WATER TEMPERATURE PREDICTION AND CONTROL STUDY

UMPQUA RIVER BASIN

By

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INTRODUCTION

In response to requests by a number of federal and state agencies the State Water Resources Board on October 31, 1962, agreed to and initiated a study on the Umpqua River for the purpose of determining the capabilities of certain proposed reservoirs for controlling downstream temperatures. The reservoirs in question, located on South Umpqua River, Cow Creek and Calapooya Creek, are currently being studied by the U. S. Army, Corps of Engineers, as part of a comprehensive study for the development of the water resources of the Umpqua River Basin.

The background of the temperature study, methodology adopted and agencies participating in the project were described in the State Water Resources Board publication of February 1963, entitled: "Organization for Water Temperature Prediction and Control Study - Umpqua River Basin". A second report was issued by the board in June 1963 entitled: "Preliminary Report on Water Temperature Prediction and Control Study - Umpqua River Basin". It described the energy-budget method as used for temperature determinations and disclosed interim results of the study which was in progress.

The temperature study has since been completed and the present, and final, report gives the results of all evaluations undertaken to determine reservoir behavior and stream temperature levels for selected reservoir regulations. In order to make the present report self-contained, certain material on the energy-budget methodology and data collection, contained in the earlier reports, is being repeated.

SUMMARY

1. Tiller Reservoir

   In an average year the reservoir is capable of holding water temperatures in South Umpqua River below 70° F. for a wide range of regulation schedules. In a year of maximum temperature, it will also hold temperatures below 70° F. but flexibility of operation will be restricted. Regulations designed to control water temperatures in South Umpqua River will have no significant influence on water temperatures in the main stem of the Umpqua River because of the large volume contributed by the unregulated North Umpqua River.

2. Galesville Reservoir

   The reservoir has the capability to hold water temperatures in Cow Creek below 70° F. in an average year provided nearly the entire storage capacity is regulated for temperature control. In a year of maximum temperature, only about one-half of the length of Cow Creek below the reservoir can be held below 70° F. for the entire summer.

3. Hinkle Reservoir

   The reservoir is capable of holding water temperatures in Calapooya Creek below 70° F. for all meteorological conditions. Substantial flexibility of reservoir regulation will be available in average years.

SECTION 1 - THEORY

The energy-budget equation formed the basis of reservoir and stream temperature determinations in the Umpqua River study. Methodology was basically the same as that employed by McAlister[1] on the Rogue River and by Raphael[2] on rivers in California and Washington. The Umpqua study differed in some respects from previous stream temperature studies in that it utilized more accurate basic data, particularly with respect to stream travel time, and also improved computational procedures, including development of digital computer techniques.

Temperature analysis by this method involves the identification and evaluation of the energy exchange processes between a body of water and its environment. All items of energy gain and energy loss are combined into a single algebraic expression called the energy-budget equation. Solution of the equation for a given set of conditions gives the value of the change in energy of the water and hence its change in temperature.

The modified energy-budget equation, as used for lakes and streams, states that for a given interval of time:

$$Q_\theta = Q_s - Q_b - Q_e - Q_h + Q_a$$

where Q_θ = net change in energy in the body of water

Q_s = net incoming solar radiation

Q_b = effective back radiation from the water surface

Q_e = energy loss due to evaporation

Q_h = energy loss by conduction of sensible heat from water to air

Q_a = energy advected into the water by tributary streams, precipitation, etc.

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[1] Rogue River Basin Study by W. Bruce McAlister, Water Research Associates, Corvallis, Oregon, 1961.

[2] Prediction of Temperatures in Rivers and Reservoirs by Jerome M. Raphael, Journal of the Power Division, Proceedings of the American Society of Civil Engineers, July 1962.

Methods developed from the Lake Heffner[3] study were used in determining quantities of energy involved in each of the terms of the energy-budget equation. The methods and their data needs are as follows:

a. Q_s - Net Solar Radiation

In the absence of observed values, solar radiation for the Umpqua Basin was taken from radiation maps prepared after Sternes[4]. Average daily radiation values for each of the summer months were obtained for Roseburg, which being centrally located in the basin was regarded as representative of basin conditions. These values were then adjusted for observed values available for Medford, the nearest recording solar radiation station to the basin. Average daily values, corrected for reflected radiation were computed for ten-day periods. One-half of the daily radiation was assumed to occur between 0700 and 1200 hours and the other between 1200 and 1700 hours.

To compute reflected radiation, it was necessary to obtain values for solar altitude and cloud cover. The latter was also needed for evaluating some of the other energy exchange processes. Mean solar altitude was determined for each ten-day period from declination values taken from the solar ephemeris adjusted for the latitude at Roseburg. Daily altitude was obtained by multiplying the mean altitude by 0.75. Mean sky cover at Roseburg was obtained from Weather Bureau records, which gave the information in tenths of sky covered for the periods between sunrise and sunset. These values were assumed to hold for the period from midnight to midnight. Values were averaged for ten-day periods.

b. Effective Back Radiation

Energy removed from the water by this process was determined by the equation:

$$Q_b = 0.97\sigma \ (T_w^4 - \beta T_a^4)\theta$$

where Q_b = effective back radiation

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[3] Water Loss Investigations: Lake Heffner Studies, Technical Report, Geological Survey Professional Paper 269, 1954.

[4] Oregon Sunshine by G. Sternes, U. S. Weather Bureau, Letter Supplement 5926, 1959.

σ = Stefan-Boltzmann constant

T_w = absolute temperature of water

β = atmospheric radiation factor

T_a = absolute temperature of air

θ = time in hours

The equation combined in a single expression the atmospheric radiation received on the water surface and radiation emitted by the water. Values for T_w were obtained by trial-and-error when the equation was applied to streams. For reservoirs, T_w was assumed to approximate the temperature of a stream under equilibrium conditions. Atmospheric radiation factor β was determined for sky cover and vapor pressure conditions at Roseburg according to the method developed for Lake Heffner. Weather Bureau records provided sky cover, vapor pressure and air temperature data.

c. Q_e - Energy Loss Due to Evaporation

The following empirical equation, which was found to agree with data collected at Lake Heffner, was used for determining energy loss due to evaporation from reservoirs:

$$Q_e = 0.34\ U(e_w - e_a)\theta$$

where Q_e = energy loss in BTU/ft^2

U = wind speed in miles per hour

e_w = vapor pressure of water in saturated air at the temperature of the water surface in milibars

e_a = vapor pressure of water in air

θ = time in hours

The equation was modified for application to streams by changing the coefficient from 0.34 to 0.57, thus making allowance for the higher rate of evaporation from streams than that from reservoirs. The equation also gave the energy gain due to condensation.

Vapor pressure and wind speed were obtained for Roseburg from Weather Bureau records. Values for e_w were computed with the aid of physical tables.

d. Q_h - Energy Transfer Due to Conduction

Energy transferred by conduction between the water surface and the air was computed with the aid of the equation:

$$Q_h = 0.138\ U(t_a - t_w)\theta$$

where Q_h = energy transferred by conduction in BTU/ft^2

U = wind speed in miles per hour

t_a = temperature of air in degrees Fahrenheit

t_w = temperature of water in degrees Fahrenheit

θ = time in hours

This equation combines the expression for energy loss by evaporation and the Bowen Ration which established a relationship between energy lost through evaporation and that lost through transfer of sensible heat. Values for wind speed and air temperature were obtained from Weather Bureau records while water temperatures were estimated. The constant 0.138 allowed for barometric pressure of 29.5 inches of mercury which was assumed to be representative of average summer conditions.

e. Q_e - Advected Energy

This term identifies energy transfer to and from reservoirs and streams caused by inflow and outflow, groundwater seepage, direct precipitation and other factors. Energy advected by inflow and outflow was computed on the basis of recorded and estimated discharge rates and temperatures. Effects of groundwater seepage, precipitation, etc., were not considered of sufficient significance to be included in the evaluations.

SECTION II - METHOD OF ANALYSIS

1. Streams

Temperature predictions were made for all streams subject to regulation by the proposed reservoirs. Streams affected, which are indicated on Plate 1, include South Umpqua River below Tiller, Cow Creek below Galesville, Calapooya Creek below Hinkle Creek and the main stem of the Umpqua River above Elkton. Temperatures were determined for reservoir release rates and release temperatures consistent with reservoir capabilities. They were made for the months of June through October for average meteorological conditions occurring during the first ten days of each month. Except for June, these periods coincide with periods of maximum temperature for average meteorological conditions. Maximum temperatures in June normally occur during the last ten days of the month. Computed temperatures were used as a basis for estimating temperature values for other periods in the months considered.

Stream temperature for each reservoir release condition was determined with respect to that parcel of water subject to maximum solar radiation. The highest temperature levels in the stream were therefore obtained for the various reservoir release conditions. Computations were made for 0700, 1200, 1700 and 2400 hours of each day for the entire period during which the parcels of water remained in the stream. All computations were carried out with the aid of a digital computer program[5] developed for this purpose by the Civil Engineering Department of Oregon State University. Curves of maximum temperature vs. stream mile were then developed for the various release conditions.

Of the extensive array of data needed for the temperature determinations, one of the most important was that of travel time. Special field exercises were undertaken to obtain this data. Cooperating agencies supplied personnel for these studies while the U. S. Geological Survey provided the direction and much of the equipment. Time of travel was determined for three discharge values for all streams with the exception of Calapooya Creek where only

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[5] Stream Temperature Prediction by Digital Computer Techniques by Oran L. Albertson, et al., Oregon State University.

one determination was made. Discharge values were selected, as far as possible, to represent the range of reservoir releases adopted for the study. Travel time was measured with the aid of a tracer technique. A fluorescent dye, Rhodamine-B, was introduced into a stream at a known time and point and the time taken by the dye to reach downstream points was observed. Sampling at these points was performed with a fluorometer. Stream discharge was measured simultaneously and travel time determinations related to discharge for each stream reach. Curves were then prepared, for each stream, of travel time vs. river mile for each discharge value adopted.

Information was also needed on stream widths and changes in these widths with changes in discharge. Stream widths for the South Umpqua River and the main stem of the Umpqua River were obtained by measurement from aerial photographs. Available photographs permitted width measurements for each stream mile for two or more discharge values. Curves of width vs. discharge were then plotted for each stream mile to cover the range of discharge rates attainable by reservoir regulation. For Cow Creek, only one set of aerial photographs were available and stream width curves developed were therefore partly based on judgment. No photographs were available for Calapooya Creek and width curves for that stream were based on limited field observations.

While the Umpqua study was in progress, the participating agencies undertook a special verification study on the Coast Fork Willamette River. The purpose of this study was to determine the reliability of methodology adopted for temperature analysis on the Umpqua River. The Willamette Coast Fork was selected for this purpose because the flow could be carefully regulated with existing storage structures, thus creating conditions comparable to those that would exist if the proposed dams in the Umpqua Basin were constructed.

Time available for meeting the deadline set for this report did not permit completion of the evaluation of the results of the verification study at the same time. Preliminary evaluations of data gathered on the verification study demonstrated the reliability of the method, at least for the meteorological and other conditions experienced during the study. They indicated, however, that computed temperatures tended to be slightly higher than observed values for a 24-hour cycle. This tendency was also evident in comparisons of computed and observed temperatures in the Umpqua Basin. Stream temperature predictions made in this report are therefore regarded as conservative and control of temperatures provided by reservoirs in actual operation may be even greater than indicated herein.

The difference between computed and observed temperatures, cited above, is attributed to the lack of precision in the available methods of determining evaporation from swift flowing streams. This is the subject of more detailed research proposed to be carried out at Oregon State University in cooperation with the State Water Resources Board.

Further evaluations of the results of the verification study are necessary before all needed refinements in techniques are fully identified.

It is anticipated that a technical paper giving a detailed analysis of the techniques and methodology utilized in the Umpqua study, including knowledge contributed by the verification study, will be published by the Water Resources Board at a later date.

2. Reservoirs

The proposed reservoirs, locations of which are shown on Plate 1, are relatively deep, depths at full pool being about 380, 210 and 220 feet respectively for Tiller, Galesville and Hinkle Reservoirs. Their regulation will call for minimum pools in the fall to provide storage space for flood control. They will be filled during winter and spring, the period of minimum stream temperature. During the summer they will be drafted, releases being made from selected elevations to maintain water quality, chiefly with respect to temperature.

In evaluating reservoir temperatures for the summer months, several assumptions had to be made, principally because of inadequate knowledge of the thermal behavior of deep reservoirs operated for stream temperature control. At the beginning of April, each reservoir was assumed to be at constant temperature throughout its depth, with the exception of the surface layer. From April onwards, temperature gradients were assumed to occur, the gradients changing with time due to energy exchange processes across the water surfaces and advected energy caused by inflow and releases. Temperature gradients were assumed to be the same at any vertical section in a reservoir at any one time. Surface layers were generally assumed to be at temperatures approximating those of a stream which had reached equilibrium temperatures for identical meteorological conditions. Cow Creek at Riddle was assumed to satisfy these conditions and reservoir surface temperatures were therefore based, for most summer months, on thermograph records for this station.

The change in reservoir energy was computed for each month from April through October for each reservoir regulation schedule. This energy change was then distributed throughout the reservoir, taking into account the quantity and temperature of water released, so that the resulting temperature gradients followed the pattern of those observed in existing reservoirs in western Oregon.

Based on these energy distributions, curves were developed for each regulation schedule giving the average monthly temperature at any elevation in the reservoir. The curves indicated not only the predicted thermal changes within the reservoir for each regulation schedule, but also the capability of the reservoir to meet the requirements of the particular regulation schedule.

Preliminary evaluations indicated differences in capabilities of the reservoirs and in susceptibility of the stream to reservoir control. It was therefore evident that each stream will be held at a different temperature level when subject to the maximum control available. It was desirable to adopt, as a common upper limit, a temperature level attainable in the majority of streams. A temperature of 70° F. was found to be a suitable limiting value. In the reservoir regulations studied, stream temperatures were maintained below 70° F. Exceptions to this rule were the regulations aimed at minimum stream temperatures. It should be noted that for all regulations, limiting temperature values occur in the lower reaches of the streams.

Performance of Tiller and Galesville Reservoirs were studied for four regulation schedules, three of which were for average meteorological conditions, while the fourth was for the maximum temperature year, 1958. Due to limited reservoir capability in the maximum temperature year, this regulation had the single purpose of holding downstream temperatures below 70° F. For the average meteorological conditions, reservoir capabilities were expected to extend beyond that needed solely for stream temperature control. These three regulations therefore attempted to determine the limits of these capabilities under these average conditions.

The first of the three regulations under average meteorological conditions aimed at keeping stream temperatures at a minimum, the entire storage being used for downstream control. The aim of the second regulation was to keep reservoir temperatures as low as possible while keeping downstream temperatures below 70° F. This regulation provides information on the optimum thermal environment that can be maintained in the reservoirs while also providing for adequate downstream control. Such information is necessary for determining reservoir capabilities to support desirable species of fish life. In this regard, it should be noted that the assumption previously referred to of constant temperature gradients at all points of a reservoir at any one time may not apply to reservoirs which are irregular in plan. In such reservoirs, higher average temperatures may prevail in the long narrow "arms" than in the main body of the reservoir. The third regulation under average meteorological conditions attempted to maintain downstream temperatures below 70° F. while conserving stored water to provide a large holdover storage.

Hinkle and Galesville Reservoirs have similar physical characteristics and consequently the thermal behavior of one will closely approximate that of the other, for similar regulation schedules. Performance of Galesville Reservoir was therefore taken as indicative of thermal capability of Hinkle Reservoir. However, one regulation was performed on Hinkle Reservoir for the purpose of determining the maximum holdover storage consistent with downstream temperature control.

