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STREAM TEMPERATURE PREDICTION METHODOLOGY

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This working paper contains preliminary data and information primarily intended for internal use by the Columbia River Basin staff and cooperating agencies. The material presented in this paper has not been fully evaluated and should not be considered as final.

METHODOLOGY FOR THE COMPUTATION OF STREAM TEMPERATURES

The purpose of this report is to describe the methods used to find the increase in river water temperature as a parcel of water moves downstream.

The elements of the problem are: (1) the mass of water affected in a given time period; (2) the energy input per unit of area for this period; (3) the exposed area of the water surface. These three parts when put in equation form give:

$$\frac{\text{(Constant) (Area) (Energy Input)}}{\text{Mass = (Discharge) (Time)}} = \underset{\text{(Change in Temperature)}}{\triangle T}$$

The problem then is to find the value of area and energy input for a given set of weather and discharge conditions. This subject will be solved in parts as follows:

I. Development of Energy Budget Table and Its Application;

II. Development of Travel Time Curves for Constant Discharges;

III. Development of Exposure Area Curves for Constant Discharges.

The three subject areas will then be tied together to arrive at values for specific conditions.

I. Development of the Energy Budget Table and Its Application (Table 1)

There are nine columns shown. Columns 7, 8, and 9 can be obtained from standard physics textbooks and may be calculated from Stephan-Boltzmann's Law: $Q_b = 0.97\sigma T_w^4$.

Column 1 need not be discussed except that it is up to the investigators as to how many days to include in a given time period.

ENERGY BUDGET TABLES

(1)	(2)	(3)				(4)				(5)				(6)				(7)	(8)	(9)
MONTH	Qsn Net Solar Radiation Ly/day	Qbn EFFECTIVE BACK RADIATION (% Qbs)				MEAN VAPOR PRESSURE (mb)				MEAN WIND (MPH)				MEAN TEMPERATURE °F (Air)				Water Temp. oF	Qbs B.B. Radiation for Water Ly/day	Saturation Vapor Pressure Air Ly/day
		0600	1000	1600	2100	0600	1000	1600	2100	0600	1000	1600	2100	0600	1000	1600	2100			
Jan. 1-10	82																	40	674	8.4
11-20	93																	41	680	8.7
21-31	112																	42	686	9.1
Feb. 1-10	177																	43	691	9.4
11-20	174																	44	696	9.8
21-28	201																	45	702	10.2
Mar. 1-10	241																	46	707	10.5
11-20	274																	47	713	10.9
21-31	285																	48	719	11.3
Apr. 1-10	373																	49	724	11.8
11-20	367																	50	730	12.3
21-30	436																	51	735	12.7
May 1-10	442																	52	741	13.2
11-20	510																	53	746	13.7
21-31	536																	54	753	14.2
June 1-10	535	.17	.18	.17	.17	12.5	12.4	13.6	13.4	3	6	10	6	53	64	72	61	55	759	14.8
11-20	559	.17	.17	.17	.17	12.3	12.4	13.7	13.4	3	6	11	6	54	65	73	62	56	765	15.3
21-30	580	.19	.19	.19	.19	12.7	12.8	13.2	13.3	3	8	12	7	55	63	76	64	57	771	15.8
July 1-10	630	.21	.20	.20	.20	12.3	13.3	13.0	13.1	2	6	12	6	55	69	81	66	58	777	16.4
11-20	625	.20	.20	.20	.20	13.1	14.2	13.9	13.8	3	7	12	6	57	71	85	69	59	783	17.0
21-31	598	.21	.21	.22	.21	12.9	13.6	12.2	13.3	3	8	14	7	57	72	87	70	60	789	17.7
Aug. 1-10	523	.21	.20	.20	.20	11.9	13.0	12.7	12.8	3	7	12	6	54	70	83	68	61	793	18.3
11-20	479	.20	.19	.20	.19	12.1	13.0	11.9	13.1	2	7	12	7	54	68	82	67	62	802	18.9
21-31	465	.20	.19	.20	.19	11.8	13.0	12.2	12.9	3	7	12	6	53	69	80	65	63	807	19.6
Sept. 1-10	423																	64	813	20.4
11-20	340																	65	819	21.1
21-30	313																	66	826	21.8
Oct. 1-10	224																	67	832	22.5
11-20	219																	68	839	23.3
21-31	163																	69	845	24.2
Nov. 1-10	140																	70	851	25.0
11-20	114																	71	858	25.8
21-30	103																	72	864	26.7
Dec. 1-10	90																	73	871	27.6
11-20	71																	74	878	28.6
21-30	78																	75	884	29.6
																		76	891	30.6
																		77	898	31.6
																		78	905	32.7

TABLE 1

For the values tabulated under the remaining columns we proceed as follows:

<u>Column 2</u> (Solar Radiation)

For several stations the total incoming solar radiation is measured directly by means of a pyrheliometer, but the stations are far apart and few in number. Solar radiation intensity charts may be used. See reference to these charts in final Umpqua Report (page 2, reference 4--Appendix A). Nomographs have been prepared (see page 89, Proceedings of the Twelfth Pacific Northwest Symposium on Water Pollution Research, Corvallis, Oregon, November 7, 1963). Some work on correlation of radiation and degree days seems to have some merit, but more for confirming other methods than as a method in its own right. The quantities in the Energy Budget Table, Column 2, are derived from several items.

