

REPORT

A MATHEMATICAL MODEL FOR PREDICTING
TEMPERATURE IN RIVERS AND RIVER-RUN RESERVOIRS

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Acknowledgments

The development and testing of the temperature prediction model described in this paper has benefited from the cooperation and contributions of several individuals, as well as various public and private agencies.

Initial development and programming of the model was done by Mr. William Morse * of the FWPCA, Pacific Northwest Water Laboratory, Corvallis, Oregon.

The hydraulic calculations are adapted from techniques developed by Dr. Bruce Tichenor and Mr. Alden Christianson of the FWPCA, Pacific Northwest Water Laboratory, Corvallis, Oregon.

Mr. Robert Cleary, a graduate student in chemical engineering at the University of Massachusetts, Amherst, Massachusetts, provided technical support while working for the FWPCA, Northwest Regional Office, Portland, Oregon, as a temporary employee during the summer of 1968.

A major part of developing and testing the model has been the compilation and organization of necessary data. The author wishes to thank the US Army Corps of Engineers; Weather Bureau; Bureau of Commercial Fisheries; US Geological Survey; Federal Aviation Agency; Atomic Energy Commission; Chelan, Grand and Douglas County PUD's and Battelle Northwest, for providing hydraulic, meteorologic and water temperature data.

* Mr. Morse is presently a mathematician with the Bonneville Power Administration, Portland, Oregon.

Summary

A one-dimensional temperature prediction model has been developed and tested on the Columbia River. The model in its present form is operational for use on rivers for which:

- (1) Cross-sectional characteristics, including water surface width and cross-sectional area are available.
- (2) Adequate meteorologic data is available.
- (3) Water surface elevation data is available.
- (4) Evaporation and sensible heat flux can be evaluated in terms of regional weather data and the results of representative field studies.
- (5) Lateral and vertical variations in temperature are negligible.
- (6) The flow can be considered quasi-steady.

Punched cards containing the FORTRAN statements shown in Appendix C can be obtained from the FWPCA, Northwest Regional Office, Portland, Oregon. The program can also be executed directly from the FWPCA data cell at the Department of the Interior Computer Center in Washington, D. C.

INTRODUCTION

Thermal loads imposed upon rivers as a result of heat rejection from manufacturing and power generating industries, impoundment by dams, and irrigation diversion have made temperature an important water quality parameter. Effective water resource planning must, therefore, include adequate methods for predicting and evaluating temperature changes. To fulfill this need the Federal Water Pollution Control Administration, Northwest Regional Office, is developing a computerized system of mathematical models which can be used to predict temperature in rivers and reservoirs.

The model described in this document has been developed primarily for predicting temperatures in rivers which are regulated by dams with run-of-the-river, or small usable storage capacity reservoirs; and which may also have reaches which are free-flowing.

In the river-run model, finite volumes of water, or water parcels, are released from an upstream starting point at specified intervals of time. Individual parcels are followed downstream through reservoirs and open river reaches, and changes in the parcel temperature due to weather, flow regulation, and advected sources are predicted.

The model development program was initiated at the beginning of FY 1968, and was conducted as the Columbia River Temperature Study, a Technical Project of WAPDA, Northwest Regional Office, until February 1968. Since that time the temperature prediction efforts have been incorporated, with the biological effects studies, into the Columbia River Thermal Effects Study. The purpose of the Study, a two-year program, is to provide a scientific basis for the evaluation of the temperature regime of the main stem Columbia River and its effects on the river's ecology, particularly upon the economically important anadromous fishery.

During FY 1968 a mathematical model of river-run reservoir water temperatures was developed and programmed. The model was tested on the portion of the Columbia River between Grand Coulee and Priest Rapids Dams. (See Figure 2.1) This model was limited to river systems which had no advected sources and provided reliable temperature predictions over periods of 10-14 days only. These restrictions have been eliminated in the present model, and portions of the net heat flux calculations have been updated, as well. In addition, test runs have been made on the Columbia River between Priest Rapids and Bonneville Dams, excluding the Hanford Operations area.

This model has been developed for the purpose of predicting temperatures in rivers which are regulated by dams with small storage capacity. It is essential for application of the model that the cross-sectional characteristics of the river be given. Furthermore, it has been assumed that:

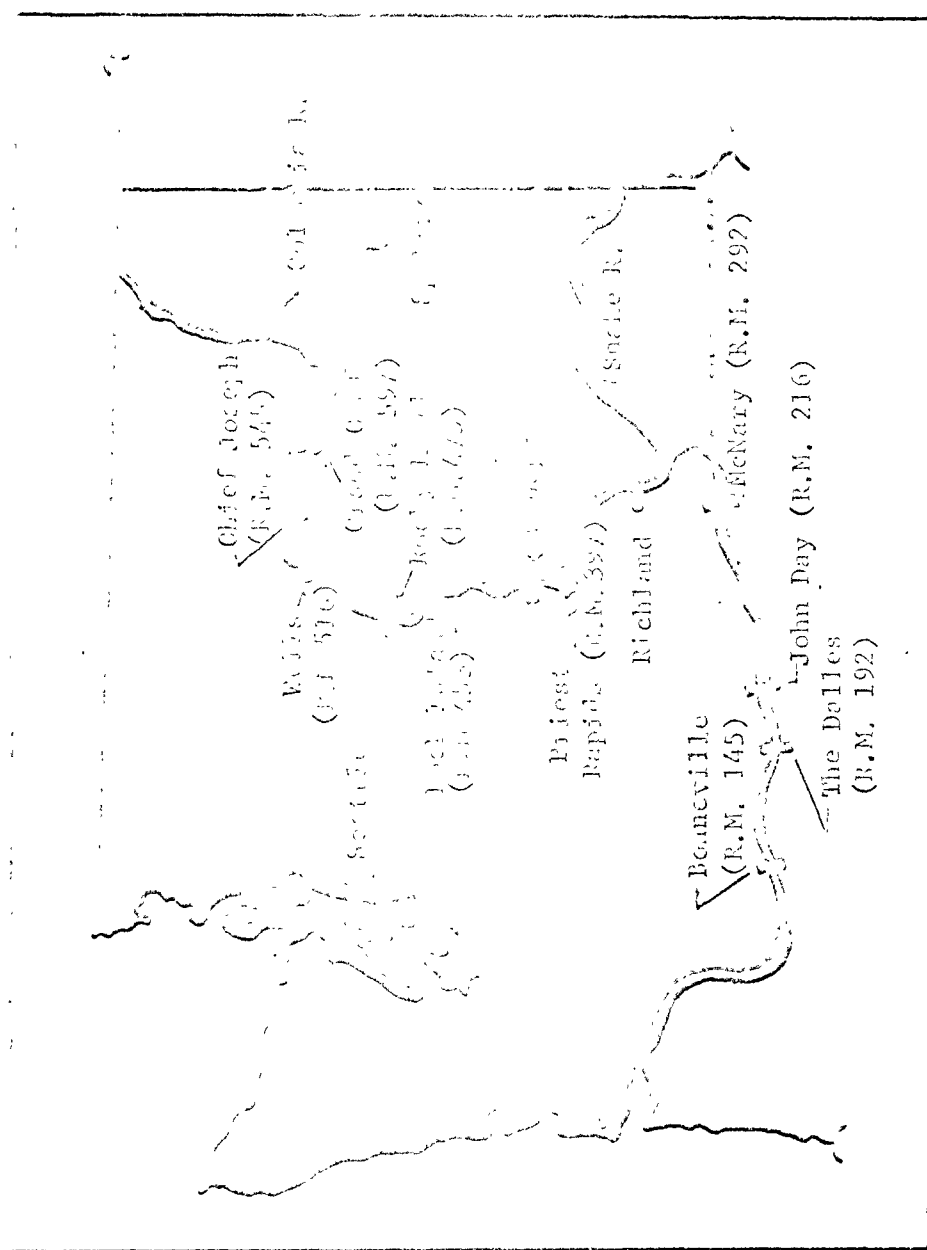
- (1) The prototype is thermally well-mixed vertically and laterally.
- (2) Longitudinal diffusion and dispersion can be neglected
- (3) The water surface profile between dams is a function of longitudinal distance only. (Water surface profile refers to the shape of the water surface as seen in a longitudinal section and does not imply an absolute surface elevation.
- (4) Weather data from a representative station is adequate for describing conditions along a specified portion of the river.
- (5) Empirically derived coefficients can be used to evaluate heat and mass transfer at the air-water interface.
- (6) Longitudinal variations in cross-sectional characteristics are important only insofar as they effect the water velocity.

Given the above assumptions, temperature changes can be predicted from the one-dimensional energy equation:

$$\frac{\partial T}{\partial t} + U \frac{\partial T}{\partial x} = \frac{Q}{\rho C_p D} \quad (3.1)$$

where

- T = water temperature
- U = longitudinal water velocity
- Q = net heat flux at the water surface
- t = time
- D = depth of water
- C_p = specific heat of water
- ρ = density of water



The heat flux, Q , is composed of the following terms:

- (1) Q_s - short wave incident solar radiation
- (2) Q_r - short wave reflected solar radiation
- (3) Q_a - net atmospheric radiation
- (4) Q_b - back, or emitted radiation from the water surface
- (5) Q_e - evaporative heat flux
- (6) Q_h - sensible heat conduction

$$Q = Q_s - Q_r - Q_a - Q_b - Q_e + Q_h \quad (3.2)$$

In the model, the net heat flux, Q , can be expressed as either a linear or parabolic function of the water temperature, T . The model has been programmed so that either function can be chosen, however, comparison of the two indicates that the linear function is adequate for normal conditions.

For the linear function:

$$Q = a_1 + b_1 T \quad (3.3)$$

and equation (3.1) becomes

$$\frac{dT}{dt} = \frac{a_1 + b_1 T}{\rho c_p \delta} \quad (3.4)$$

Integrating equation (3.4).

$$\frac{T - a_1/b_1}{T_0 - a_1/b_1} = e^{-b_1(T - T_0)/\rho c_p \delta} \quad (3.5)$$

where:

T_0 - the initial temperature

$a_1 = -A_1/3$

$b_1 = -A_2$

$T - T_0$ = exposure time

When the net heat flux, Q , is expressed as a parabolic function of the water temperature, T ,

$$Q = a_1 T^2 + a_2 T + a_3 \quad (3.6)$$

the integration yields:

$$\frac{T - T_0}{T_0 - T_0} = \frac{(T - T_0)}{(T_0 - T_0)} = \frac{-a_1(T - T_0)}{2a_1} \quad (3.7)$$

where

T_0 = the initial temperature

$$a_1 = \frac{-Q_1 - Q_2 - Q_3}{T_1^2 - T_2^2 - T_3^2}$$

$$a_2 = \frac{-Q_1 - Q_2 - Q_3}{T_1 - T_2 - T_3}$$

$$a_3 = \frac{-Q_1 - Q_2 - Q_3}{1}$$

$t - t_0$ = the exposure time

It should be pointed out that the sum of the heat fluxes in equation 3.2 is zero, when $T = a_2/a_1$, or, $T = a_2/a_1 = T_0$.

The temperature, T_0 , is referred to as the equilibrium water temperature.

Finally, if the velocity of the particle, $U(x,t)$, is known, the exposure time, $(t - t_0)$, can be determined from the equation:

$$t - t_0 = \frac{T - T_0}{U} \quad (3.8)$$

and the predicted temperature, T , can be determined from either equation 3.5 or 3.7.

To accommodate advected sources, such as tributary streams, the temperature of the advected source is mixed completely with the temperature calculated in equations 3.5 or 3.7, according to the ratios of their respective discharges.

Net Heat Flux- The functional relationship between the net heat flux, Q , and the water temperature, T , is determined by calculating the heat flux over a selected range of water temperature, say 50°F . to 60°F ., and fitting the resulting points to either a first- or second-order polynomial by the Method of Least Squares.

The following weather data is needed for these calculations:

- (1) incident solar radiation
- (2) wind speed
- (3) cloud cover
- (4) air temperature
- (5) wet-bulb temperature or dew-point
- (6) barometric pressure

This data should be obtained from a station with weather typical of the region in which the river system is located.