SECTION III - RESULTS AND CONCLUSIONS

1. South Umpqua River

Temperatures for the South Umpqua River below Tiller were determined for release rates of 1600, 1200 and 700 cfs at release temperatures of 40°, 50° and 60° Fahrenheit. Resulting curves of maximum temperature vs. stream mile for the months of June through October are given in Figures 1 through 5. They show that for July, the month of critical temperature, stream temperature levels in the entire stream will be held below 70° F. for reservoir releases of 1200 and 1600 cfs at temperatures of 50° F. or less.

These graphs also indicate the lengths of stream below Tiller Reservoir that will be held at temperatures of less than 70° F. for the various releases. A tabulation of this data is given in Table 1.

TABLE 1

SOUTH UMPQUA RIVER
STREAM MILES BELOW TILLER RESERVOIR
HELD BELOW 70° F

RELEASE RATE Cfs	RELEASE TEMP. °F	RELEASE PERIOD JUNE 1-10	JULY 1-10	AUG. 1-10	SEPT. 1-10	OCT. 1-10
1600	40	77*	77	77	77	77
	50	77	77	77	77	77
	60	77	54	77	77	77
1200	40	77	77	77	77	77
	50	77	77	77	77	77
	60	77	27	77	77	77
700	40	77	73	77	77	77
	50	77	54	77	77	77
	60	37	20	30	77	77

* Entire length of stream below Tiller Reservoir.

The proposed Tiller Dam, as shown on Plate 1, is located near stream mile 77 on the South Umpqua River. At full pool elevation, the reservoir will have a depth of 380 feet and a storage capacity of 450,000 acre-feet. Area-capacity curves are shown on Figure 6. Average annual yield at the damsite, based on 20 years of gaging records, is about 735,000 acre-feet. The minimum recorded annual yield, for water year 1941, was 394,000 acre-feet.

All regulations assumed a full pool at the beginning of June. This condition will be satisfied for most years without the use of holdover storage. With such storage, a full pool at the beginning of summer may be attainable even in a critical year. Performance of the reservoir was studied for four regulation schedules, as already described, for release rates of 700, 1200 and 1600 cfs.

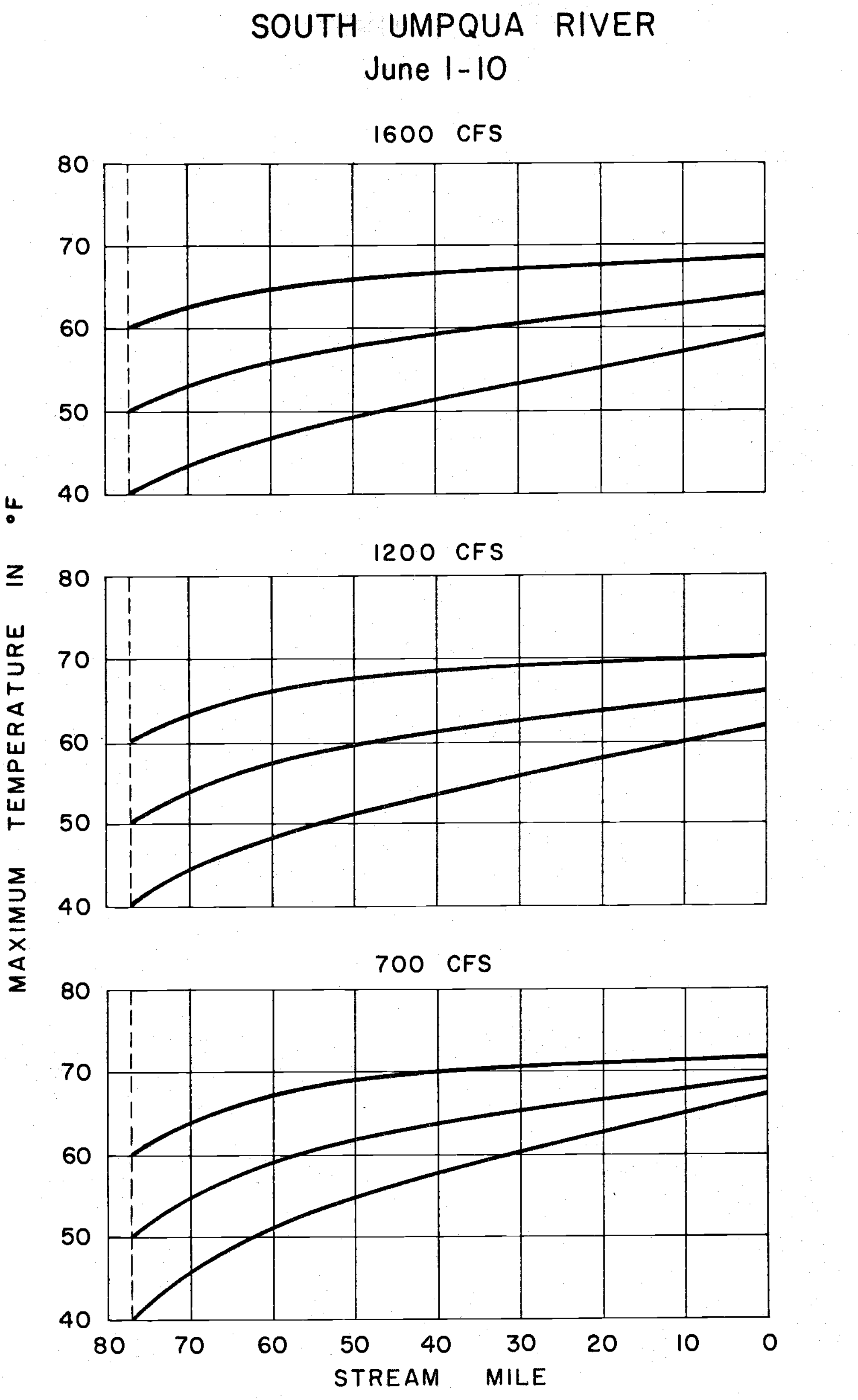


FIGURE 1. Maximum stream temperatures for indicated releases from Tiller Reservoir.

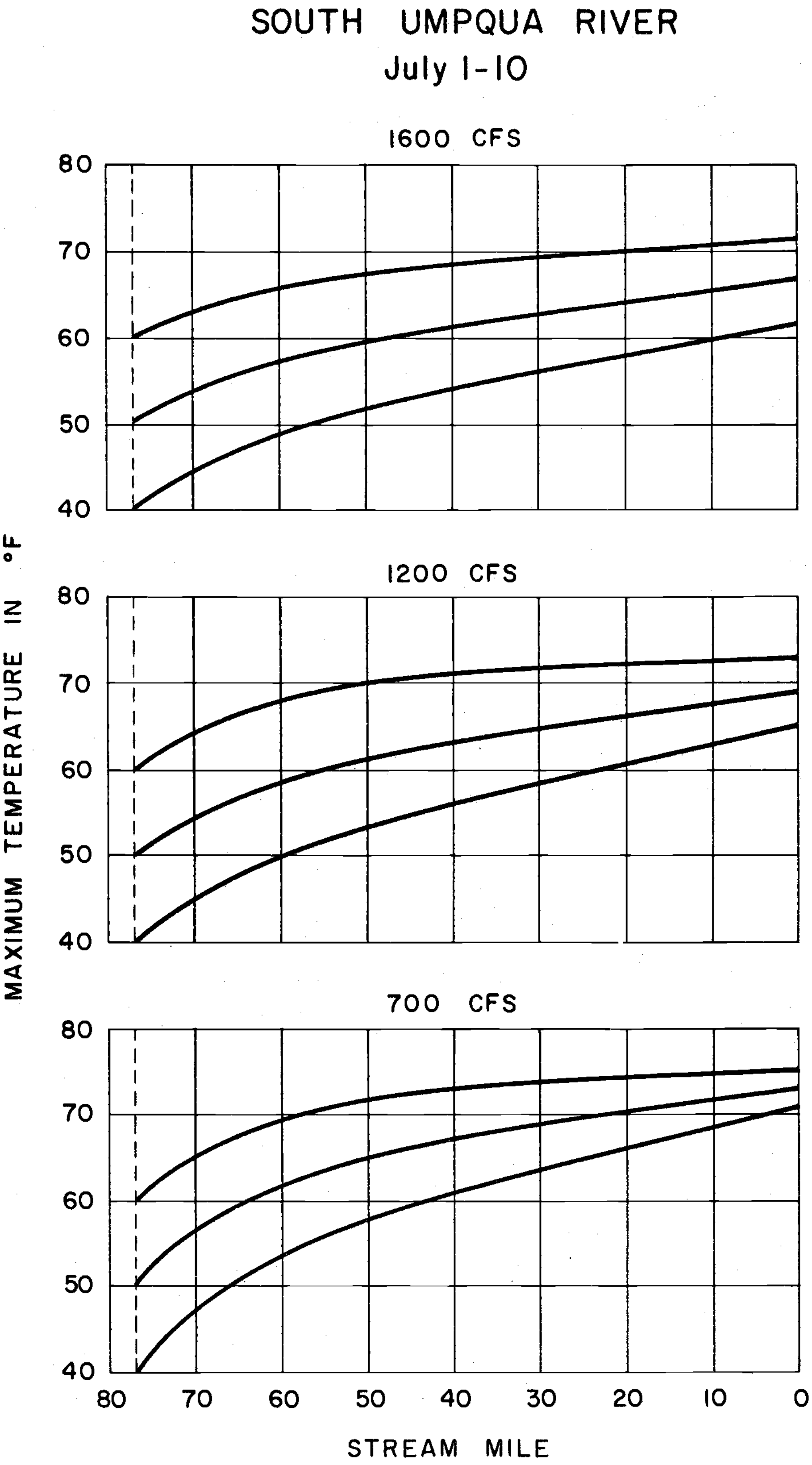


FIGURE 2. Maximum stream temperatures for indicated releases from Tiller Reservoir.

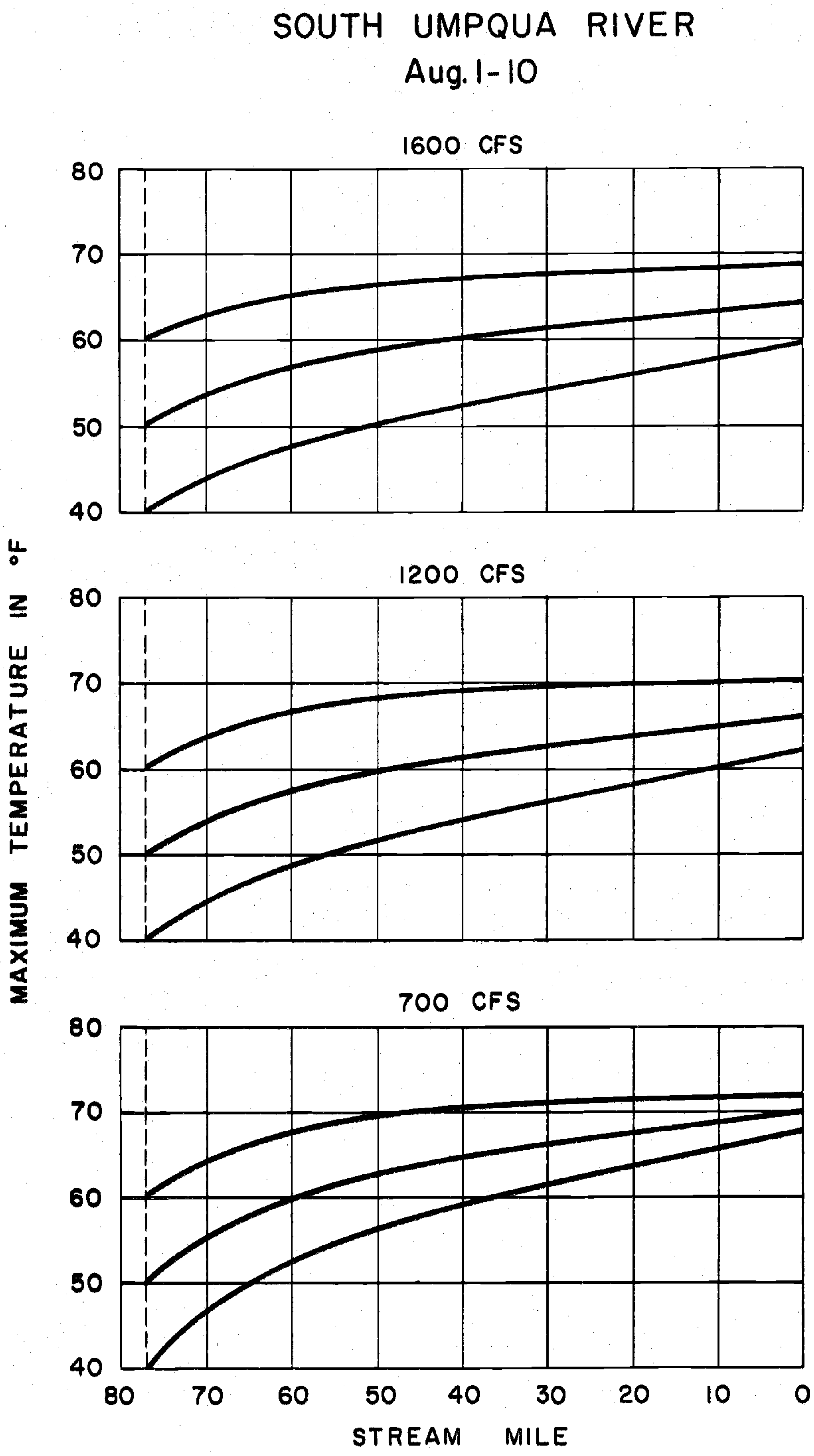


FIGURE 3. Maximum stream temperatures for indicated releases from Tiller Reservoir.