Incoming solar radiation, as just discussed, is the total quantity and not the effective radiation since part of this is reflected back by earth and water. To obtain the reflected radiation, we apply a percent to the incoming solar radiation (see Data Tables for energy budget computations). This percentage reflectivity to be applied is computed by using the reflectivity of water surface which, in turn, is dependent upon mean solar altitude and sky cover. (See Lake Hefner Studies--Figure 63, page 87.) To obtain the net incoming solar radiation, subtract the reflected from the total; this is the quantity entered in column 2.

The quantities shown in column 2 are for Roseburg, Oregon; and quantities for other regions have to be determined independently using the above-suggested data. Correlation studies are needed, using one or several methods, to determine the values for a given area.

Column 3

This column lists the factor β which influences the back radiation of the water surface. This factor is determined for varying sky cover and vapor pressure conditions. See Figure 1. (Jerome Raphael, ASCE Journal, Power Division, July 1962, page 169, Figure 6.)

Sky cover is obtained from U. S. Weather Bureau records for daylight conditions only. See Column 4 below for discussion of vapor pressure.

Column 4

This column lists the mean vapor pressure in millibars which may be obtained from vapor pressure records at meteorological stations. Usually these records are kept in terms of relative humidity, dry-and wet-bulb temperatures. The mean vapor pressure may be computed from such data.

Column 5 (Wind--U. S. Weather Bureau Records)

An adjustment may be necessary to adjust the mean wind values to effective wind values as follows: USWB data list all winds below three miles per hour (mph) as "no wind." According to McAlister, stream motion of about one mph will give apparent wind speed even with still air. To account for the above phenomenon, add "+2" to wind speed of two mph; "+1" to three and four mph; and no corrections above five mph.

Wind speeds below three mph are, of necessity, estimates using total wind travel/day and known values/hour.

Column 6 (Temperatures by Hour from U. S. Weather Bureau Records)

The computations using this information to find the energy input function for a given temperature of a parcel of water are discussed in the Umpqua Report, Appendix A, pages 1-4. To facilitate making repeated computations, nomographs may be prepared to obtain the energy input quantity for any temperature for specific periods of the year (i.e., June 1-10; 7 a.m. to 12 noon; temperature of the water, 45°F). Such a computation is shown on page 73, Proceedings of the Twelfth Pacific Northwest Symposium on Water Pollution Research. Repeated computations for various starting temperatures will give the values for the nomographs desired.

A list of tables showing the data requirements for the preparation of the Energy Data Table is shown in Appendix B.

II. Development of Travel Time Curves for Constant Discharges

Travel time studies are necessary to determine the length of time a given parcel of water is in transit. (See Appendix C.) Travel time studies are executed under conditions of increasing discharge in downstream direction, Figure 2.

For purposes of study, however, a reach of river may be assumed to have a constant discharge. *If three travel time studies at incremental* discharge values have been executed, an arithmetical or logarithmic plot of the velocity (from travel time studies) versus discharge can be made. When this is executed for each reach, a line drawn at the discharge level of interest will give the corresponding travel time for each reach, Figure 3.

Dividing the velocities thus found into the length of the reach, we find the time of travel for a given discharge for the reach.

$$\text{Thus } \frac{L_1}{V_1} = T_1$$

A plot of T_1, T_2, T_3, etc., versus river mile starting at the source then gives the travel time curves for constant discharge. This can be repeated for any number of discharge values, Figure 4.

III. Development of Exposure Area Curves for Constant Discharges

The exposure area for constant discharges is developed as follows:

The physical configuration of the river is determined from aerial photographs or direct measurement. Knowledge of mean depth and discharge velocity values may provide a coarse estimate, but it should be kept in mind that the accuracy of the forecast is directly proportional to the accuracy of the estimated area of water exposed. In the energy exchange processes, as well as the estimate of the energy input function, a ten percent error on the area-exposed estimate means an "X + 10%" on the temperature rise estimate. The sensitivity of each error fades as the temperature rises because of the exponential nature of the temperature gain process ("X" represents percent error of energy estimate). The manner of area determination from aerial photographs is to take five to six width measurements per mile of river and average them. The tabulated values are then dated by their photographs and an estimate made of the hydrological condition of each reach, i.e., discharge estimates for each mile are made from a discharge versus river mile curves such as shown in Figure 5.