Before the net heat flux is calculated the meteorological data are averaged over a specified number of days. The individual fluxes are then determined in the following manner:

- (a) Q_s - obtained by measurement in an area with radiation characteristics similar to those of the river system

$$(b) Q_r = A_s \frac{Q_s}{A_r} \quad (4.1)$$

where A_s = sun's area
and A and B are functions of cloud cover as given in reference (2).

$$(c) Q_a = \frac{0.075}{A} \left(\frac{P}{P_0} \right)^{0.75} \left(\frac{T}{T_0} \right)^{1.25} \quad (4.2)$$

where k = Boltzmann's constant

T_0 = air temperature, $^{\circ}\text{Rankine}$

P = function of vapor pressure and cloud cover as given in reference (2).

$$(c) Q_3 = 0.47 \rho V (T_w - T_a) \quad (4.3)$$

where ρ and V are as previously defined, and
 T_w = water temperature

$$(d) Q_4 = \lambda K_1 \rho V (e_{ws} - e_a) \quad (4.4)$$

where
 λ = latent heat of vaporization
 K_1 = an empirical constant
 e_s = vapor pressure of water in saturated air at the temperature of the water
 e_a = vapor pressure of water in the ambient air
 V = wind speed

$$(e) Q_5 = \lambda K_2 \rho V (p_a - p_w) (T_a - T) \quad (4.5)$$

where ρ and V are as defined previously and
 K_2 = an empirical constant
 p_a = atmospheric pressure
 p_w = air pressure
 T_a = air temperature
 T = water temperature

Recapitulating:

$$Q = Q_1(1 - \alpha) + 0.47 \rho V (T_w - T_a) \rho + \lambda K_1 \rho V (e_{ws} - e_a) + \lambda K_2 \rho V (p_a - p_w) (T_a - T) \quad (4.6)$$

The values of Q_0 , h , h_0 , u , u_0 , h_1 , h_2 , and p_a are obtained either directly or indirectly from the meteorologic data and are fixed for each averaging period. The net heat flux, q , is determined by specifying the water temperature, T . A linear or second-order polynomial can be generated for each averaging period by calculating the heat flux, Q , for a range of water temperatures, T , and fitting the appropriate curve to the resulting points. As an example, weather data from Richland for the period August 20-29, 1967, collected by Donald E. Stormont and made available by the U.S. Atomic Energy Commission, has been used to determine heat flux-water temperature relationships for the Columbia River below Priest Rapids Dam (see Figure 2.1). The meteorologic data for the four six-hour daily periods, averaged over ten days is given in Table 4.1. For water temperatures between heat flux and water temperature for each of the four periods are shown in Table 4.2.

Exposure Time - The period of time during which each water particle is exposed to heating and cooling is determined from equation 3.8. This requires calculating the longitudinal velocity, $U(x,t)$, for the particle.

In order to make the calculations compatible with numerical analysis, the water particle has been replaced by a finite volume of water, or water parcel. Associated with each parcel as it leaves a particular dam is the dam discharge, Q_D , and the tailwater elevation, T_L , for that time period when it is discharged. The parcel retains these values until it reaches an advected source, or the next dam.

Assuming that the water surface profile is a known function of the longitudinal distance from the dam, and is independent of pool elevations and discharge; and given the geometric characteristics of cross-sectional

DATE PERIOD	TOTAL SOLAR RADIATION, BTU/FT. ² /HR	WIND SPEED, M.P.H.	CLOUD COVER, TENTHS	AIR TEMP., °F	WET BULB, °F	ATMOSPHERIC HUMIDITY, %
0000-0600	1.9	14.2	2	69.5	54.6	29.2
0600-1200	155.0	8.0	4	81.3	57.2	29.9
1200-1800	145.7	9.5	5	91.5	67.8	29.9
1800-2400	1.0	10.0	3	78.3	57.1	29.9

TABLE 4.1

Weather Data From Lichland for Year (4) daily
Period: Averaged Over Ten Days (August 20-29 1967)

TIME PERIOD	LINEAR RELATIONSHIP $Q = H_0 / ft. / h_0^2 / h_0, t. / h_0$	PARABOLIC RELATIONSHIP $Q = H_0 / ft. / h_0^2 / h_0, t. / h_0$
0000-0600	$Q = 332 \pm 6.31T$	$Q = 228 \pm 2.50T + 0.0268T^2$
0600-1200	$Q = 377 \pm 3.55T$	$Q = 334 \pm 1.96T + 0.616T^2$
1200-1800	$Q = 417 \pm 4.67T$	$Q = 334 \pm 2.29T + 0.516T^2$
1800-2400	$Q = 389 \pm 6.96T$	$Q = 287 \pm 3.25T + 0.622T^2$

TABLE 4.2 Linear and Parabolic equations relating heat flux and water temperature for the meteorology given in Table 4.1.

area and water surface width, as a function of longitudinal distance and water surface level, the pool geometry can be determined.

The water surface profile, determined from the difference between the tailwater elevation of the upstream dam and the water surface elevations at selected stations can be obtained from backwater calculations or available stage records. Profiles obtained from backwater calculations or stage records are generally a function of dam discharge and pool elevation, and it is necessary to define a "representative" profile which will be independent of these effects.

Location of the profile is determined by the tailwater elevation of the upstream dam. This will give a satisfactory water surface level providing dam discharges and pool elevations are varied gradually, and that stretches of the river which are free-flowing are either very small or very large compared to that part which is impounded.

The geometric characteristics of cross-sectional area and water surface width are determined from available data such as sounding charts. River reaches between dams are divided into sub-reaches and representative cross-sectional data are assigned to each sub-reach.

Figure 4.1 is a schematic diagram of the idealized river as used in the model. The river reach between dam 1 and dam 2 is divided into sub-reaches. The longitudinal distance of each section, N , from the origin is $X(N)$. The water surface profile is determined by the values, $CTE(N)$, which are functions of longitudinal distance only. The absolute surface elevation at each section, N , is:

$$E(N) = T_1 - CTE(N) \quad (4.7)$$

where T_1 is the tailwater elevation of the upstream dam referenced to some datum.

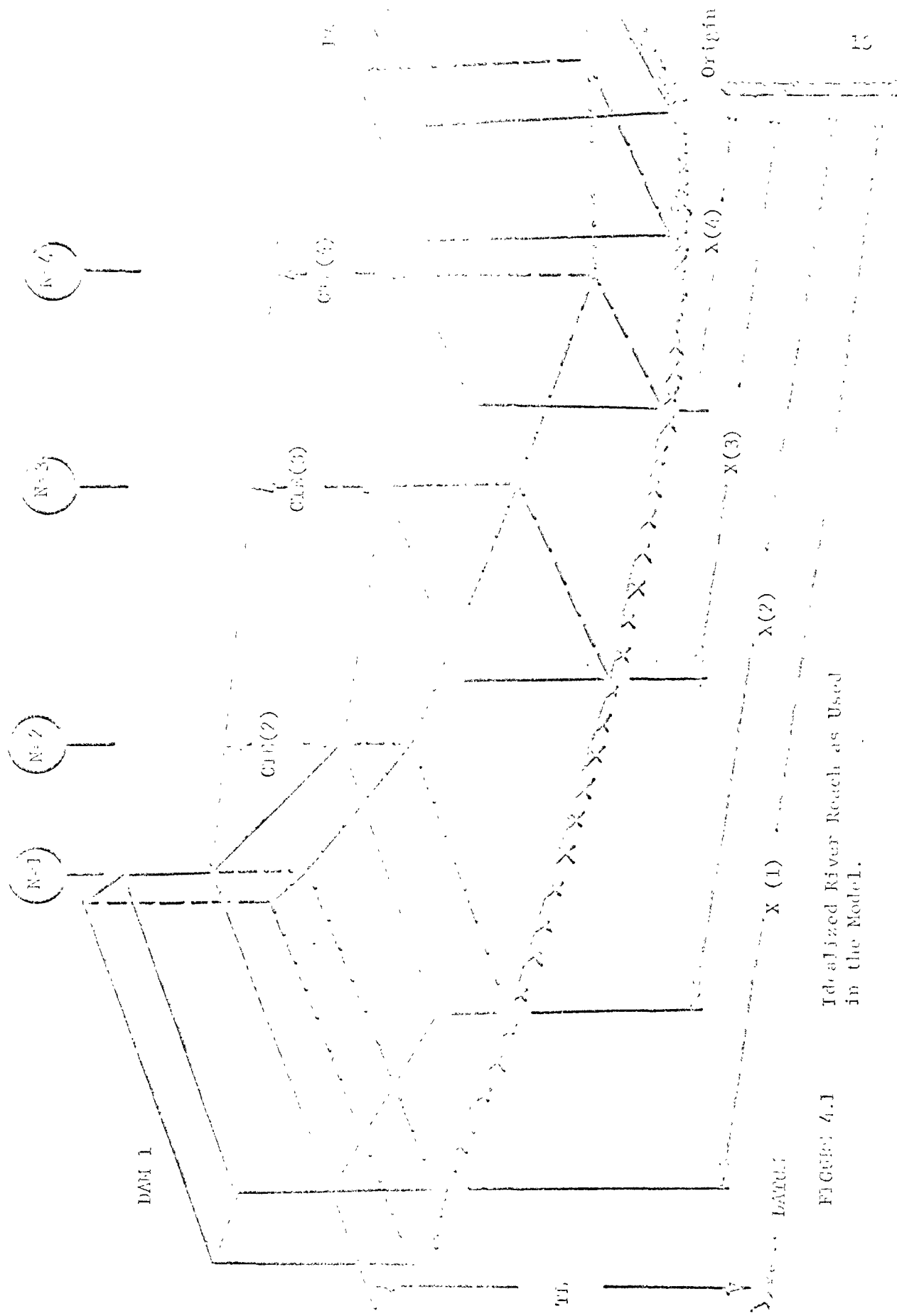


FIGURE 4.1 Idealized River Reach as Used in the Model.

Representative cross-sectional characteristics are given at each of the sections, N . The cross-sectional characteristics at each station must be specified for various surface elevations, covering the entire range of elevations which are occur during the modelling period.

If the maximum tailwater elevation at the upstream dam is TW_{max} and the minimum is TW_{min} and the distance below the tailwater is $OTD(N)$ at section N , then the table containing cross-sectional characteristics must cover the range of heights.

$$TW_{min} - OTD(N) \leq TW_{max} - OTD(N)$$

$Z(N)$ is the water surface height at which the cross-sectional area and water surface width are specified. The manner in which this data must be prepared is described in more detail in Appendix B.

Parcel velocities are calculated as follows:

- (1) The leading edge of the parcel, P , is flagged as it leaves the dam (Figure 4.2a). Associated with the parcel is the dam tailwater elevation and discharge for the time period during which the parcel is released.
- (2) The geometrical characteristics of the sub-reach in which the parcel is located is taken as the average of these values at section N and $N+1$, which constitute the upstream and downstream boundary of the sub-reach respectively.

The surface elevation at section N is

$$Z_p(N) = TW_p - OTD(N)$$

and at $N + 1$

$$Z_p(N+1) = TW_p - OTD(N+1)$$

The values of $Z_p(N)$ and $Z_p(N+1)$ are used to enter the tables containing cross-sectional area, $AX(Z_p(N), N)$ and $AX(Z_p(N+1), N+1)$ and water surface width $WX(Z_p(N), N)$ and $WX(Z_p(N+1), N+1)$.