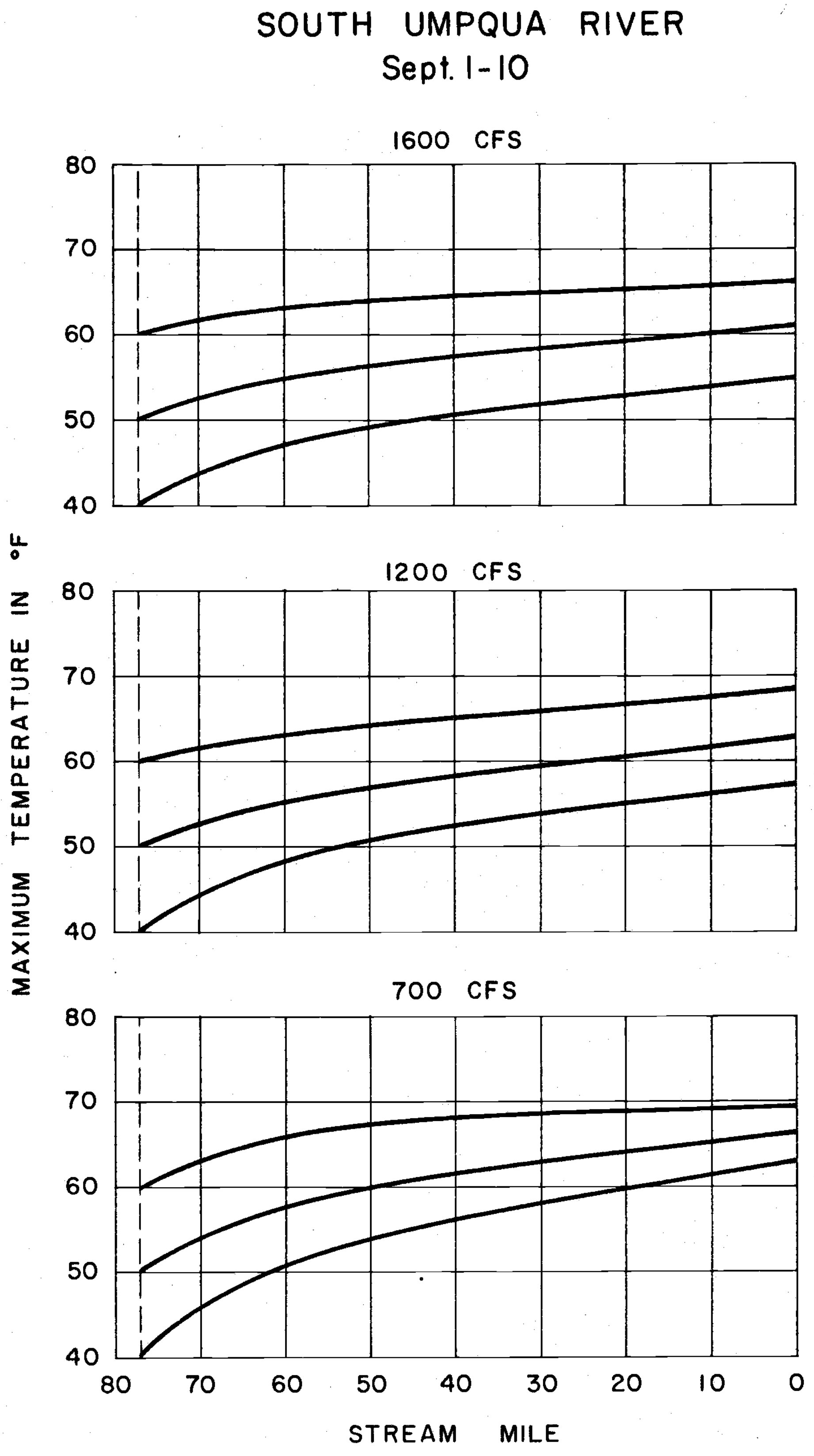


FIGURE 4. Maximum stream temperatures for indicated releases from Tiller Reservoir.

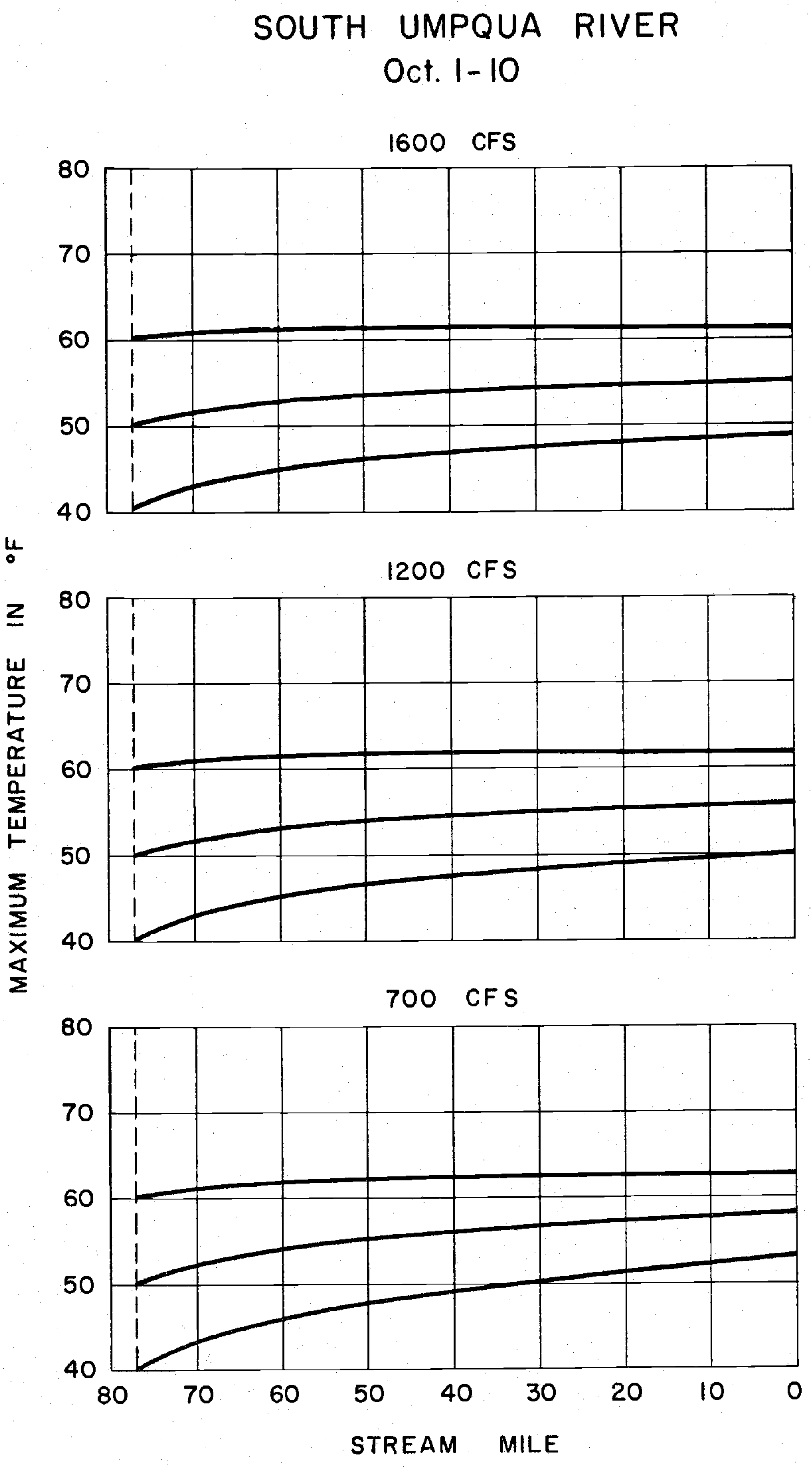


FIGURE 5. Maximum stream temperatures for indicated releases from Tiller Reservoir.

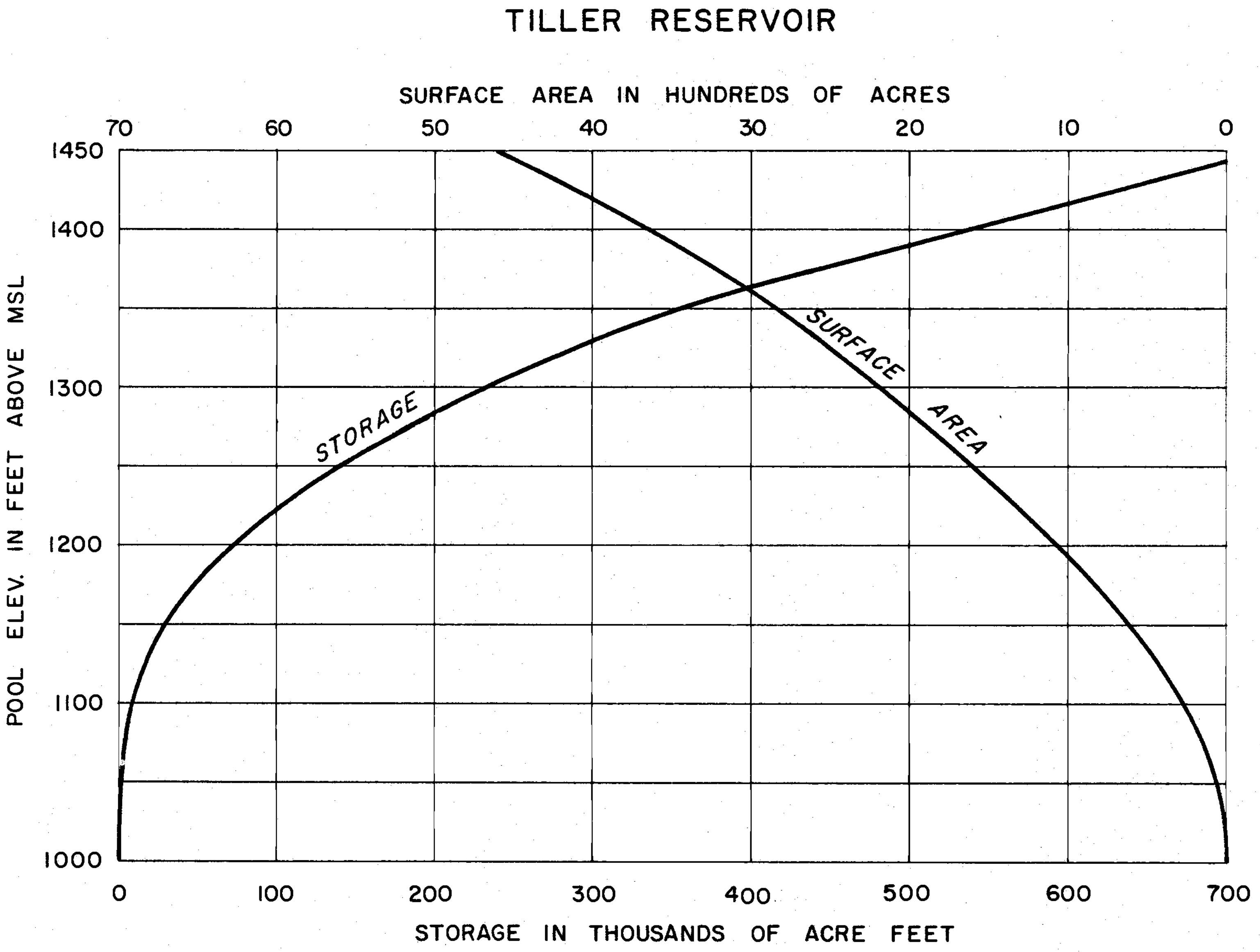


FIGURE 6. Capacity and surface area of proposed Tiller Reservoir on the South Umpqua River.

Details pertaining to the first regulation, to maintain minimum stream temperatures, are given in Table 2 and the corresponding reservoir temperatures are illustrated in Figure 7. The maximum release rate of 1600 cfs was adopted for the entire period from June through October. This analysis indicated that the reservoir was capable of supplying 50° F. water in June and July, 55° F. water in August and September and 60° F. water in October. For these releases, stream temperature analyses indicated temperatures in South Umpqua River of 68° F. or less, under average meteorological conditions. Average reservoir temperatures, for this regulation, rose from 52° F. in June to about 60° F. in September. All but 29,000 acre-feet of reservoir capacity was used for downstream temperature suppression.

Details of the second regulation, for low reservoir temperatures under average meteorological conditions, are given in Table 3 and Figure 8. Two release rates were used, 1600 cfs for June and 1200 cfs for July through October. Average reservoir temperature reached a maximum of about 52° F. in August. Maximum temperature below the surface layer reached 58° F. in August. A residual storage of 127,000 acre-feet was left in the reservoir at the end of October.

Table 4 gives details of the third regulation, to maintain maximum holdover storage, and corresponding reservoir temperatures are shown in Figure 9. Minimum release rates were used, consistent with downstream temperature control. Releases of 1200 cfs were used for June and July and 700 cfs for August through October. At the end of the regulation, about 242,000 acre-feet remained in storage, more than one-half of total reservoir capacity.

Details of the regulation to maintain downstream temperatures below 70° F. during the maximum temperature year, 1958, are given in Table 5. Figure 10 shows reservoir temperatures for the same year. Using a release rate of 1600 cfs for the entire regulation, the reservoir was capable of providing release temperatures adequate to maintain downstream temperatures below 70° F. Average reservoir temperature, however, rose to nearly 63° F. while only 29,000 acre-feet of storage remained unused at the end of the regulation.

Results of the four regulations indicate that Tiller Reservoir has more than adequate capability to maintain temperatures in South Umpqua River below 70° F. for all meteorological conditions that can be foreseen.

TABLE 2

REGULATION OF TILLER RESERVOIR FOR MAINTAINING MINIMUM STREAM TEMPERATURES UNDER AVERAGE METEOROLOGICAL CONDITIONS

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	390,800	42.0	86,500	45.0	27,300	460	46.0	3.2	450,000	45.2
MAY	450,000	45.2	63,600	49.5	63,600	1030	53.0	4.0	450,000	49.2
JUNE	450,000	49.2	30,700	59.5	95,200	1600	50.0	3.0	385,500	52.2
JULY	385,500	52.2	10,200	72.0	98,400	1600	50.0	2.9	297,300	55.1
AUG.	297,300	55.1	4,700	68.5	98,400	1600	55.0	2.1	203,600	57.2
SEPT.	203,600	57.2	4,900	61.0	95,200	1600	55.0	2.7	113,300	59.9
OCT.	113,300	59.9	14,500	49.5	98,400	1600	60.0	-6.5	29,400	53.4

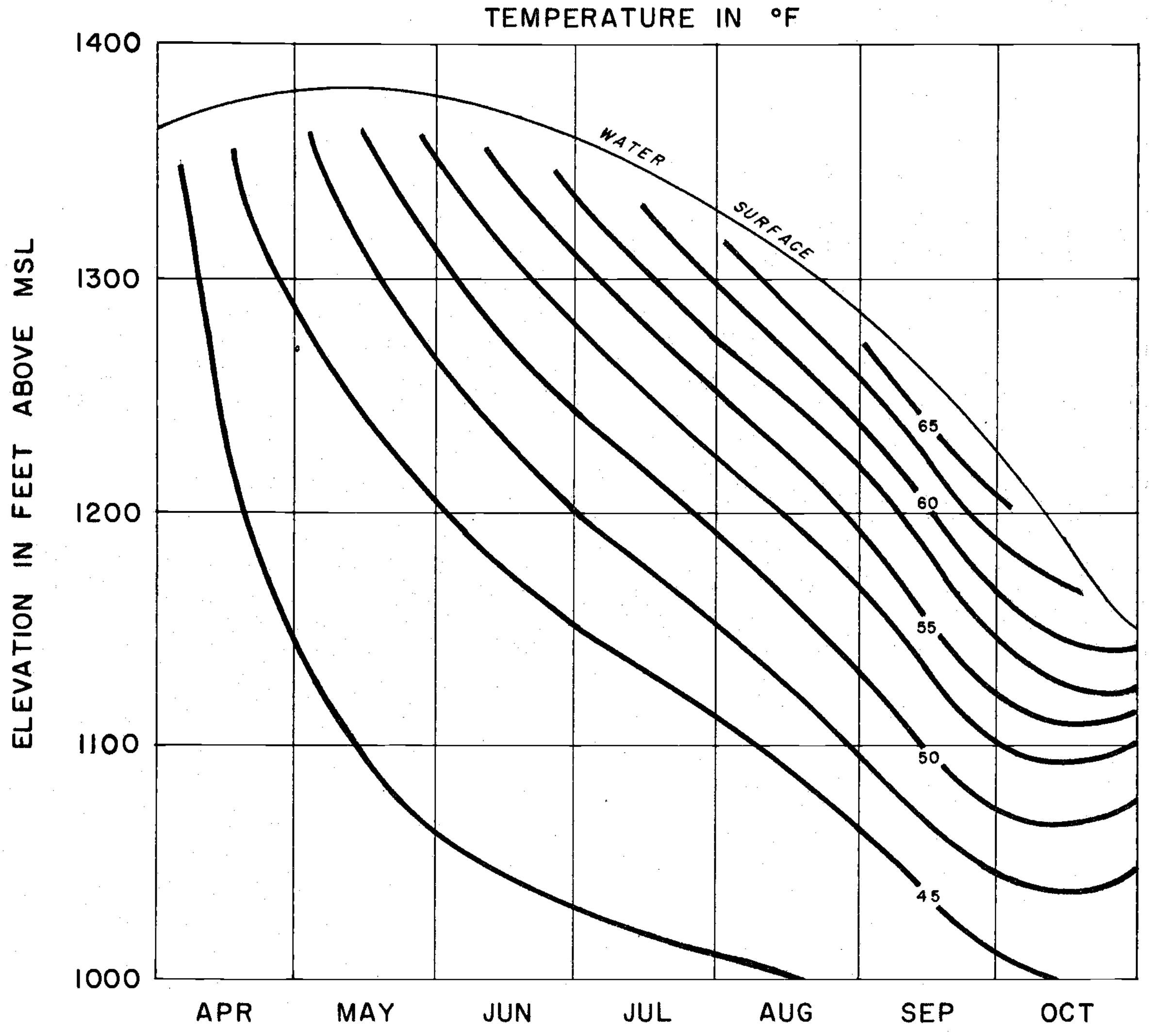


FIGURE 7. Monthly temperature distribution for the regulation shown in Table 2.

