to define confidence intervals. For example, 90 percent of the predicted values fall within $\Delta \pm t_{0.1} S_\Delta$ of the observed values. Postcalibration statistics

Figure 24. Tributary temperatures; postcalibration, including distributed flow temperature model.



for the tributaries indicate that predicted values are on the average 0.28 C (Δ) higher than the published values, and 90 percent of the predicted values can be expected to fall between 0.85 above and 0.29 C below the published water temperature (S_Δ = 0.32 C, n = 12). The model fit could be improved with additional adjustment of T_{off}, Z, and α. However, it was decided that additional calibration be postponed until research is completed to define reasonable physical limits of these parameters.

Once the tributary predictions had been improved, the entire mainstem/tributary system essentially was calibrated, and no additional parameter adjustments were attempted. Statistics for the mainstem are Δ = -0.05 C, S_Δ = 0.17 C, n = 28. Figure 25 presents these statistics as computed for each month.

Figure 25. Temperature model calibration statistics for tributary predictions.

	n	Δ (C)	S_Δ (C)
June 1981	2	-2.08	0.98
July 1981	1	0.41	-
August 1981	6	0.59	0.17
September 1981	6	-0.002	0.30
June 1982	2	0.08	0.31
July 1982	3	-0.89	0.16
August 1982	4	0.19	0.40
September 1982	4	0.14	0.10
Average	28	-0.05	0.17

The statistics for June 1981 indicate a poor fit. This is understandable since the three required initial water temperatures

(Cantwell, Chulitna, and Talkeetna) were synthesized with linear regression models. This is the only month which had all three initial temperatures synthesized. A more reasonable estimate of the simulation performance for the mainstem is obtained by eliminating this month from the computations: $\Delta = 0.10$ C, $S_{\Delta} = 0.13$ C, n = 26. The corresponding 90 percent confidence interval is 0.10 ± 0.22 C. Appendix C provides longitudinal temperature predictions for the 1981 and 1982, June through September periods.

RESULTS AND DISCUSSION

The Susitna River temperature model has been validated and calibrated for the months of June through September 1981 and 1982. We estimate that mainstem temperature predictions will be within 0.32 to -0.11 C of actual values, and upper tributary temperature predictions will be within 0.85 to -0.29 C of actual values (90 percent confidence intervals). This estimate assumes that the statistics computed from simulations using two years of historical data will apply to project conditions and there is no way of knowing if this assumption is valid. Nevertheless, these statistics are a measure of the model's performance given the best possible conditions and the available input data. Tributary and mainstem temperature data from the 1983 field season are expected to improve estimates of the model's accuracy and precision.

Additional analysis of distributed flow and temperature regimes and tributary flow regimes will be required if the model's predictive capabilities are to be improved, especially with respect to the upper basin tributaries. We used a ground temperature model to estimate the temperature of distributed flow. This model has not been validated with data from within the Susitna Basin. If the parameter values defining the model can be measured, or at least assigned physically relevant constraints, the model can be applied with confidence to simulations of the proposed project.

FUTURE APPLICATIONS AND ENHANCEMENTS

AEIDC will continue the Susitna flow and stream temperature analysis by the following steps.

1. Normal and extreme flow regimes within the basin will be defined by statistical analysis of the pre- and postproject 32-year flow records.
2. Using statistical analysis, AEIDC will determine the location where postproject flows are significantly different from natural flows. This will identify the area facing possible hydrologic/hydraulic impacts.
3. Combinations of hydrology and meteorology which produce normal and extreme stream temperature changes will be determined from simulations using recorded meteorologic and hydrologic data.
4. Ranges of expected flows and temperatures resulting from the filling and operational phases of the project will be used as input to the temperature model for simulating downstream effects. These simulations will use normal and extreme basin hydrology and meteorology.
5. Results of these simulations will be analyzed and a zone of predictable impacts identified. This zone will be partially defined by estimates of the model's performance statistics.
6. Weekly prediction capabilities will be pursued if the need is indicated by analysis of the monthly simulations.
7. Results of the 1983 field season will be incorporated into the model and new model performance statistics calculated.
8. Techniques will be developed for improving the groundwater temperature model.
9. Fall and winter conditions will be used for water temperature simulations to provide estimates of the most upstream limit of ice cover. If the stream temperature model reliably predicts the recorded limits, the model will be applied to proposed project conditions. Ice observations by R&M will be used for validation of these simulations.

BIBLIOGRAPHY

Acres American, Inc. 1983a. Application for license for major project, Susitna Hydroelectric Project, before the Federal Energy Regulatory Commission. Vol. 5A. Exhibit E, Chaps. 1 and 2 (figures). Alaska Power Authority. Susitna Hydroelectric Project. 1 vol.

_____. 1983b. Slough hydrogeology report. Draft Report. Alaska Power Authority. Susitna Hydroelectric Project. 27 pp.

_____. 1982. Susitna Hydroelectric Project. Feasibility report. Vol. 4. Appendix A. Hydrologic studies. Final draft. Prepared for the Alaska Power Authority. 1 vol.

Aitken, G.W. 1964a. Ground temperature observations, Big Delta, Alaska. Cold Regions Research and Engineering lab., U.S. Army, Hanover, NH. CRREL Technical Report 104. 15 pp.

_____. 1964b. Ground temperature observations, Gulkana, Alaska. Cold Regions Research and Engineering Lab., U.S. Army, Hanover, NH. CRREL Technical Report 106. 13 pp.

Alaska Dept. of Fish & Game. 1983. Susitna hydro aquatic studies, phase 2 basic data report. Vol. 4. Aquatic habitat and instream flow studies, 1982. Preliminary draft report. Anchorage, AK. Alaska Power Authority. Susitna Hydro Aquatic Studies. Report for Acres American, Inc. 7 vols.

_____. 1981. Aquatic habitat and instream flow project. Final draft report. Anchorage, AK. Alaska Power Authority. SuHydro Aquatic Studies. Report for Acres American, Inc. 2 vols. in 3.

Alaska, University, Arctic Environmental Information and Data Center. 1983. Methodological approach to quantitative impact assessment for the proposed Susitna hydroelectric project. Alaska Power Authority. Susitna Hydro Aquatic Studies. Anchorage, AK. Report for Harza/Ebasco Susitna Joint Venture. 71 pp.

Bigelow, B.B. 1983. Letter, March 8. U.S. Geological Survey, Anchorage, AK. 7 pp.

Bredthauer, S., and B. Drage. 1982. River morphology. R & M Consultants Inc., Anchorage, AK. Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 vol.

Brett, J.R. 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the freshwater ecology of sockeye salmon (Oncorhynchus nerka). American Zoologist. 11:99-113.

Cherry, D.S., K.L. Dickson, and J. Cairns. 1975. Temperatures selected and avoided by fish at various acclimation temperatures. Journal of the Fisheries Research Board of Canada. 32:485-491.

Coffin, J. 1983. Personal communication. Telephone conversation. R&M Consultants, Inc., Anchorage, AK.

Coutant, C.C. 1970. Thermal resistance of adult coho (Oncorhynchus Kisutch) and jack chinook (O. tshawytscha) salmon, and adult steelhead trout (Salmo gairdneri) from the Columbia River. Battelle, Pacific Northwest Labs., Richland, WA. USEAC R&D Dept., BNWL-1508.

Kilday, G.D. 1974. Mean monthly and annual precipitation in Alaska. National Weather Service, U.S. National Oceanic and Atmospheric Administration, Anchorage, AK. NOAA technical memorandum. NWSAR-10. 1 vol.

McKendrick, J. 1982. Plant ecology studies. Final Report. Agricultural Experiment Station, University of Alaska, Palmer, AK. Alaska Power Authority. Susitna Hydroelectric Project. 124 pp.

Nelson, G. 1983. Personal communication. Telephone conversation. U.S. Geological Survey, Anchorage, AK.

Quane, T. 1983. Personal communication. Interview. Alaska Dept. of Fish & Game, SuHydro, Anchorage, AK.

R&M Consultants, Inc. 1982a. Field data collection and processing, Supplement 1. Task 3-Hydrology. Alaska Power Authority. Susitna Hydroelectric Project. Prepared for Acres American, Inc. 215 pp.

_____. 1982b. Field data collection and processing. Vol. 3. Task 3-Hydrology. Alaska Power Authority. Susitna Hydroelectric Project. Prepared for Acres American, Inc. 1 vol.

_____. 1982c. Field data index. Anchorage, AK. Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 vol.

_____. 1982d. Hydraulic and ice studies. Anchorage, AK. Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 vol.

_____. 1982e. Processed climatic data. Vol. 6. Devil Canyon Station. Anchorage, AK. Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 vol.

_____. 1982f. Processed climatic data. Vol. 5. Watana Station. Anchorage, AK. Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 vol.

_____. 1981. Susitna River mile index: Mouth to Susitna Glacier. Attachment D to Hydrographic Surveys. Anchorage, AK. Alaska Power

Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 vol.

R&M Consultants, Inc. 1980. Field data index. Anchorage, AK. Alaska Power Authority. Susitna Hydroelectric Project. Report for Acres American, Inc. 1 vol.

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of salmonids. No. 1. in U.S. Forest Service. Influence of forest and rangeland management on anadromous fish habitat in western North America. Anadromous Fish Habitat Program. General Technical Report PNW-96. 54 pp.

Sauntner, J. 1983. Personal communication. Interview. Alaska Dept. of Fish & Game, SuHydro, Anchorage, AK.

Schoch, C. 1983. Personal communication. Telephone conversation. R&M Consultants, Inc., Anchorage, AK.

Siefert, R.D. 1981. A solar design manual for Alaska. Institute of Water Resources, University of Alaska, Fairbanks, AK. Bulletin No. 6. 163 pp.

Theurer, F., and K. Voos. 1982. An instream water temperature model of the upper Colorado River basin. Unpublished. Paper for presentation at the International Symposium on Hydrometeorology, Denver, CO. 6 pp.

Theurer, F., K. Voos, and W. Miller. 1983. Instream water temperature model. Draft report. Instream Flow and Aquatic Systems Group, U.S. Fish and Wildlife Service, Fort Collins, CO. Instream Flow Information Paper No. 16. 263 pp.

Trihey, E.W. 1983. Personal communication. Interview. Private consultant, Anchorage, AK.

U.S. Geological Survey. 1981. Water resources data for Alaska. Anchorage, AK. Water-Data Report AK-81-1. 395 pp.

______. 1980. Water resources data for Alaska. Anchorage, AK. Water-Data Report AK-80-1. 373 pp.

U.S. National Weather Service. 1980. Climatological data national summary, Vol. 30, No. 9. Washington, DC.

______. 1970. Climatological data national summary, Vol. 20, No. 8. Washington, DC.

______. 1969. Climatological data national summary, Vol. 19, No. 7. Washington, DC.

______. 1968. Climatological data national summary, Vol. 18, No. 6. Washington, DC.

U.S. Soil Conservation Service. 1982. Precipitation and water yield. Alaska Rivers Cooperative Study, Susitna River Basin, Matanuska-Susitna Borough, Alaska. 4 pp.

Williams, G.P., and L.W. Gold. 1976. Ground temperatures. CBD180 in National Research Council Canada. Canadian Building Digests 151-200. Ottawa, Canada, 1979.

Wise, J.L. 1983. Personal communication. Interview. Arctic Environmental Information and Data Center, University of Alaska, Anchorage, AK.

_____. 1979. Alaska solar radiation analysis. Arctic Environmental Information and Data Center, University of Alaska, Anchorage, AK. 27 pp.

_____. 1977. Mean annual precipitation in inches. Arctic Environmental Information and Data Center, University of Alaska, Anchorage, AK. 1 map (scale 1:2,500,000).

World Meteorological Organization. 1982. Monthly climatic data for the world, Vol. 35, No. 1. National Climatic Center, Asheville, NC.

_____. 1981. Monthly climatic data for the world, Vol. 34, No. 1. National Climatic Center, Asheville, NC.

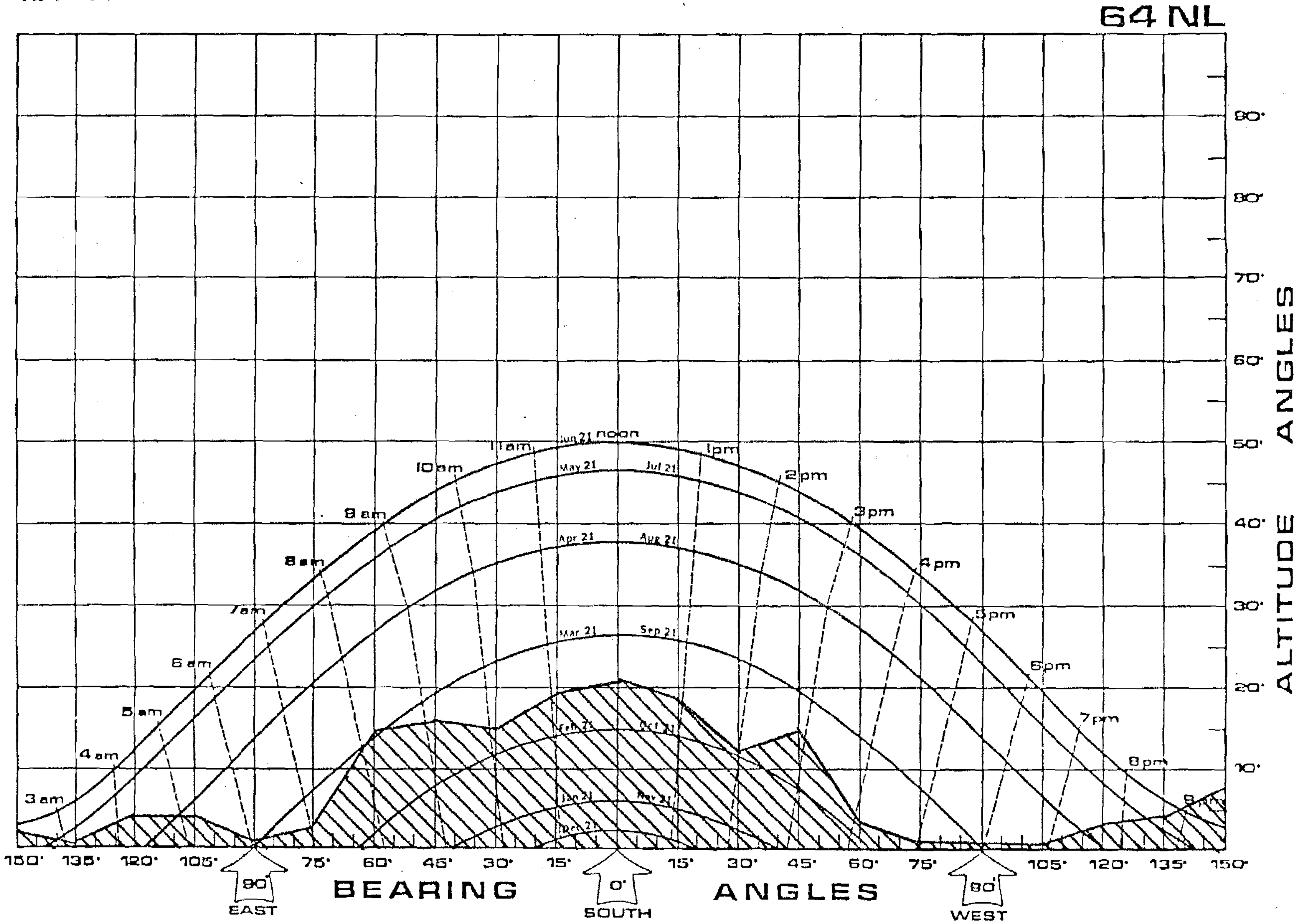
APPENDIX A

TOPOGRAPHIC SHADING

TOPOGRAPHIC SHADING

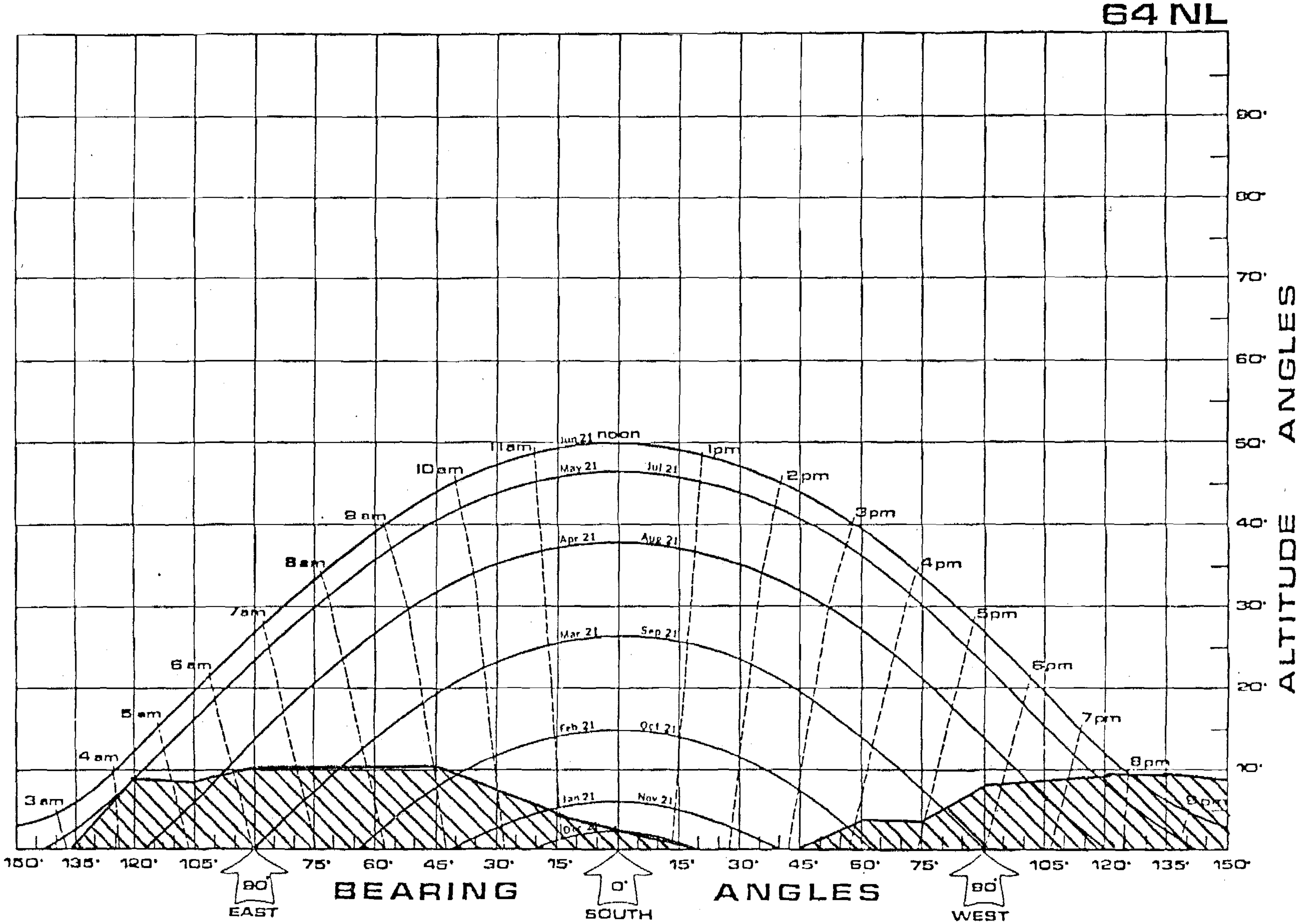
These plots present the solar shading characteristics of the Susitna reaches (refer to Figure 10). Mainstem reaches 9 and 10 and the Talkeetna and Trapper tributaries were estimated to be unshaded for all months. Fog Creek was assigned the same shading characteristics as reach 1. The synthetic tributary (Cheechin) was assigned the same characteristics as reach 4. The continuous curves represent the path of the sun for each month. The hatched area represents the potential shading of the surrounding terrain.