The discharge values may be obtained from U. S. Geological Survey Water Supply Papers for the dates obtained from photographs. Correlation studies for streams having little or no discharge flow data may be required. Where no photographs are available, X-sections at representative intervals should be taken.

It is desirable to have four or more different discharge values for each reach and miles within the reach so that the discharge versus area curve may be plotted for each river mile or reach.

A curve, as shown in Figure 5, will be obtained for rivers having banks as shown in Figure 6.

From the series of curves such as Figure 6, a summation of width or area curve with river mile is prepared by entering the curves for each mile at selected discharges and finding the corresponding width, Figure 7.

It is now possible to find the exposure area for any given time period. We plan to find an area that is exposed for Q_2 in five hours. Enter the travel time versus river mile curve at five hours, move horizontally to Q_2 curve, Figure 8.

From here drop to Σ-width curve for Q_2 below, then move left horizontally to find the area exposed. At this stage, all the components for solving the problem are complete to find ΔT of the parcel of water.

$$\frac{K\ (E)\ (A)}{Q\ t} = \Delta T$$

K = constant to make the equation dimensionally and numerically homogeneous

E = energy input function/unit of area

A = area of the mass exposed to E

Q = discharge of mass affected

t = time

ΔT = temperature change

These computations may be performed by use of a digital computer. This enables the investigator to obtain a wide range of values on which to base his recommendations. Such a program is described in Appendix D.