TABLE 3

REGULATION OF TILLER RESERVOIR FOR MAINTAINING LOW RESERVOIR TEMPERATURES UNDER AVERAGE METEOROLOGICAL CONDITIONS

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	390,800	42.0	86,500	45.0	27,300	460	46.0	3.2	450,000	45.2
MAY	450,000	45.2	63,600	49.5	63,600	1030	53.0	4.0	450,000	49.2
JUNE	450,000	49.2	30,700	59.5	95,200	1600	60.0	0.4	385,500	49.6
JULY	385,500	49.6	10,200	72.0	73,800	1200	50.0	1.9	321,900	51.5
AUG.	321,900	51.5	4,700	68.5	73,800	1200	55.0	0.8	252,800	52.3
SEPT.	252,800	52.3	4,900	61.0	71,400	1200	60.0	-2.4	186,300	49.9
OCT.	186,300	49.9	14,500	49.5	73,800	1200	65.0	-3.8	127,000	46.1

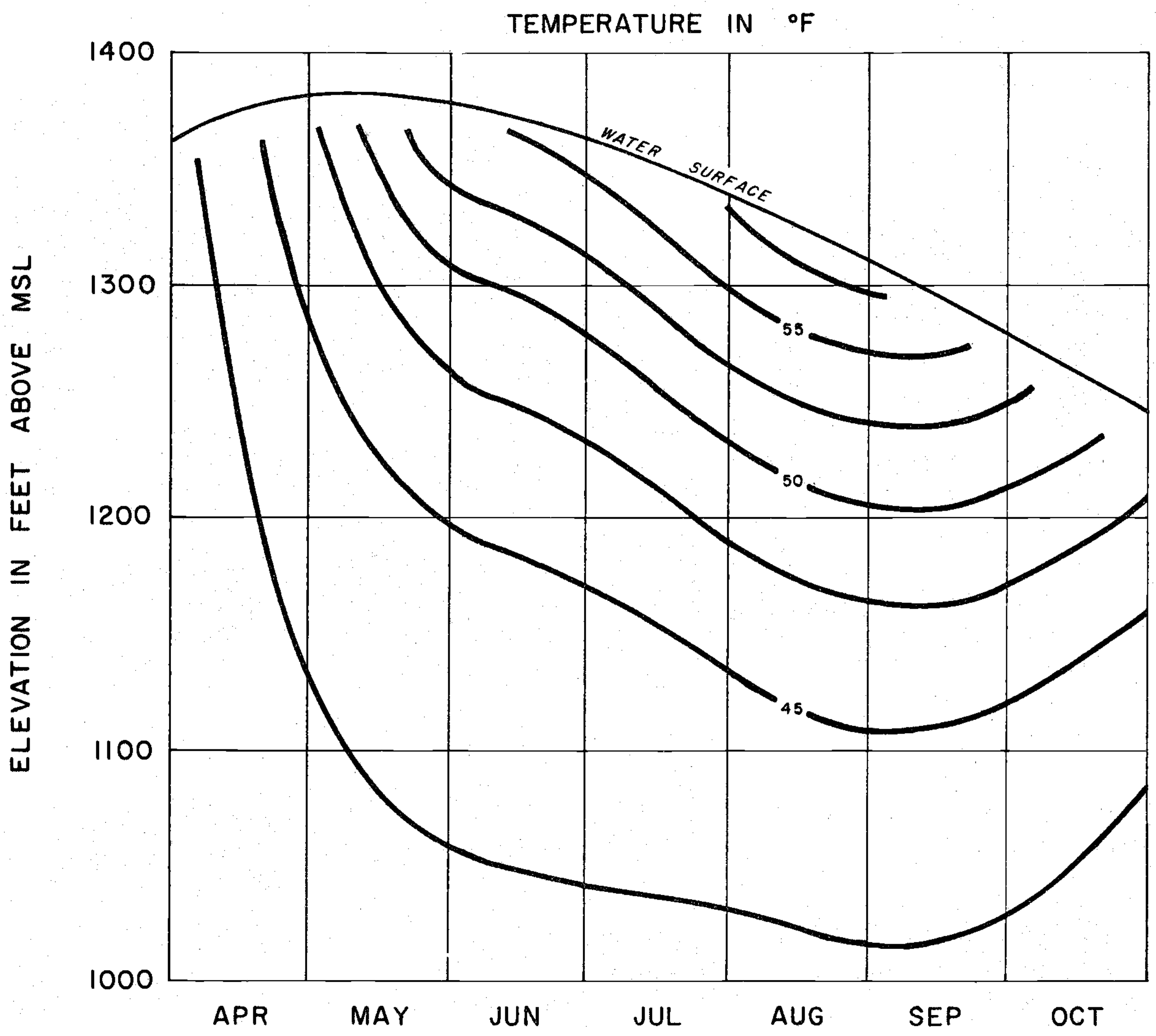


FIGURE 8. Monthly temperature distribution for the regulation shown in Table 3.

TABLE 4

REGULATION OF TILLER RESERVOIR FOR MAINTAINING HIGH RESERVOIR HOLDOVER UNDER AVERAGE METEOROLOGICAL CONDITIONS

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	390,800	42.0	86,500	45.0	27,300	460	46.0	3.2	450,000	45.2
MAY	450,000	45.2	63,600	49.5	63,600	1030	53.0	4.0	450,000	49.2
JUNE	450,000	49.2	30,700	59.5	71,400	1200	60.0	1.1	409,300	50.3
JULY	409,300	50.3	10,200	72.0	73,800	1200	50.0	2.1	345,700	52.4
AUG.	345,700	52.4	4,700	68.5	43,000	700	55.0	1.3	307,400	53.7
SEPT.	307,400	53.7	4,900	61.0	41,700	700	55.0	0.2	270,600	53.9
OCT.	270,600	53.9	14,500	49.5	43,000	700	60.0	-2.0	242,100	51.9

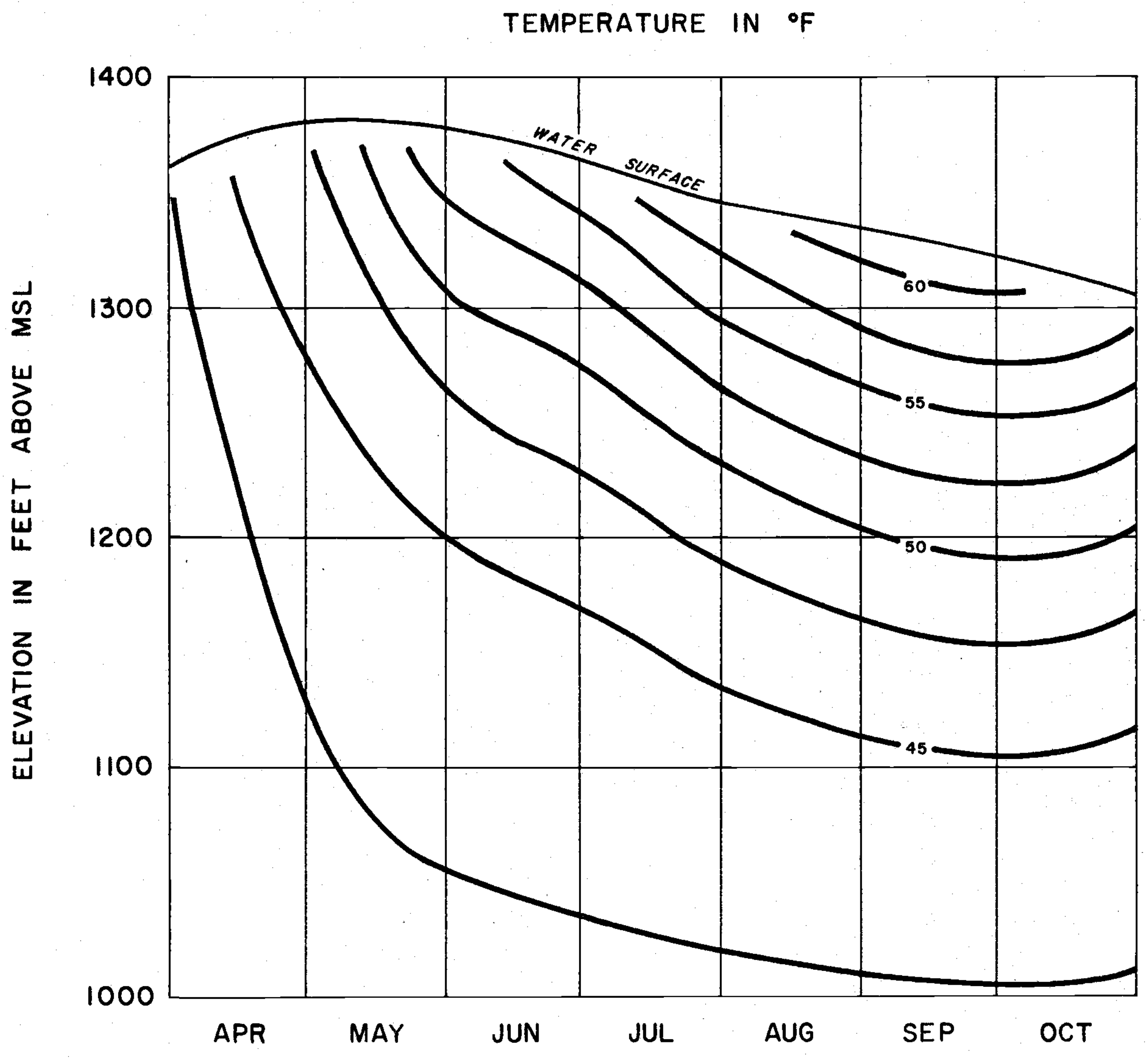


FIGURE 9. Monthly temperature distribution for the regulation shown in Table 4.

TABLE 5

REGULATION OF TILLER RESERVOIR FOR MAINTAINING DESIRABLE STREAM TEMPERATURES DURING MAXIMUM TEMPERATURE YEAR (1958)

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	390,800	42.0	86,500	45.0	27,300	460	48.0	3.7	450,000	45.7
MAY	450,000	45.7	63,600	49.5	63,600	1030	60.0	4.9	450,000	50.6
JUNE	450,000	50.6	30,700	59.5	95,200	1600	58.0	3.0	385,500	53.6
JULY	385,500	53.6	10,200	72.0	98,400	1600	55.0	4.3	297,300	57.9
AUG.	297,300	57.9	4,700	68.5	98,400	1600	58.0	4.1	203,600	62.0
SEPT.	203,600	62.0	4,900	61.0	95,200	1600	62.0	0.6	113,300	62.6
OCT.	113,300	62.6	14,500	49.5	98,400	1600	63.0	-6.2	29,400	56.4

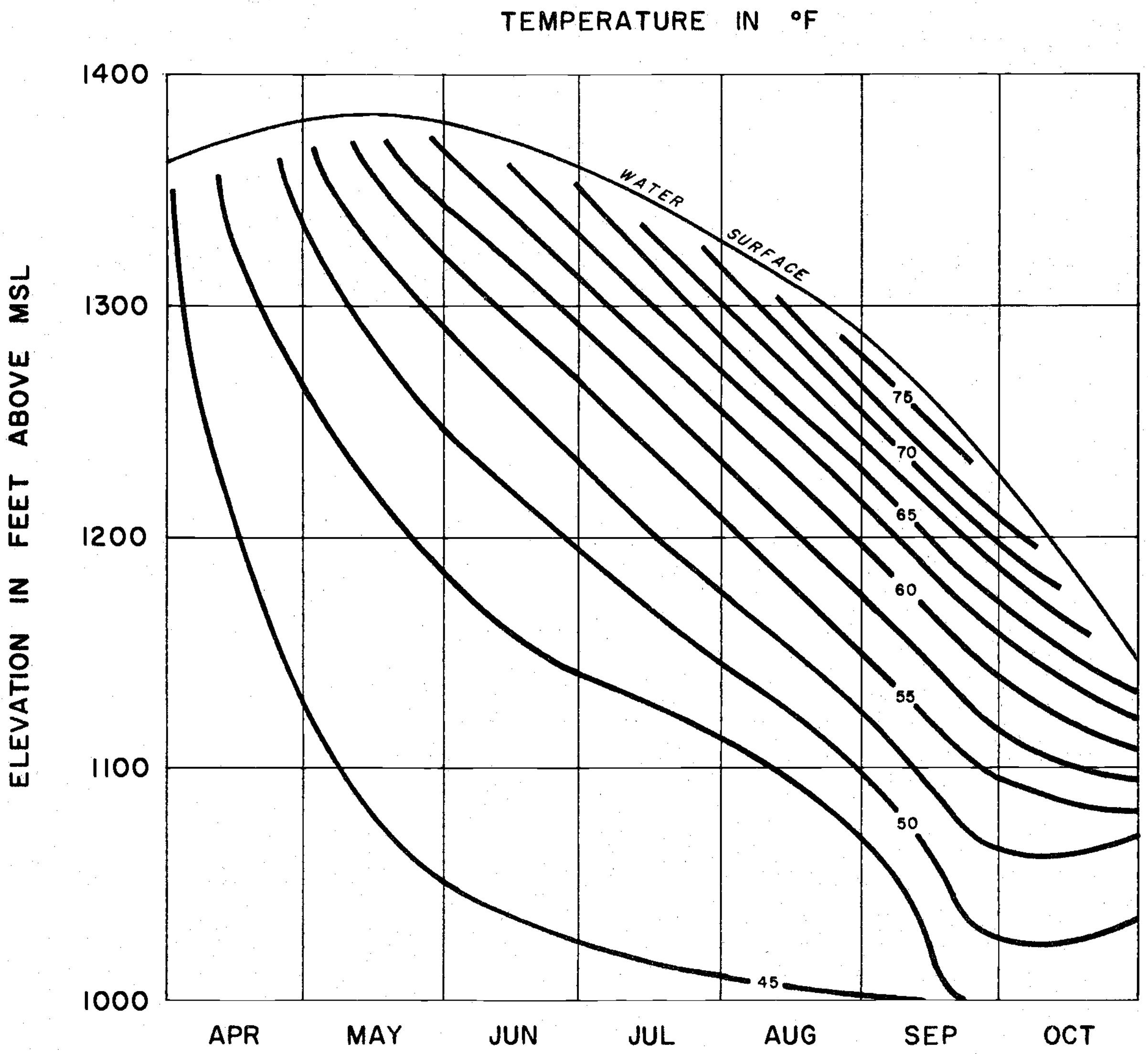


FIGURE 10. Monthly temperature distribution for the regulation shown in Table 5.