Reach 1
RM 179.5-184.5



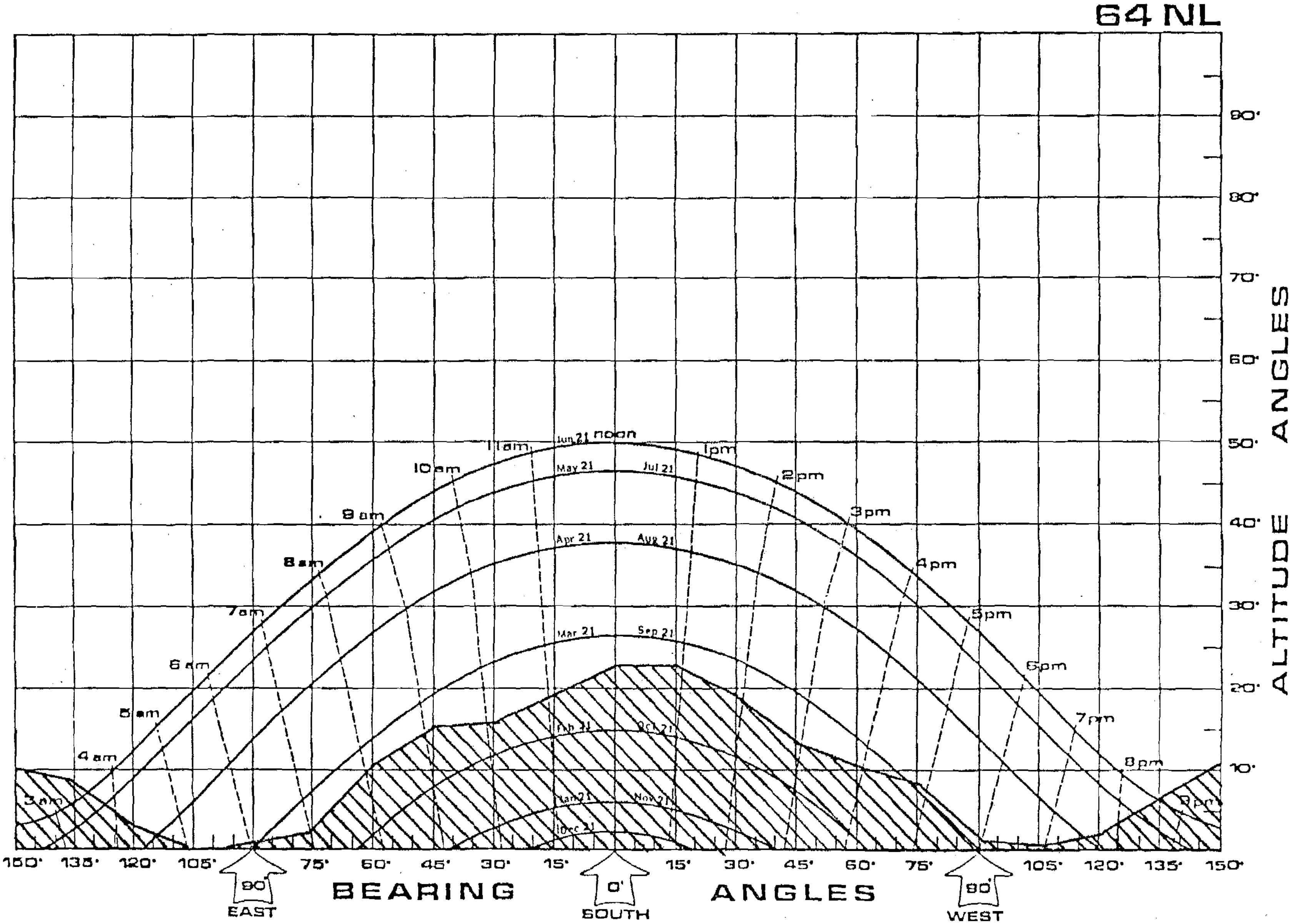
Sun path diagram for 64°N latitude.

Reach 2
RM 175.5-179.5



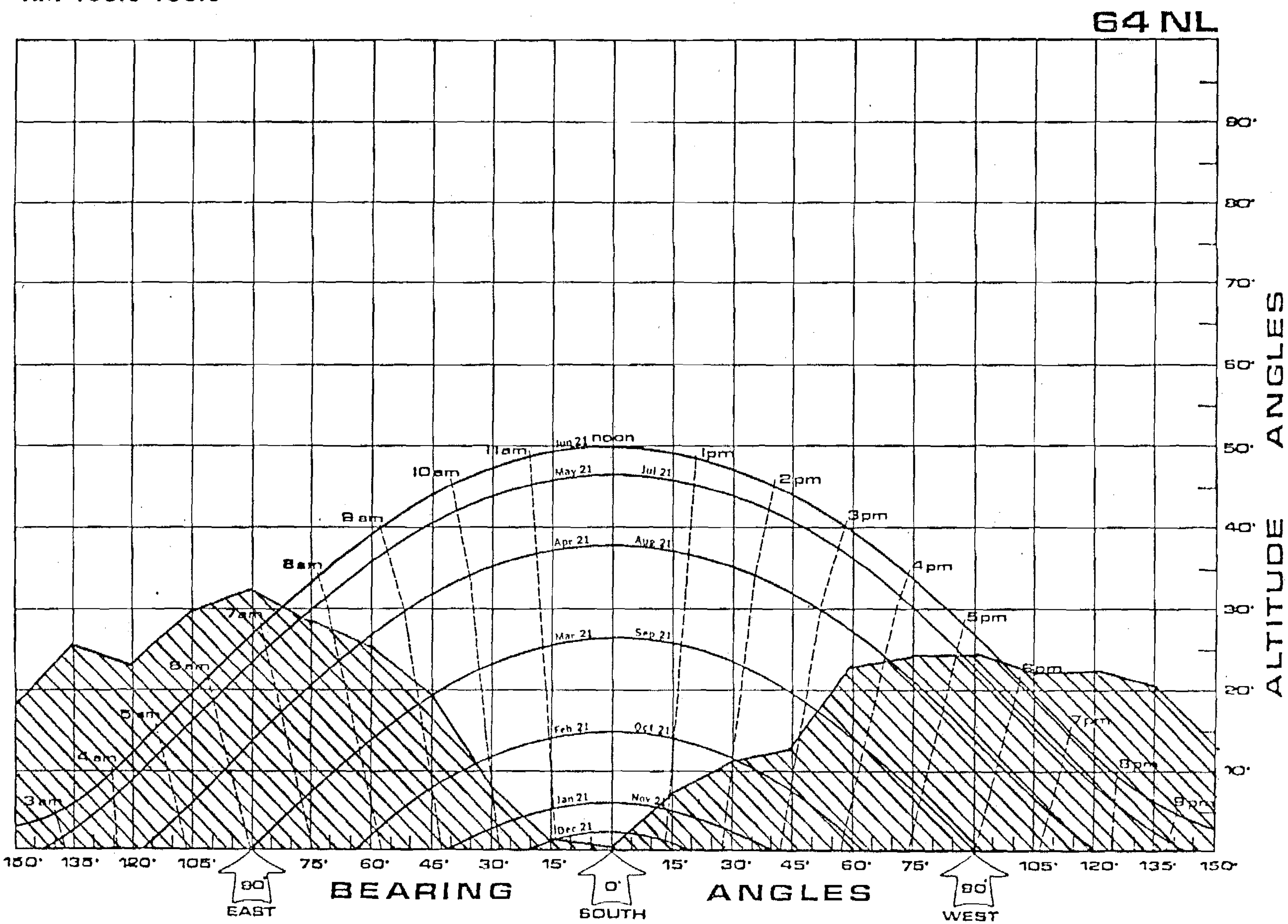
Sun path diagram for 64°N latitude.

Reach 3
RM 166.0-175.5



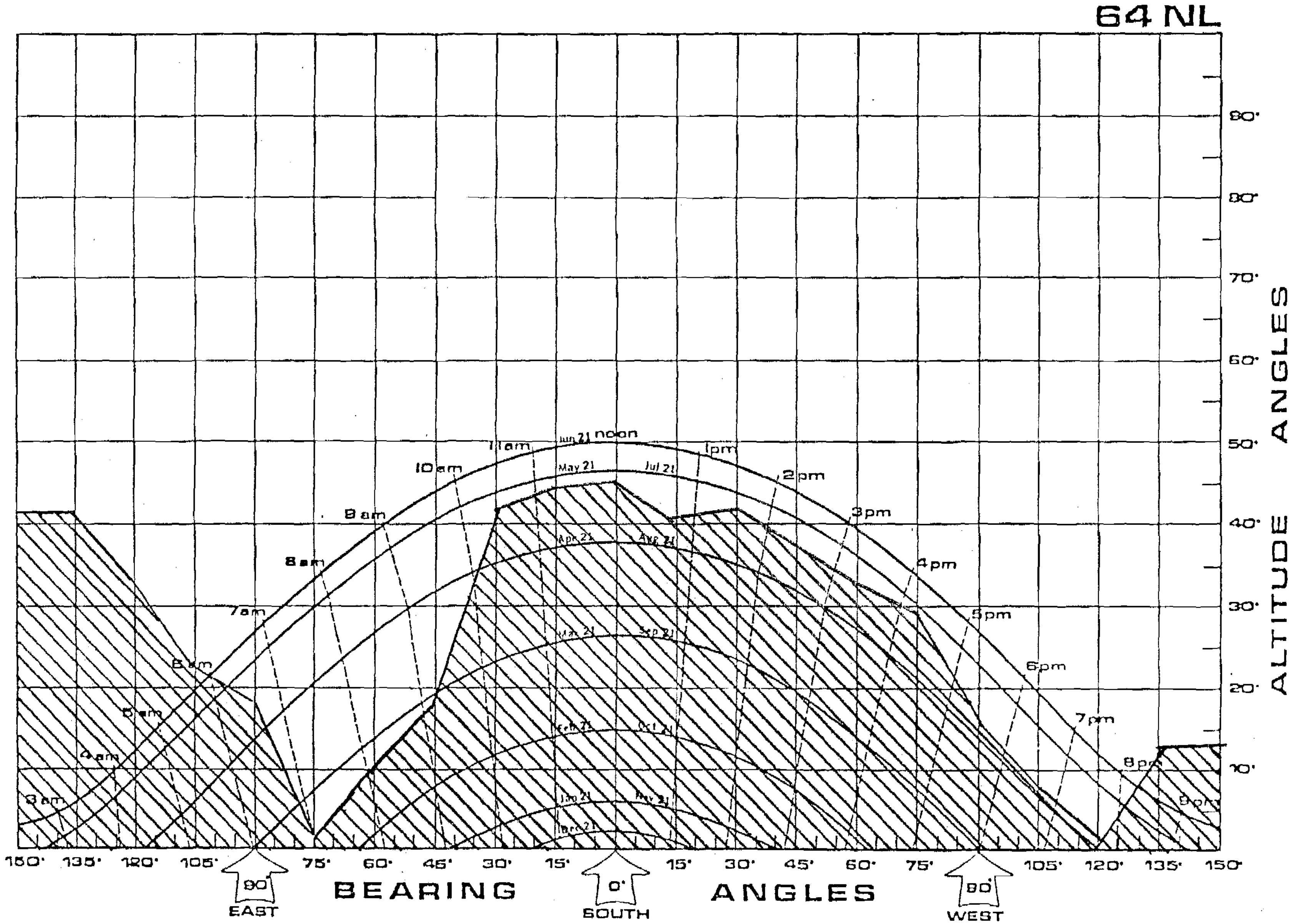
Sun path diagram for 64°N latitude.

Reach 4
RM 163.0-166.0



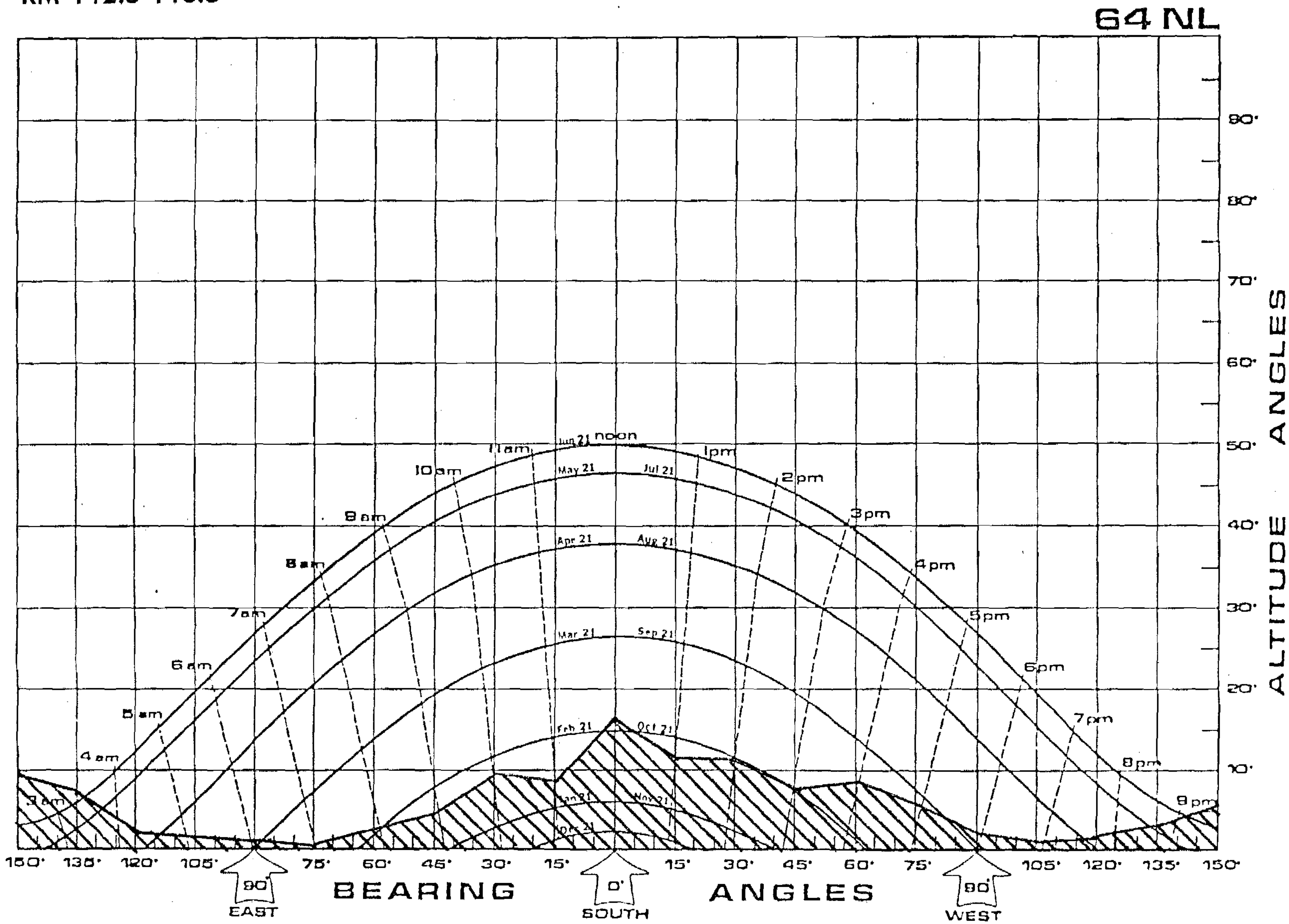
Sun path diagram for 64°N latitude.

Reach 5
RM 146.5-163.0



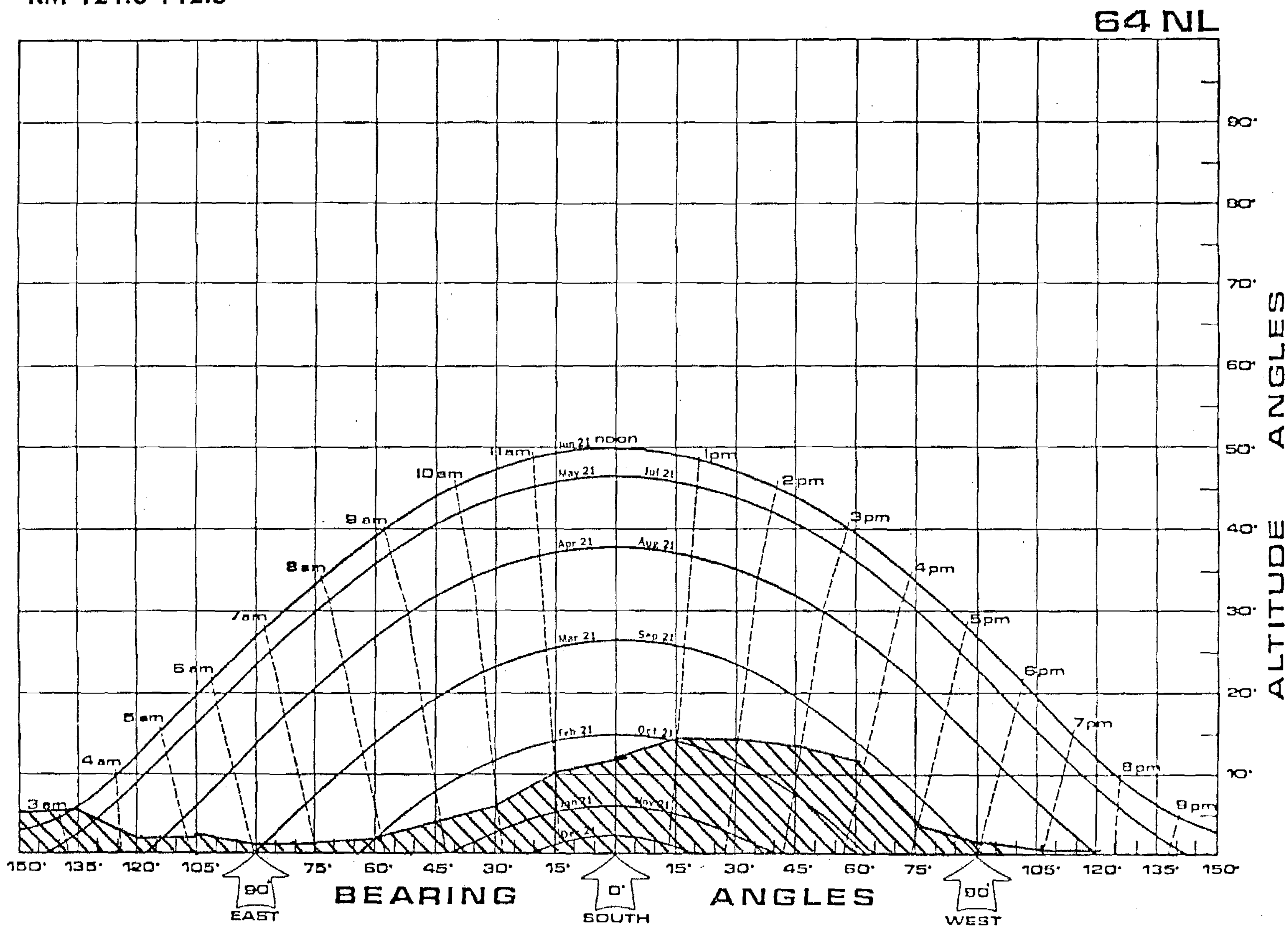
Sun path diagram for 64°N latitude.