Atmospheric Radiation Factor, β

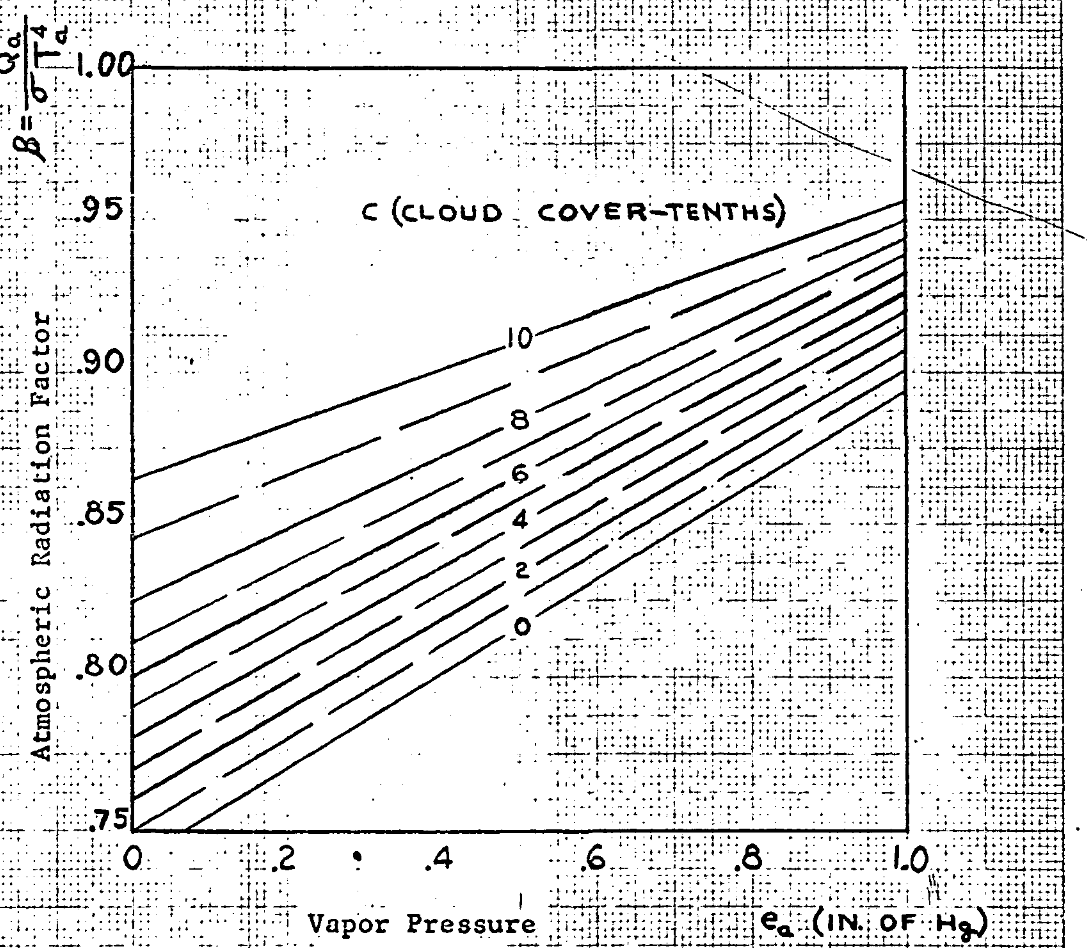

FIG. 1

Stream discharge profile

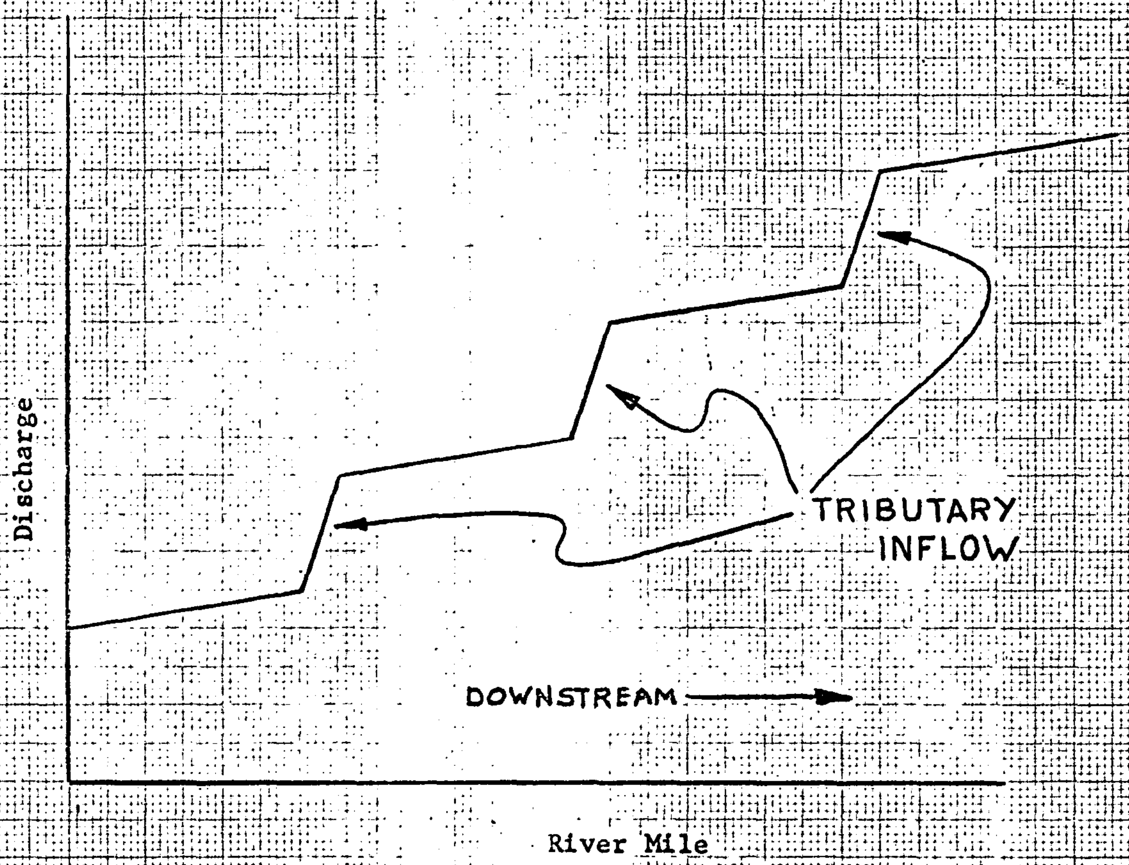

FIG. 2