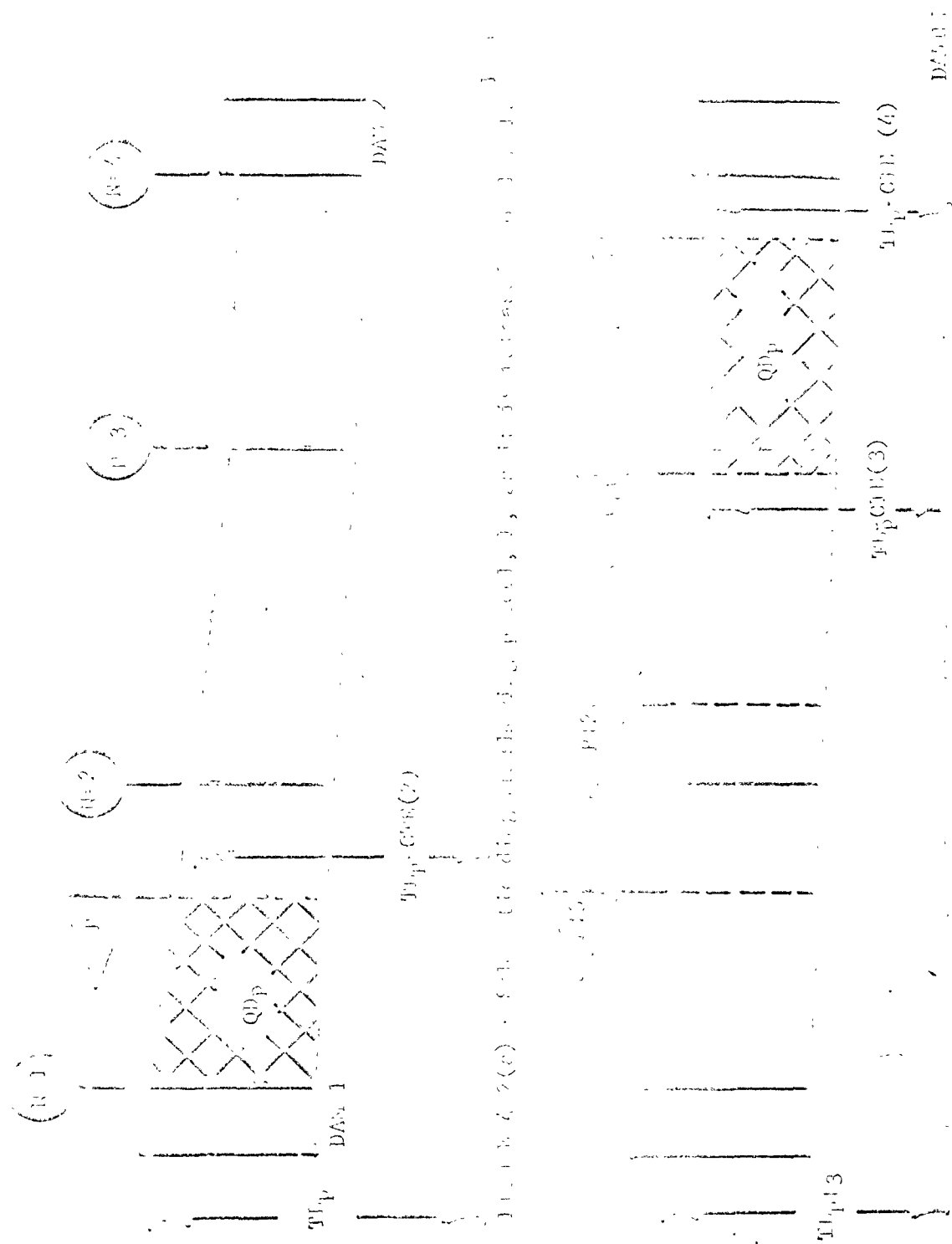


FIGURE 4.2(b) - Schematic diagram showing panel, P, after processing through two river sections.

(3) The average cross-sectional area and width are calculated:

$$\langle AX \rangle = \frac{AX(Z_p(N), N) + AX(Z_p(N+1), N+1)}{2}$$

$$\langle AX \rangle = \frac{AX(Z_p(N), N) + AX(Z_p(N+1), N+1)}{2}$$

(4) The discharge used to determine the velocity of parcel, P , is a function of all the parcels in the reach behind P . This is so because the hydraulic model is a kinematic model and involves only a solution of the continuity equation. To account for the effect of parcels behind parcel, P , the velocity, Q_p , is:

$$Q_p = Q_p \frac{Q_p}{Q_p}$$

where in the example of Figure 4.1b

$$QD_p^i = \frac{(QD_p + (QD_{p+1}^2 + Q_{p+2}^2 QD_{p+3}^2))}{QD_p} \\ \frac{1 + (QD_{p+1} + Q_{p+2} + QD_{p+3})}{QD_p}$$

For constant cross-sectional area, it can be shown that QD_p^i is a length average of QD_p , QD_{p+1} , Q_{p+2} , and QD_{p+3} .

The nominal depth is

$$D = \frac{Q_p}{Q_p}$$

The value of the longitudinal velocity, $\bar{U}_p$, is used in equation 3.6, to determine the exposure time, (t_{exp}) , which, in turn, is used with $\bar{U}_p$, and the $\bar{C}_p$, $\bar{D}_p$, and $\bar{T}_p$ values appropriate to that time period, for predicting the water temperature. The value of $\bar{U}_p$ is also used to determine how far the front of the parcel has traveled.

When a new reach is encountered the longitudinal velocity, $\bar{U}_p$, and nominal depth, $\bar{D}_p$, are recalculated. The same discharge, QD_p , is used, but new geometric characteristics will be necessary.

If a new time period begins the values of $\bar{C}_p$, $\bar{D}_p$, and $\bar{T}_p$ are updated.

(5) Parcel temperature, T_p , is recorded or reinitialized as the flagged portion reaches those stations at which these operations have been specified.

(6) When the parcel, p , reaches stations with an advected source, the temperature, T_{ADV} , of the source is mixed into the main stream according to equation (3.5)

(7) Upon leaving the advected source, the parcel will have a new discharge:

$$QD_p = QD_p + QD_{ADV}$$

but the same tailwater, TW_p .

(8) When the parcel, p , for the last time period, reaches a new dam the parcel assumes a discharge and tailwater elevation equal to that of the new dam for the time period during which the parcel arrived at the new dam. If the new dam is the last dam, calculations begin for the second time period as parcel, $p+1$, from the first dam.

MODEL TESTING

The model has been tested using Gold and River main-stem reservoirs as prototypes. Description of the various cases is given in Table 5.1, and Figure 2.1 shows the location of the projects. Temperatures of parcels at selected points for one case are shown in Figure 5.1 - 5.5. Where sufficient data were available, predicted temperatures were compared with observed.

Suitable data for comparison of predicted and observed travel times were not available.

In all the test cases, heat flux associated with evaporation and sensible heat conduction have been calculated from equation 4.4 and 4.5, using the empirical constants obtained from the Lake Meiner study (1). It would be possible to find the best fit between observed and predicted data by varying these empirical constants. This would not be meaningful unless errors in other heat flux calculations, hydraulic calculations, observed temperature data and meteorologic data could be controlled more precisely.

CONDITION	DATE	FIRST DAM	LAST DAM	SECTION PROPOSED - MILLBURY CO. DAM
1	July 22-31 1966	Grand Coulee (R.M. 597)	Priest Rapids (R.M. 397)	Venture PWA
2	August 20 Sept. 12, 1967	Priest Rapids (R.M. 397)	Bear Valley (R.M. 145)	Harvard
3	Sept. 14, 1967	Wing (R.M. 510)	Red Bluff (R.M. 453)	Venture PWA

TABLE 5.1

Description of conditions used for testing the one-dimensional temperature model.

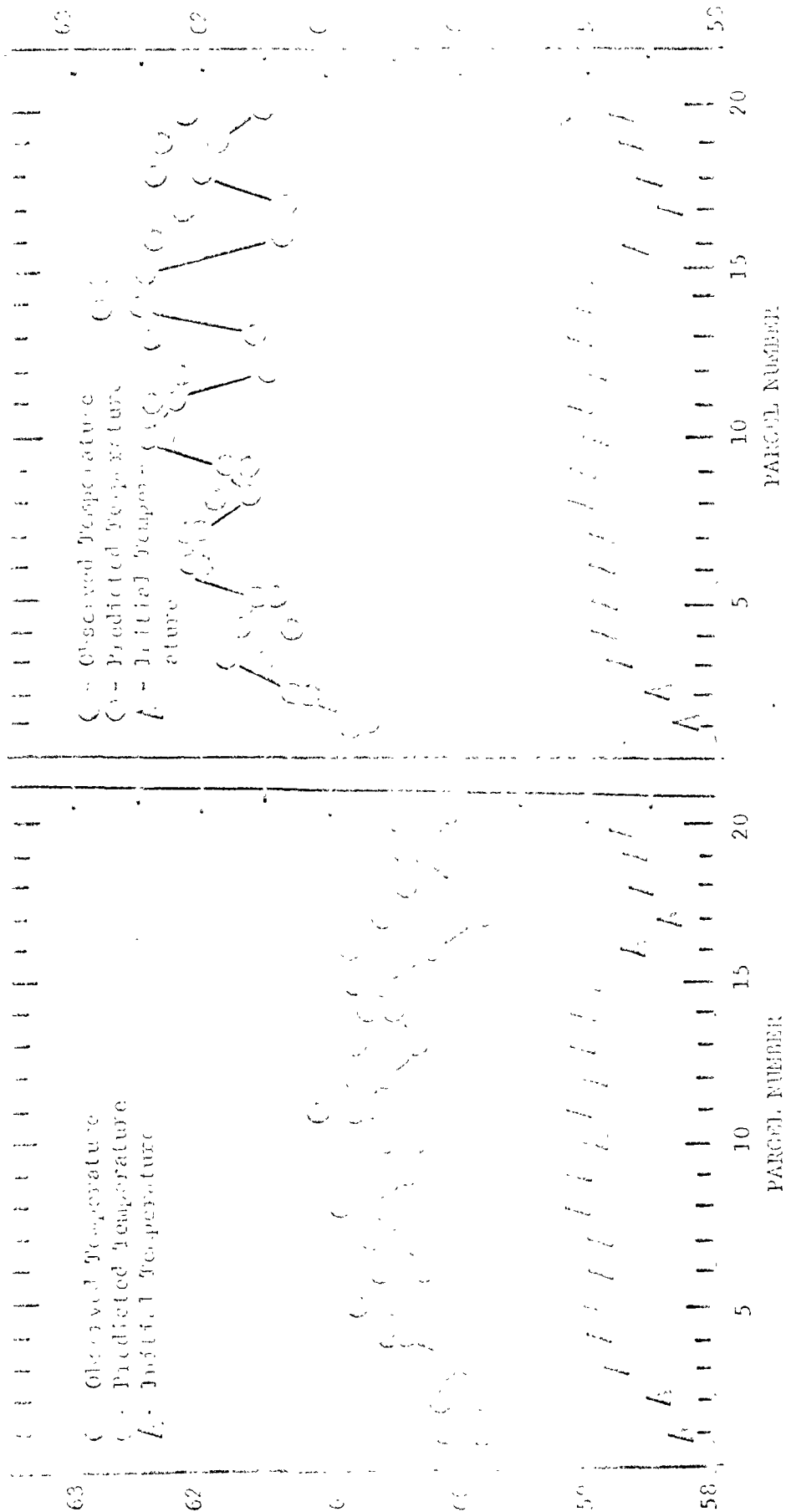


FIGURE 5.1 Analysis of Water Temperatures at Rocky Reach Dam For Condition 1 In Table 5.1

FIGURE 5.2 Analysis of Water Temperatures at Priest Rapids Dam For Condition 1 In Table 5.1