Reach 6
RM 142.5-146.5



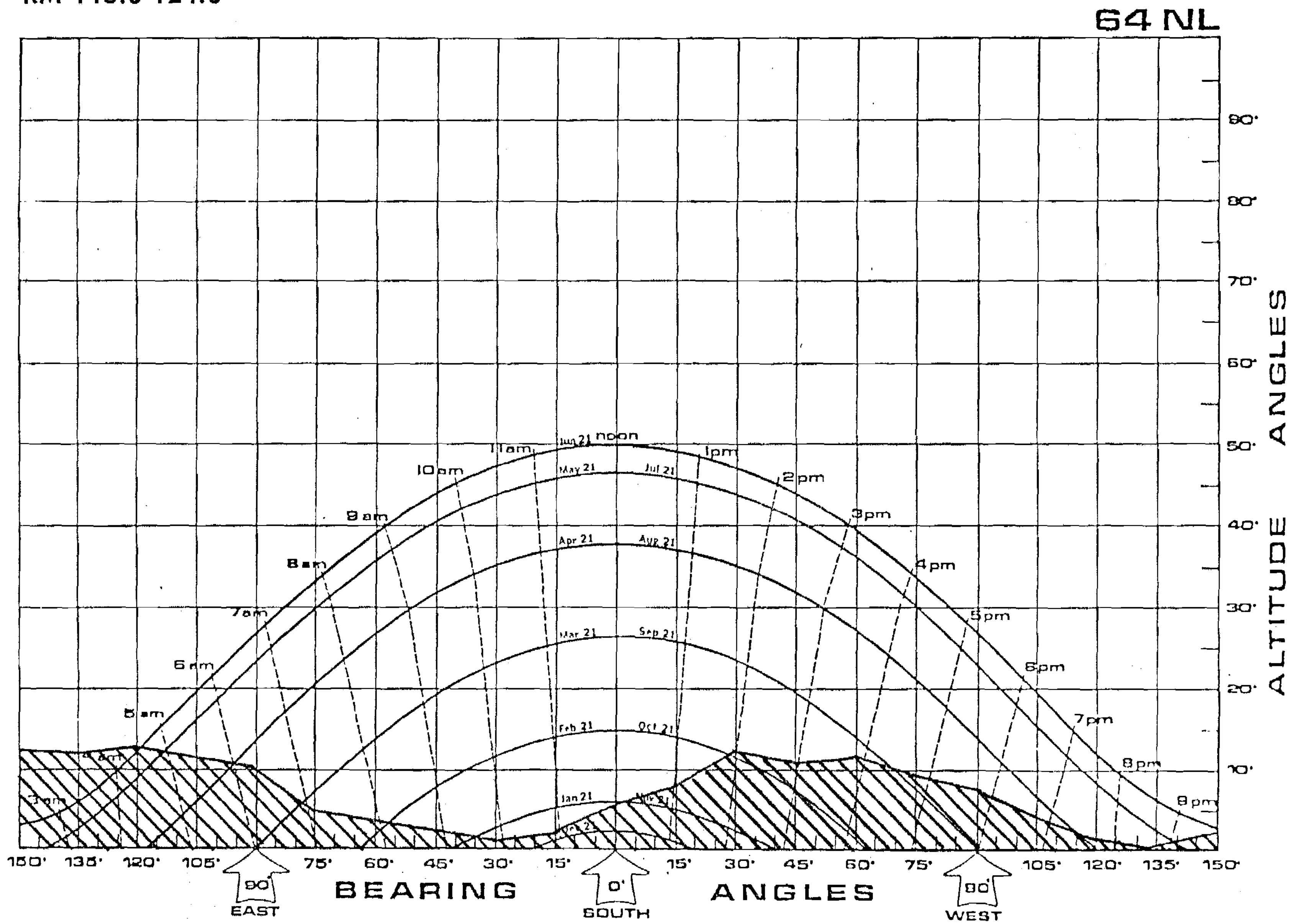
Sun path diagram for 64°N latitude.

Reach 7
RM 124.0-142.5



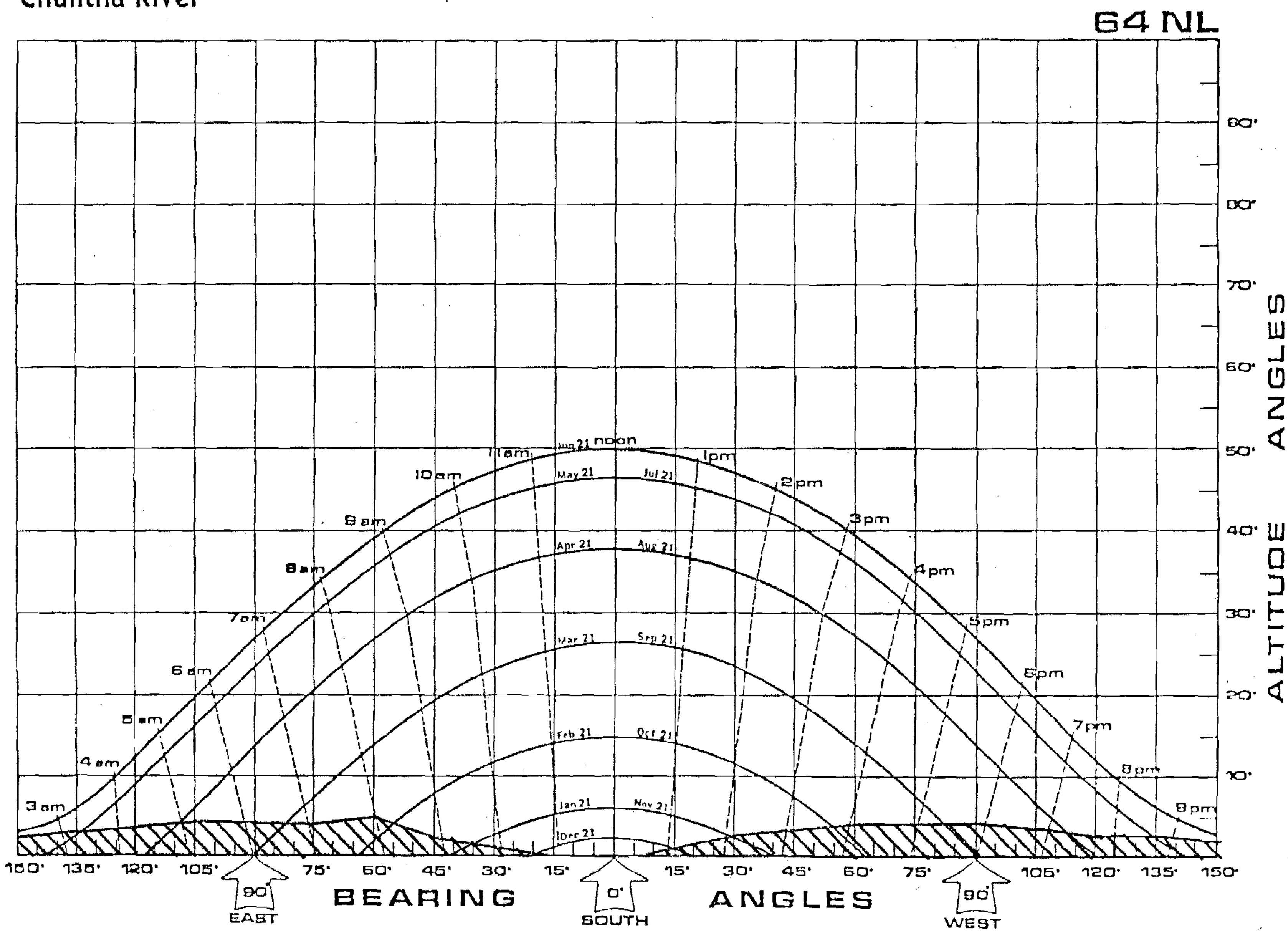
Sun path diagram for 64°N latitude.

Reach 8
RM 115.0-124.0

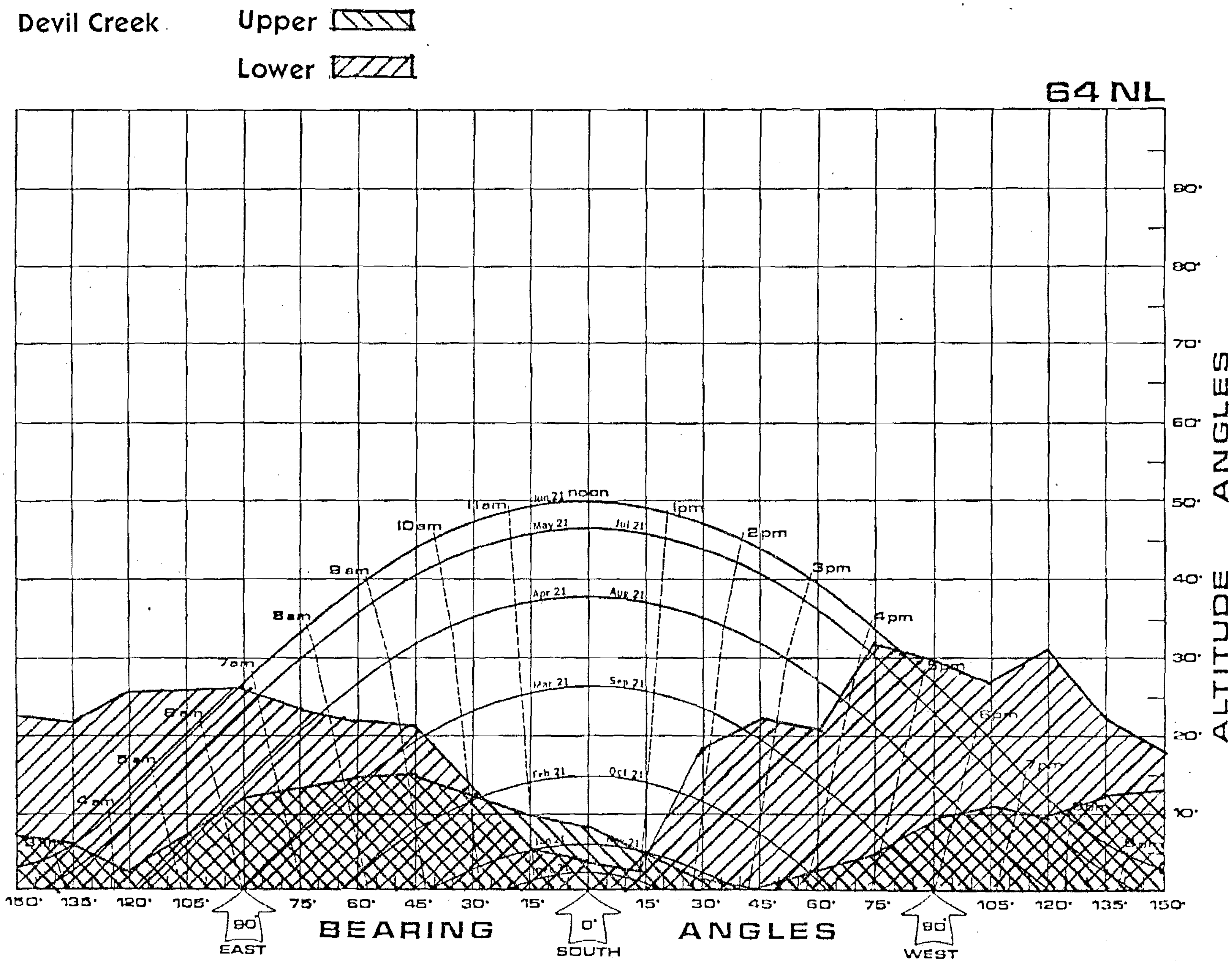


Sun path diagram for 64°N latitude.

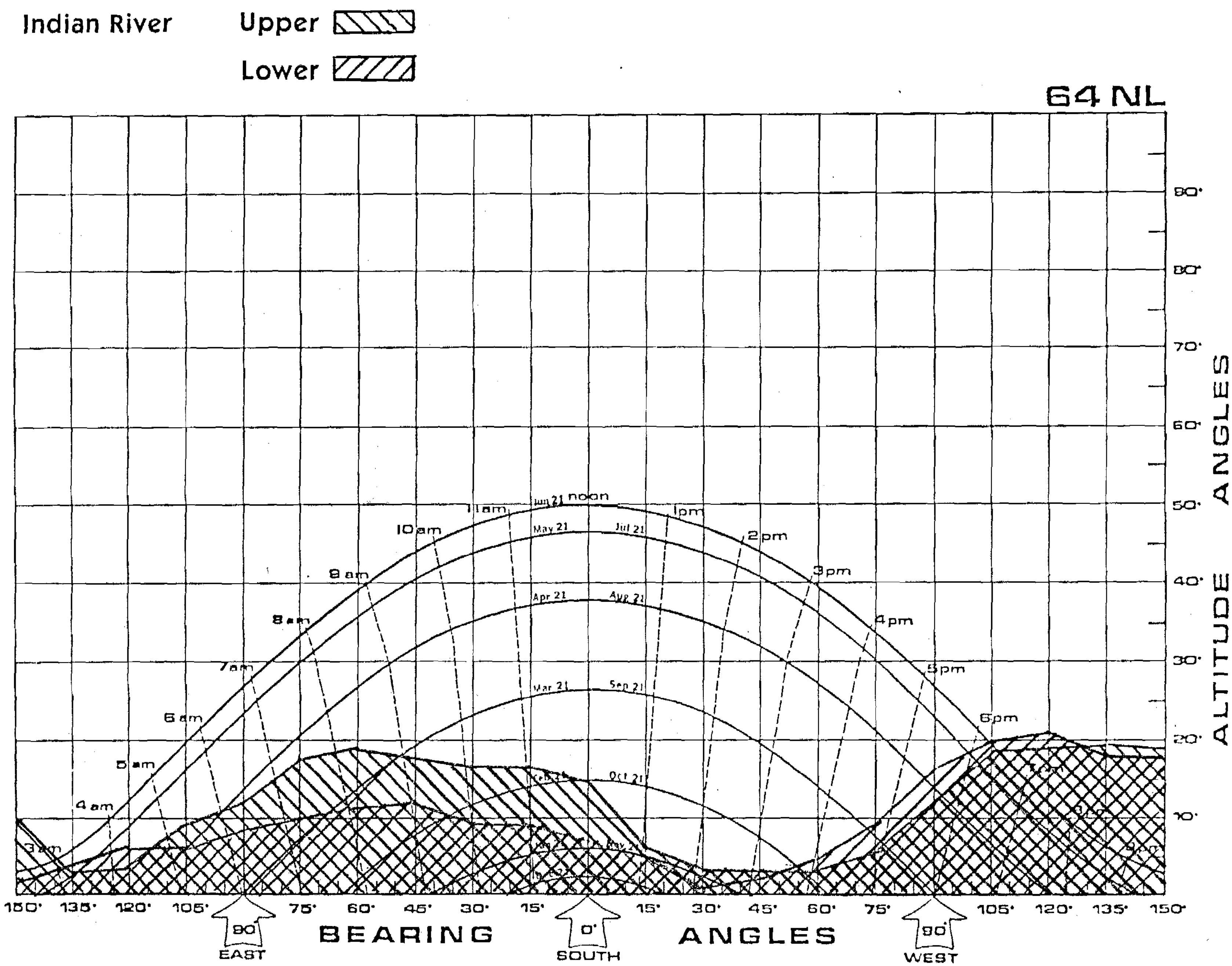
Chulitna River



Sun path diagram for 64°N latitude.

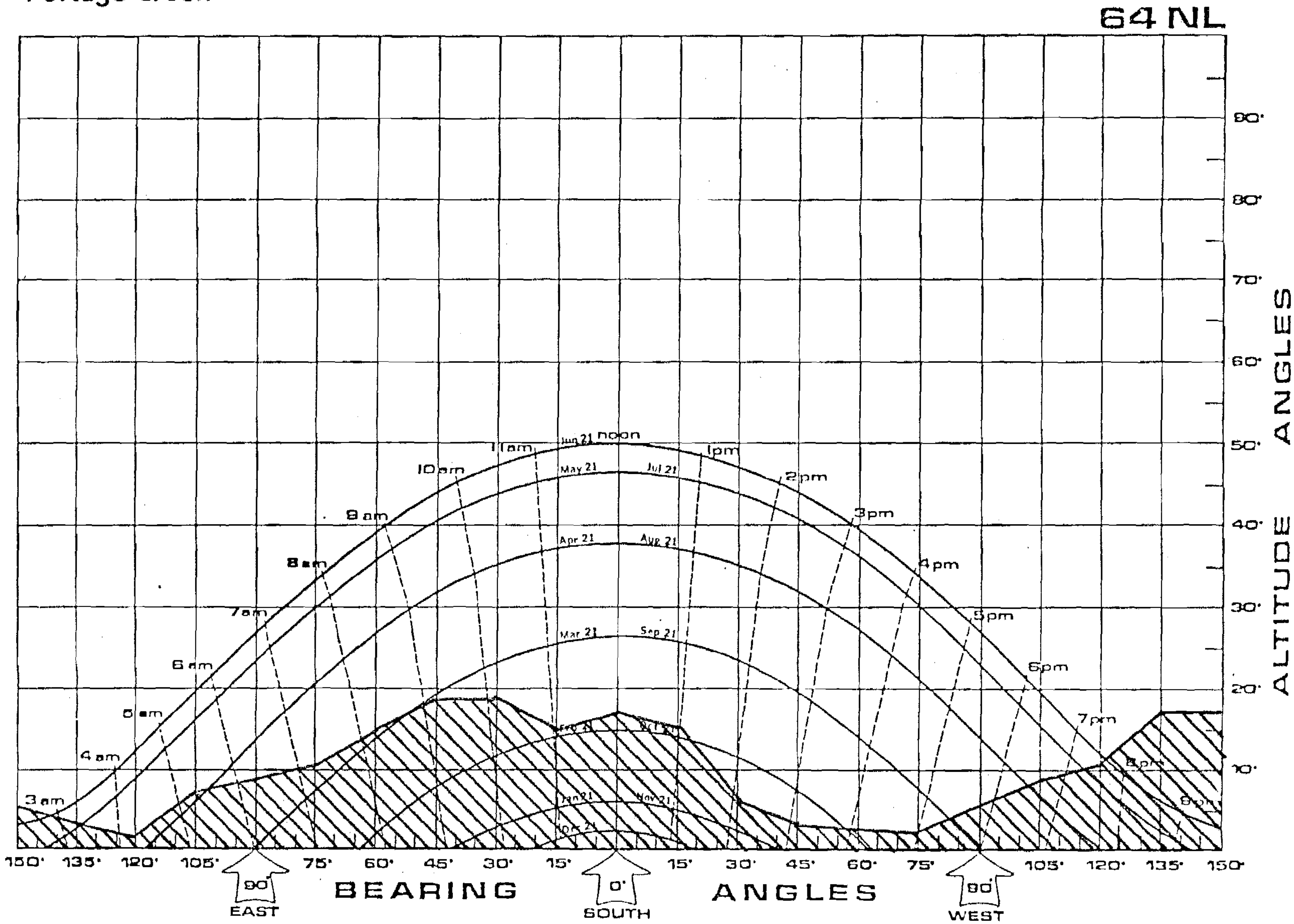


Sun path diagram for 64°N latitude.



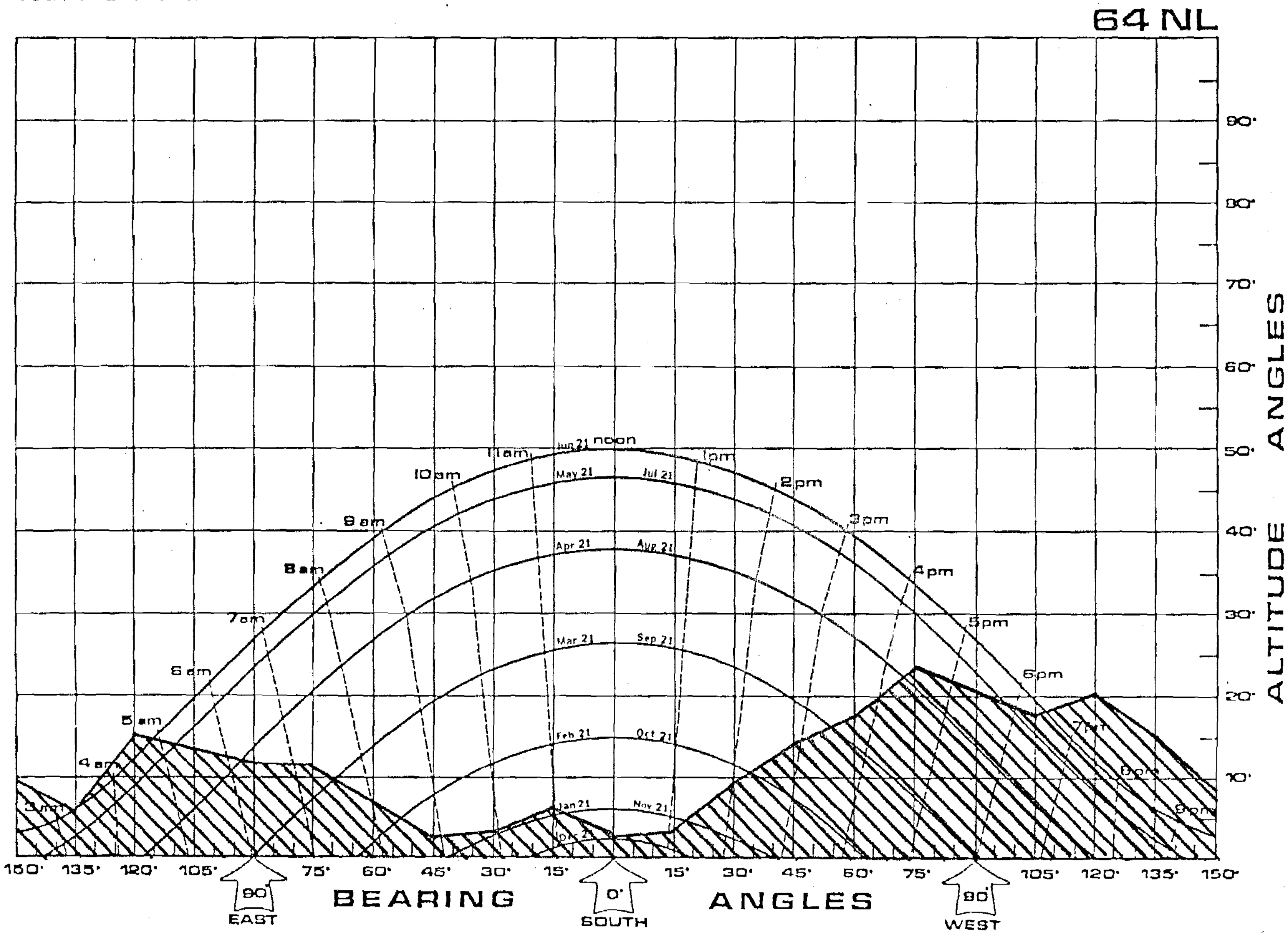
Sun path diagram for 64°N latitude.