Velocity - Discharge Curves for Three Reaches

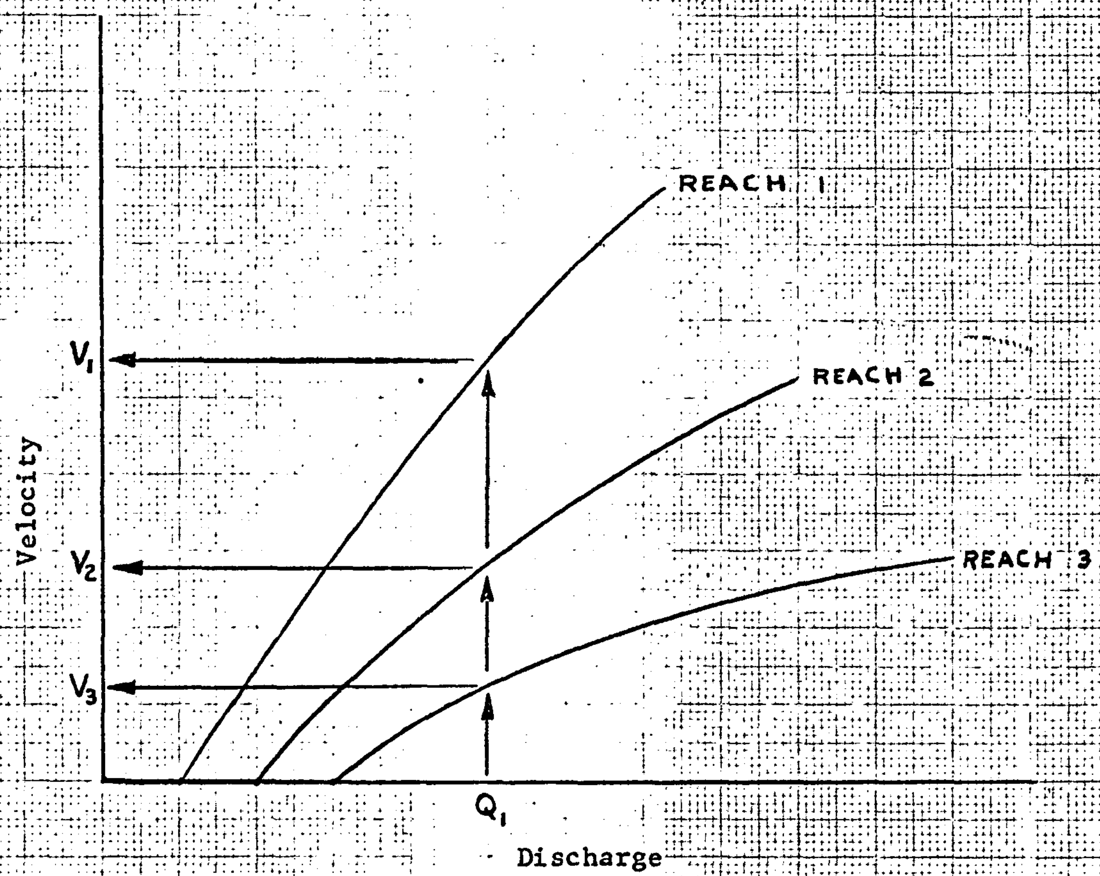

FIG. 3

Travel Time Curves at Constant Discharge

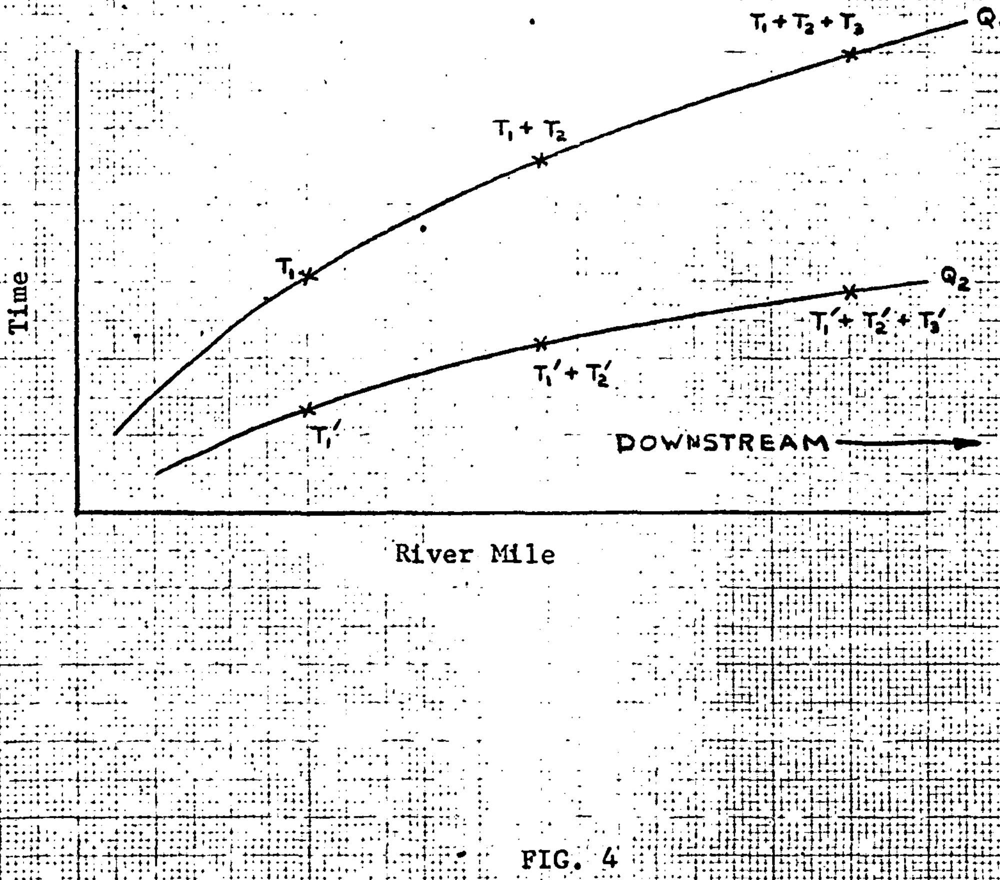