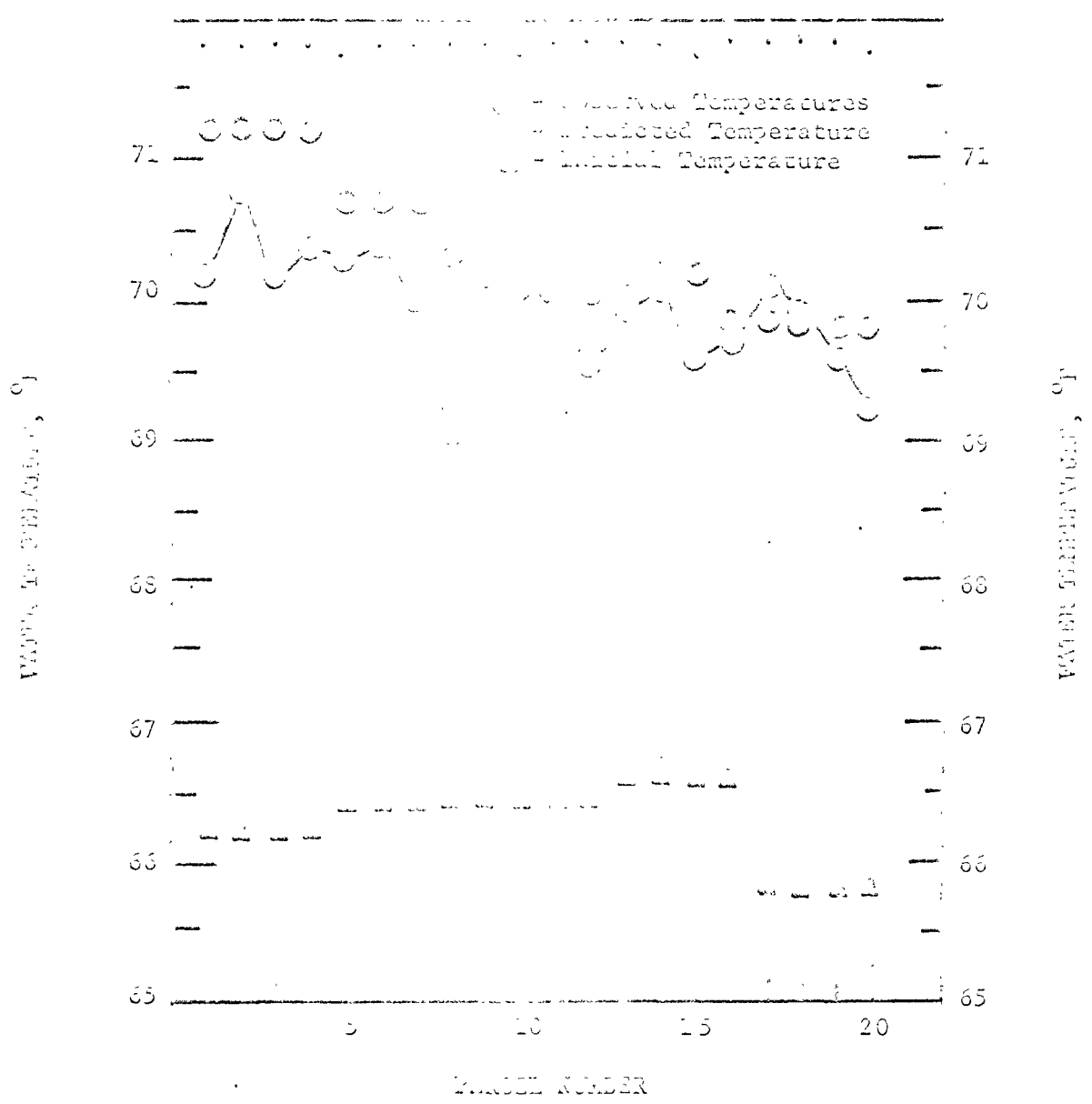


FIGURE 5.1 Analysis of
Water Temperatures at Bonneville
Dam for Condition 2 in Table 5.1

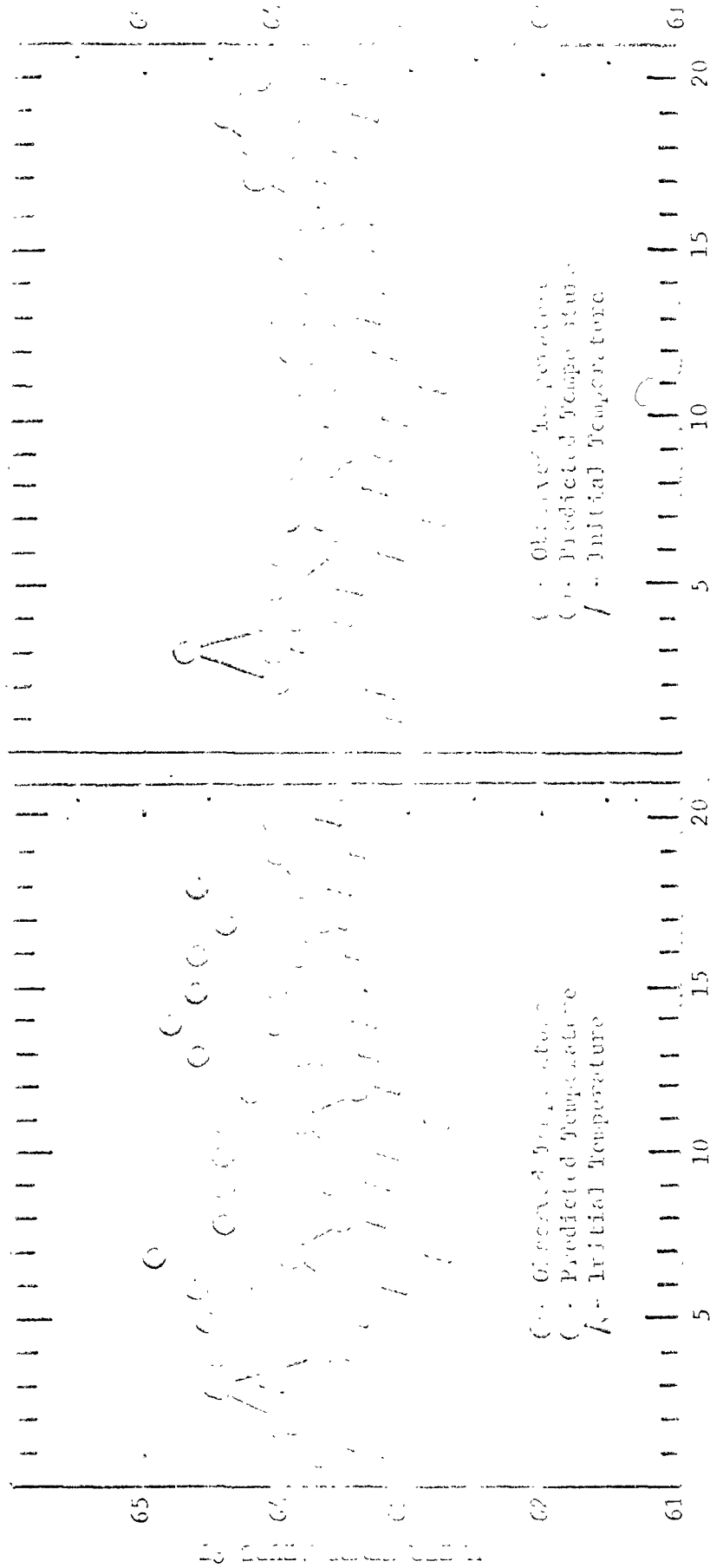


FIGURE 5.4 Analysis of Water Temperature at Rocky Keyhole Den for Condition 3 in 1965

FIGURE 5.5 Analysis of Water Temperature at Rocky Keyhole Den for Condition 3 in 1961

Two subroutines are being developed which will eliminate some of the restrictions associated with the present model. One subroutine calculates solar radiation using available techniques (3) and the other subroutine calculates backwater profiles (4).

Study of other problem areas, including evaporation and sensible heat fluxes, diffusion and dispersion processes and unsteady flow, will continue.

- (1) _____ "Water-Loss Investigations, Lake Refner Studies, Technical Report," U.S.C.S. Professional Paper 169, U.S. Government Printing Office, Washington, D.C.:1954
- (2) Raphael, J.M., "Prediction of Temperature in Rivers and Reservoirs," Journal of the Power Division, ASCE, July 1962, pp 157-161.
- (3) _____ "Heat and Mass Transfer between a Water Surface and the Atmosphere," (Preliminary edition)", Tennessee Valley Authority, Norris, Tennessee, July, 1967.
- (4) Prasad, R., _____ "A Numerical Method of Computing Gradually Varied Flow Profiles", Specialty Conference of Hydraulics Division, ASCE, I.I.T., Cambridge, Massachusetts, August, 1968.

A-1. Description of the Computer Program

The computer program, which calculates water temperatures according to the principles described in the main portion of the report, has been coded in FORTRAN IV. The program contains one MAIN program and nine sub-programs. The MAIN program is a controlling program only, the function of the other programs is as follows:

- (1) HYRMD - Reads in river geometry, dam discharge and tailwater elevation and advected source discharge.
- (2) TMRMD - Reads in meteorological data and averages the data over specified periods.
- (3) TMRSD - Reads in temperature input, stations at which parcel temperatures are to be reinitialized, stations where temperatures are to be printed, and temperatures of advected sources.
- (4) TMDV1 - Reads in α and β and proceeds down the river, making use of subprograms TMDV2 and TMDV2 for determination of parcel temperatures and travel times.
- (5) TMDV2 - Calculates parcel velocity using the method of Section 4.
- (6) TMDV3 - Calculates the parcel temperature using equation (3.5) or (3.7), depending upon whether a linear or parabolic function relating heat budget and water temperature is desired.
- (7) TMDV4 - Calculates the net heat flux, Q , using relationships described in Section 4. An array of heat budget versus water temperature is generated for each averaging period and the appropriate coefficients in equation (3.3) or (3.6) are calculated from the end of CRVXZQ.
- (8) CRVXZQ - A curve fitting routine using the Method of Least Squares.
- (9) TMDV5 - Prints and predicts, observed and initial parcel temperatures, as well as arrival times and travel times, for each parcel at specified stations.

The intention has been to design the program in modular form, so that various parts of the program, particularly input and output, can be easily

modified.

A-2. Data Requirements

Data requirements for running the program can be divided into four categories:

I. Hydraulic Data

1. Section number
2. River mile of each section
3. Distance of water surface level below the tailwater elevation of the upstream dam, in feet.
4. Cross-sectional area, in square feet, and water surface width, in feet, for various water levels at each section.
5. Dam discharges in 1000 cfs and tailwater elevations in feet above datum.
6. Discharge from advanced sources, in 1000 cfs.

II. Meteorologic Data

1. Incident solar radiation in Langley's or BTU/ft.²/hr.
2. Cloud cover in number of eighths
3. Air pressure in inches of mercury
4. Wind speed in knots or miles per hour
5. Air temperature in °F or °C.
6. Wet-bulb temperature or dew-point in °F or °C.

III. Water Temperature Data

1. Initial temperature of parcels
2. Station numbers associated with temperature input
3. Station numbers associated with output temperatures
4. Station numbers whose parcel temperatures are to be reinitialized (a subset of III.2 above)

IV. Systems Information

1. Seven cards are reserved for supplying labelling information such as location of river basin, stations providing meteorology data, time periods covered by analysis, etc.

APPENDIX A

A.1. Preparation of Cards

The data cards are prepared in four groups, corresponding to those described in the Appendix A-1. A sample set of data as arranged on punched cards is given in Appendix A.1. The numbers in the left edge of the sample data print-out correspond to the numbers given below.

A.1.1 FORMAT (6I5, F15.10)

NADV - number of advected sources
 NDAMS - number of dams
 NDAYS - number of days parcels are released from the first dam
 NDQ - number of days of discharge
 NPD - number of periods into which each day is divided
 NSECT - number of sections into which river is divided
 DZ - the height increment at which cross-sectional area and water surface width are specified

A.1.2 FORMAT (I5, F6.1, F4.1, F5.0, 5(F7.0, F5.0), I1)

N_i - section number, beginning with one (1) at the first upstream dam and increasing consecutively downstream. The first station is at the downstream face of the first dam. Between dams the river may be divided into as many sections as are needed. At subsequent downstream dams, however, there must be a station at the upstream face and the downstream face, to account for the drop taken by the dam.

X(N) - river name or section, N

CTE(N) - distance in feet, of the water surface at station N below the tailwater of the upstream dam.