Portage Creek



Sun path diagram for 64°N latitude.

Tsusena Creek



Sun path diagram for 64°N latitude.

APPENDIX B

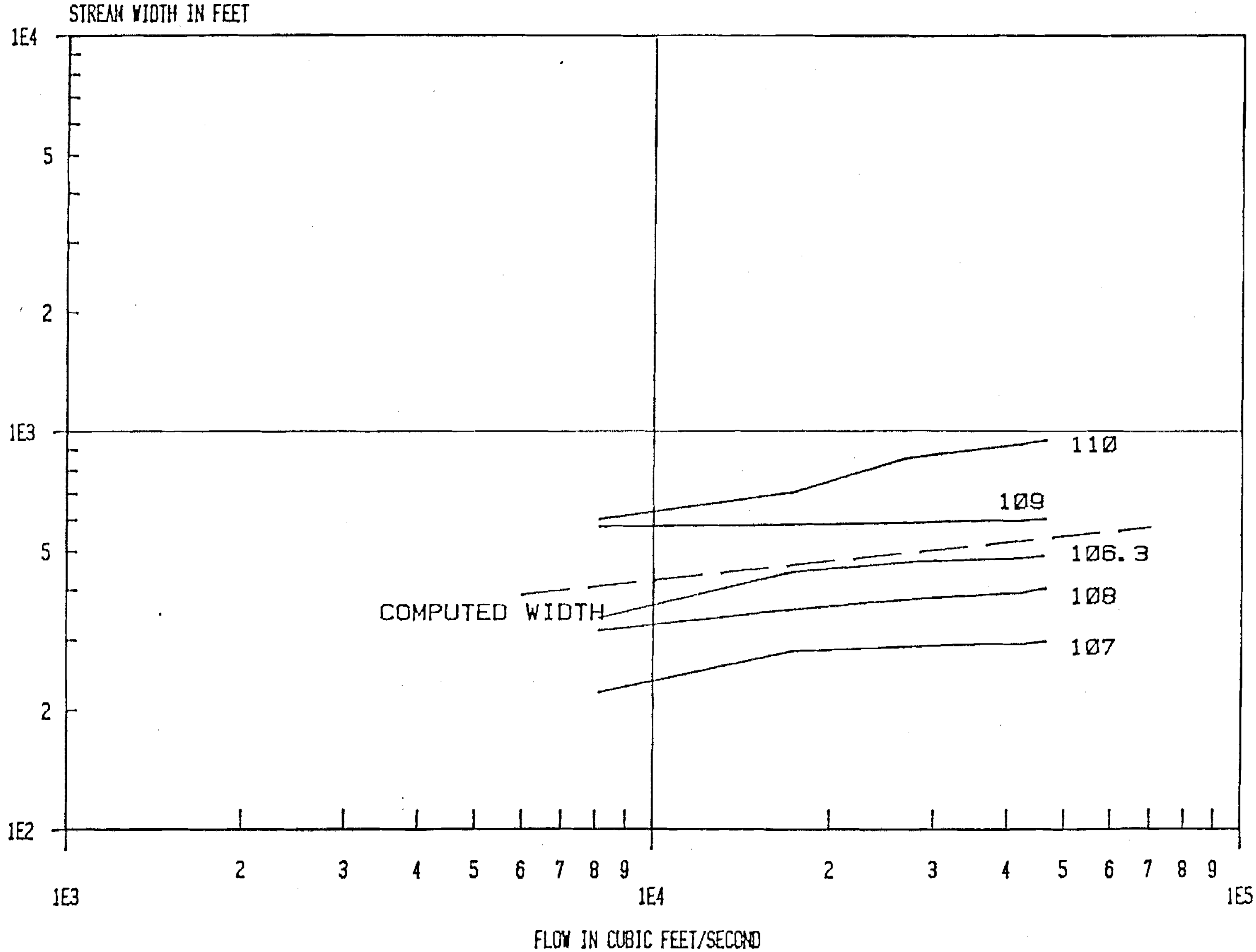
WIDTH/FLOW FUNCTIONS

WIDTH/FLOW FUNCTIONS

These graphs represent the relationship of wetted river width to flow on a log/log scale. The solid lines connect HEC-2 predicted widths for the six different flows used in the R&M (1982d) simulations. The numbers associated with these solid lines are R&M cross-section identifiers. Several R&M cross-sections were used for each reach as defined for the SNTEMP network (refer to Figure 10). For more readable plots, several plots are presented for a single reach when necessary. The dashed line presents the flow/width function used in the SNTEMP simulations.