FIG. 4

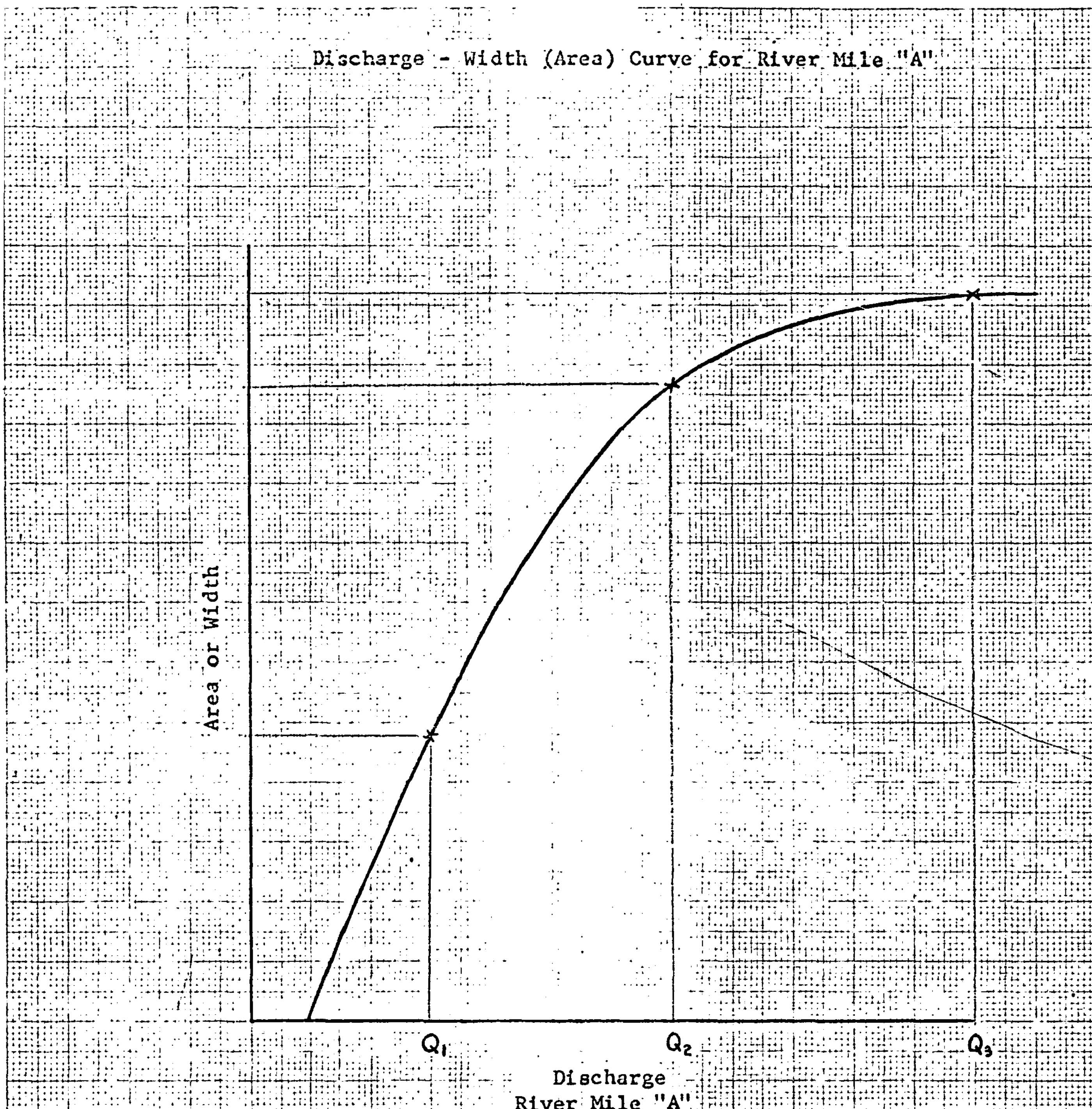
Discharge - Width (Area) Curve for River Mile "A"
Area or Width
Q1
Q2
Q3
Discharge
River Mile "A"