CD(N) - lowest elevation at station N for which cross-sectional area and water surface width are specified

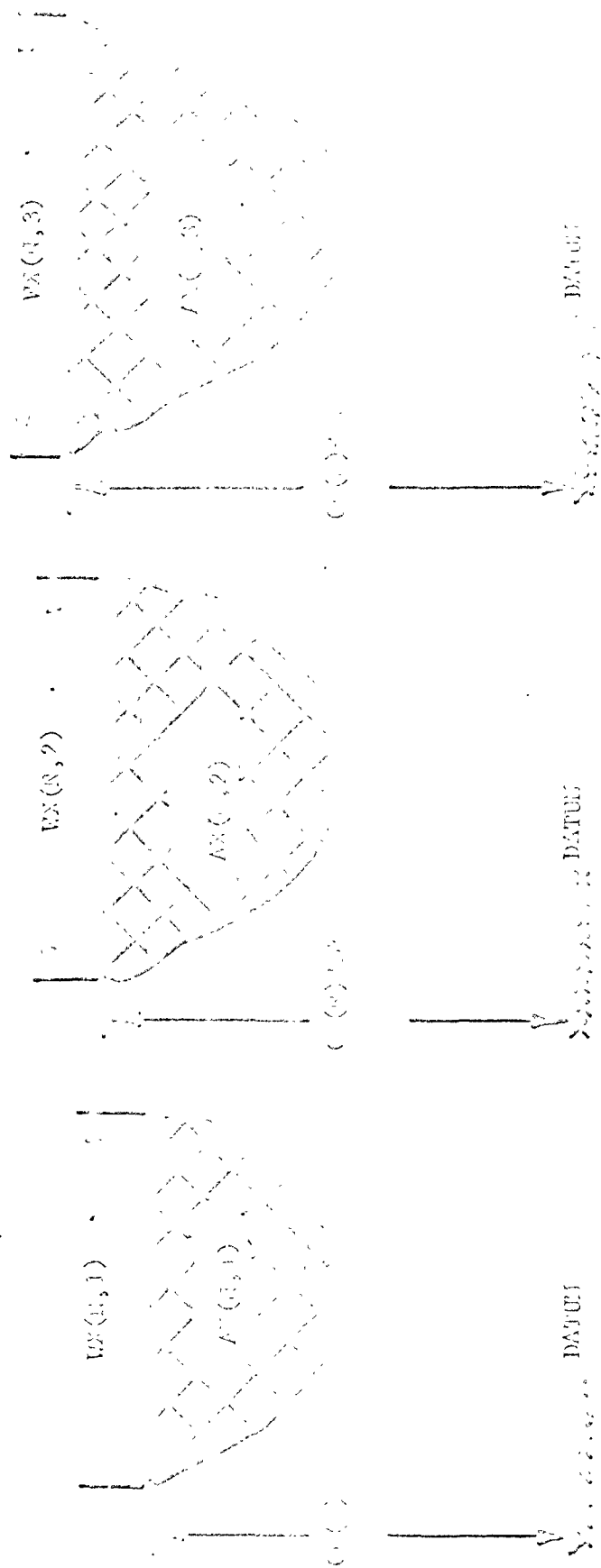


FIGURE 11-2.1 Schematic Diagram Showing Low Cross-Sectional Data to be Specified at Station N.

AX(N,1) - cross-sectional area at station N for the water surface elevation, CD(N), in ft². See Figure B.2-1.

WX(N,1) - water surface width, in feet, at station N for the water surface elevation CD(N). See Figure B.2-1.

AX(N,2) - as above for water surface level, CD(N)+DZ

WX(N,2) - as above for water surface level, CD(N)+DZ

AX(N,3) CD(N)+2DZ

WX(N,3) CD(N)+2DZ

AX(N,4) CD(N)+3DZ

WX(N,4) CD(N)+3DZ

AX(N,5) CD(N)+4DZ

WX(N,5) CD(N)+4DZ

IOK - an indicator for determining the last geometry card for each station. If IOK = 0, there are more cards to follow. IOK = 1 indicates the last geometry card for station N.

Continue in the above manner until all station geometry is recorded.

1.3 FORMAT (211, 12N, 5 (10.1, 11)

M - dam number

ID(M) - section number of dam M. Corresponds to section number at the downstream face of dam M.

ELF(M,1) - elevation elevation of dam M, in feet on day 1 of the simulation.

QD(M,1) - discharge in 100 cfs for first daily time period

QD(M,2) - as above for second time period, if necessary

QD(M,3) - as above for third time period, if necessary

QD(M,4) - as above for fourth time period, if necessary

Continue as above for as many days as there are dam discharges.

1.4 FORMAT (111, 10N, 4 (10.1, 11)

N - number of stations

QADV(A) - section number of advected source

QADV(A,1) - discharge in adv. sed. source, or in 1000 cfs for
the first time period.

QADV(A,2) - as above for the second time period, if necessary

QADV(A,3) - as above for the third time period, if necessary

QADV(A,4) - as above for the fourth time period, if necessary

III.1 FORMAT (515)

NDNET - number of days of meteorologic data

NMVG - number of days over which meteorologic data is averaged

NMD - number of meteorologic variables per day

MAXT - maximum water temperature for heat budget calculations

MINT - minimum water temperature for heat budget calculations

III.2 FORMAT (955.C)

PHI - the index of the river system

DISTL - the difference between local time of the river system and
standard time. Positive if the local meridian is greater
than the standard meridian, negative otherwise (for
west longitude only.)

DAY1 - first day of analysis

III.3 FORMAT (715)

IS1 = 1 Radiation in BTU, 10^4 /hr
= 2 Radiation in Langley/s

IS2 = 1 wind speed in mph
= 2 wind speed in knots

IS3 = 1 air temperature in °C
2 air temperature in °F

IS4 = 1 wet bulb temperature as input
= 2 dew point temperature as input

IS5 = 1 solar radiation as input

IS6 = 1 water head as the information
= 2 as for water head budget information

17 = 1 linear input-output relationship
 = 2 parabolic input-output relationship

51

III.4 FORMAT (1210.0)

C10 - evaporation coefficient lb./mile/ft.²/°F

C14 - sensible heat evaporation coefficient, lb./mile/ft.²/°F.

III.5 FORMAT (1004)

PLAT - FORMULA in FORMAT statement for reading meteorological data

III.6 FORMAT - specification of data (see above III.5). Data must appear in the following order, however:

A9 - incident solar radiation in langley/hr or BTU/ft.²/hr

B9 - cloud cover in number of tenths

C9 - wind speed in mph or knots

D9 - air temperature in °C or °F

E9 - wet bulb or dew point temperature in °C or °F

F9 - air pressure in mm. Hg.

III.1 FORMAT (15)

NTI - number of stations when temperature input

III.2 FORMAT/315/(1000.0)

IDIN(N) - station number of temperature input

NTIN(N) - number of temperature values at station N

ICFIN = 1 if °F
 = 2 if °C

THR(N,J) - temperature at station N for time period. J=1,
 NTIN(N) if °F or °C

III.3 FORMAT (15)

NCRNG - number of stations at which temperature is to be
 reinitialized.

III.4 FORMAT (20 A4/15)

XCRNG(N,J) - label for station in at which parcel temperatures
 are to be reinitialized

INDCING(N) - number of stations at which temperature is to be
measured.

III.5 FORMAT (415)

NIP - number of stations at which parcel temperatures are
to be predicted.

TEMPRT = 1 if parcel surface temperature is $^{\circ}\text{C}$

III.6 FORMAT (26 14 14)

LOCN (N,C) - location of primary temperature output location

IDTP(N) - order of location of the high temperature output
location

III.7 FORMAT (101,10, 10 10)

TEMPIN = 1 if meteorological temperature is in $^{\circ}\text{C}$
= 2 if meteorological temperature is in $^{\circ}\text{F}$

INDV(N,C) - component of recorded source at station N.
C = 1,2,3,4,5,6,7,8,9,10,11,12,13

IV.1 FORMAT (1014)

NOT REC (N,C) - number of organization performing work,
and covered by analysis, and date of analysis
C = 1,2,3,4,5,6,7,8,9,10,11,12,13

A listing of the program and a sample of the output are given in
Appendix C and D.