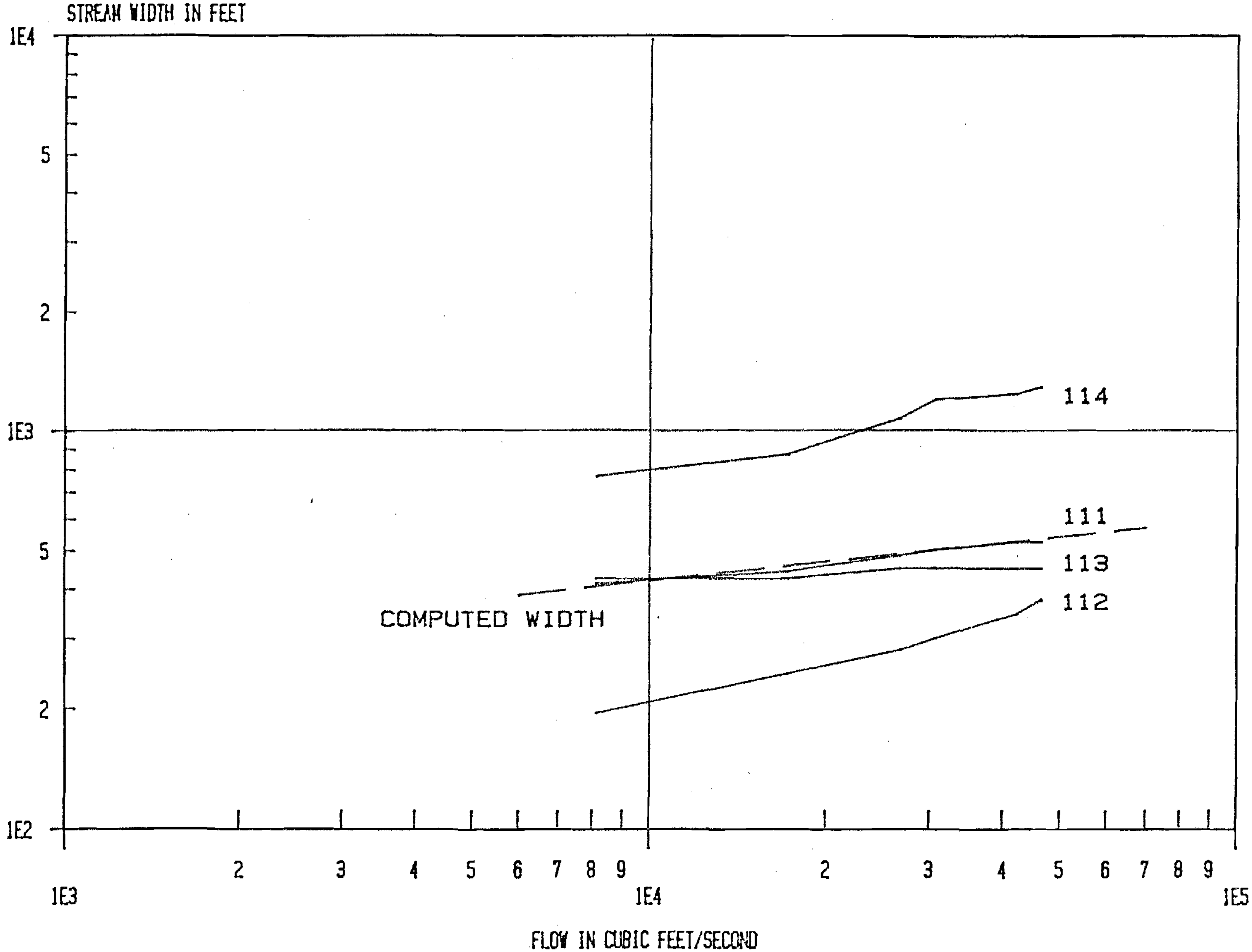
REACH 1

CROSS SECTIONS 106.3 - 110: GRAPH 1 OF 2



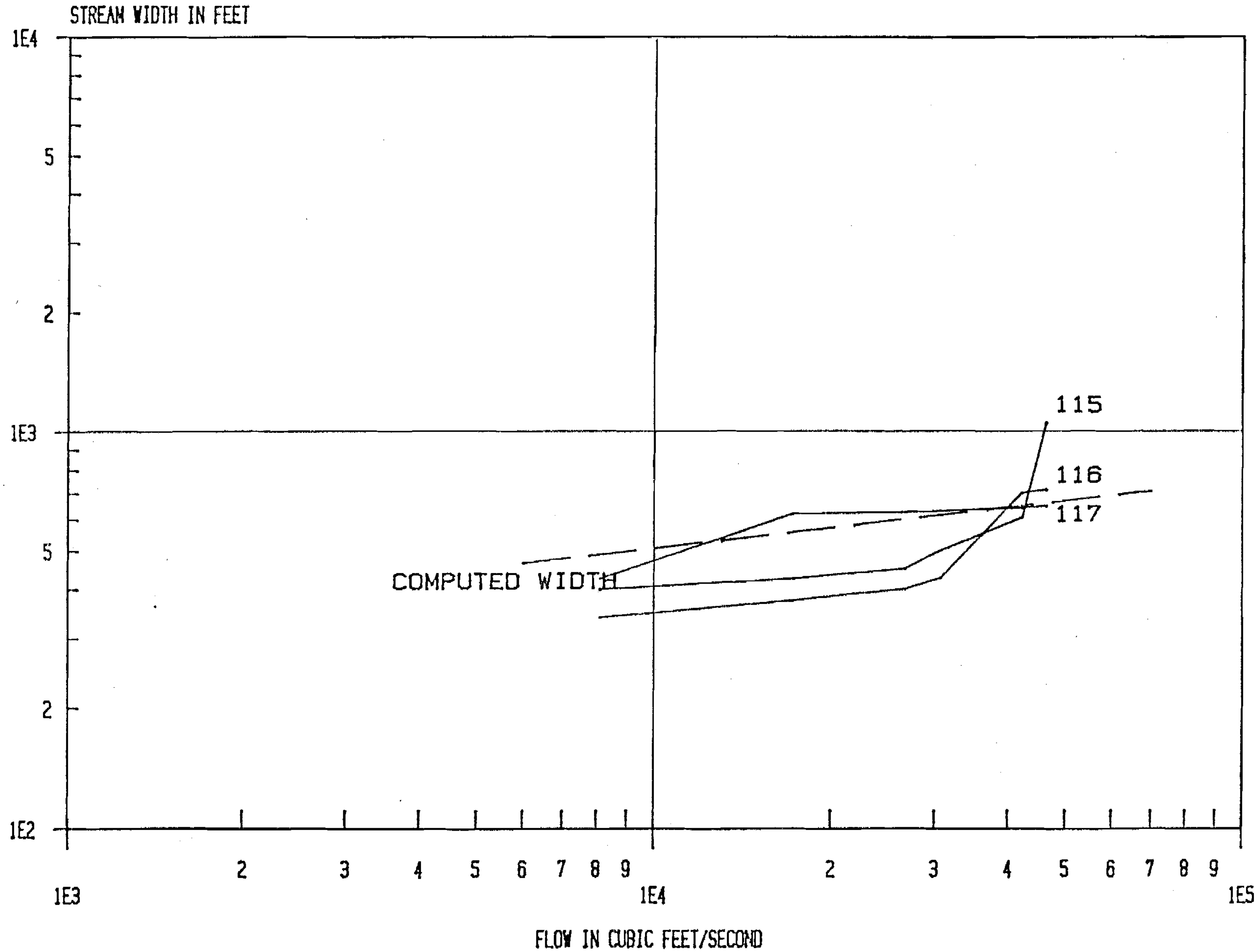
REACH 1

CROSS SECTIONS 111 - 114 : GRAPH 2 OF 2



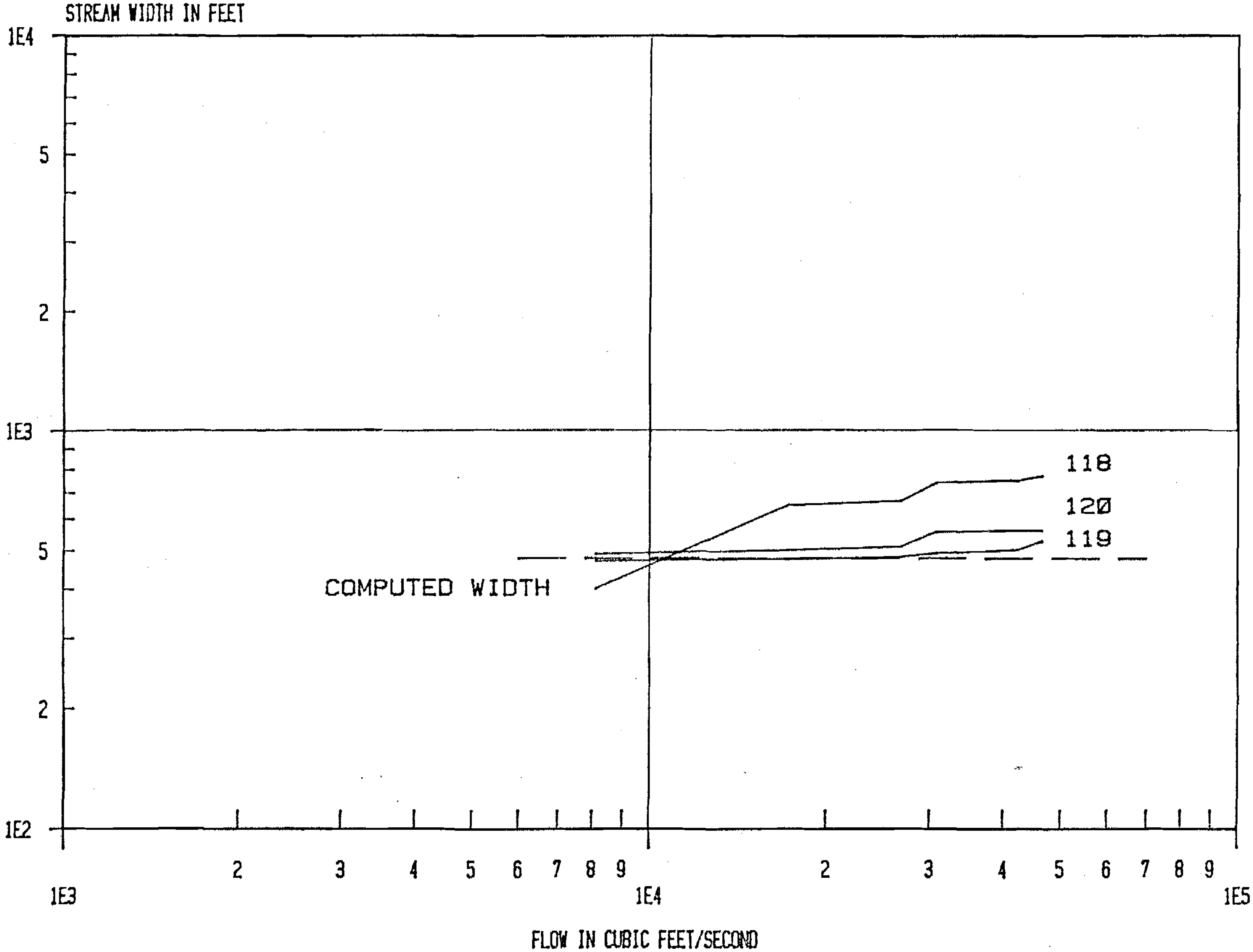
REACH 2

CROSS SECTIONS 115 - 117 : GRAPH 1 OF 1



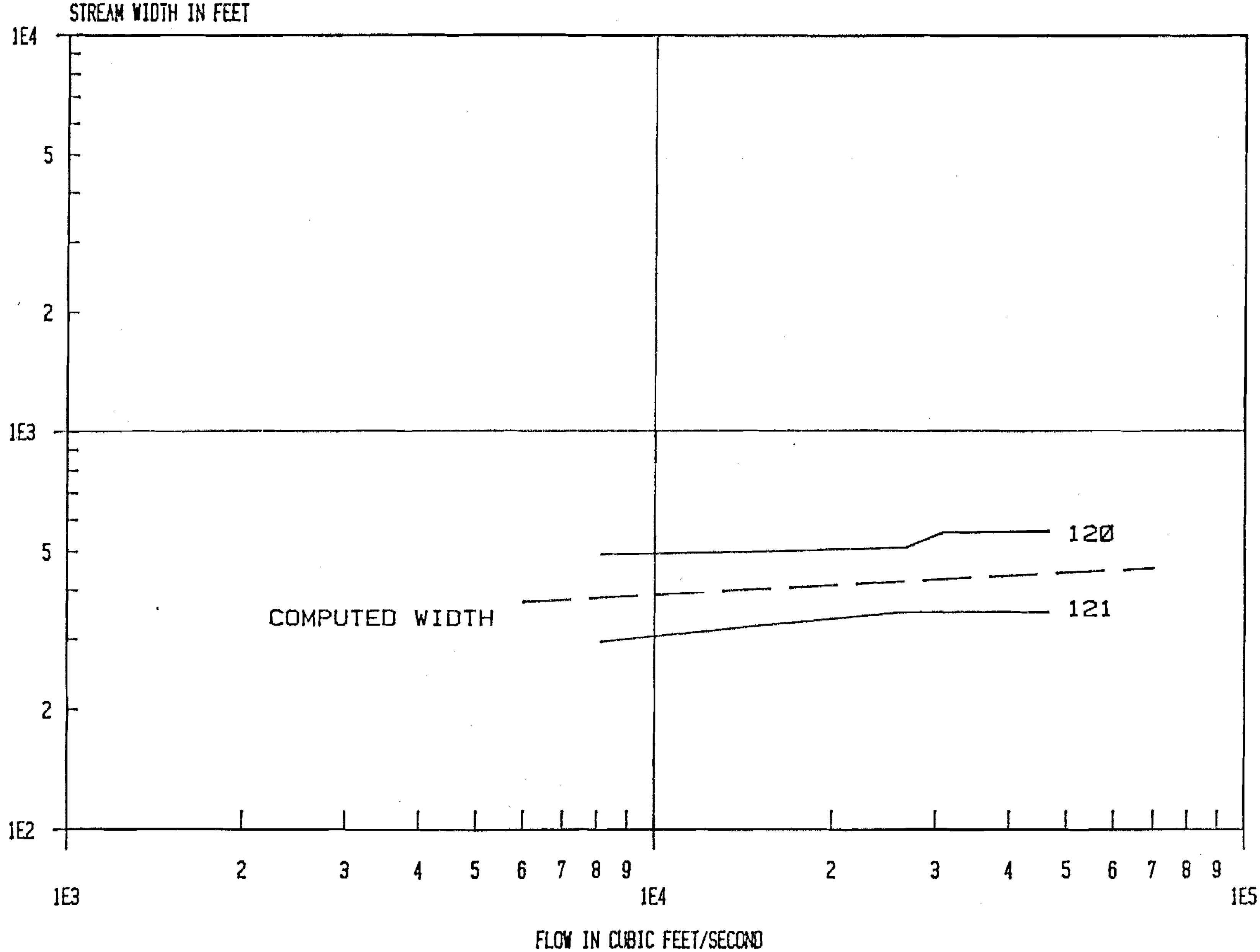
REACH 3

CROSS SECTIONS 118 - 120 : GRAPH 1 OF 1



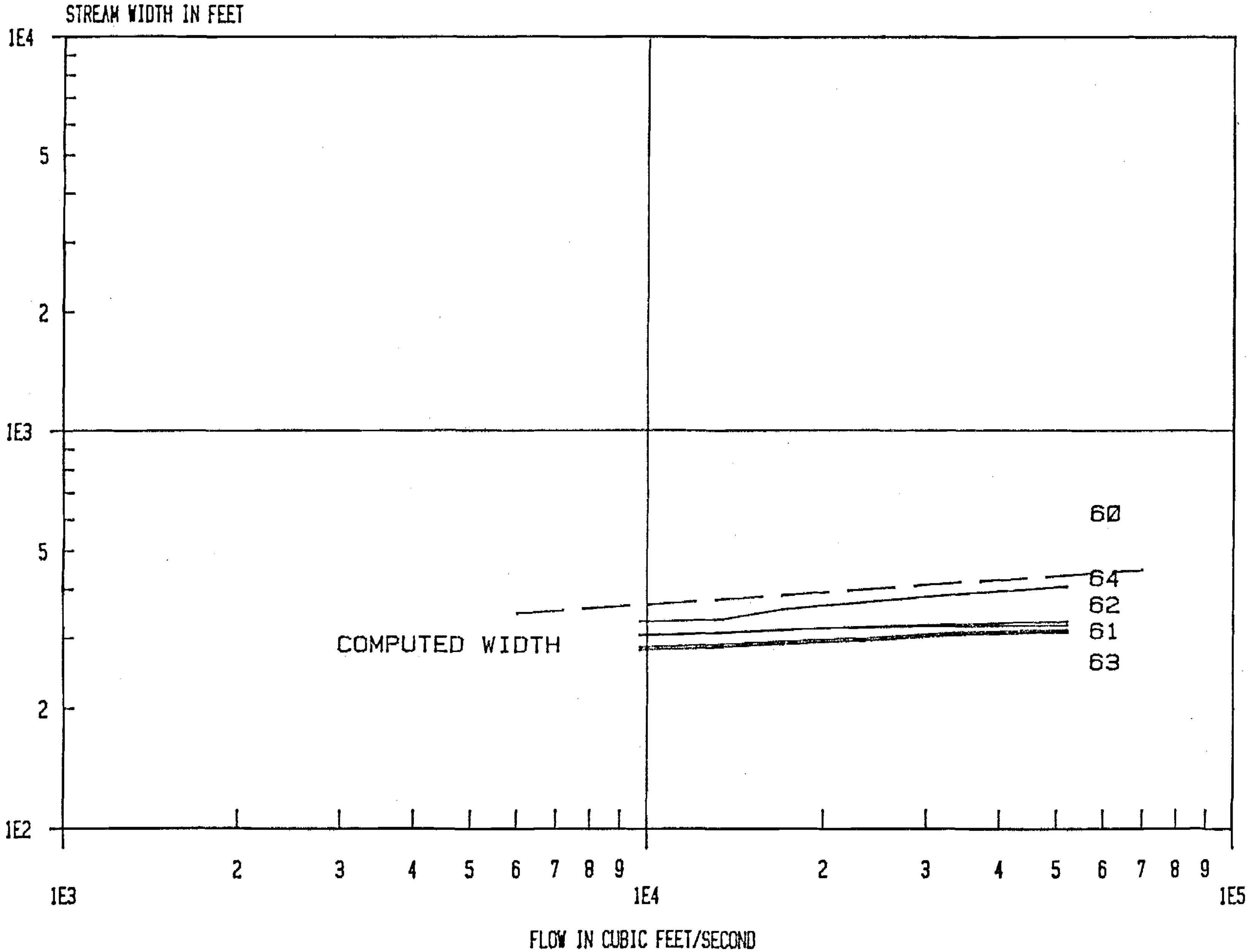
REACH 4

CROSS SECTIONS 120 - 121 : GRAPH 1 OF 1



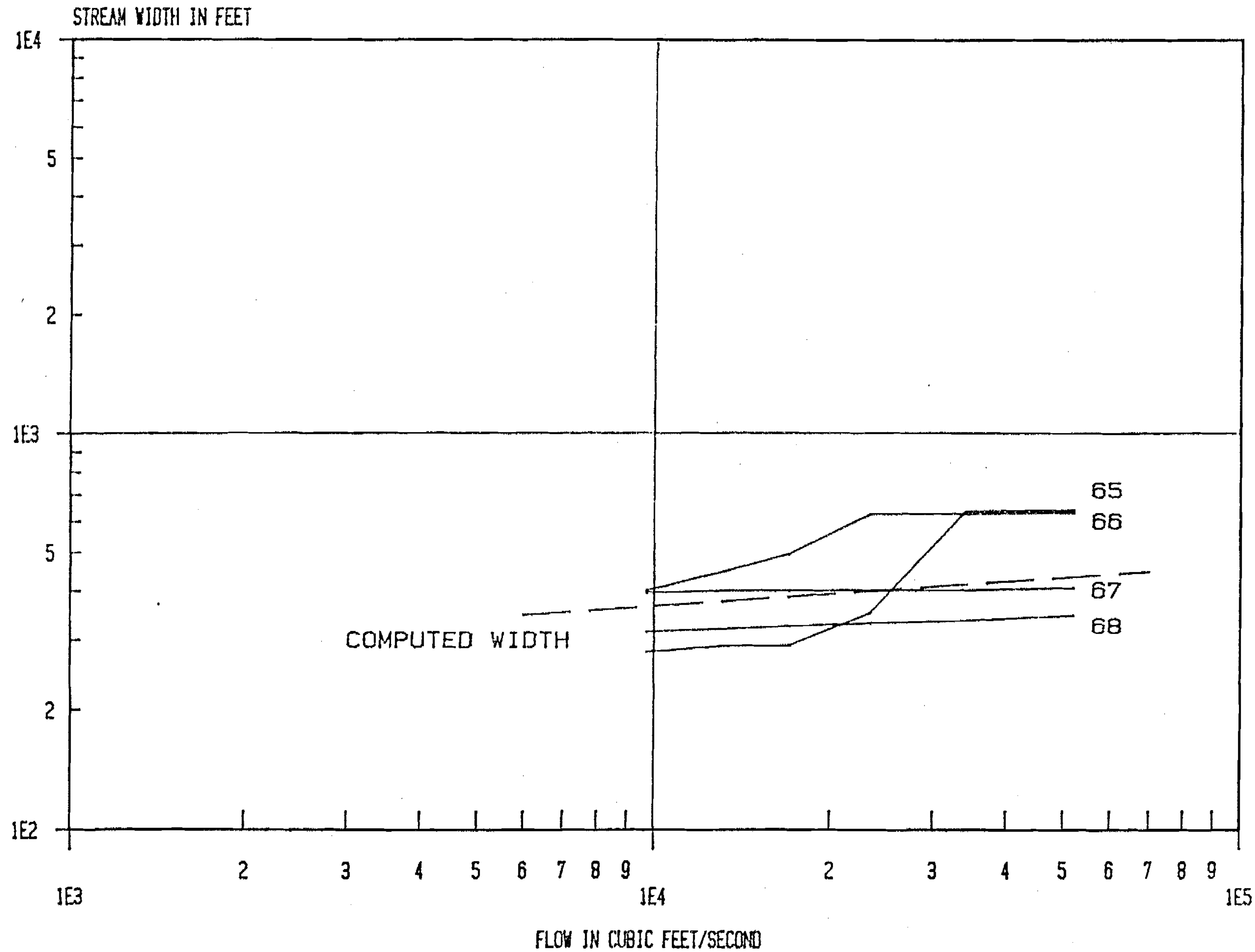
REACH 5

CROSS SECTIONS 60- 64 : GRAPH 1 OF 2



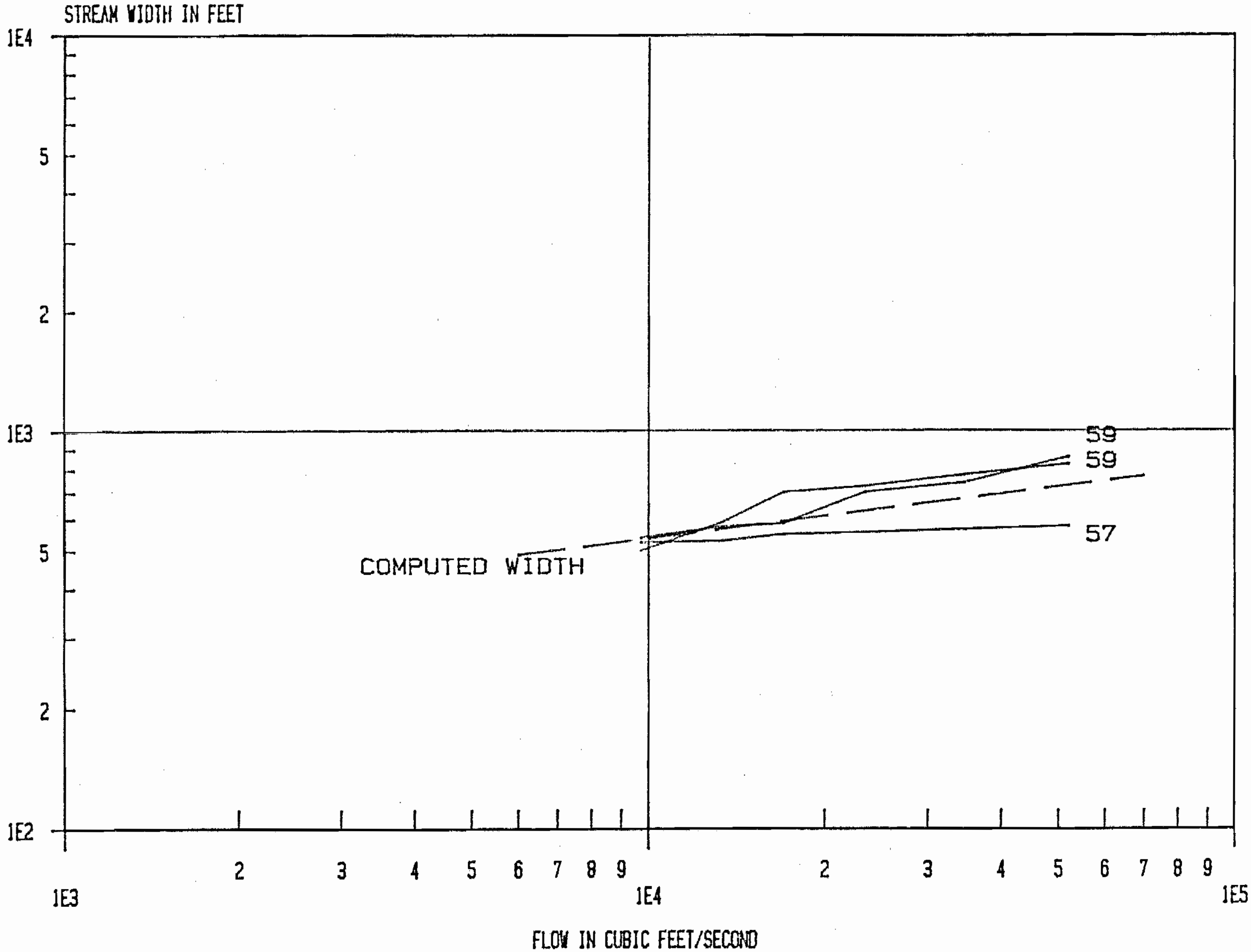
REACH 5