FIG. 5

Typical Stream Cross-Section for Discharge - Width (Area) Determinations

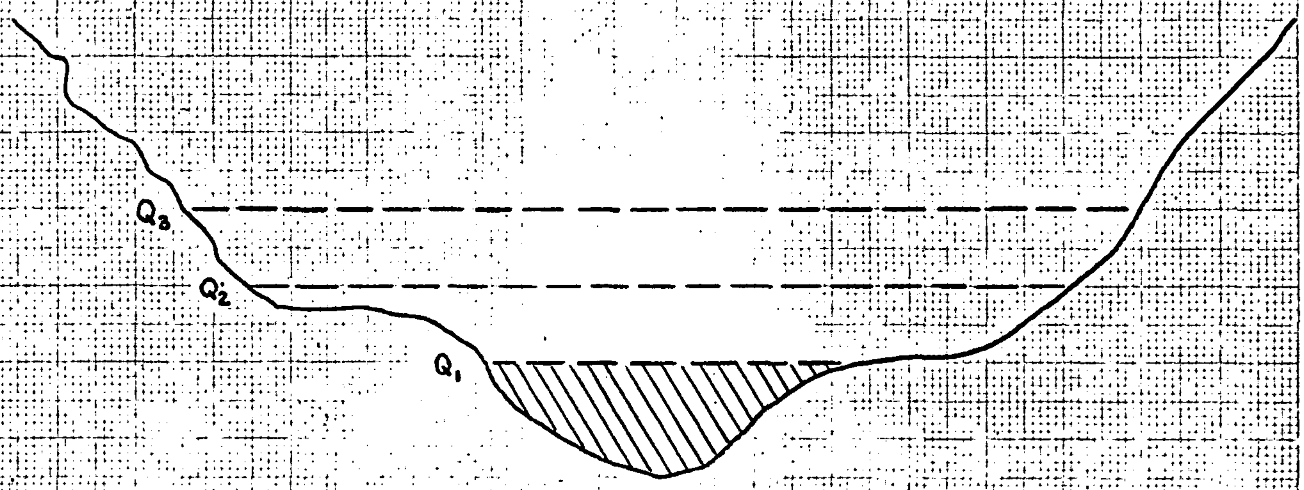

FIG. 6

Accumulative Width (Area) Curves at Selected Discharges

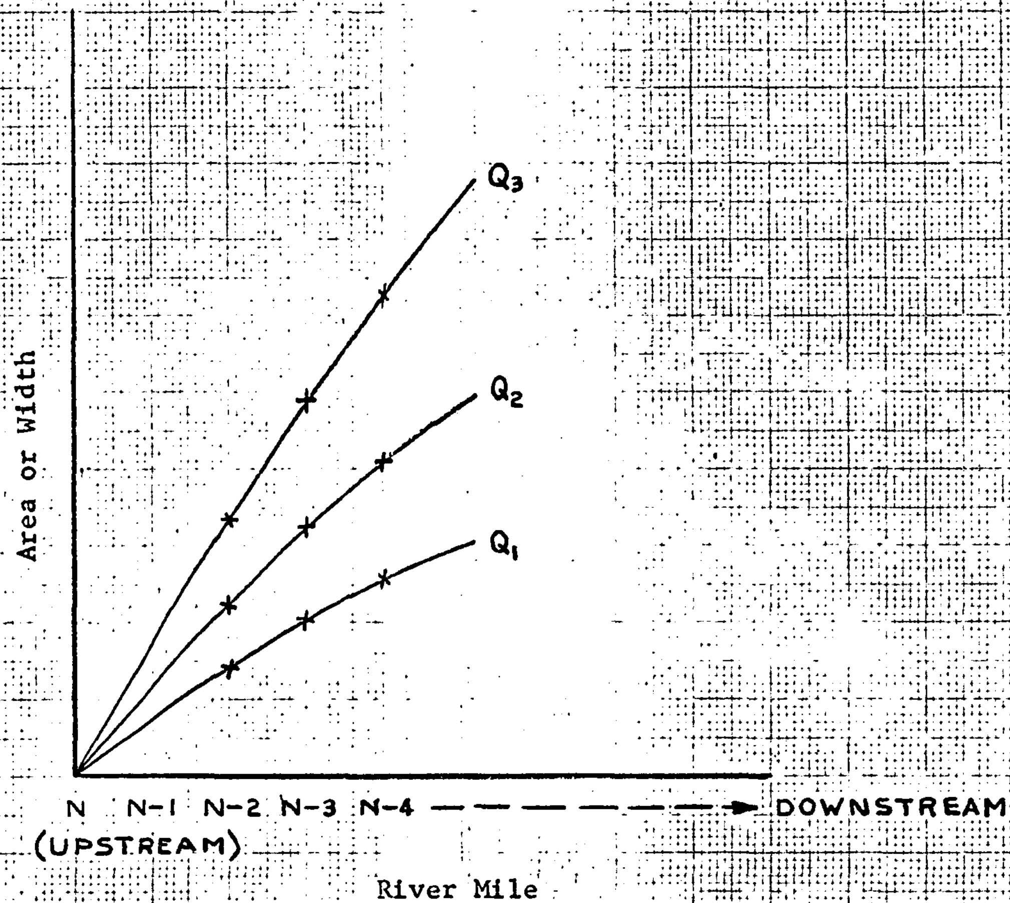

FIG. 7

Surface Area Exposure Curves at Selected Travel Times and Discharges

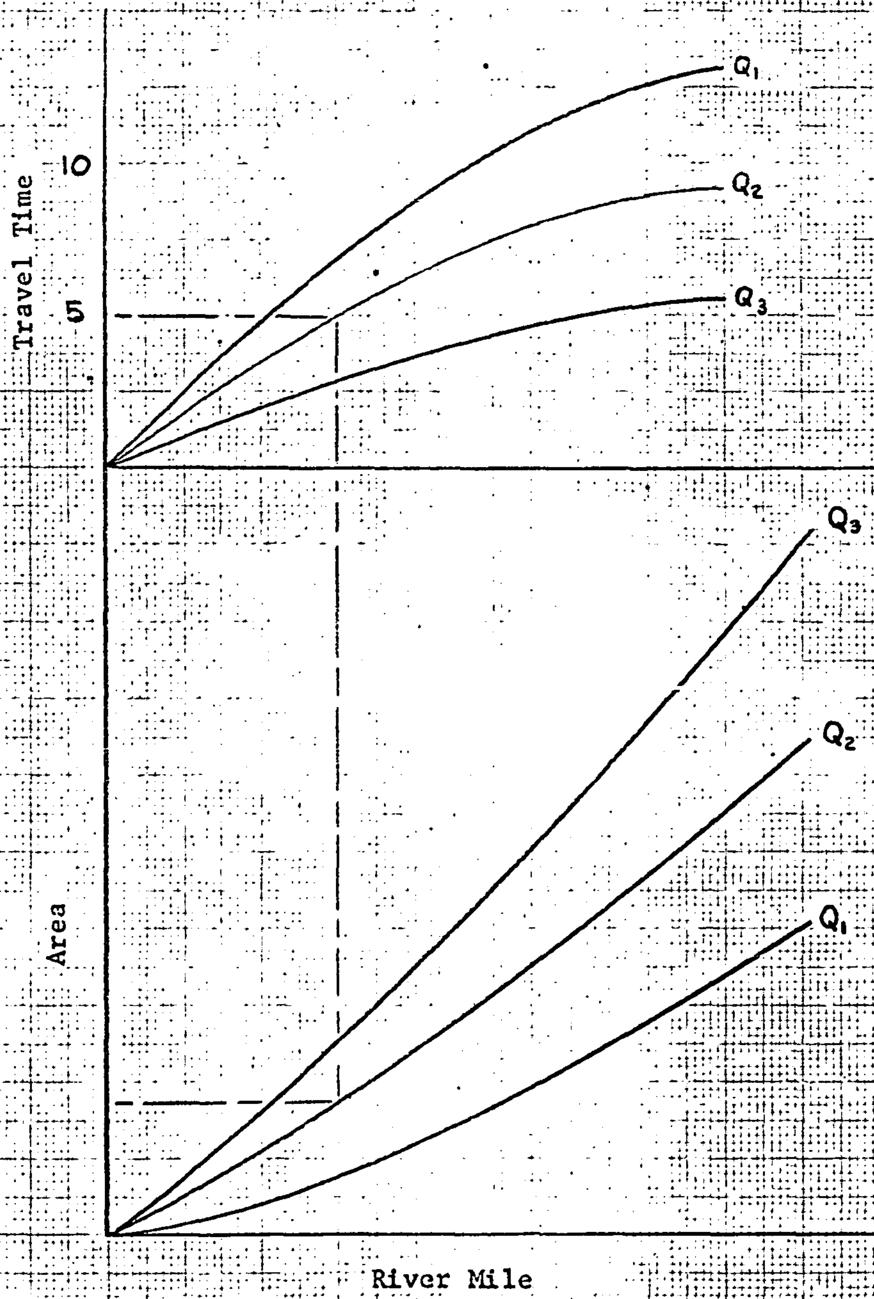

FIG. 8

APPENDICES

A. Water Temperature Prediction and Control Study, Umpqua River Basin; Oregon State Water Resources Board; February 1964.

B. Meteorological Data--Roseburg, Oregon.

C. Travel Time Study of Rivers Using Fluorometric Techniques, by John Seaders.

D. Stream Temperature Prediction by Digital Computer Techniques, Oregon State University, 1963.