Temperatures of 68° F. are indicated for the regulation designed to keep stream temperatures at a minimum. In average years a substantial part of the storage will be available for other purposes which cannot be served by water regulated for temperature control. Average reservoir temperatures can be maintained within tolerable limits for desirable species of fish life. Tiller Reservoir has little influence, as will be shown later, over temperatures in the main stem of the Umpqua River.

2. Cow Creek

Stream temperatures were computed for reservoir release rates of 300, 200 and 100 cfs at release temperatures of 50° and 60° F. No computations were made for 40° F. releases because significant quantities of water at this temperature were not available, according to reservoir analyses.

Two sets of temperature computations were performed, one based on the stream width curves, referred to previously, and the other based on the assumption that stream widths remained relatively constant within the range of discharge values. The latter computations provided a check and where necessary, a means of adjustment of temperatures computed on the basis of stream width curves. These curves, as previously described, were based partly on judgment, and were thus subject to inaccuracies. Using both sets of computations, curves of maximum temperature vs. stream mile were developed for the various release conditions and are given in Figures 11 through 15.

TABLE 6

COW CREEK
STREAM MILES BELOW GALESVILLE
RESERVOIR HELD BELOW 70° F

RELEASE RATE Cfs	RELEASE TEMP. °F	RELEASE PERIOD				
		JUNE 1-10	JULY 1-10	AUG. 1-10	SEPT. 1-10	OCT. 1-10
300	50	61*	61	61	61	61
	60	61	23	61	61	61
200	50	61	40	61	61	61
	60	23	14	22	34	61
100	50	21	19	21	30	61
	60	10	8	10	24	61

* Entire length of stream below Galesville Reservoir.

These figures indicate that, for most of the releases, peak temperatures in the lower reaches of Cow Creek will exceed 70° F. Table 6 gives, for average meteorological

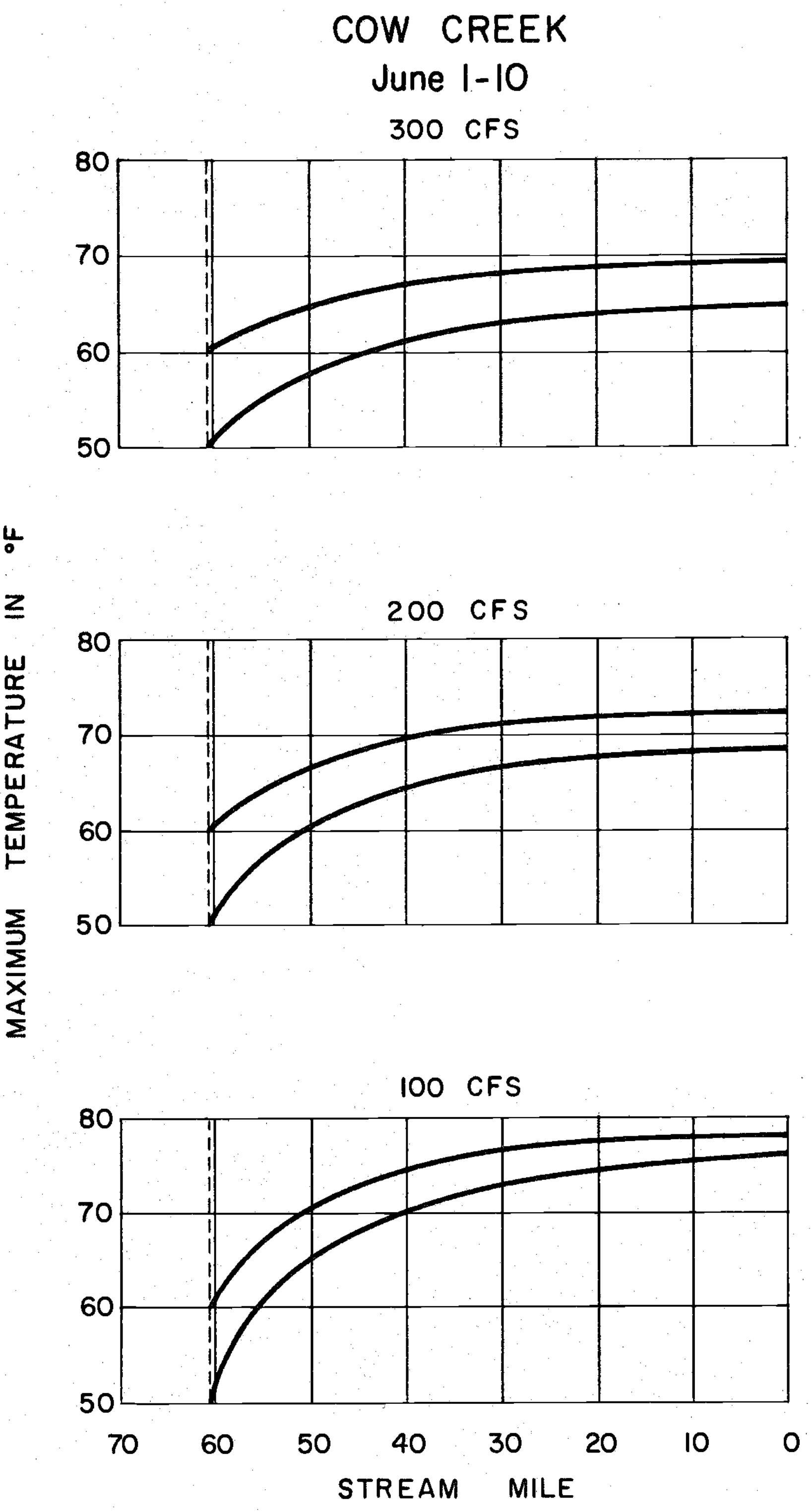


FIGURE 11. Maximum stream temperatures for indicated releases from Galesville Reservoir.

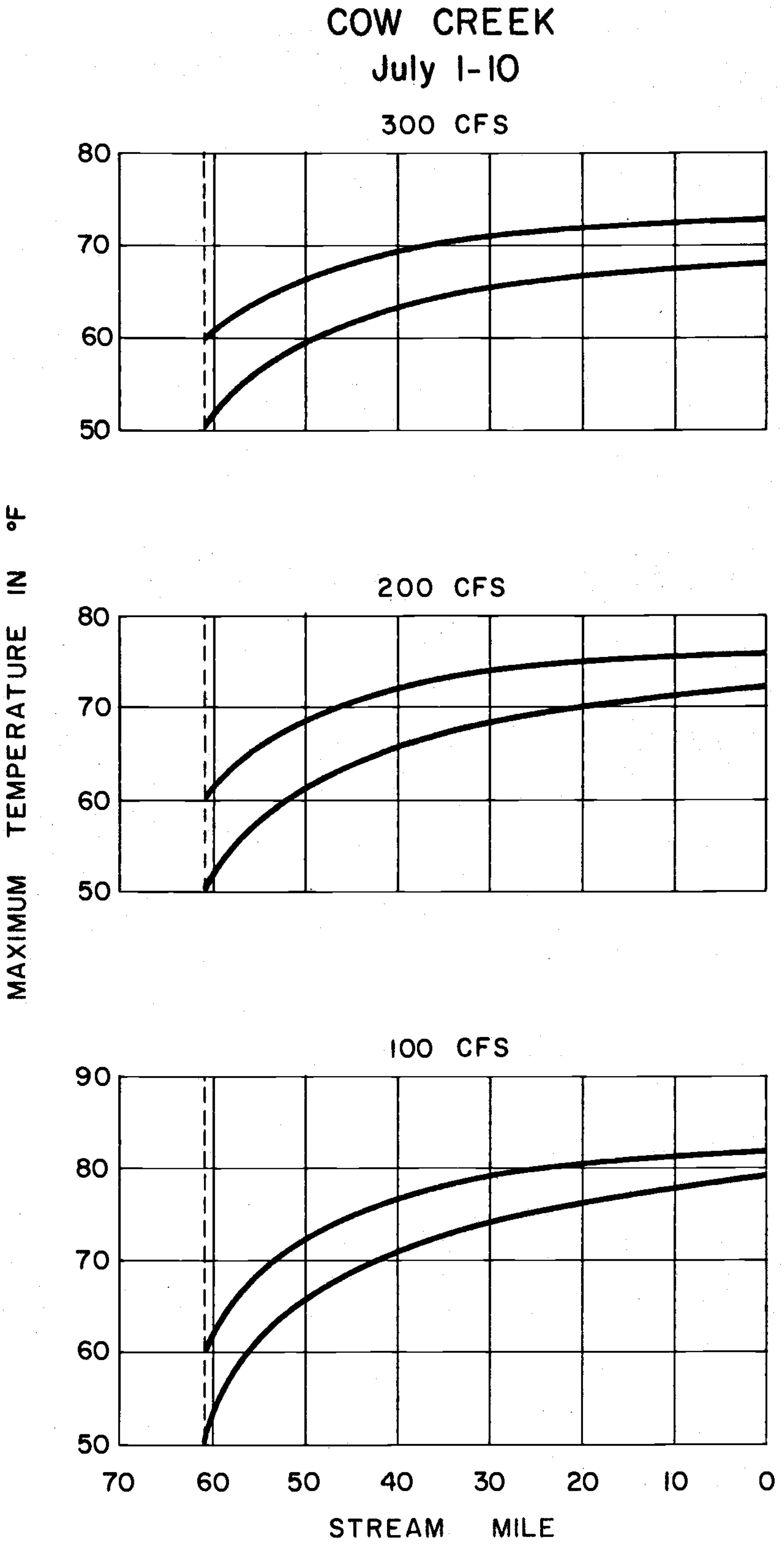


FIGURE 12. Maximum stream temperatures for indicated releases from Galesville Reservoir.

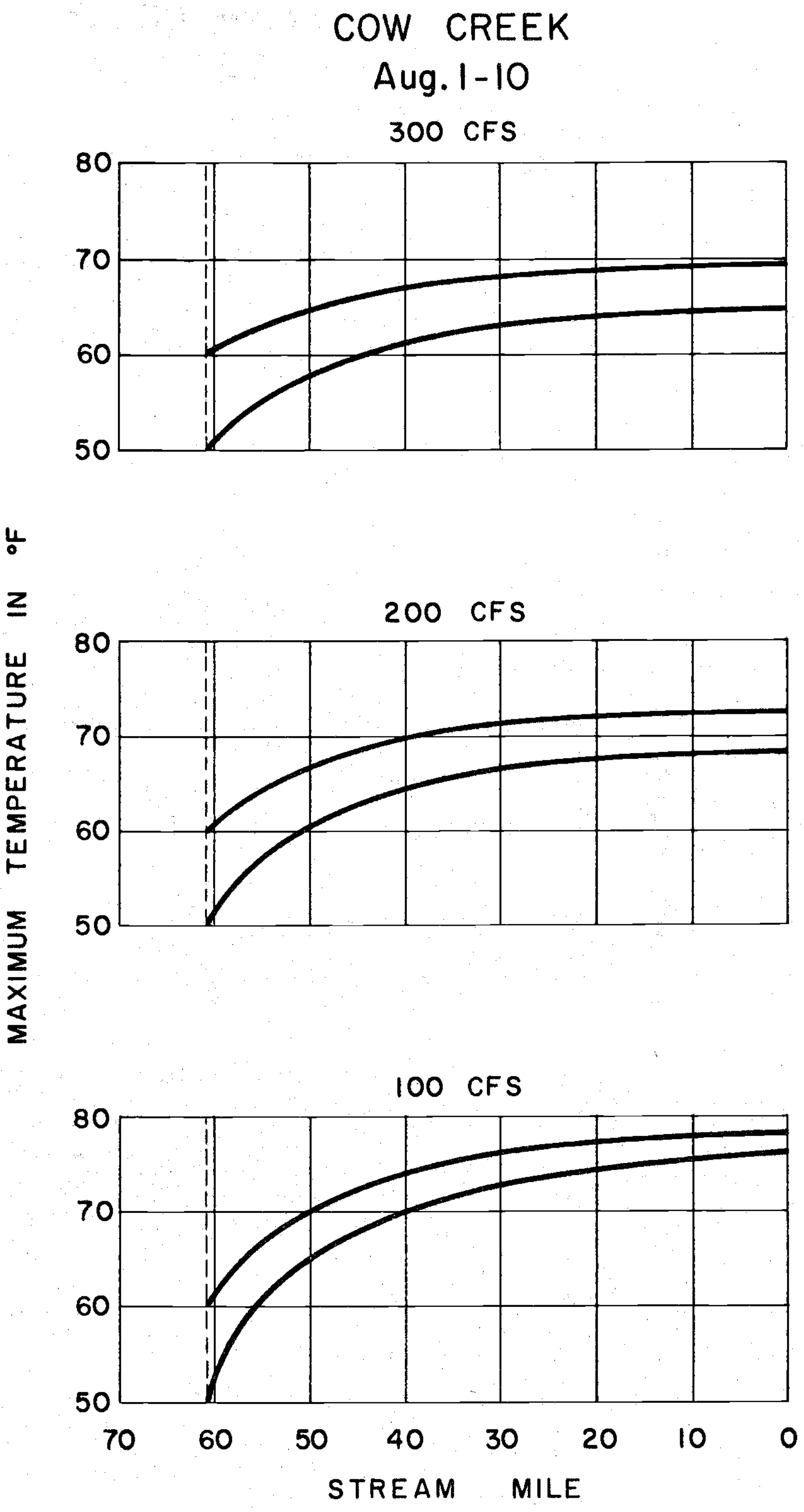


FIGURE 13. Maximum stream temperatures for indicated releases from Galesville Reservoir.