CROSS SECTIONS 65- 68 : GRAPH 2 OF 2



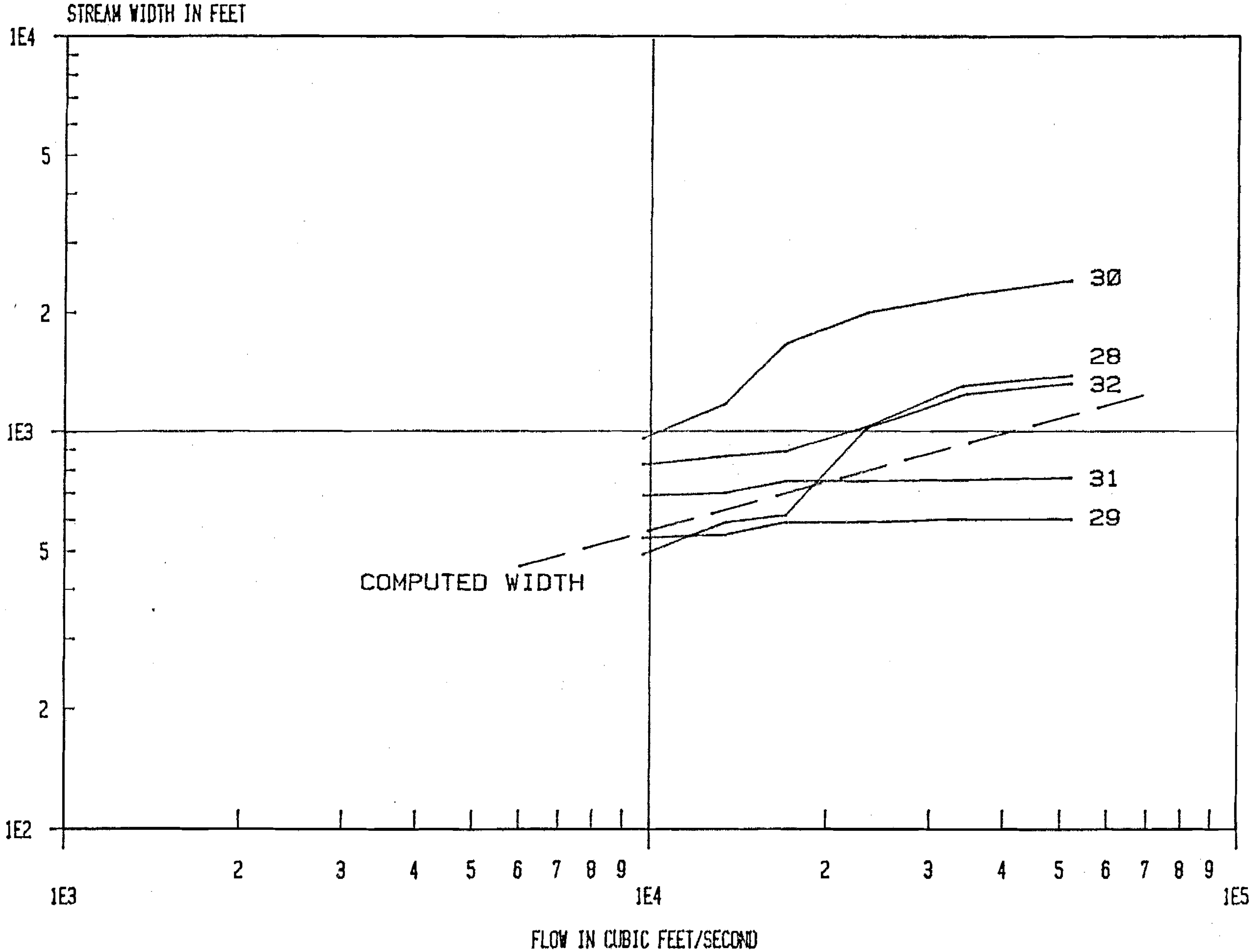
REACH 6

CROSS SECTIONS 57 - 59 : GRAPH 1 OF 1



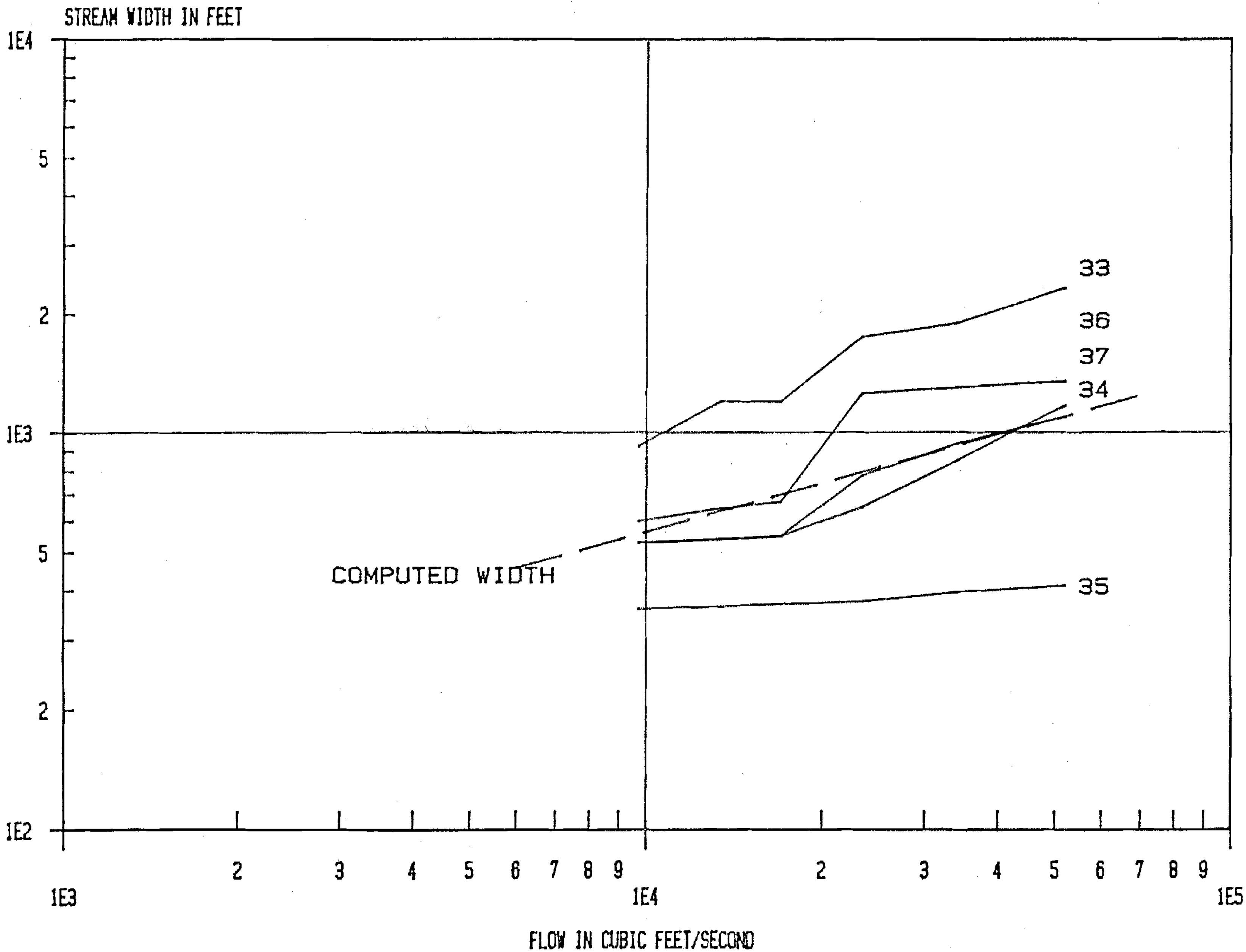
REACH 7

CROSS SECTIONS 28 - 32 : GRAPH 1 OF 6



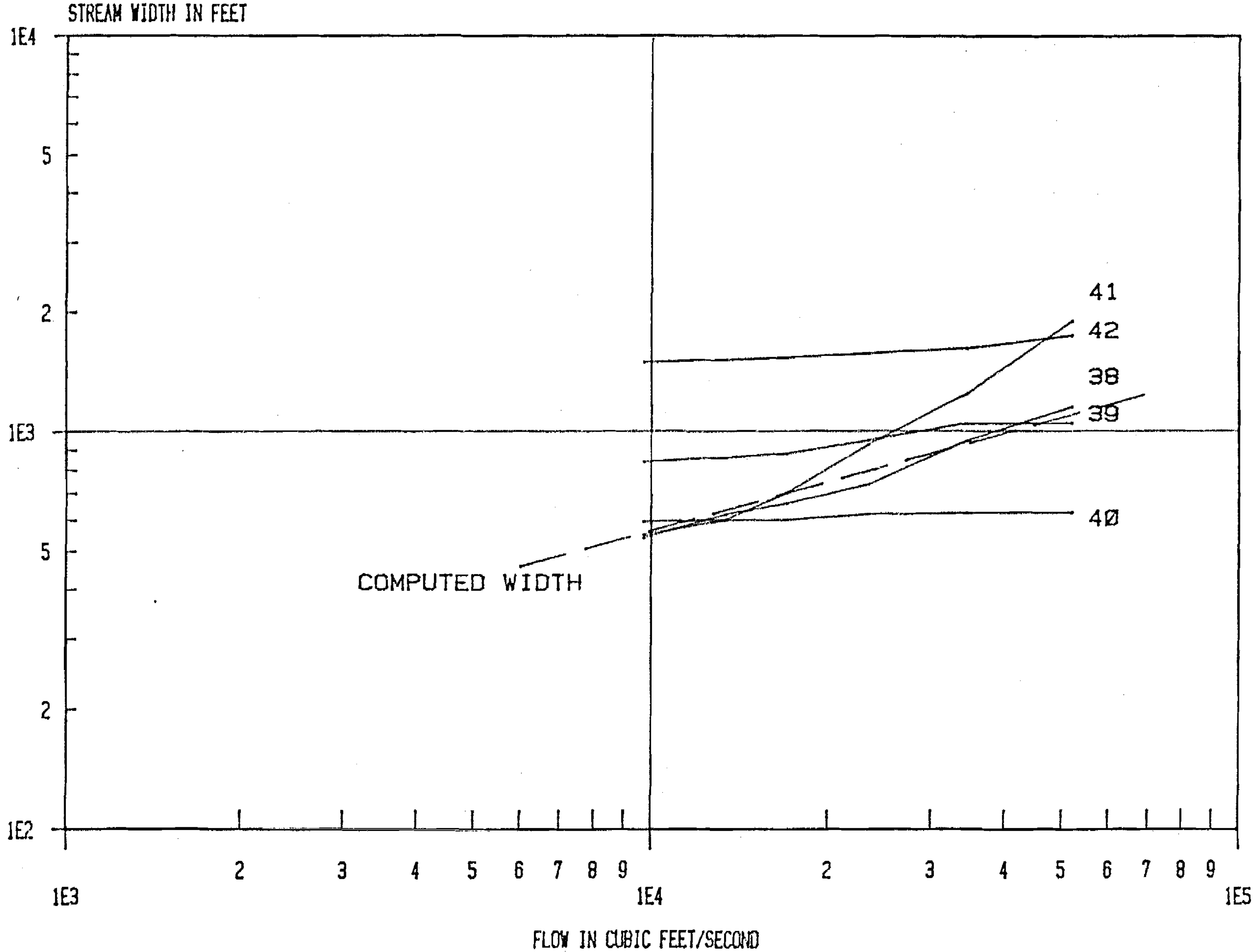
REACH 7

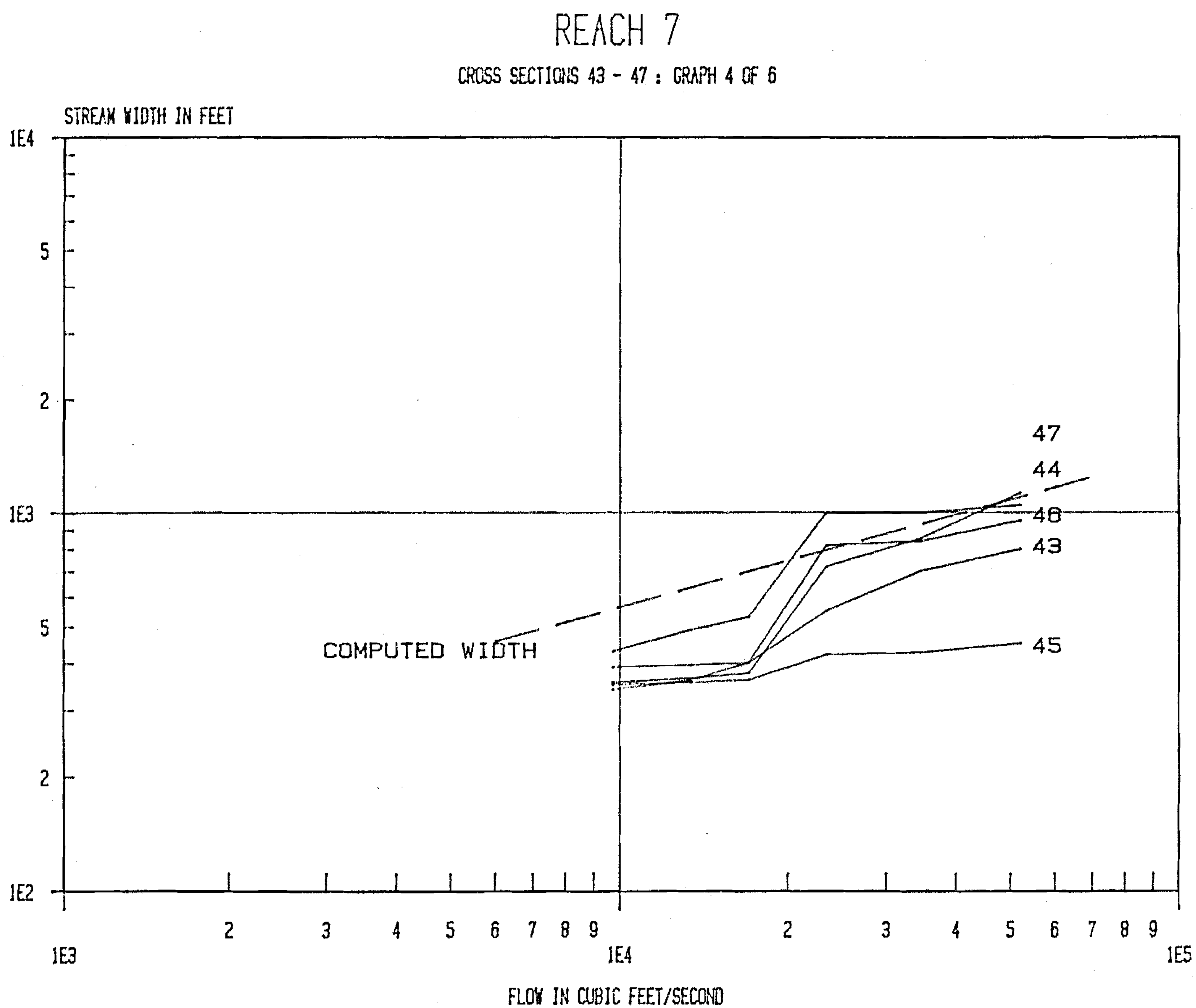
CROSS SECTIONS 33 - 37 : GRAPH 2 OF 6



REACH 7

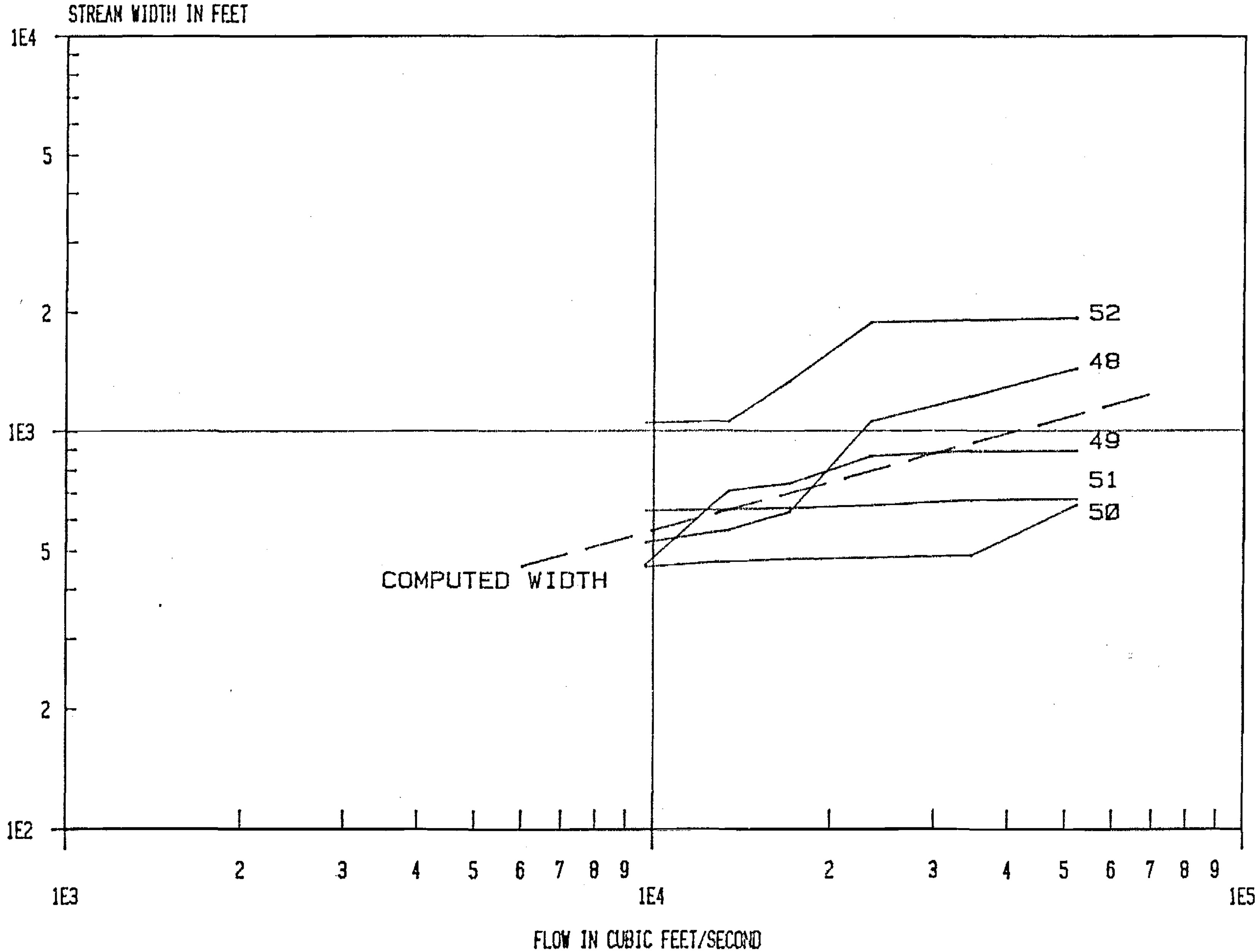
CROSS SECTIONS 38 - 42 : GRAPH 3 OF 6




REACH 7
CROSS SECTIONS 43 - 47 : GRAPH 4 OF 6
STREAM WIDTH IN FEET
1E4
5
2
1E3
5
2
1E2
47
44
46
43
45
COMPUTED WIDTH
2
3
4
5
6
7
8
9
1E3
1E4
1E5
FLOW IN CUBIC FEET/SECOND