[illegible]

```

10  (C1,C2,C3) = CO 10 20
100  CONTINUE
101  C1 = C1 + 1
102  C2 = C2 + 1
103  C3 = C3 + 1
104  IF (C1 .EQ. 10) GO TO 100
105  IF (C2 .EQ. 10) GO TO 100
106  IF (C3 .EQ. 10) GO TO 100
107  CONTINUE
108  C1 = C1 + 1
109  C2 = C2 + 1
110  C3 = C3 + 1
111  IF (C1 .EQ. 10) GO TO 100
112  IF (C2 .EQ. 10) GO TO 100
113  IF (C3 .EQ. 10) GO TO 100
114  CONTINUE
115  C1 = C1 + 1
116  C2 = C2 + 1
117  C3 = C3 + 1
118  IF (C1 .EQ. 10) GO TO 100
119  IF (C2 .EQ. 10) GO TO 100
120  IF (C3 .EQ. 10) GO TO 100
121  CONTINUE
122  C1 = C1 + 1
123  C2 = C2 + 1
124  C3 = C3 + 1
125  IF (C1 .EQ. 10) GO TO 100
126  IF (C2 .EQ. 10) GO TO 100
127  IF (C3 .EQ. 10) GO TO 100
128  CONTINUE
129  C1 = C1 + 1
130  C2 = C2 + 1
131  C3 = C3 + 1
132  IF (C1 .EQ. 10) GO TO 100
133  IF (C2 .EQ. 10) GO TO 100
134  IF (C3 .EQ. 10) GO TO 100
135  CONTINUE
136  C1 = C1 + 1
137  C2 = C2 + 1
138  C3 = C3 + 1
139  IF (C1 .EQ. 10) GO TO 100
140  IF (C2 .EQ. 10) GO TO 100
141  IF (C3 .EQ. 10) GO TO 100
142  CONTINUE
143  C1 = C1 + 1
144  C2 = C2 + 1
145  C3 = C3 + 1
146  IF (C1 .EQ. 10) GO TO 100
147  IF (C2 .EQ. 10) GO TO 100
148  IF (C3 .EQ. 10) GO TO 100
149  CONTINUE
150  C1 = C1 + 1
151  C2 = C2 + 1
152  C3 = C3 + 1
153  IF (C1 .EQ. 10) GO TO 100
154  IF (C2 .EQ. 10) GO TO 100
155  IF (C3 .EQ. 10) GO TO 100
156  CONTINUE
157  C1 = C1 + 1
158  C2 = C2 + 1
159  C3 = C3 + 1
160  IF (C1 .EQ. 10) GO TO 100
161  IF (C2 .EQ. 10) GO TO 100
162  IF (C3 .EQ. 10) GO TO 100
163  CONTINUE
164  C1 = C1 + 1
165  C2 = C2 + 1
166  C3 = C3 + 1
167  IF (C1 .EQ. 10) GO TO 100
168  IF (C2 .EQ. 10) GO TO 100
169  IF (C3 .EQ. 10) GO TO 100
170  CONTINUE
171  C1 = C1 + 1
172  C2 = C2 + 1
173  C3 = C3 + 1
174  IF (C1 .EQ. 10) GO TO 100
175  IF (C2 .EQ. 10) GO TO 100
176  IF (C3 .EQ. 10) GO TO 100
177  CONTINUE
178  C1 = C1 + 1
179  C2 = C2 + 1
180  C3 = C3 + 1
181  IF (C1 .EQ. 10) GO TO 100
182  IF (C2 .EQ. 10) GO TO 100
183  IF (C3 .EQ. 10) GO TO 100
184  CONTINUE
185  C1 = C1 + 1
186  C2 = C2 + 1
187  C3 = C3 + 1
188  IF (C1 .EQ. 10) GO TO 100
189  IF (C2 .EQ. 10) GO TO 100
190  IF (C3 .EQ. 10) GO TO 100
191  CONTINUE
192  C1 = C1 + 1
193  C2 = C2 + 1
194  C3 = C3 + 1
195  IF (C1 .EQ. 10) GO TO 100
196  IF (C2 .EQ. 10) GO TO 100
197  IF (C3 .EQ. 10) GO TO 100
198  CONTINUE
199  C1 = C1 + 1
200  C2 = C2 + 1
201  C3 = C3 + 1
202  IF (C1 .EQ. 10) GO TO 100
203  IF (C2 .EQ. 10) GO TO 100
204  IF (C3 .EQ. 10) GO TO 100
205  CONTINUE
206  C1 = C1 + 1
207  C2 = C2 + 1
208  C3 = C3 + 1
209  IF (C1 .EQ. 10) GO TO 100
210  IF (C2 .EQ. 10) GO TO 100
211  IF (C3 .EQ. 10) GO TO 100
212  CONTINUE
213  C1 = C1 + 1
214  C2 = C2 + 1
215  C3 = C3 + 1
216  IF (C1 .EQ. 10) GO TO 100
217  IF (C2 .EQ. 10) GO TO 100
218  IF (C3 .EQ. 10) GO TO 100
219  CONTINUE
220  C1 = C1 + 1
221  C2 = C2 + 1
222  C3 = C3 + 1
223  IF (C1 .EQ. 10) GO TO 100
224  IF (C2 .EQ. 10) GO TO 100
225  IF (C3 .EQ. 10) GO TO 100
226  CONTINUE
227  C1 = C1 + 1
228  C2 = C2 + 1
229  C3 = C3 + 1
230  IF (C1 .EQ. 10) GO TO 100
231  IF (C2 .EQ. 10) GO TO 100
232  IF (C3 .EQ. 10) GO TO 100
233  CONTINUE
234  C1 = C1 + 1
235  C2 = C2 + 1
236  C3 = C3 + 1
237  IF (C1 .EQ. 10) GO TO 100
238  IF (C2 .EQ. 10) GO TO 100
239  IF (C3 .EQ. 10) GO TO 100
240  CONTINUE
241  C1 = C1 + 1
242  C2 = C2 + 1
243  C3 = C3 + 1
244  IF (C1 .EQ. 10) GO TO 100
245  IF (C2 .EQ. 10) GO TO 100
246  IF (C3 .EQ. 10) GO TO 100
247  CONTINUE
248  C1 = C1 + 1
249  C2 = C2 + 1
250  C3 = C3 + 1
251  IF (C1 .EQ. 10) GO TO 100
252  IF (C2 .EQ. 10) GO TO 100
253  IF (C3 .EQ. 10) GO TO 100
254  CONTINUE
255  C1 = C1 + 1
256  C2 = C2 + 1
257  C3 = C3 + 1
258  IF (C1 .EQ. 10) GO TO 100
259  IF (C2 .EQ. 10) GO TO 100
260  IF (C3 .EQ. 10) GO TO 100
261  CONTINUE
262  C1 = C1 + 1
263  C2 = C2 + 1
264  C3 = C3 + 1
265  IF (C1 .EQ. 10) GO TO 100
266  IF (C2 .EQ. 10) GO TO 100
267  IF (C3 .EQ. 10) GO TO 100
268  CONTINUE
269  C1 = C1 + 1
270  C2 = C2 + 1
271  C3 = C3 + 1
272  IF (C1 .EQ. 10) GO TO 100
273  IF (C2 .EQ. 10) GO TO 100
274  IF (C3 .EQ. 10) GO TO 100
275  CONTINUE
276  C1 = C1 + 1
277  C2 = C2 + 1
278  C3 = C3 + 1
279  IF (C1 .EQ. 10) GO TO 100
280  IF (C2 .EQ. 10) GO TO 100
281  IF (C3 .EQ. 10) GO TO 100
282  CONTINUE
283  C1 = C1 + 1
284  C2 = C2 + 1
285  C3 = C3 + 1
286  IF (C1 .EQ. 10) GO TO 100
287  IF (C2 .EQ. 10) GO TO 100
288  IF (C3 .EQ. 10) GO TO 100
289  CONTINUE
290  C1 = C1 + 1
291  C2 = C2 + 1
292  C3 = C3 + 1
293  IF (C1 .EQ. 10) GO TO 100
294  IF (C2 .EQ. 10) GO TO 100
295  IF (C3 .EQ. 10) GO TO 100
296  CONTINUE
297  C1 = C1 + 1
298  C2 = C2 + 1
299  C3 = C3 + 1
300  IF (C1 .EQ. 10) GO TO 100
301  IF (C2 .EQ. 10) GO TO 100
302  IF (C3 .EQ. 10) GO TO 100
303  CONTINUE
304  C1 = C1 + 1
305  C2 = C2 + 1
306  C3 = C3 + 1
307  IF (C1 .EQ. 10) GO TO 100
308  IF (C2 .EQ. 10) GO TO 100
309  IF (C3 .EQ. 10) GO TO 100
310  CONTINUE
311  C1 = C1 + 1
312  C2 = C2 + 1
313  C3 = C3 + 1
314  IF (C1 .EQ. 10) GO TO 100
315  IF (C2 .EQ. 10) GO TO 100
316  IF (C3 .EQ. 10) GO TO 100
317  CONTINUE
318  C1 = C1 + 1
319  C2 = C2 + 1
320  C3 = C3 + 1
321  IF (C1 .EQ. 10) GO TO 100
322  IF (C2 .EQ. 10) GO TO 100
323  IF (C3 .EQ. 10) GO TO 100
324  CONTINUE
325  C1 = C1 + 1
326  C2 = C2 + 1
327  C3 = C3 + 1
328  IF (C1 .EQ. 10) GO TO 100
329  IF (C2 .EQ. 10) GO TO 100
330  IF (C3 .EQ. 10) GO TO 100
331  CONTINUE
332  C1 = C1 + 1
333  C2 = C2 + 1
334  C3 = C3 + 1
335  IF (C1 .EQ. 10) GO TO 100
336  IF (C2 .EQ. 10) GO TO 100
337  IF (C3 .EQ. 10) GO TO 100
338  CONTINUE
339  C1 = C1 + 1
340  C2 = C2 + 1
341  C3 = C3 + 1
342  IF (C1 .EQ. 10) GO TO 100
343  IF (C2 .EQ. 10) GO TO 100
344  IF (C3 .EQ. 10) GO TO 100
345  CONTINUE
346  C1 = C1 + 1
347  C2 = C2 + 1
348  C3 = C3 + 1
349  IF (C1 .EQ. 10) GO TO 100
350  IF (C2 .EQ. 10) GO TO 100
351  IF (C3 .EQ. 10) GO TO 100
352  CONTINUE
353  C1 = C1 + 1
354  C2 = C2 + 1
355  C3 = C
```

[illegible]

```

V(R) = GS/11 + V(R)
TA(R) = D9/11 + TA(R)
V'(R) = (9/11 + V(R))
AP(R) = I9/11 + AP(R)
35 CONTINUE
DO 48 R = 1,NPB
QS(R) = QS(R)/XDL
IF (IS1,EQ,2) QS(R) = 3.6866431*QS(R)
CC(M) = CC(M)/XDL
W(R) = W(R)/XDL
IF (IS2,EQ,2) V(R) = 1.1515*W(R)
TA(M) = TA(M)/XDL
IF (IS3,LO,2) TA(R) = 1.8*TA(R) + 32.
TAR(R) = TAR(R)/XDL
IF (IS3,LO,2) TAP(R) = 1.8*TAR(R) + 32.
AP(R) = AP(R)/XDL
45 CONTINUE
ITERIS = 1
CALL ITERC(ITERIS)
49 CONTINUE
1000 IERR = 1 (515)
1001 IERR = 1 (515)
1002 IERR = 1 (515)
1003 IERR = 1 (515)
1004 IERR = 1 (515)
1005 IERR = 1 (515)
1006 IERR = 1 (515)
RETURN
END

```

```

(3) SUBROUTINE THR44B
C SUBROUTINE THR44B READ RECORDS IN THE STRUCTURE DATA. THIS ROUTINE
C INPUT THE STRUCTURE (0741)065, 5741015, THE STRUCTURES /RE
C REFUTIALIZED, THE GRADIENTS FROM ADJECED SOURCES, AND LOCATIONS
C OF OUTPUT THE GRADIENTS,
C COMMON/TEMPER/TEMP(5,365), THR(5,365), ADV(5,365)
C COMMON/NUMBER/ADV, RADAS, NDAYS, NPD, NPLR, NSECT, N1; NCHNG,
C 1 NTP, NTHIN(15), NPO
C COMMON/IDENT/ID(15), IDIR(15), ADV(15), IDTP(15), IDCHNG(15)
C COMMON/NAME/XCHNG(5,40), XOUT(10,40)
C INSECT = NSECT
C READ(5,1000) NT1
C DO 9 I = 1,N1
C READ(5,1005) IDIR(I), RIN; ICFIN, (THR(I,J), J = 1,NTH)
C NTHIN(I) = NTH
C IF (ICFIN(10,2)) GO TO 9
C DO 8 K = 1,NP1
C TERRY = TH(1,4)
C TH(I,K) = TERRY*TH(I,K) / ADV
C 8 CONTINUE
C 9 CONTINUE
C READ(5,1075) (XCHNG(K,I), I = 1,20), TECHN(1,1)
C 19 CONTINUE
C 20 READ(5,1027) NTP, ICFOUT
C WRITE(6,1027) NTP, ICFOUT
C DO 29 K = 1,N1P
C READ(5,1030) (XOUT(K,I), I = 1,20), IDTP(K))
C 29 CONTINUE
C 45 CONTINUE
C IF (ADV(5,0) GO TO 100
C DO 49 I = 1,ADV
C READ(5,1045) ICFIN, (ADV(I,J), J = 1,NPO)
C IF (ICFIN(5,2)) GO TO 49
C DO 49 M = 1,NPO
C TERRY = ADV(I,M)
C ADV(I,M) = 1.8*TERRY 32.0

```

```

48 (0.0,18.0)
49 (0.0,110)
1000 FOR I = 1 (0.5)
1005 FOR J = 1 (7.515/(1615.0))
1025 FOR K = 1 (2074/15)
1027 FOR L = 1 (215)
1030 FOR M = 1 (2074/15)
1045 FOR N = 1 (710X, 15/(1615.0))
100 RETURN
END

```

```

(4) SUBROUTINE TROUT
C SUBROUTINE TROUT ROUTES THE PARCELS DOWN THE RIVER. SUBROUTINE
C TEMP IS USED IN CONJUNCTION WITH TROUT TO DETERMINE PARCEL
C TEMPERATURES.
COMMON/NUMBER/NADV, NDAMS, NDAYS, NPD, NPER, NSECT, NTL, NCHNG,
1 NTP, NTHIN(15), NPO
COMMON/IDENT/ID(15), IDIN(15), IDADV(15), IDTP(15), IDCHNG(15)
COMMON/HOURLNG/TIML(10,400)
COMMON/TEMPER/THETA(5,365), THR(5,365), TADV(5,365)
COMMON/GFOM/AX(100,25), WX(100,25), X(100), CTE(100), CD(100), DZ
DIMENSION T(20), DELTAT(20)
T(1) = 24.0/NPD
DO 99 I = 1,NPER
11 = 1
10 = 1
1 = 1
MADV = 1
N = 1
NTH = 0
THI = THL(1,1)
NREV = 2
15 N = N + 1
20 DX = (X(N) - X(N-1))*5280.
25 CALL HYDRA2(1), JQ, H, MADV, N, U, 7)
DIST = T(1)*U
DIST = DIST + DX
IF (DTEST) 30,35,45
30 DX = DX - DIST
DT = T(1)
DELTAT(1) = DT
CALL TEMP(IQ, 11, MADV, N, N, DT, Z, THI)
11 = 11 + 1
IF (11.GT.NPO) GO TO 75
L = 1
GO TO 25
35 DT = T(L)
DELTAT(L) = DT
CALL TEMP(IQ, 11, MADV, N, N, DT, Z, THI)
N = N + 1
IF (N.GT.IDADV(MADV)) MADV = MADV + 1