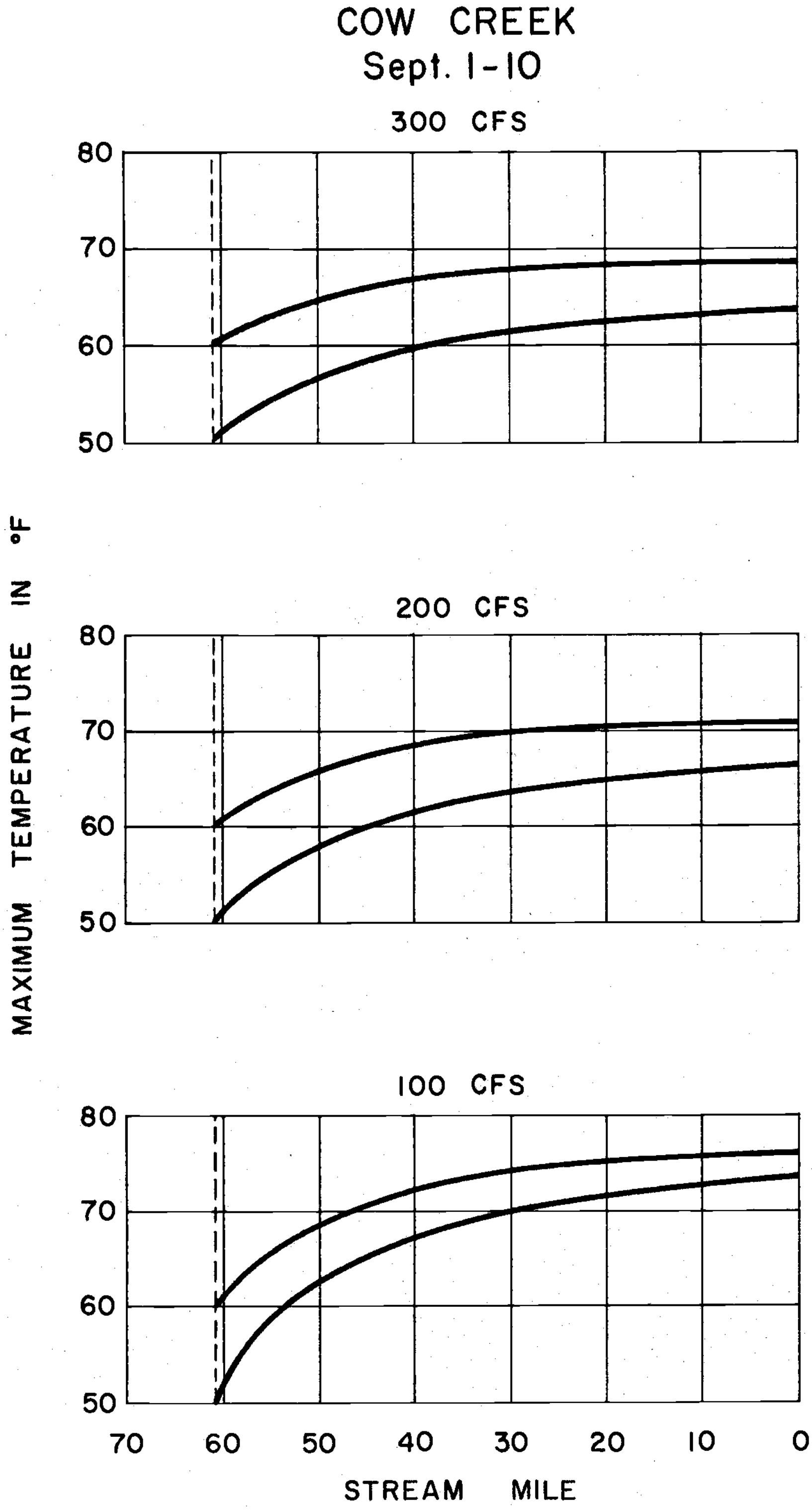


FIGURE 14. Maximum stream temperatures for indicated releases from Galesville Reservoir.

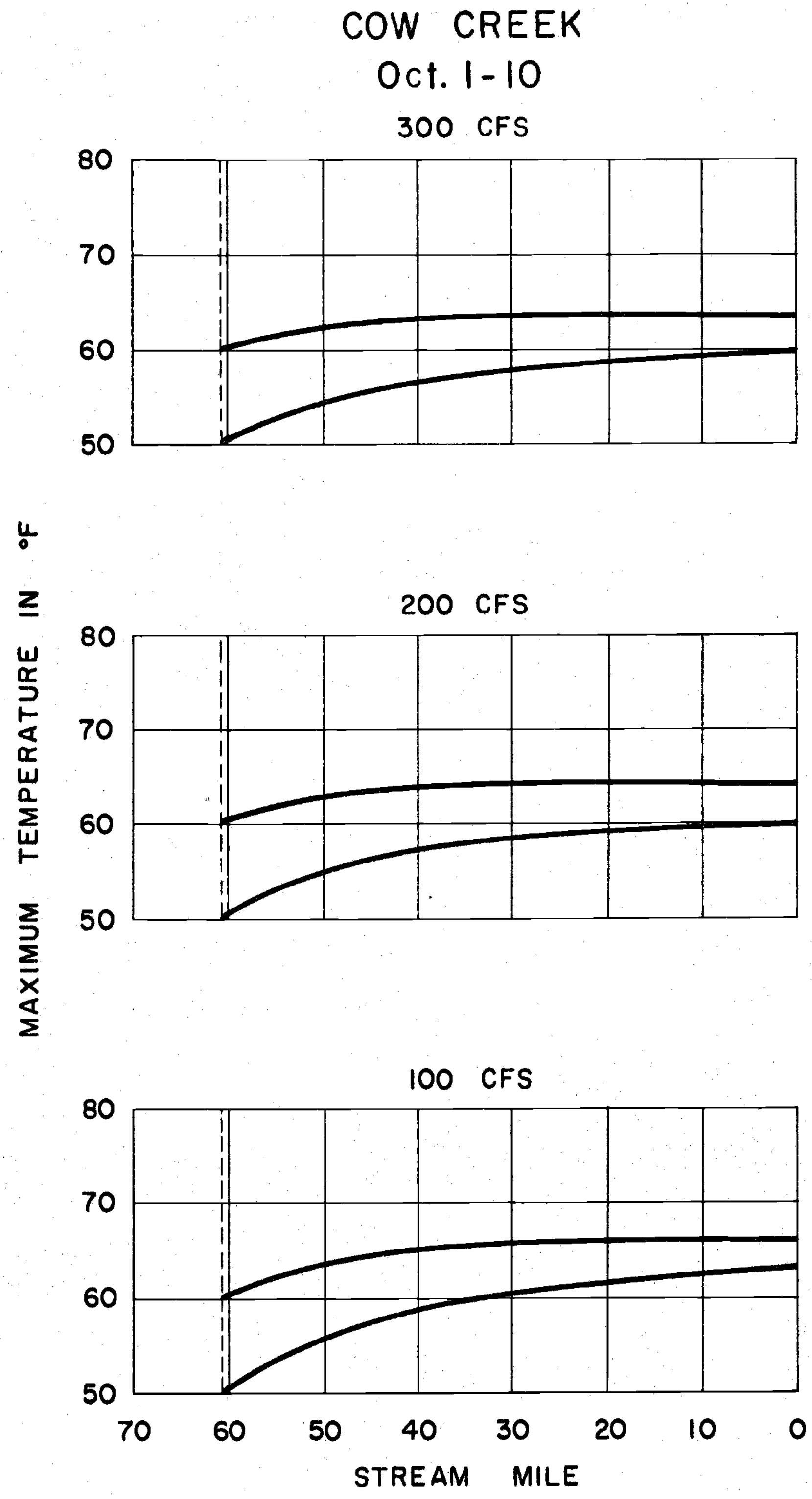


FIGURE 15. Maximum stream temperatures for indicated releases from Galesville Reservoir.

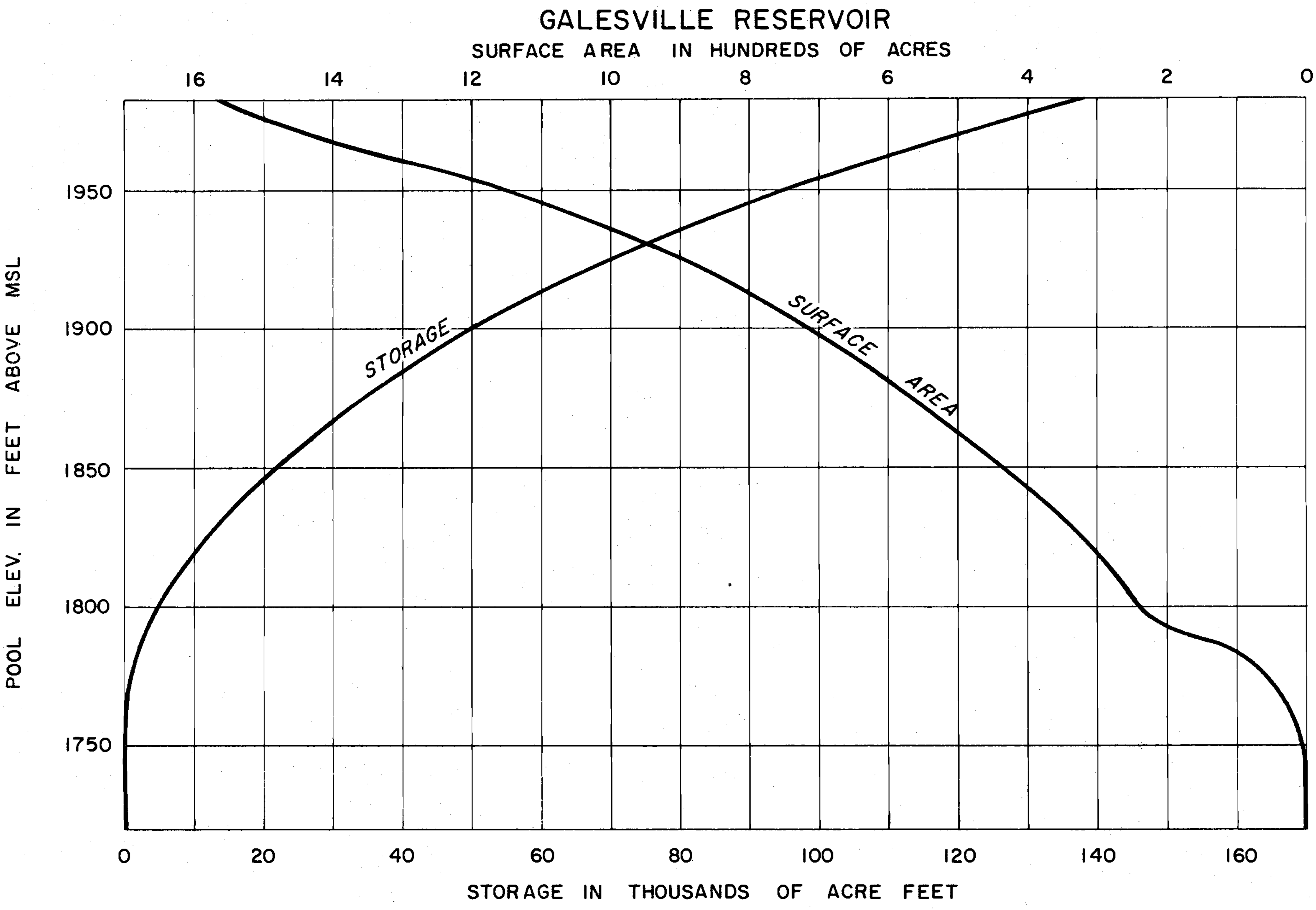


FIGURE 16. Capacity and surface are of proposed Galesville Reservoir on Cow Creek.

conditions, the length of stream below the dam in which temperatures can be held below 70° F. for each reservoir release condition.

The proposed Galesville Dam is located on Cow Creek near stream mile 61. Area-capacity curves, Figure 16, show a capacity of 75,000 acre-feet at the full pool depth of 210 feet. Average yield at the damsite, based on 32 years of gaging records, is 76,000 acre-feet. The minimum annual yield recorded, for the 1931 water year, was 21,000 acre-feet.

In all four regulations the reservoir was assumed to be at full pool at the beginning of June. This condition will not occur in certain low yield years. With the use of holdover storage, however, a full or nearly full reservoir may be attainable for most years. Release rates ranging from 100 cfs to 300 cfs were used in the regulations.

Details of the three regulations for minimum downstream temperature, low reservoir temperature and maximum holdover storage are given in Tables 7, 8 and 9, respectively. Reservoir temperatures corresponding to these regulation schedules are graphically illustrated in Figures 17, 18 and 19. All three regulations showed the reservoir capable of satisfying release requirements necessary to maintain Cow Creek temperatures below 70° F. Stream temperatures for most months were held below 69° F. for the regulation designed for minimum downstream temperature. Residual storage amounted to 9,000 acre-feet and average reservoir temperature reached a maximum of about 68° F. When regulated for low reservoir temperature, the average value reached a maximum of about 60° F. and residual storage was 9,000 acre-feet, as before. Maximum holdover storage amounted to 21,000 acre-feet, while average reservoir temperatures reached a maximum of almost 68° F. For the foregoing regulations, maximum reservoir temperatures either approached or exceeded the 70° F. level.

The regulation for the maximum temperature year, 1958, showed that reservoir capability is inadequate to control temperatures for the entire length of stream below 70° F. Only about half of the stream below Galesville Dam could be held below 70° F. for the entire five months. Table 10, which gives details of this regulation, shows release temperatures of 70° F. for September and October. Meteorological conditions for these two months will cause a drop in temperature as released water moves downstream. Average reservoir temperature reaches a maximum of 73° F., while the temperature near the surface reached 80° F.

TABLE 7

REGULATION OF GALESVILLE RESERVOIR FOR MAINTAINING MINIMUM STREAM TEMPERATURES UNDER AVERAGE METEOROLOGICAL CONDITIONS

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	70,000	42.0	8,500	48.5	3,500	60	52.0	5.5	75,000	47.5
MAY	75,000	47.5	4,800	53.0	4,800	80	56.0	7.6	75,000	55.1
JUNE	75,000	55.1	2,500	62.9	17,800	300	59.0	3.1	59,700	58.2
JULY	59,700	58.2	1,100	67.9	18,400	300	55.0	4.2	42,400	62.4
AUG.	42,400	62.4	700	68.5	15,400	250	60.0	2.7	27,700	65.1
SEPT.	27,700	65.1	700	61.8	14,900	250	62.0	3.1	13,500	68.2
OCT.	13,500	68.2	1,700	52.1	6,100	100	62.0	-10.0	9,100	58.2

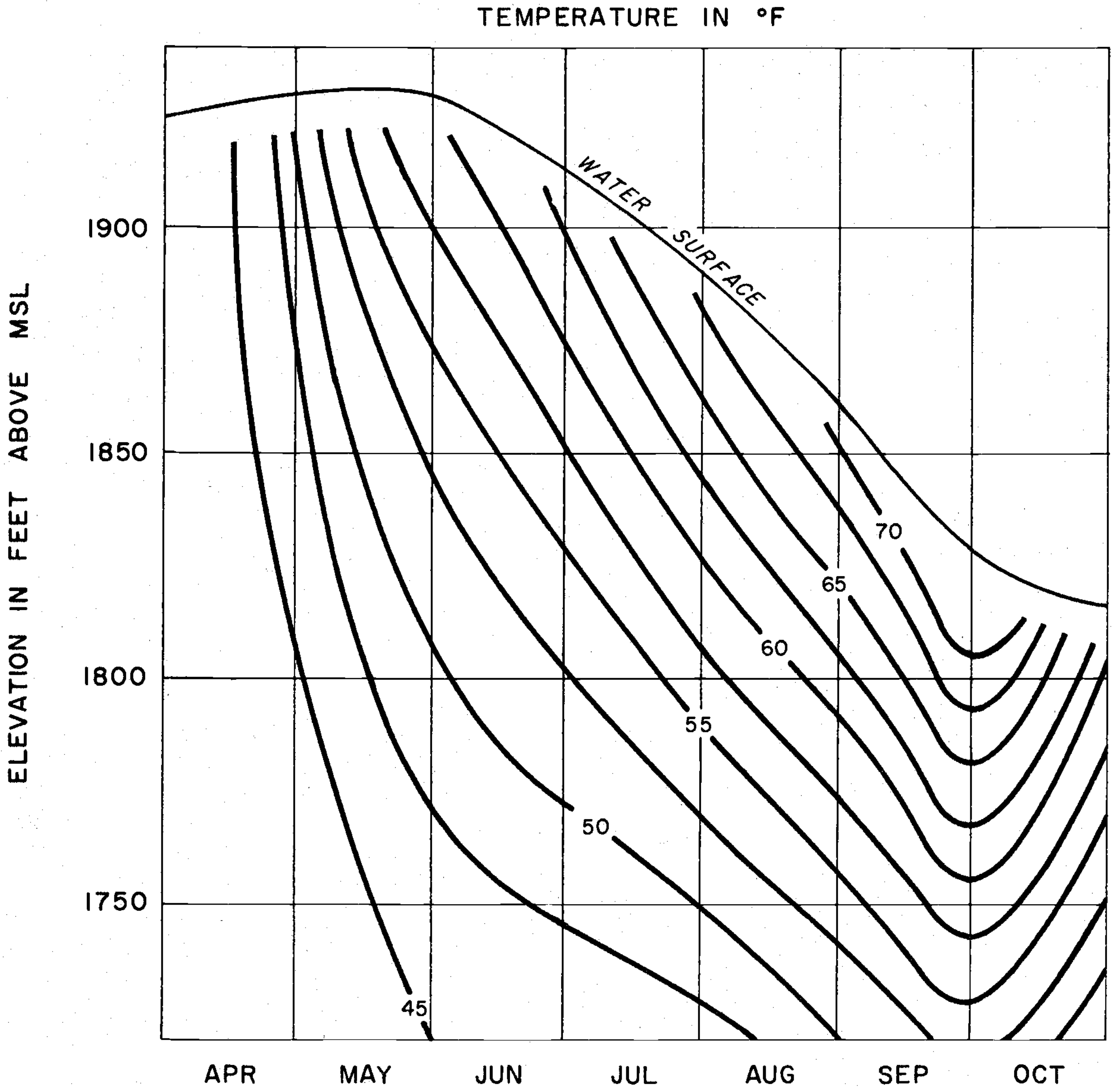


FIGURE 17. Monthly temperature distribution for the regulation shown in Table 7.