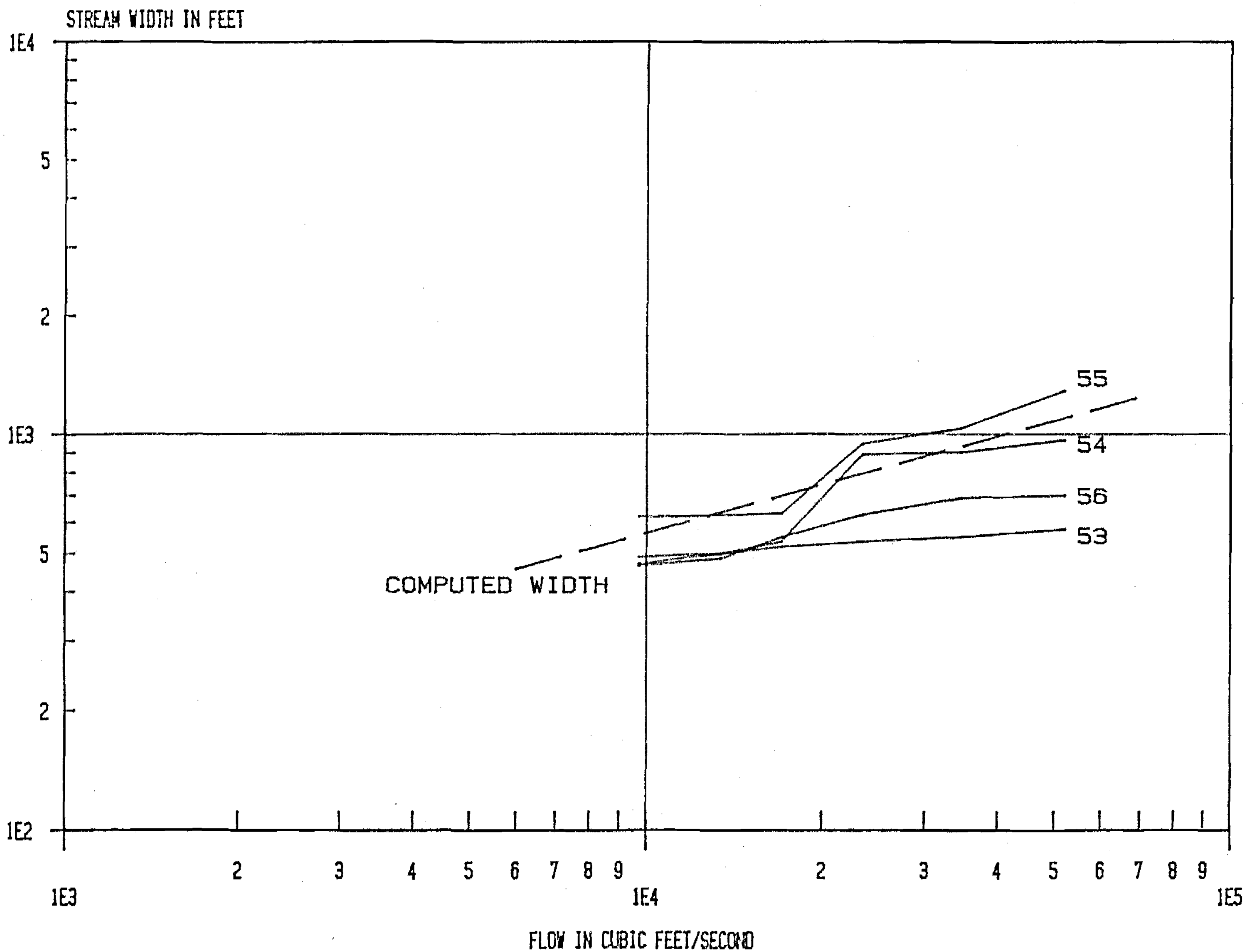
REACH 7

CROSS SECTIONS 48 - 52 : GRAPH 5 OF 6



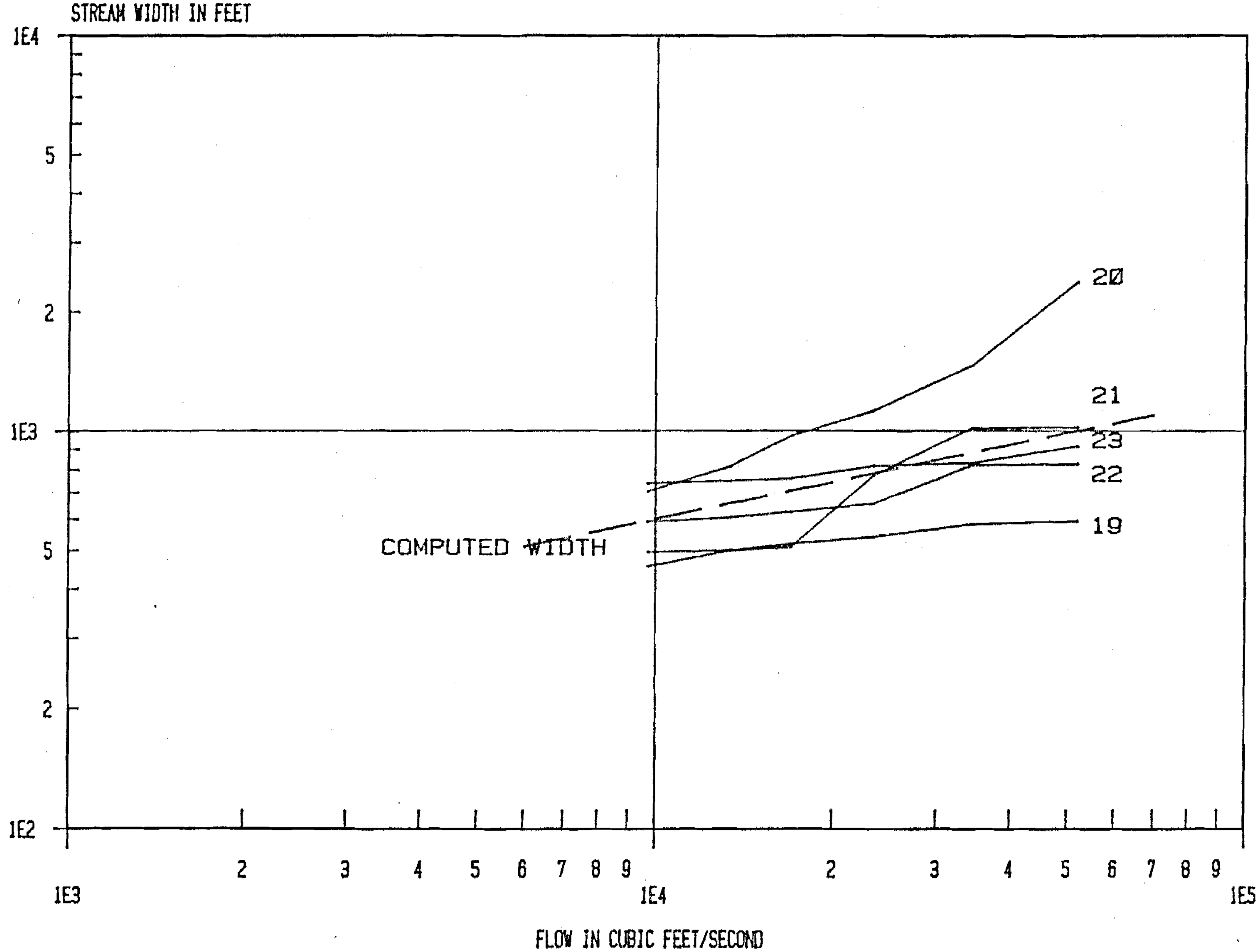
REACH 7

CROSS SECTIONS 53 - 56 : GRAPH 6 OF 6



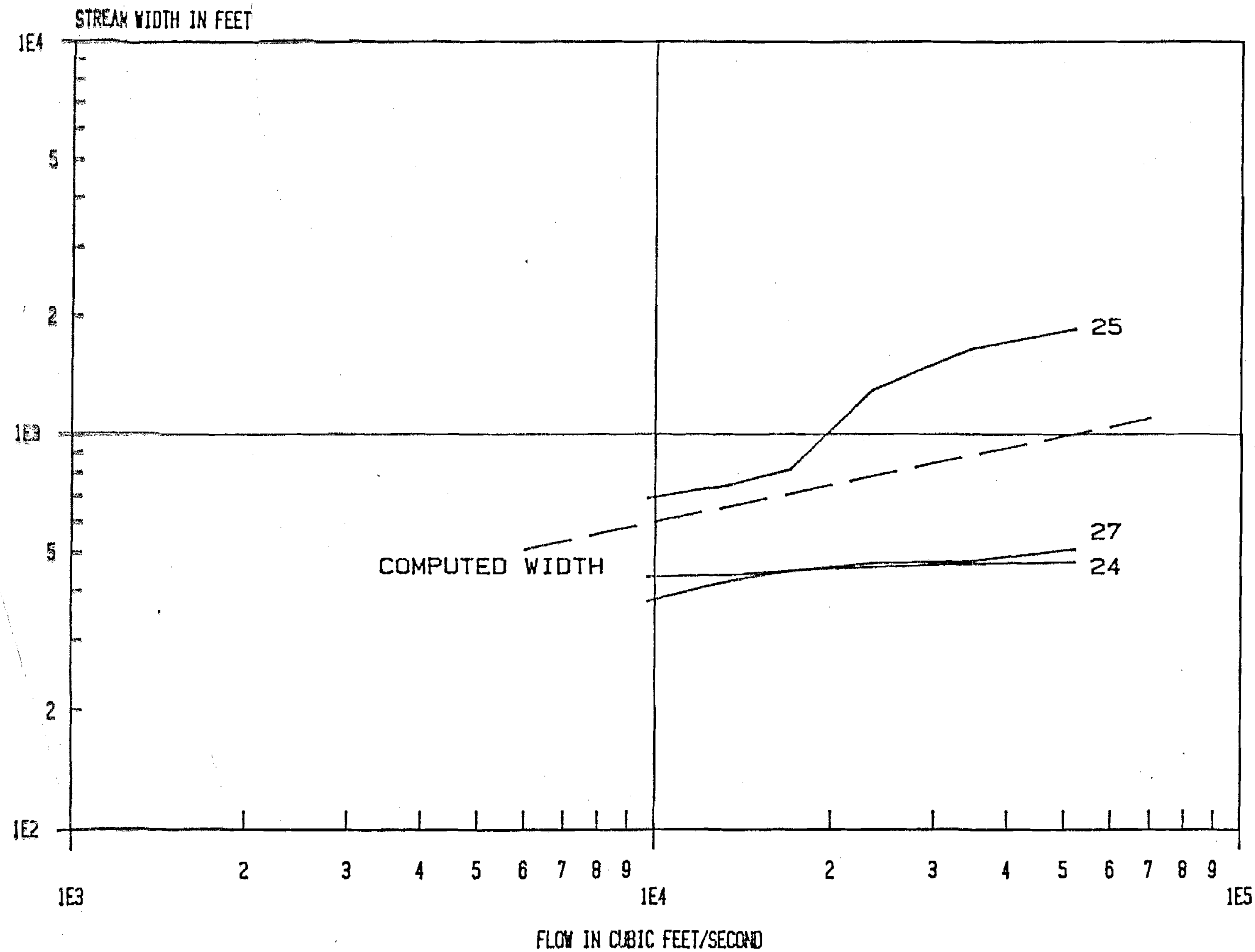
REACH 8

CROSS SECTIONS 19 - 23 : GRAPH 1 OF 2



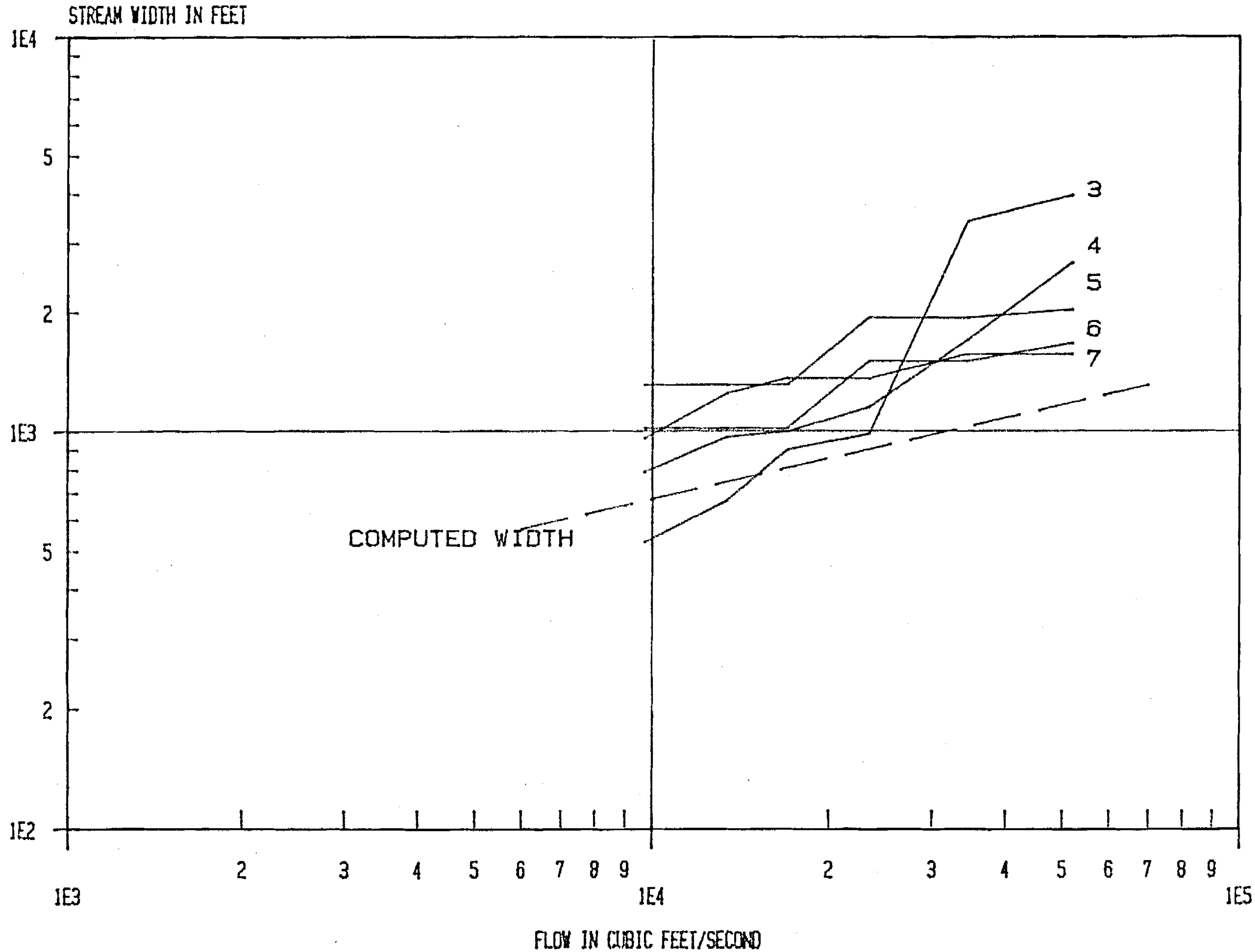
REACH 8

CROSS SECTIONS 24 - 27 : GRAPH 2 OF 2



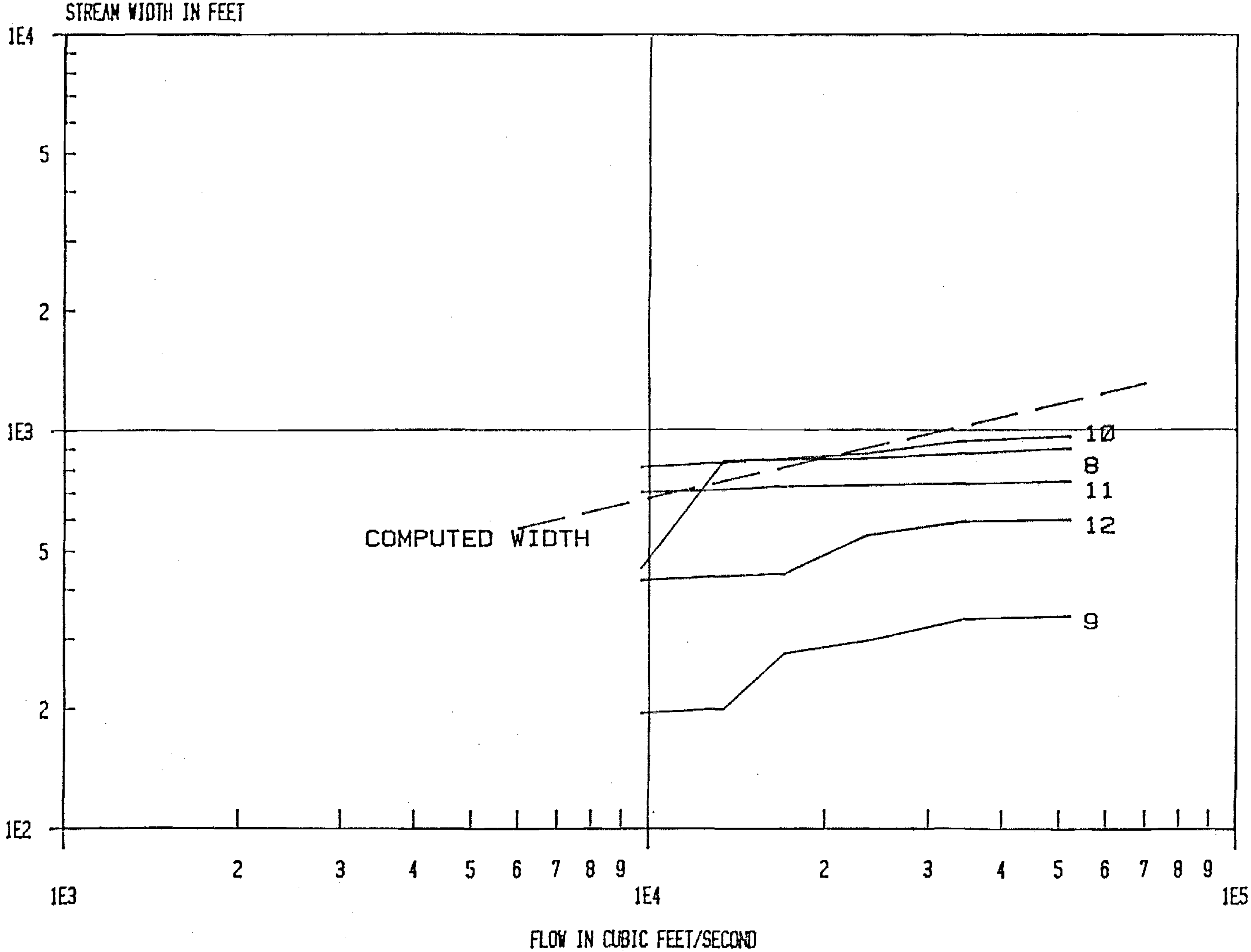
REACH 9

CROSS SECTIONS 3 - 7 : GRAPH 1 OF 3



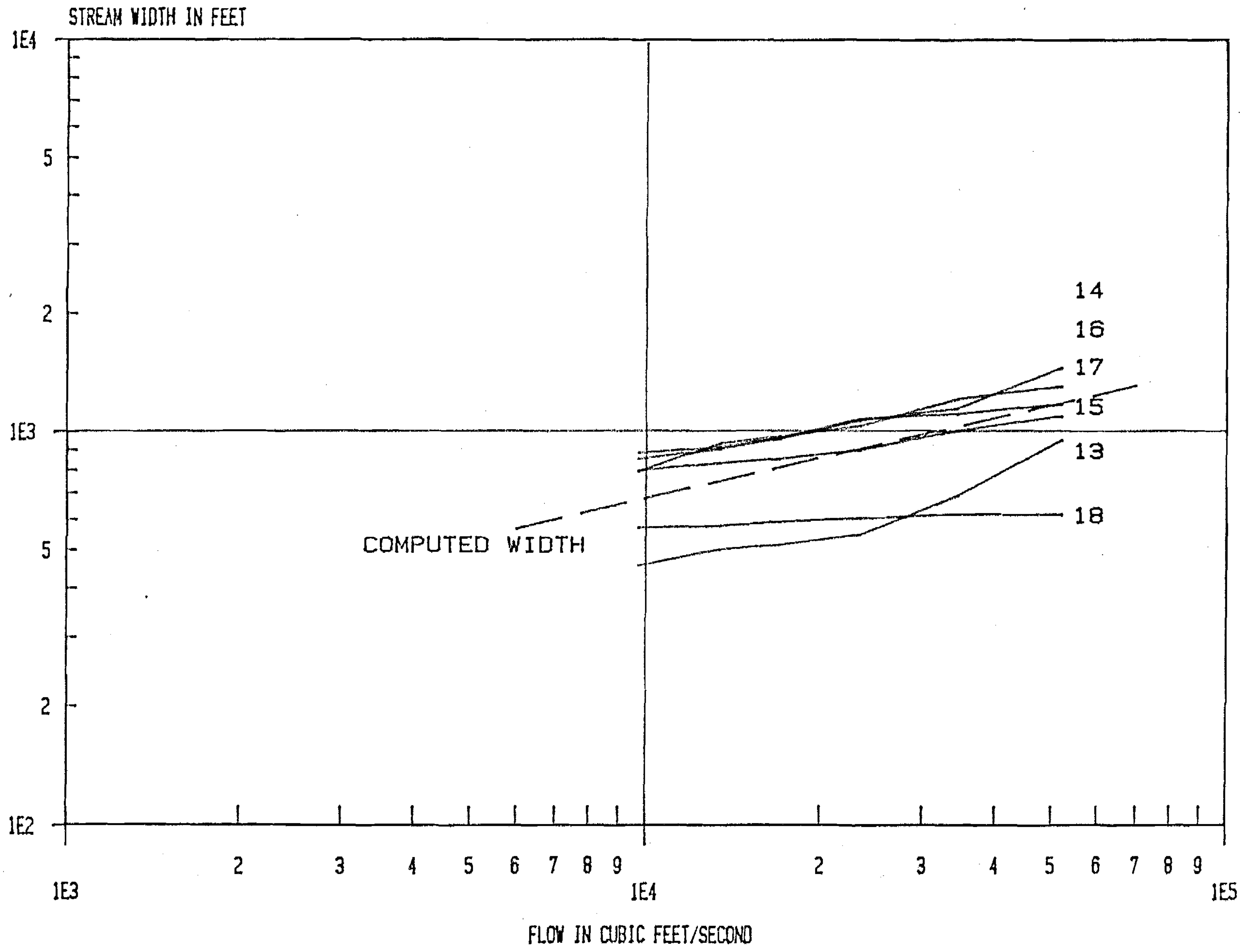
REACH 9

CROSS SECTIONS 8 - 12 : GRAPH 2 OF 3



REACH 9

CROSS SECTIONS 13 - 18 : GRAPH 3 OF 3



APPENDIX C

LONGITUDINAL TEMPERATURE PROFILES

JUNE TO SEPTEMBER 1981-1982

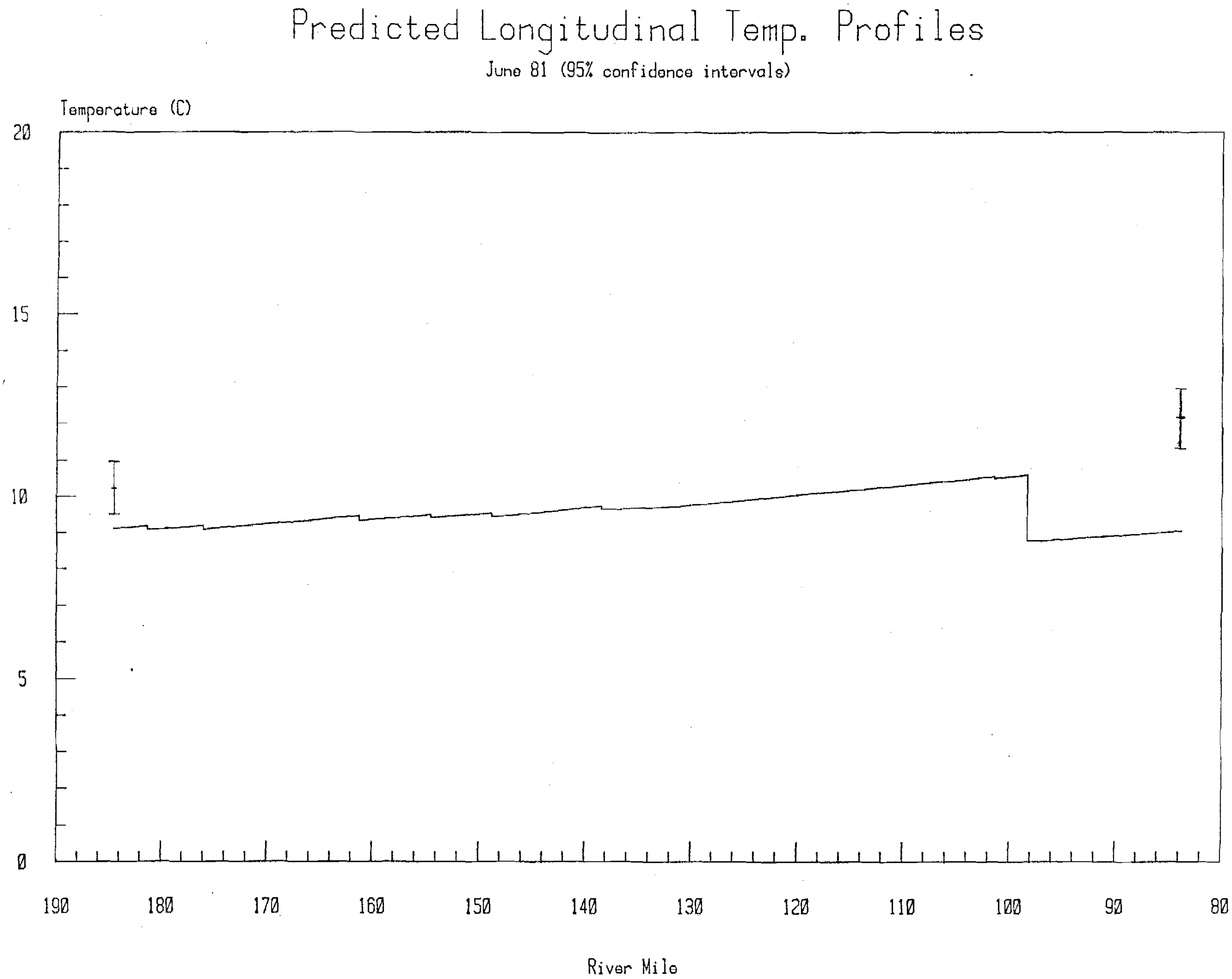
LONGITUDINAL TEMPERATURE PROFILES

JUNE TO SEPTEMBER 1981-1982

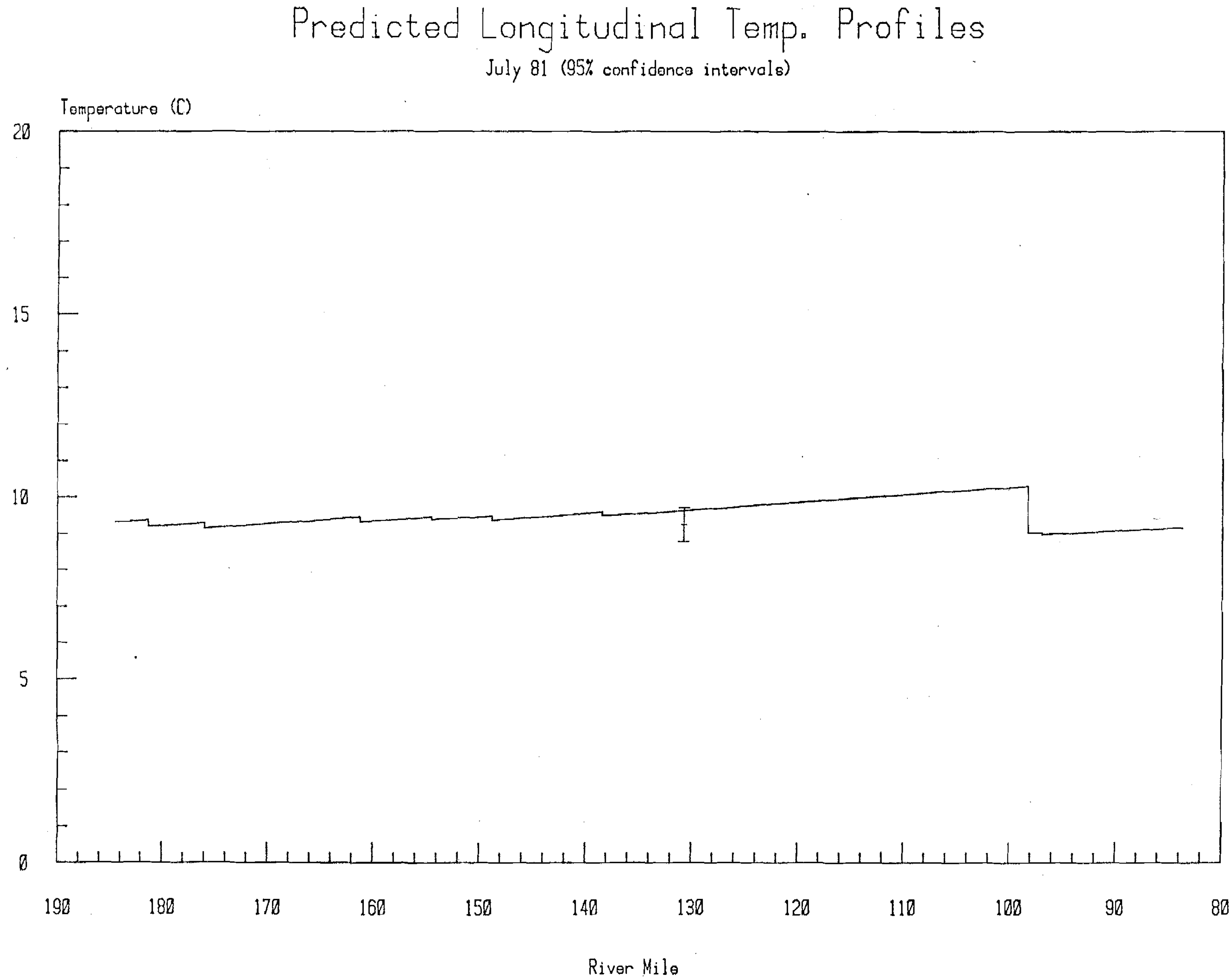
These graphs represent both the predicted and observed temperatures for the June, July, August, and September period of 1981 and 1982.