```

```

IF (N.RE.JDCHRG(NREH)) GO TO 36
THJ = THR(NREH,11)
NNEW = NNEW + 1
36 CONTINUE
GO TO 46
45 L = L + 1
T(L) = DX/U
DT = T(L)
DELTA(T(L)) = DT
CALL TEMP(IQ, II, MADV, M, N, DT, Z, THJ)
T(L) = T(L-1) + T(L)
N = N + 1
IF (N.GT.10ADV(MADV)) MADV = MADV + 1
IF (N.RE.JDCHRG(NREH)) GO TO 46
THJ = THR(NREH,11)
MADV = MADV + 1
46 CONTINUE
DO 49 K = 1,NTP
IF (N.RE.JDTP(K)) GO TO 49
THJ(K,1) = THJ
SUM = 0.0
DO 48 KI = 1,1
SUB = SUM + DELTA(T(KI))
48 CONTINUE
TIME(K,1) = (II - 1)*T(1) + SUM
49 CONTINUE
IF (DTEST.EQ.0.0) L = 1
IF (DTEST.EQ.0.0) II = II + 1
IF (II.GT.NPQ) GO TO 75
N1 = N + 1
IF (N1.LT.ID(N+1)) GO TO 20
M = M + 1
IF (M.GE.NDAMS) GO TO 99
IQ = II
GO TO 15
75 NDUM = 0
80 NDUM = NDUM + 1
IF (N.GE.IDTP(NDUM)) GO TO 80
NDIF = NTP - NDUM + 1
DO 89 IDIF = 1,NDIF

```



```

(5) SUBROUTINE RATIO2(JJ, I0, I1, IADV, P, Q, 7)
C SUBROUTINE RATIO2 CALCULATES DEPTH AND VELOCITY OF THE FLOOD AS
C REQUIRED BY SUBROUTINE RATIO.
C CALLS C/NUMBER/RAOV, NDAYS, NDAYS, NPD, RPER, RSECT, R3, NCHAG,
J RPD, RTHIR(15), RPD
COMMON/HYDRO/FL(12,400), QD(12,400), QADV(5,400), QZ
COMMON/IDENT/ID(15), IDN(15), IDADV(15), IDIP(15), IDCHRG(15)
COMMON/CHCK/JJMAX(400)
COMMON/GFOR/IX(100,25), WX(100,25), X(100), CIL(100), CD(100), DZ
DIMENSION AR(2), WR(2), QDUMMY(10)
IDAY = (I0 - 1)/NPD + 1
DO 20 L = 1,2
RL = N + L - 1
LL = LL(6,NDAYS) + CIL(RL)
10 D(17) = (P1 + (PARK)) / D2 + 3.0
K = D(17)
L3 = L + 3
L4 = L + 4
WR(1) = P1 / D(17) + (D(17) + P1) / (CIL(RL) + P1)
WR(2) = P2 / D(17) + (D(17) + P2) / (CIL(RL) + P2)
15 C(17) = 0.0
P1 = (P1(1) + P2(1)) / 2.0
P2 = (P2(1) + P1(1)) / 2.0
16 R(NE,1D(1)) GO TO 25
QADV = 0.0
RTEST = RADV
NTEST = IDADV(RADV)
25 CONTINUE
IF (NULT, IDADV(RTEST)) GO TO 40
IF (N,NE,NTEST) GO TO 35
1QADV = 1)
NTEST = IDADV(RADV)
GO TO 40
35 CONTINUE
SUM1 = 0.0
SUM2 = 0.0
DO 30 J = 1QADV,1)
R/DJ = RADV + J
R/110 = QADV(RADV,1)/QADV(RADV,1QADV)
SUM1 = SUM1 + RATIO

```

```

      SUM2 = SUM2 + RATIO*ODRXY(LAB2,I)
36 CONTINUE
      ITEMP = RADV * LUSIP
      ODRXY(ITEMP) = SUM2/SUM1
      QADD = 0.0
      DO 39 I = 1,ITEMP
      QADD = QADD + ODRXY(I)
39 CONTINUE
      SUM1 = 0.0
      SUM2 = 0.0
      DO 49 I = 1,10,I)
      RATIO = CD(R,I)/OD(R,10)
      SUM1 = SUM1 + RATIO
      SUM2 = SUM2 + RATIO*OD(R,I)
49 CONTINUE
      C = SUM2/SUM1 + 0.15
      B = C/H
      I = R/H*V
      O = C
      RATIO =

```

```

C(0) SUBROUTINE THERM(T, QADV, TTRIB, TQADV, TQ101, TTH)
C SUBROUTINE THERM(CALCULATES PACKET TEMPERATURES AS A QUANTITY)
C SUBROUTINE THERM
COMMON/RODTS/ASPHL(40,24), BITA(40,24), CALCUL(40,24)
COMMON/IDUT/ID(15), IDIR(15), IDADV(15), IDIR(15), IDIRRG(15)
COMMON/HYDRO/EUT(12,400), QD(12,400), QADV(15,400), 0
COMMON/TEMPER/THETA(5,365), THIR(5,365), TADV(5,365)
COMMON/RUBELL/RAADV, NDAYS, NDAYS, NPD, NPFR, NSICT, NTL, NCHRG,
1 NTP, NTHIR(15), NPO
COMMON/CONST/ NDREL, NAVG, NED, IS1, IS2, IS3, IS4, IS5, IS6, IV,
1 IJAST, IJHT
NPD/AVG = NAVG*NPD
INDIFT = (EDIFT - 1) / KAVG + 1
IADV = (1 - 1) / P, DADV = 1
IF (IADV(1,1)) IADV = INDIFT
IADV = 1 + ((1 - 1) / 800) * IADV
I = 1 / 100 * IADV * INDIFT / ((1 - 1))
GO TO (10,20), IV
10 IADV = THIR(1,1), DADV = NDAYS
IADV = IADV(1,1)
IADV = IADV(1,1), IADV = IADV
GO TO 20
20 IADV = (IADV(1,1) * IADV(1,1)) / (IADV + IADV(1,1))
IADV = IADV * IADV
IADV = (IADV(1,1) * IADV) + BET(1,1) * IADV / (1.0 - IADV)
25 TH = IADV
IF (R,NE,1,DADV(IADV)) GO TO 100
TMAIN = THIR*Q
TTRIB = IADV(NDAYS,11)*QADV(IADV,11)
Q101 = 0 + QADV(IADV,11)
TH = (THAIRTRIB)/Q101
100 RETURN
END

```

[illegible]

```

1A = (A/25.832)
80 B/FA = A/(1.63) + F/(1.1) + LA
   IF (156.4E-3) GO TO 90
85 WRITE(6,1000)I/VC, I, B/FA, FA, RH, FS
WRITE(6,1010) V(1), AV(1), TV(1), TAV(1), CC(1), QS(1)
WRITE(6,1020)
90 OBI = SORT(B/FA)
   OBI = QBI*(1A) + 459.4)*62
*****
*      COMPUTING REFLECTED SOLAR RADIATION
*****
DAY = DAY1  (I/AVC - J)*I/AVC  NAVC/2.0
PJ = 2.14159
PH = (H/41)/3.5
DCL1 = 23.4563/60.0
DCL1A = DCL1A*CU(2 ( , J))2.0 DCL1/575.0)
XJ = J
I2 = I1*(2.053) 3.0)/2.0
ICA = I2 - 32.0 - DCL1
LI = I2 - I1/2.0
ALPH = SQRT(1.0 - I2)  (05.01)2.0 (P/1.21 (1) )
ALPH = 115.411563
ALPH = 160.0*ALPH/6)
ALPHR = ABS(ALPH)
   IF (ALPHR.LT.0.0) ALPHR = 0.0)
   CLOUD = CC(J)
   IF (CLOUD.LT.1.0) RS = 1.18*ALPHR*(-0.77)
   IF (CLOUD.GE.1.0.AND.CLOUD.LT.6.0) RS = 2.20*ALPHR*(-0.97)
   IF (CLOUD.GE.6.0.AND.CLOUD.LT.9.0) RS = 0.95*ALPHR*(-0.75)
   IF (CLOUD.GT.9.0) RS = 0.35*ALPHR*(-0.45)
*****
*      GENERAL ARRAY OF HEAT FLUX AS A FUNCTION OF WATER
*      TEMPERATURE, FOR EACH DAILY TIME PERIOD
*****
DO 96 J = 1, NM
   TWC = 5.0*(TW(J) - 32.0)/9.0
   HV = -0.545*TWC + 595.85
   HV = 1.8*HV
   TWC2 = TWC/2.
   NGG = TWC2 + 1

```

```

YESG = YESG + 1,
EW = GOICRA(REQ) + (TYPE-2)*RC((CON-GA*(PLOC)) GO, CHA(PLOC))
IW = (IW/33,8639
CI) = 0,97,
CI2 = 1,728-09
QE = HV*CI3*E(1)*(IW - I(A)
OH = HV*CI4*E(1)*AP(1)*(I(A) - IW(J))
QB = (IW(J) + 459,4)*.2
QR = (QB - Q3)*(QB + Q3)*CI1*(I2
91 Q1(J) OS(1)*(1,0-RS)-QB-QE QH
GO TO 95
95 CONTINUE
IF (ISG,10,1) PRINT(6,1030) IW(J), Q1(J), Q3, Q5, Q6, Q7, Q8,
1 IW, TH(J)
96 CONTINUE
IVP = IV
CALL CRV2(I,IV)
GO TO (1,2,3,4,5) IV
97 CALL(I,IVC,1) = C(1)
CALL(I,IVC,1) = C(1)/C(1)
WRITE(6,1040) I,IV,1, (I,IVC,1), I,IVC,1, (I,IVC,1)
GO TO 99
98 C(1) = C(1)*V(1) + 4,2-((I,IVC,1)
C(1)/IVC,1) = SOL(I,IVC,1)
ALPHA(IVC,1) = ((I2) + GAMMA(IVC,1))/(I,IVC,1)
BETA(IVC,1) = (C(1) - GAMMA(IVC,1))/(I,IVC,1)
WRITE(6,1047) C(1), C(2), C(3)
WRITE(6,1050) I,AVG,1, ALPHA(IVC,1), I,AVG,1, BETA(IVC,1),
1 I,AVG,1, GAMMA(IVC,1)
99 CONTINUE
1000 FORMAT (23H ENERGY BUDGET PERIOD ,I3,/,14H DAILY PERIOD ,I3,/,/,
13H ATMOSPHERIC RADIATION FACTOR = ,F8,3,2X, 6H FA = , F8,3, 2X,
26H RH = ,F8,3, 2X, 6H IS = ,F8,3,/)
1010 FORMAT (20H,
1 20H WIND SPEED = ,F8,3/
2 20H AIR PRESSURE = ,F8,3/
3 20H AIR TEMPERATURE = ,F8,3/
4 20H WET BULB TEMP = ,F8,3/
5 20H CLOUD COVER = ,F8,3/
6 20H SOLAR RADIATION = ,F8,3)
1020 FORMAT (10H//10X, 3H TW, 9X, 3H OT, 9X, 3H OS, 9X, 3H OR, 9X,

```

```

1300 08, 92, 30 01, 92, 30 01, 92, 20 11, 92, 30 11, 11, 11
1050 FORMAT (1H, 9F12.2)
1060 FORMAT (1H0//1H BELA(,13, 1H, 12, 4H) = f(,3/
      1H GAMMA(,13, 1H, 12, 4H) = f(,3)
1047 FORMAT (//10X,4H0, F7.2,4H (,F9.6,6H)1 (,F9.7,5H)11,12)
1050 FORMAT (1H0//7H ALPHA(,13, 1H, 12, 4H) = f(,3/
      1H BELA(,13, 1H, 12, 4H) = f(,3/
      1H GAMMA(,13, 1H, 12, 4H) = f(,3)
1060 FORMAT (1X,2F4.2,F6.1,F3.2)
      DATA A1/0.740, 0.154, 0.750, 0.151, 0.761, 0.145, 0.770, 0.143,
      10.781, 0.137, 0.791, 0.134, 0.800, 0.132, 0.810, 0.129, 0.827,
      20.117, 0.845, 0.105, 0.868, 0.087/,
      30H GR/76.100, 7.055, 8.129, 9.347, 10.72, 12.27, 14.02, 15.98,
      418.17, 20.63, 23.37, 26.43, 29.05, 33.61, 37.00, 42.43, 47.65,
      55.20, 62.42, 66.26, 73.76, 82.67, 91.67, 101.60, 111.62, 123.65/
RETURN
END