TABLE 8

REGULATION OF GALESVILLE RESERVOIR FOR MAINTAINING LOW RESERVOIR TEMPERATURES UNDER AVERAGE METEOROLOGICAL CONDITIONS

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	70,000	42.0	8,500	48.5	3,500	60	52.0	5.5	75,000	47.5
MAY	75,000	47.5	4,800	53.0	4,800	80	56.0	7.6	75,000	55.1
JUNE	75,000	55.1	2,500	62.9	17,800	300	60.0	2.8	59,700	57.9
JULY	59,700	57.9	1,100	67.9	18,400	300	57.0	3.3	42,400	61.2
AUG.	42,400	61.2	700	68.5	15,400	250	60.0	2.0	27,700	63.2
SEPT.	27,700	63.2	700	61.8	14,900	250	63.0	-0.1	13,500	63.1
OCT.	13,500	63.1	1,700	52.1	6,100	100	65.0	-14.2	9,100	48.9

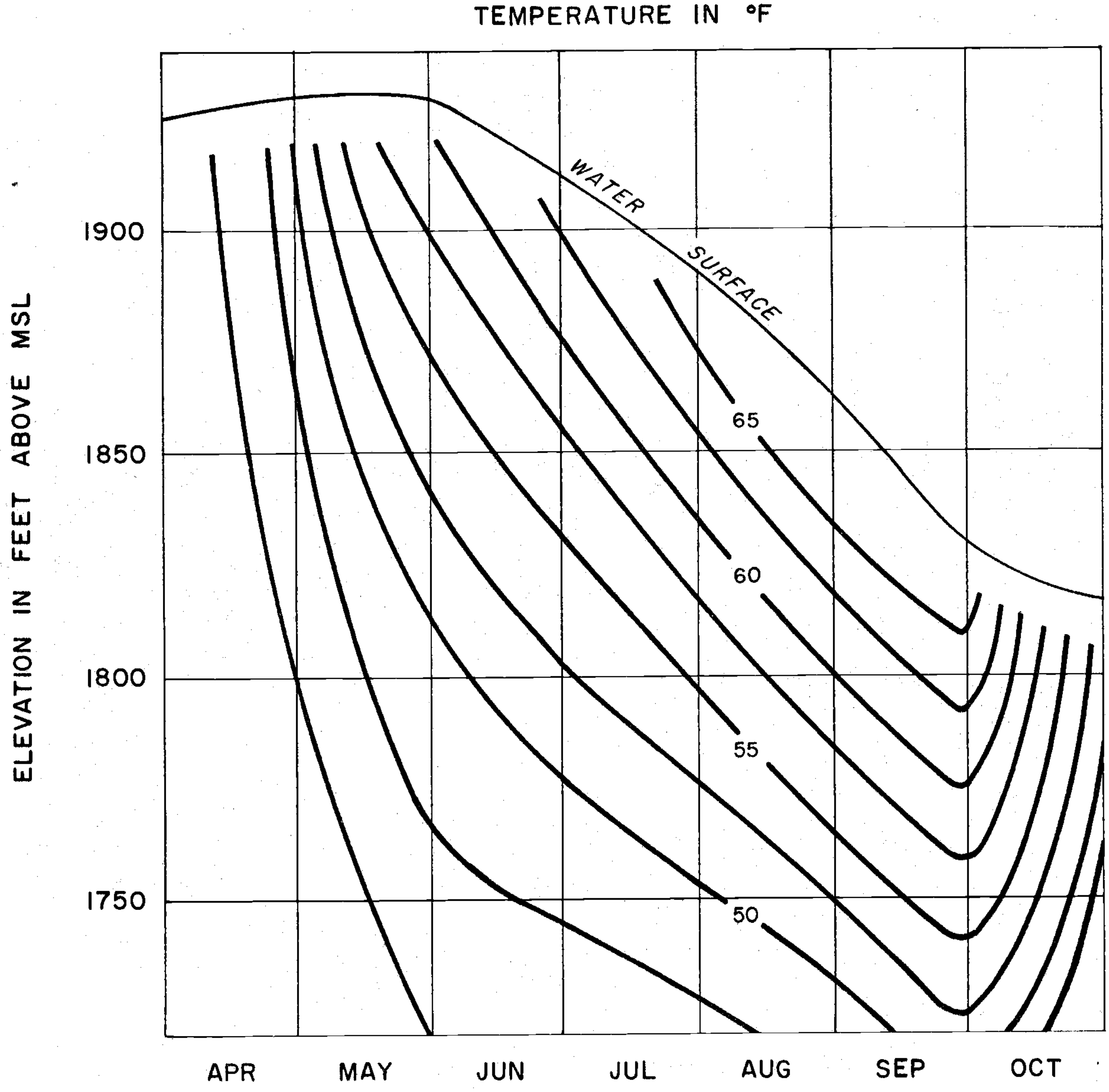


FIGURE 18. Monthly temperature distribution for the regulation shown in Table 8.

TABLE 9

REGULATION OF GALESVILLE RESERVOIR FOR MAINTAINING HIGH RESERVOIR HOLDOVER UNDER AVERAGE METEOROLOGICAL CONDITIONS

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	70,000	42.0	8,500	48.5	3,500	60	52.0	5.5	75,000	47.5
MAY	75,000	47.5	4,800	53.0	4,800	80	56.0	7.6	75,000	55.1
JUNE	75,000	55.1	2,500	62.9	14,900	250	57.0	3.6	62,600	58.7
JULY	62,600	58.7	1,100	67.9	15,400	250	54.0	4.2	48,300	62.9
AUG.	48,300	62.9	700	68.5	12,300	200	57.0	3.1	36,700	66.0
SEPT.	36,700	66.0	700	61.8	11,900	200	62.0	1.6	25,500	67.6
OCT.	25,500	67.6	1,700	52.1	6,100	100	65.0	-4.8	21,100	62.8

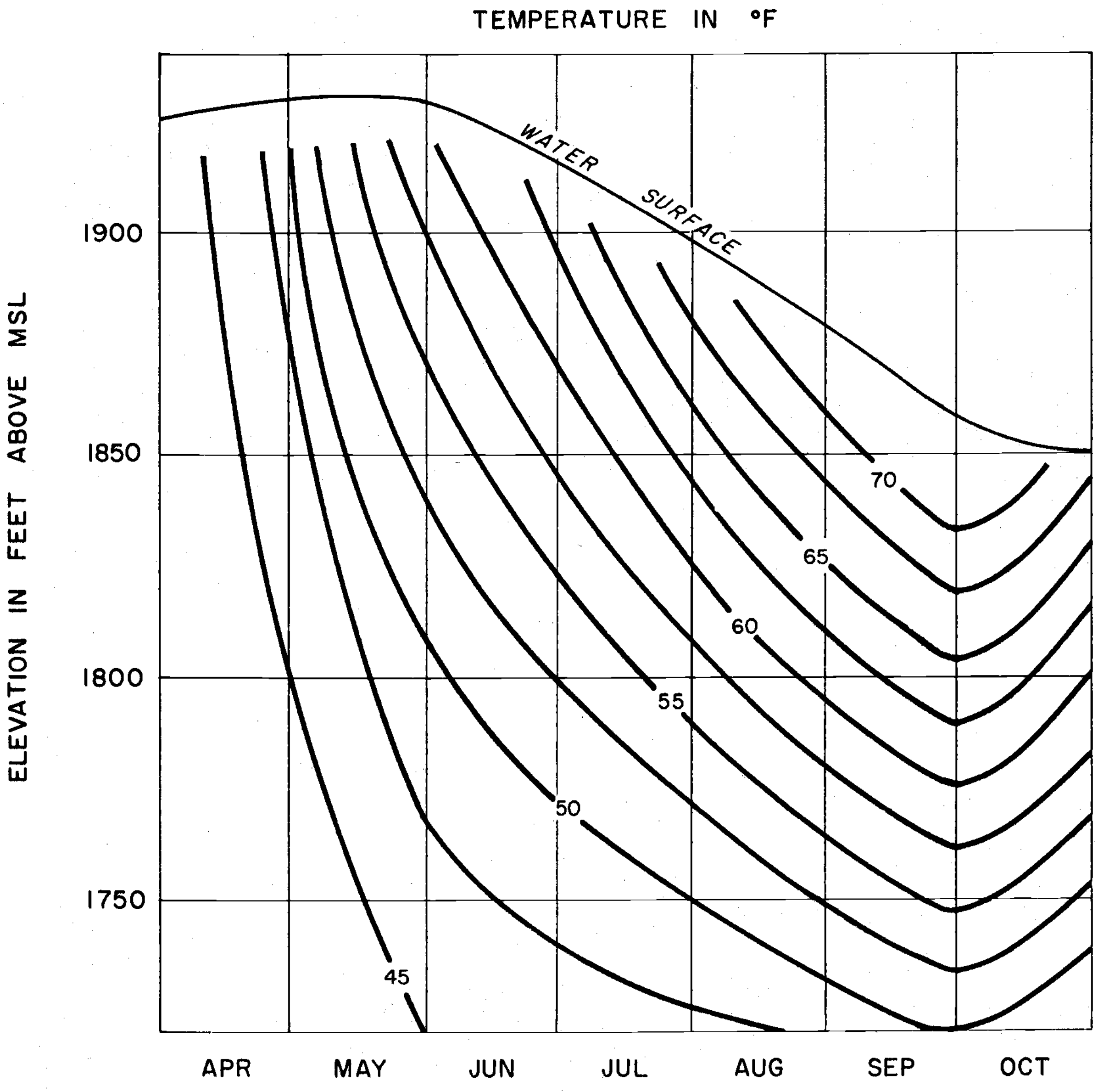


FIGURE 19. Monthly temperature distribution for the regulation shown in Table 9.

TABLE 10

REGULATION OF GALESVILLE RESERVOIR FOR MAINTAINING MINIMUM STREAM TEMPERATURES DURING MAXIMUM TEMPERATURE YEAR (1958)

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	70,000	42.0	8,500	48.5	3,500	60	53.0	6.4	75,000	48.4
MAY	75,000	48.4	4,800	53.0	4,800	80	57.0	9.5	75,000	57.9
JUNE	75,000	57.9	2,500	62.9	17,800	300	61.0	5.5	59,700	63.4
JULY	59,700	63.4	1,100	67.9	18,400	300	61.0	6.7	42,400	70.1
AUG.	42,400	70.1	700	68.5	18,400	300	67.0	3.0	24,700	73.1
SEPT.	24,700	73.1	700	61.8	14,900	250	70.0	-0.3	10,500	72.8
OCT.	10,500	72.8	1,700	52.1	6,100	100	70.0	-7.7	6,100	65.1

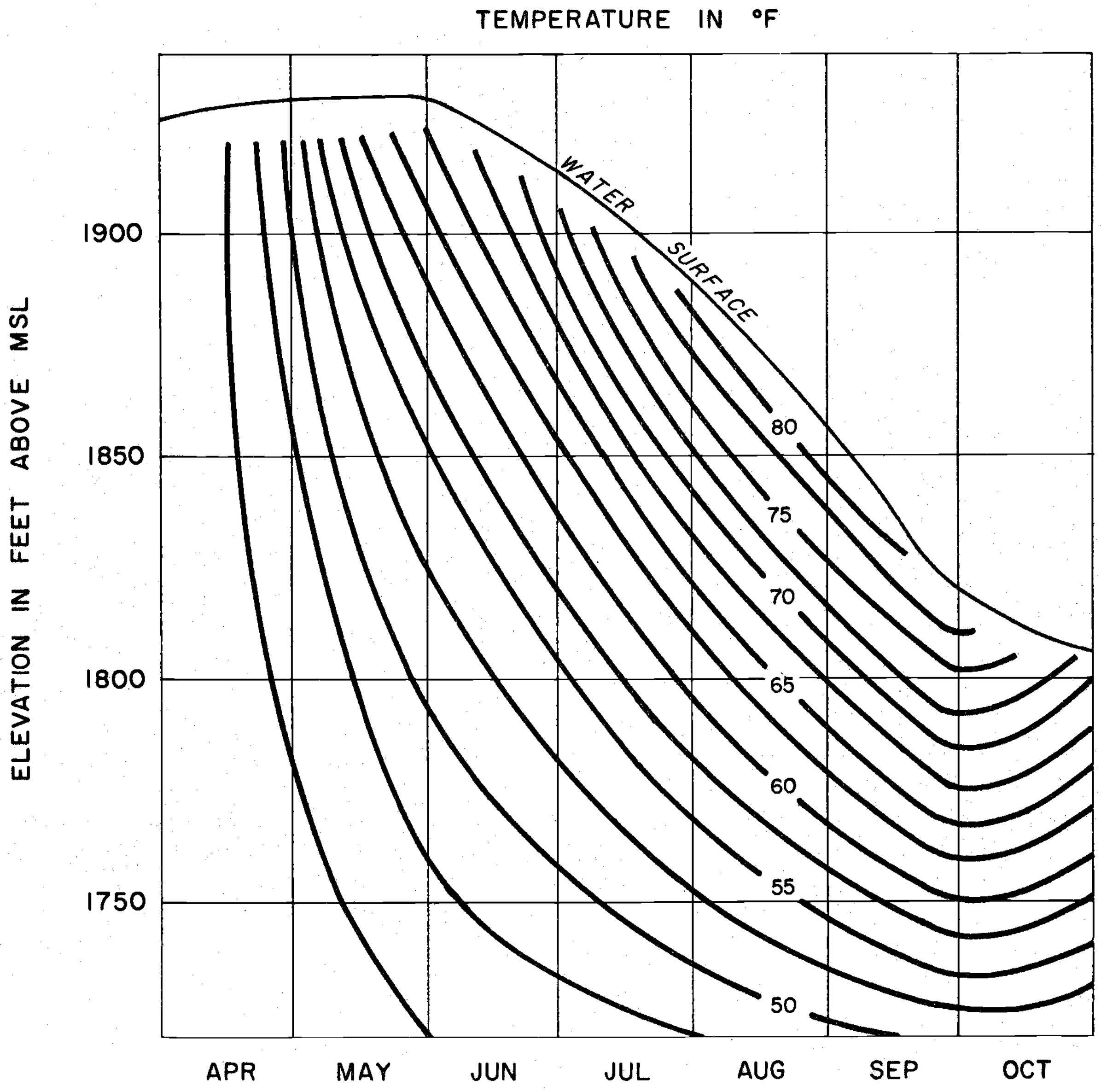


FIGURE 20. Monthly temperature distribution for the regulation shown in Table 10.