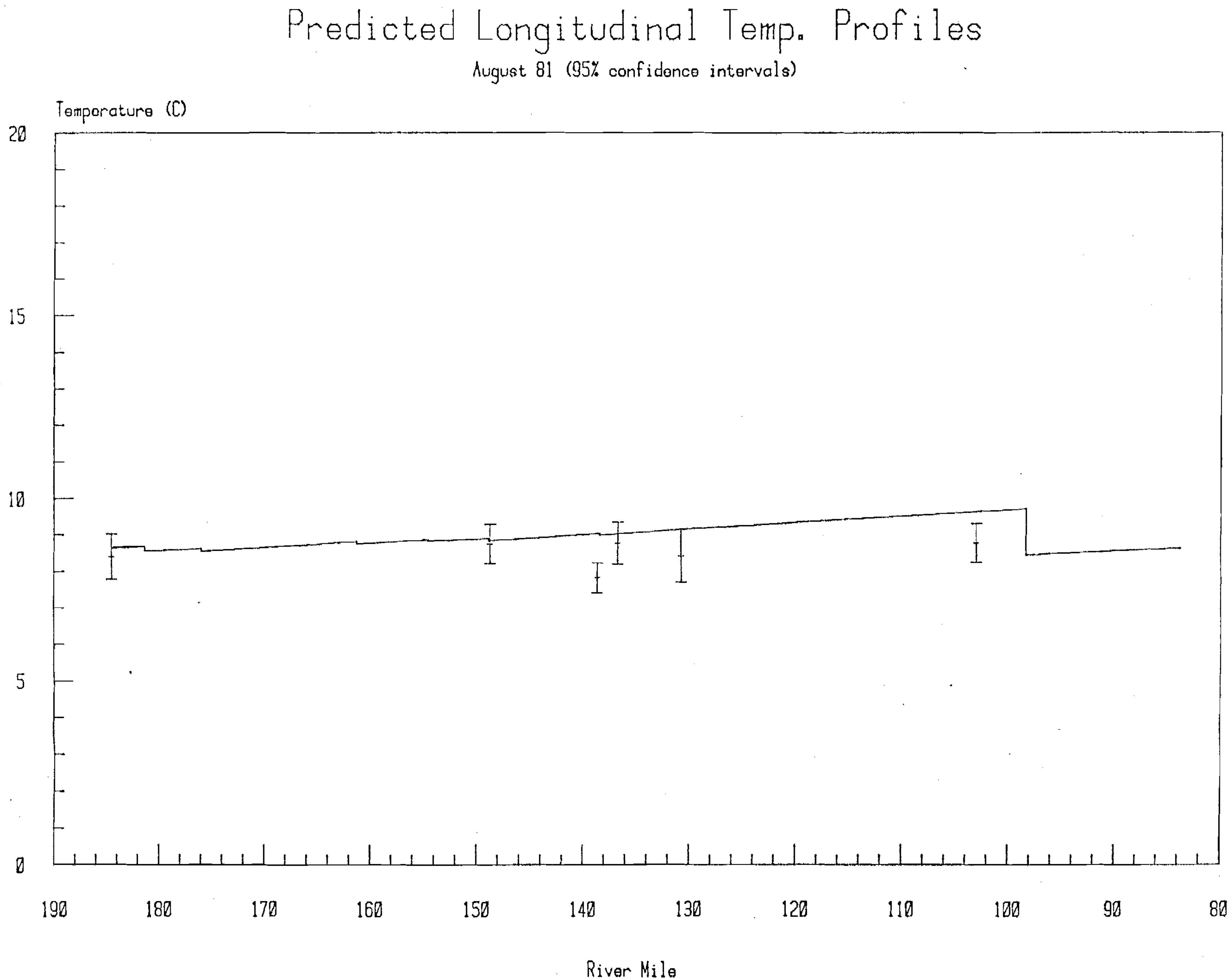
The observed data points are shown with 95 percent confidence intervals. These confidence intervals are measures of the monthly variations in the usable historical data for the Susitna Basin (Figure 13).

Predicted temperatures are from the postcalibration simulations with SNTEMP.



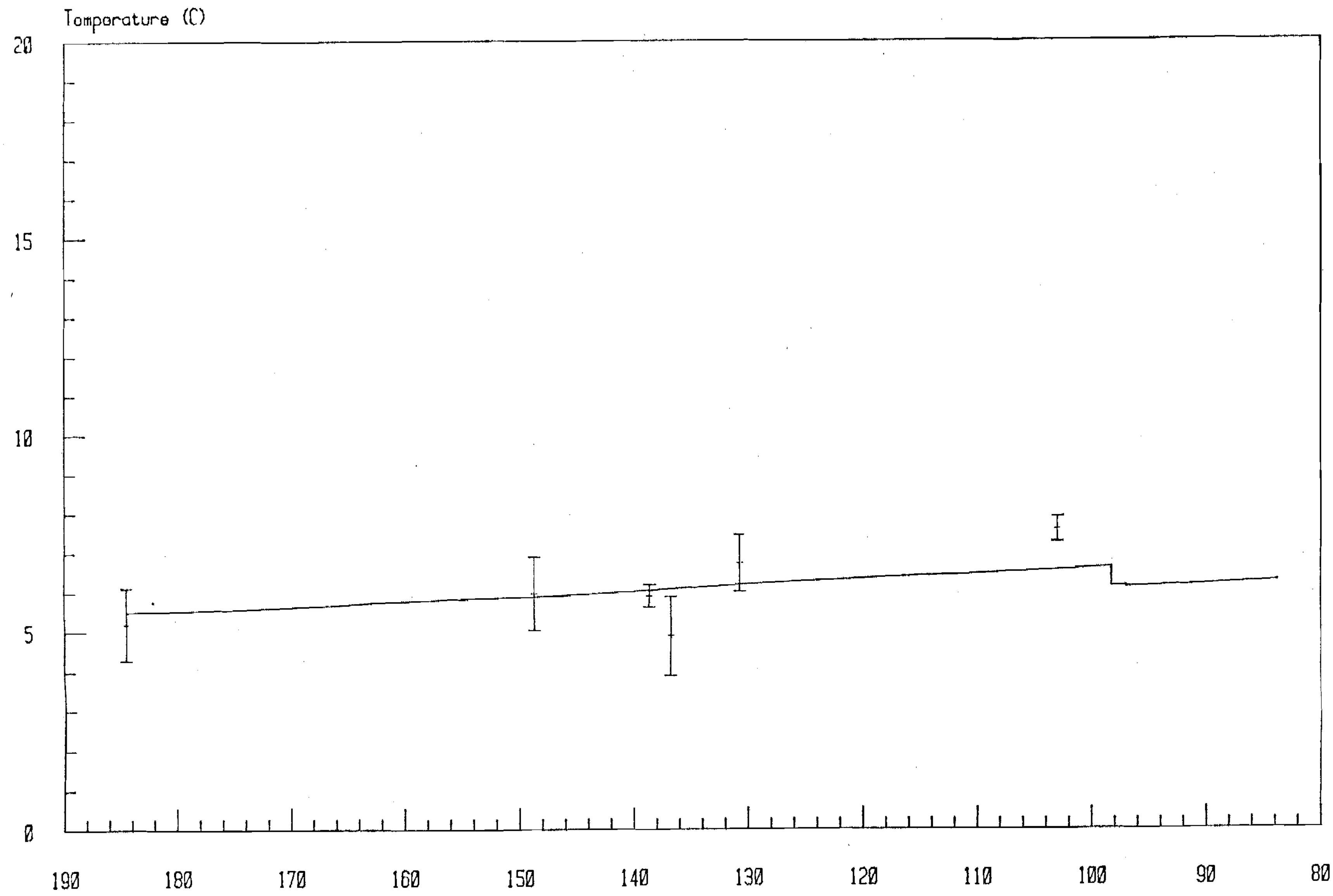
Predicted Longitudinal Temp. Profiles
June 81 (95% confidence intervals)
Temperature (C)
20
15
10
5
0
190
180
170
160
150
140
130
120
110
100
90
80
River Mile

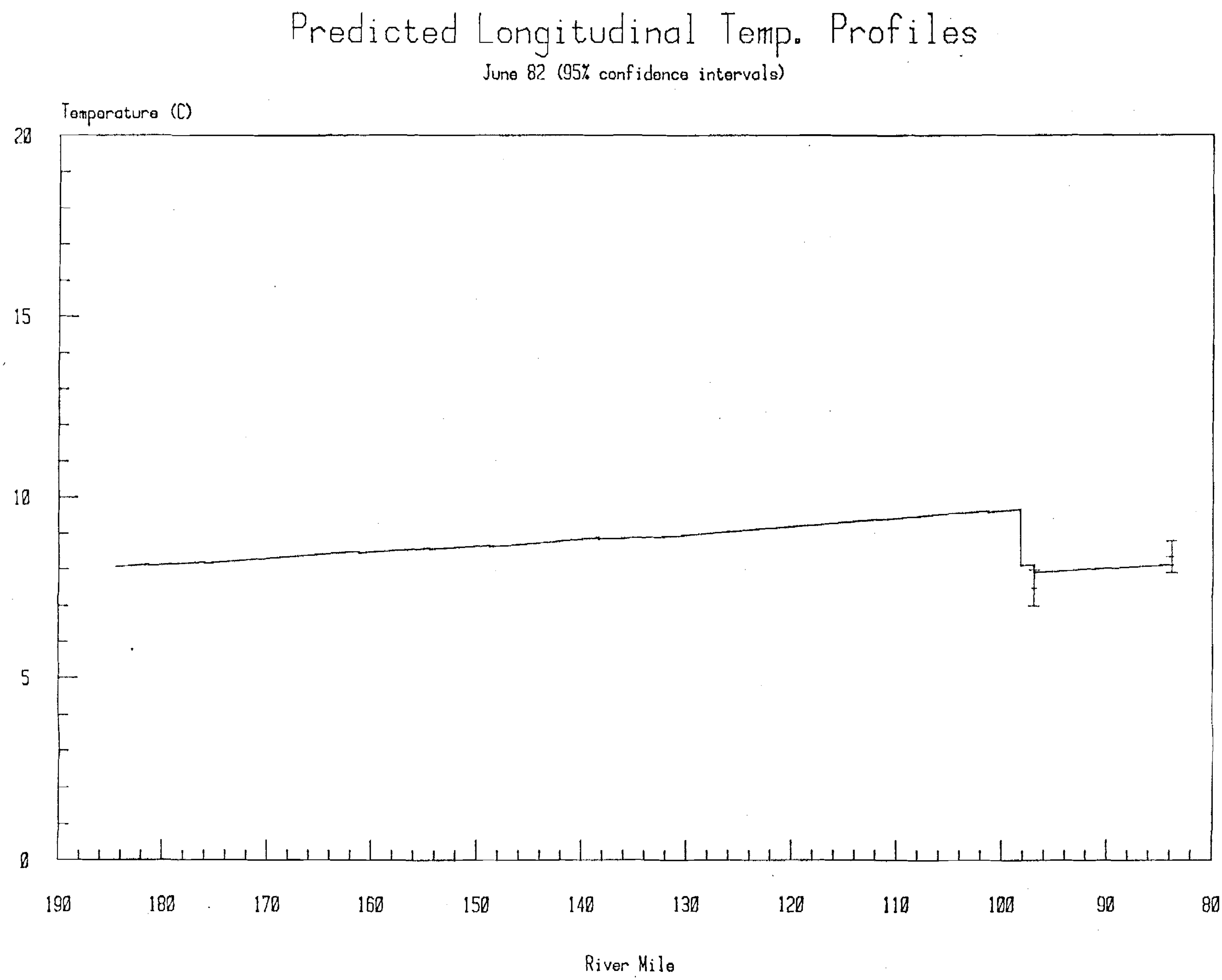

Predicted Longitudinal Temp. Profiles
July 81 (95% confidence intervals)
Temperature (C)
20
15
10
5
0
190
180
170
160
150
140
130
120
110
100
90
80
River Mile

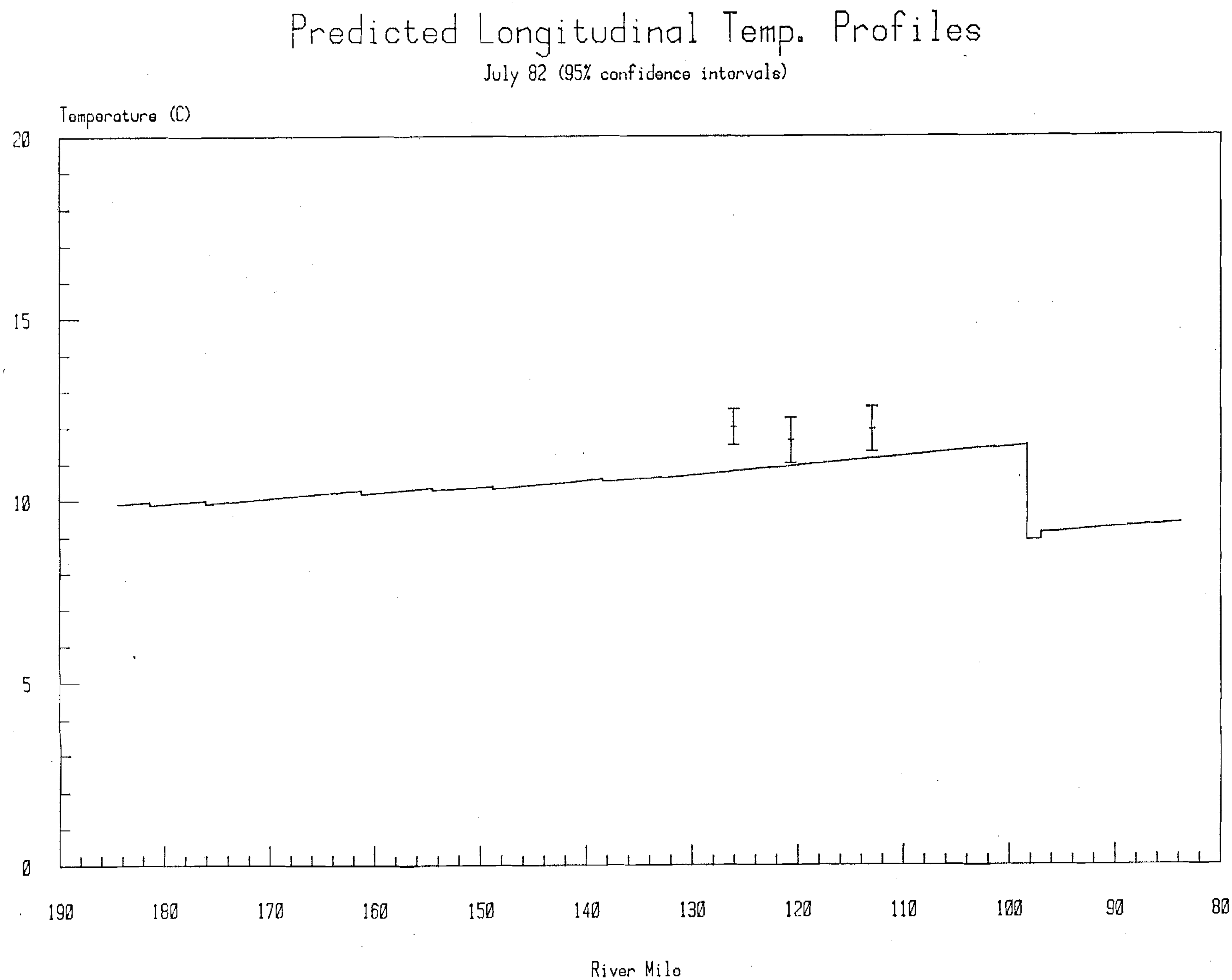

Predicted Longitudinal Temp. Profiles
August 81 (95% confidence intervals)
Temperature (C)
20
15
10
5
0
190
180
170
160
150
140
130
120
110
100
90
80
River Mile

Predicted Longitudinal Temp. Profiles

September 81 (95% confidence intervals)



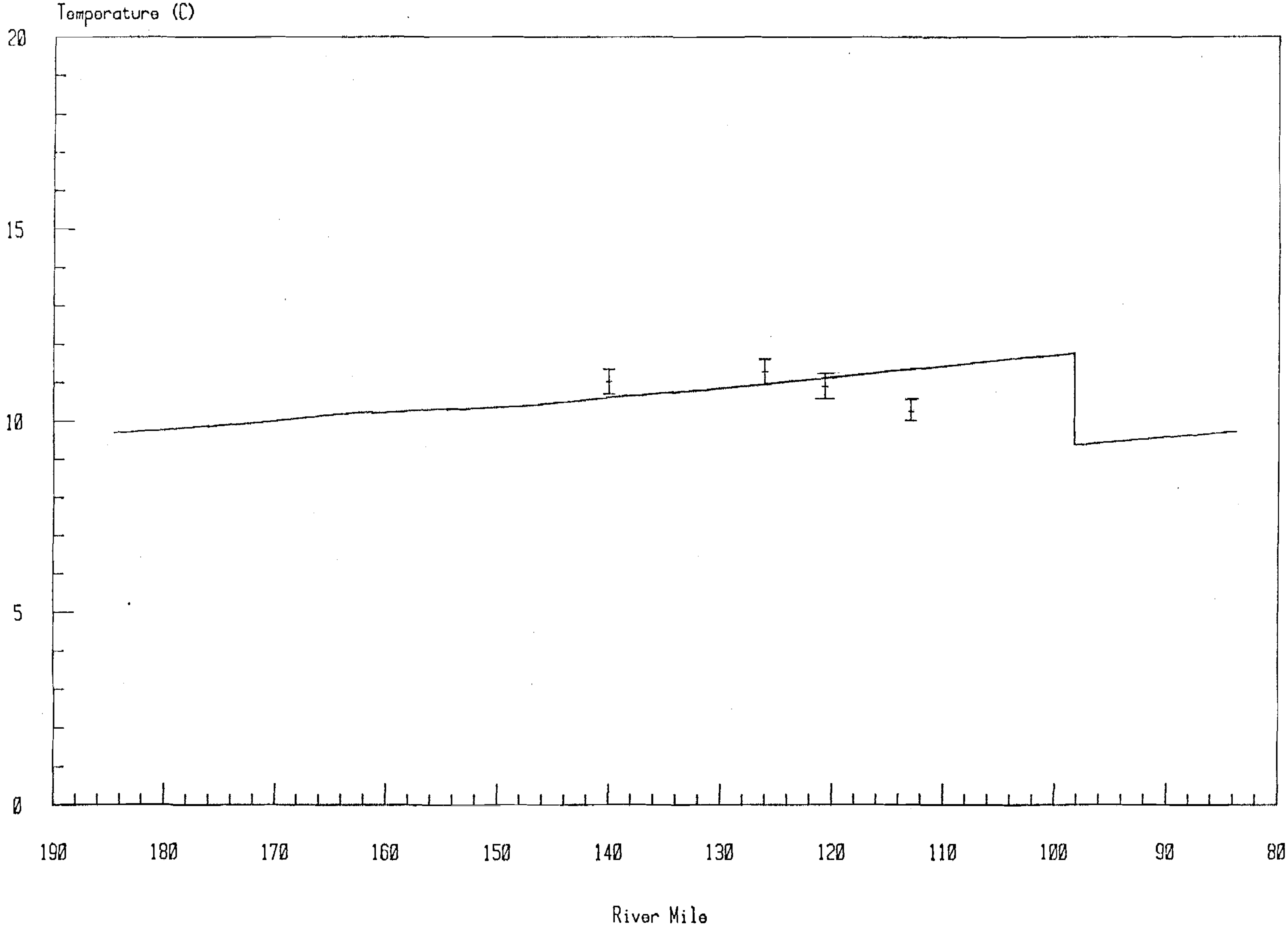

Predicted Longitudinal Temp. Profiles
June 82 (95% confidence intervals)
Temperature (C)
20
15
10
5
0
190
180
170
160
150
140
130
120
110
100
90
80
River Mile



Predicted Longitudinal Temp. Profiles
July 82 (95% confidence intervals)
Temperature (C)
20
15
10
5
0
190
180
170
160
150
140
130
120
110
100
90
80
River Mile

Predicted Longitudinal Temp. Profiles

August 82 (95% confidence intervals)



Predicted Longitudinal Temp. Profiles

September 82 (95% confidence intervals)