```

```

(8) SUBROUTINE CAY270(IV)
C     SUBROUTINE CAY270 IS A CURVE FITTING ROUTINE USING THE LEAST SQUARES
C     METHOD.
C     COEFFICIENTS ARE STORED IN Y(50), Y(50), C(10), MDIH
C     REAL*8 A(1,1), B(11), F(20)
C     IV2 = IV*2
C     DO 9 I = 1, IV2
C     P(I) = 0.0
C     DO 9 J = 1, MDIH
C     P(I) = P(I) + X(J)**I
C 9 CONTINUE
C     N = IV + 1
C     DO 19 I = 1, N
C     DO 19 J = 1, P
C     K = J - I + 2
C     IF (K) 15, 16, 17
C 10 Z(I, J) = F(K)
C 11 DO 19 I = 1, N
C 12 Z(I, J) = 1.0
C 13 CONTINUE
C 14 P(I) = 0.0
C 15 DO 19 J = 1, MDIH
C 16 P(I) = P(I) + Y(J)**I
C 17 CONTINUE
C 18 DO 19 I = 2, N
C 19 P(I) = 0.0
C 20 DO 19 J = 1, MDIH
C 21 B(I) = B(I) + Y(J)*X(J)**(I-1)
C 22 CONTINUE
C 23 N2 = N - 1
C 24 DO 89 K = 1, N2
C 25 KP1 = K + 1
C 26 L = K
C 27 DO 49 I = KP1, N
C 28 A(K) = ABS(A(I, K))
C 29 A(K) = ABS(A(L, K))
C 30 IF (A(K) - A(L)) 49, 49, 45
C 45 L = I
C 49 CONTINUE
C 50 K2 = K

```

```

11 L = K2) (0,60,50
50 DO 59 J = K2,K
    T(J) = A(K,J)
    A(K,J) = A(L,J)
    A(L,J) = T(J)
59 CONTINUE
    T(J) = B(K)
    B(K) = B(L)
    B(L) = T(J)
60 DO 89 I = KP,IP
    FACTOR = A(I,K)/A(I,L)
    A(I,P) = 0.0
    DO 69 J = KP,IP
        A(I,J) = A(I,J) + T(J)*FACTOR
69 CONTINUE
    B(I) = B(I) + FACTOR * A(I)
70 CONTINUE
    C(K) = B(K)/A(IP,IP)
    I = B(I)
90 J(I) = J(I)
    SUM = 0.0
    DO 59 J = 1,IP
        SUM = SUM + A(I,J)*C(J)
99 C(I) = (B(I) - SUM)/A(I,I)
    I = 1.1
11 IF (I) 100,100,90
100 RETURN
    END

```

[illegible]

[illegible]

I. 2

001	397,100.0	352,000,000	0,160,000,000	0,470,001,776,0645	0,01776,0645	0,02600,0645	0,004420,0645	0,001
002	10397,100.0	00352,005100	0700,602600	0,010	003500,0839	0,00000,0925	0,01260,0925	0,002
003	10397,100.0	00382,014800	1050,010000	1300,018900	1700,021000	1095,022000	1110,022000	0,003
004	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,004
005	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,005
006	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,006
007	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,007
008	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,008
009	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,009
010	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,010
011	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,011
012	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,012
013	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,013
014	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,014
015	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,015
016	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,016
017	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,017
018	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,018
019	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,019
020	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,020
021	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,021
022	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,022
023	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,023
024	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,024
025	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,025
026	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,026
027	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,027
028	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,028
029	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,029
030	10397,100.0	00382,026000	1135,028200	1160,030000	1180,032000	1200,033000	1210,033000	0,030
031	10397,100.0	00382,0260						

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 02190292,66709010255,8060136,5120136,8180136,5240109,6
 02190292,66709020253,6060097,1120086,0180087,3240086,5
 02190292,66709030253,6060097,6120086,0180096,7240086,3
 02190292,66709040253,7060085,8120086,1180086,3240086,4
 02190292,66709050253,7060086,4120086,5180087,3240087,2
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3.4.

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30.1

14 10 24 75 50

31.2

46.0 232

31.3

2 3 3 1 3 2 2

31.5

1.0 1.0 5.7 1.0

11.5

(16X, 15.0, 57, 12.0, 13.0, 8X, 14.1, 4X, 15.2)

11.6

19.26, 19.60	0.0	0.16, 0.20, 0.70	0	20.20, 1.0
19.27, 19.28	0.0	0.20, 0.20, 0.70, 7.0, 7.0, 0	0	20.20, 1.0
19.28, 19.29	0.0	0.20, 0.20, 0.70, 7.0, 7.0, 0	0	20.20, 1.0
19.29, 19.30	0.0	0.20, 0.20, 0.70, 7.0, 7.0, 0	0	20.20, 1.0
19.30, 19.31	0.0	0.20, 0.20, 0.70, 7.0, 7.0, 0	0	20.20, 1.0
19.31, 19.32	0.0	0.20, 0.20, 0.70, 7.0, 7.0, 0	0	20.20, 1.0

196708200600	656	05 6 627075,641,355,0	29,2012,0
196708200700	002	05 5 627075,641,655,0	29,2012,0
196708200800	007	05 8 627077,771,757,0	29,2012,0
196708200900	037	04 5 627075,641,655,0	29,2012,0
196708201000	043	02 4 600662,827,061,0	29,2012,0
196708201100	066	03 3 600661,391,262,0	29,2012,0
196708201200	070	01 2 600660,894,764,0	29,2012,0
196708201300	067	01 2 600662,797,765,0	29,2012,0
196708201400	059	09 2 615996,999,965,0	29,2012,0
196708201500	056	02 3 615996,999,965,0	29,2012,0
196708201600	030	02 5 622598,392,965,0	29,2012,0
196708201700	023	02 19 631593,999,162,0	29,2012,0
196708201800	002	1028 631593,999,965,0	29,2012,0
196708201900	007	1021 631593,999,965,0	29,2012,0
196708202000	002	1052 631593,999,965,0	29,2012,0
196708202100	007	1055 631593,999,965,0	29,2012,0
196708202200	006	1037 627075,641,915,0	29,2012,0
196708202300	001	0620 627075,641,915,0	29,2012,0
196708202400	004	0324 627075,641,915,0	29,2012,0
196708202500	006	0620 627075,641,915,0	29,2012,0
196708202600	005	0017 627075,641,915,0	29,2012,0
196708202700	003	0015 627075,641,915,0	29,2012,0
196708202800	000	0013 627075,641,915,0	29,2012,0
196708202900	000	0015 627075,641,915,0	29,2012,0
196708203000	004	0220 627075,641,915,0	29,2012,0
196708203100	004	0011 627075,641,915,0	29,2012,0
196708203200	007	01 7 620273,476,460,0	29,2012,0
196708203300	037	0010 631576,683,262,0	29,2012,0
196708203400	043	0016 631576,683,262,0	29,2012,0
196708203500	066	0015 631576,683,262,0	29,2012,0
196708203600	070	0515 631580,885,063,0	29,2012,0
196708203700	067	0617 631582,389,762,0	29,2012,0
196708203800	059	0722 629293,650,162,0	29,2012,0
196708203900	055	0423 631595,591,761,0	29,2012,0
196708204000	030	0017 629296,492,261,0	29,2012,0
196708204100	023	0015 631586,920,562,0	29,2012,0
196708204200	002	0018 631586,920,562,0	29,2012,0
196708204300	002	0022 631587,182,053,0	29,2012,0
196708204400	000	0024 631579,979,118,0	29,2012,0
196708204500	000	0024 631577,976,718,0	29,2012,0

196708212260	600	6074	033970, 370, 600, 0	29, 2033, 0
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196708212400	000	0020, 033574, 573, 058, 0		29, 2032, 0
196708220100	006	0025, 029271, 871, 758, 0		29, 2033, 0
196708220200	000	0018, 029270, 871, 157, 0		29, 2034, 0
196708220300	000	0010, 027070, 365, 454, 0		29, 2039, 0
196708220400	000	00 2, 024871, 863, 754, 0		29, 2032, 0
196708220500	000	00 6, 006870, 262, 353, 0		29, 2033, 0
196708220600	004	00 6, 004570, 165, 955, 0		29, 2032, 0
196708220700	017	00 5, 029268, 071, 158, 0		29, 2033, 0
196708220800	032	00 4, 033569, 373, 059, 0		29, 2032, 0
196708220900	047	00 4, 033873, 778, 160, 0		29, 2035, 0
196708221000	055	00 3, 009070, 730, 183, 0		29, 2039, 0
196708221100	056	00 3, 014570, 317, 363, 0		29, 2039, 0
196708221200	060	00 3, 014570, 317, 363, 0		29, 2039, 0
196708221300	060	00 3, 014570, 317, 363, 0		29, 2039, 0
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11.6 (cont.)

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[illegible][illegible]

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Year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100																			
Population	1,000,000	1,050,000	1,100,000	1,150,000	1,200,000	1,250,000	1,300,000	1,350,000	1,400,000	1,450,000	1,500,000	1,550,000	1,600,000	1,650,000	1,700,000	1,750,000	1,800,000	1,850,000	1,900,000	1,950,000	2,000,000	2,050,000	2,100,000	2,150,000	2,200,000	2,250,000	2,300,000	2,350,000	2,400,000	2,450,000	2,500,000	2,550,000	2,600,000	2,650,000	2,700,000	2,750,000	2,800,000	2,850,000	2,900,000	2,950,000	3,000,000	3,050,000	3,100,000	3,150,000	3,200,000	3,250,000	3,300,000	3,350,000	3,400,000	3,450,000	3,500,000	3,550,000	3,600,000	3,650,000	3,700,000	3,750,000	3,800,000	3,850,000	3,900,000	3,950,000	4,000,000	4,050,000	4,100,000	4,150,000	4,200,000	4,250,000	4,300,000	4,350,000	4,400,000	4,450,000	4,500,000	4,550,000	4,600,000	4,650,000	4,700,000	4,750,000	4,800,000	4,850,000	4,900,000	4,950,000	5,000,000	5,050,000	5,100,000	5,150,000	5,200,000	5,250,000	5,300,000	5,350,000	5,400,000	5,450,000	5,500,000	5,550,000	5,600,000	5,650,000	5,700,000	5,750,000	5,800,000	5,850,000	5,900,000	5,950,000	6,000,000	6,050,000	6,100,000	6,150,000	6,200,000	6,250,000	6,300,000	6,350,000	6,400,000	6,450,000	6,500,000	6,550,000	6,600,000	6,650,000	6,700,000	6,750,000	6,800,000	6,850,000	6,900,000	6,950,000	7,000,000	7,050,000	7,100,000	7,150,000	7,200,000	7,250,000	7,300,000	7,350,000	7,400,000	7,450,000	7,500,000	7,550,000	7,600,000	7,650,000	7,700,000	7,750,000	7,800,000	7,850,000	7,900,000	7,950,000	8,000,000	8,050,000	8,100,000	8,150,000	8,200,000	8,250,000	8,300,000	8,350,000	8,400,000	8,450,000	8,500,000	8,550,000	8,600,000	8,650,000	8,700,000	8,750,000	8,800,000	8,850,000	8,900,000	8,950,000	9,000,000	9,050,000	9,100,000	9,150,000	9,200,000	9,250,000	9,300,000	9,350,000	9,400,000	9,450,000

THE DRYLANDS TRAILHEADS - PROPOSED FOR THE
COLUMBIA RIVER FROM PRIEST RAPIDS (E. 357) TO VERMILION
CLIFFS AND HYDROLOGIC DATA FOR THE PERIOD 1900-1909
RICHARD WEAVER OFFICE FOR THE PERIOD 1900-1909
IRACA - NORTHWEST REGIONAL OFFICE
COLUMBIA RIVER TRAILHEAD EFFECTS STUDY GROUP
MARCH 1969