Results of regulations on Galesville Reservoir indicated that under average meteorological conditions and with a full reservoir in June, temperatures in Cow Creek can be held below 70° F. if nearly the entire storage is regulated for temperature control. Reservoir temperatures can simultaneously be held within tolerable limits for desirable species of fish life. However, as discussed above, even a full reservoir will permit only about half of Cow Creek to be continuously controlled below 70° F. during the maximum temperature year. If part of the stored water is not available for temperature control, or else the reservoir fails to attain full pool in June, effective temperature control will be decreased over a correspondingly longer portion on the lower section of Cow Creek. The extent and frequency of the occurrence of these conditions will determine the degree of temperature control that can be exercised over Cow Creek. It appears that an additional reservoir on West Fork would ensure that Cow Creek temperatures could be held below 70° F. for every year, but this has not been analyzed in this study.

3. <u>Calapooya Creek</u>

Stream temperatures were computed for discharge values of 200, 150 and 100 cfs at initial temperatures of 50° and 60° F. for the months of June through September. Curves of maximum temperature vs. stream miles are given in Figures 21 and 22. They indicate that a reservoir release rate of 150 cfs at a temperature of 50° F. will be capable of maintaining stream temperatures below 70° F. for all of the months considered. Stream lengths below the dam in which temperatures will be held below 70° F. for the various release conditions are given in Table 11.

TABLE 11

CALAPOOYA CREEK
STREAM MILES BELOW HINKLE RESERVOIR
HELD BELOW 70° F

RELEASE RATE Cfs	RELEASE TEMP. °F	RELEASE PERIOD			
		JUNE 1-10	JULY 1-10	AUG. 1-10	SEPT. 1-10
200	50	33*	33	33	33
	60	33	24	33	33
150	50	33	33	33	33
	60	23	15	22	33
100	50	27	19	25	33
	60	12	9	11	28

* **Entire length of stream below Hinkle Reservoir.**

The proposed Hinkle Dam is located at stream mile 33 on Calapooya Creek. The area-capacity curve, Figure 23, shows that at full pool elevation the reservoir will have a capacity of 70,000 acre-feet at a depth of 220 feet. Average annual yield at the damsite is estimated at 80,000 acre-feet and the minimum yield at 30,000 acre-feet.

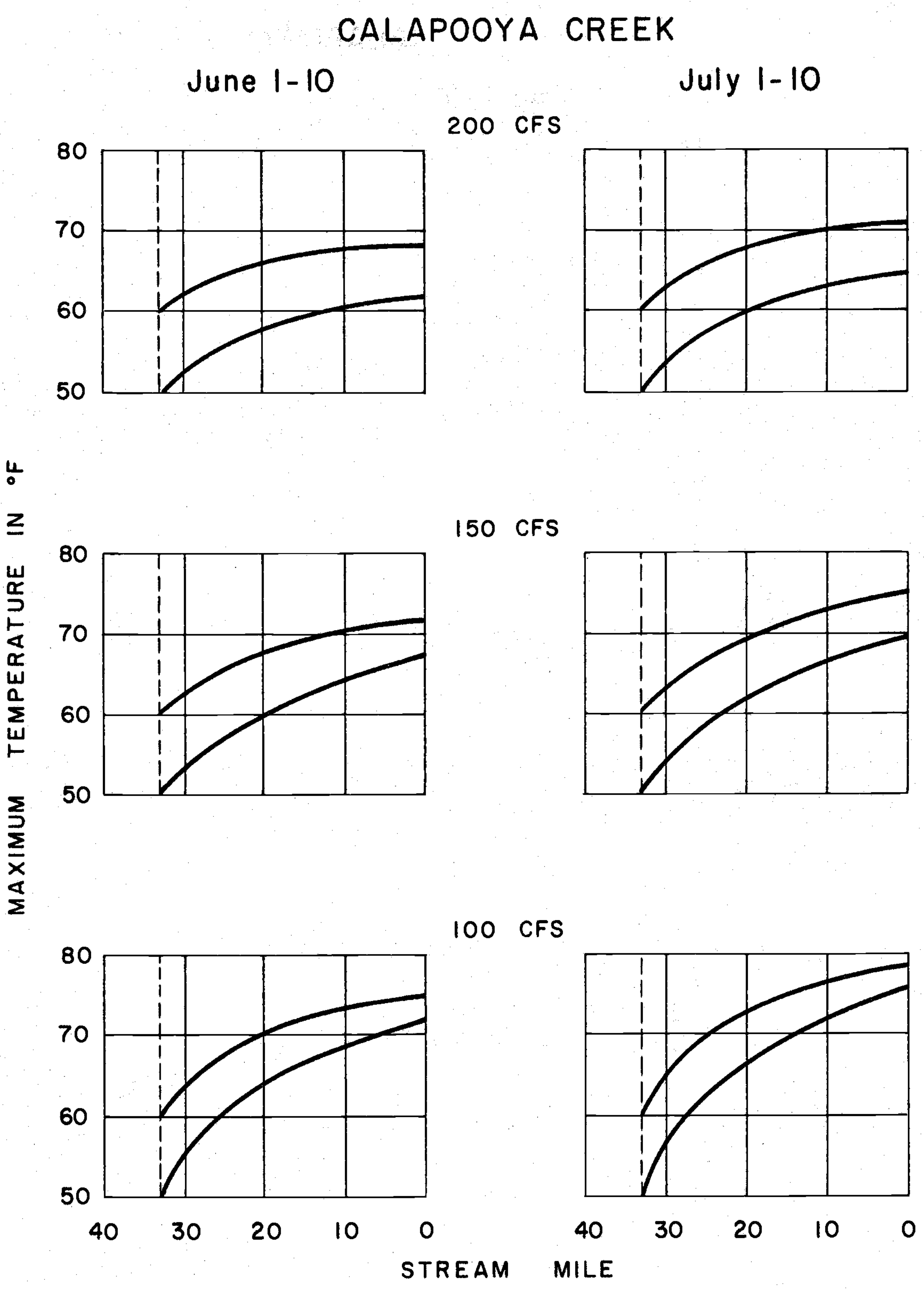


FIGURE 21. Maximum stream temperatures for indicated releases from Hinkle Reservoir.

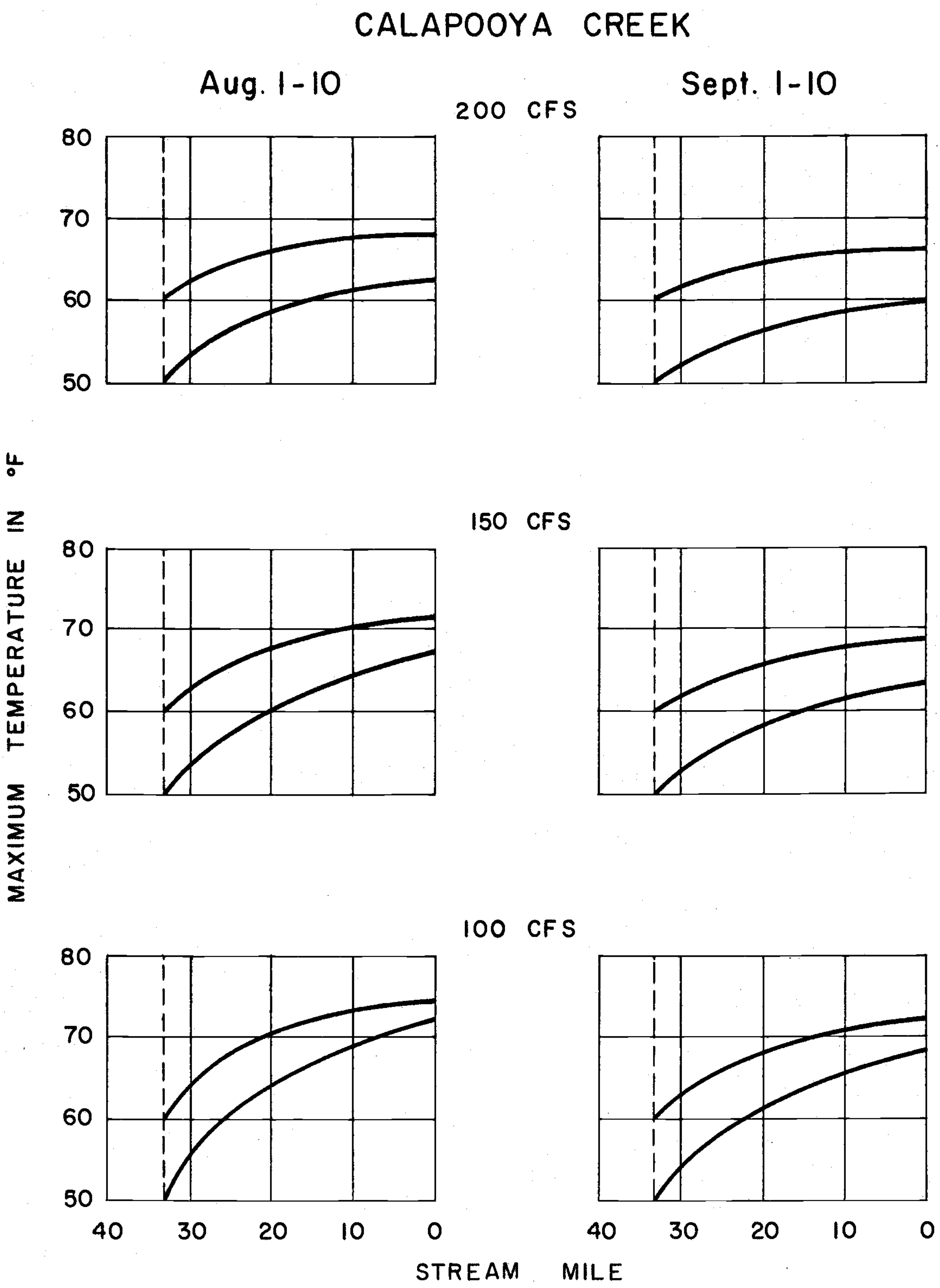


FIGURE 22. Maximum stream temperatures for indicated releases from Hinkle Reservoir.

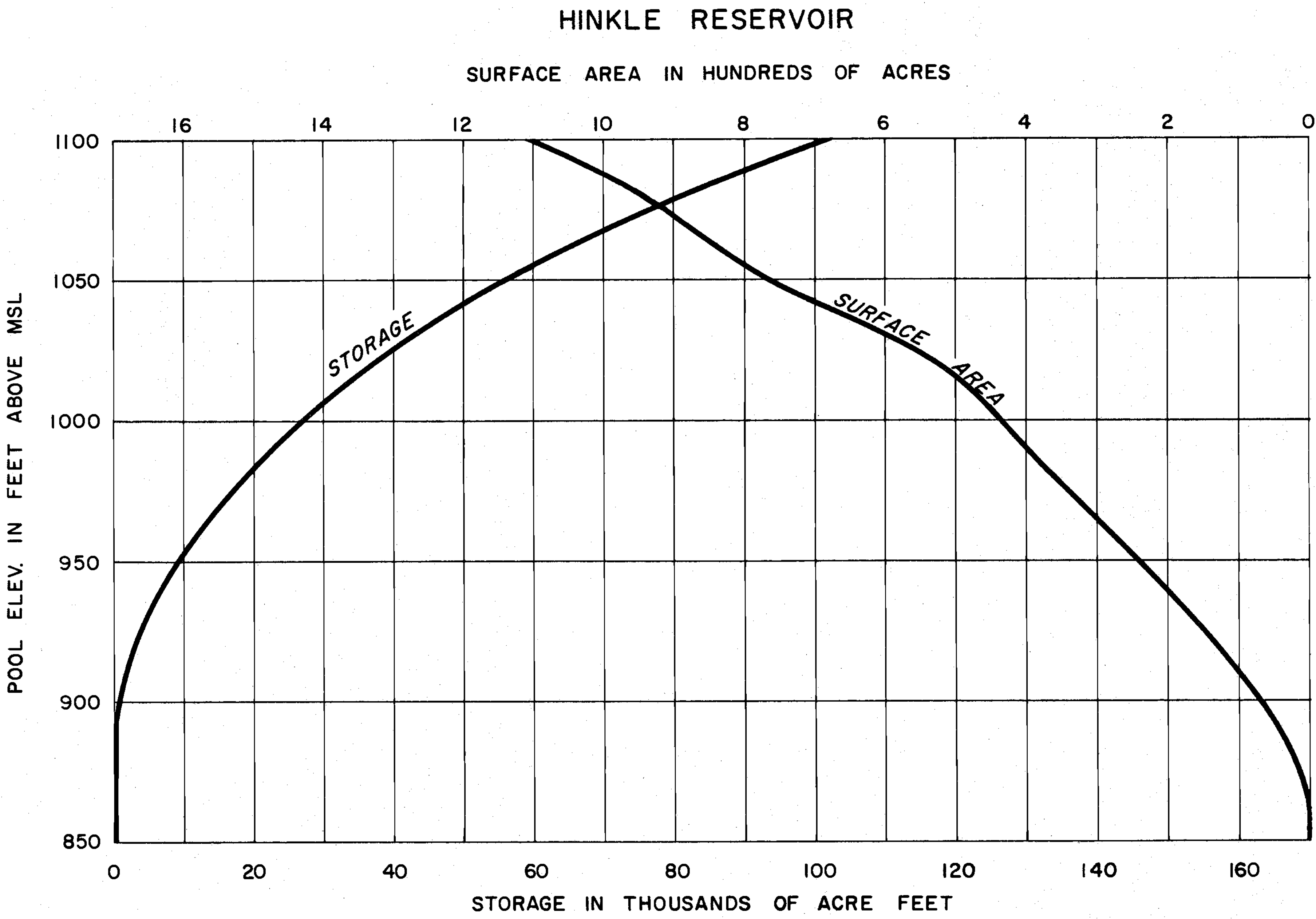


FIGURE 23. Capacity and surface area of proposed Hinkle Reservoir on Calapooya Creek.

TABLE 12

REGULATION OF HINKLE RESERVOIR FOR MAINTAINING HIGH RESERVOIR HOLDOVER UNDER AVERAGE METEOROLOGICAL CONDITIONS

MONTH	INITIAL RES. VOLUME	INITIAL RES. TEMP.	INFLOW	INFLOW TEMP.	RELEASE		RELEASE TEMP.	TEMP. GAIN	FINAL RES. VOLUME	FINAL RES. TEMP.
	Ac. Ft.	°F	Ac. Ft.	°F	Ac. Ft.	CFS	°F	°F	Ac. Ft.	°F
APRIL	70,000	42.0	8,300	49.0	8,300	140	52.0	4.8	70,000	46.8
MAY	70,000	46.8	5,700	54.0	5,700	90	54.0	7.6	70,000	54.4
JUNE	70,000	54.4	2,200	61.0	8,900	150	57.0	3.6	63,300	58.0
JULY	63,300	58.0	900	66.0	12,300	200	59.0	2.7	51,900	60.7
AUG.	51,900	60.7	600	67.0	9,200	150	57.0	1.9	43,300	62.6
SEPT.	43,300	62.6	600	58.0	6,000	100	61.0	0.1	37,900	62.7
OCT.	37,900	62.7	1,900	50.0	6,100	100	65.0	-2.6	33,700	60.1

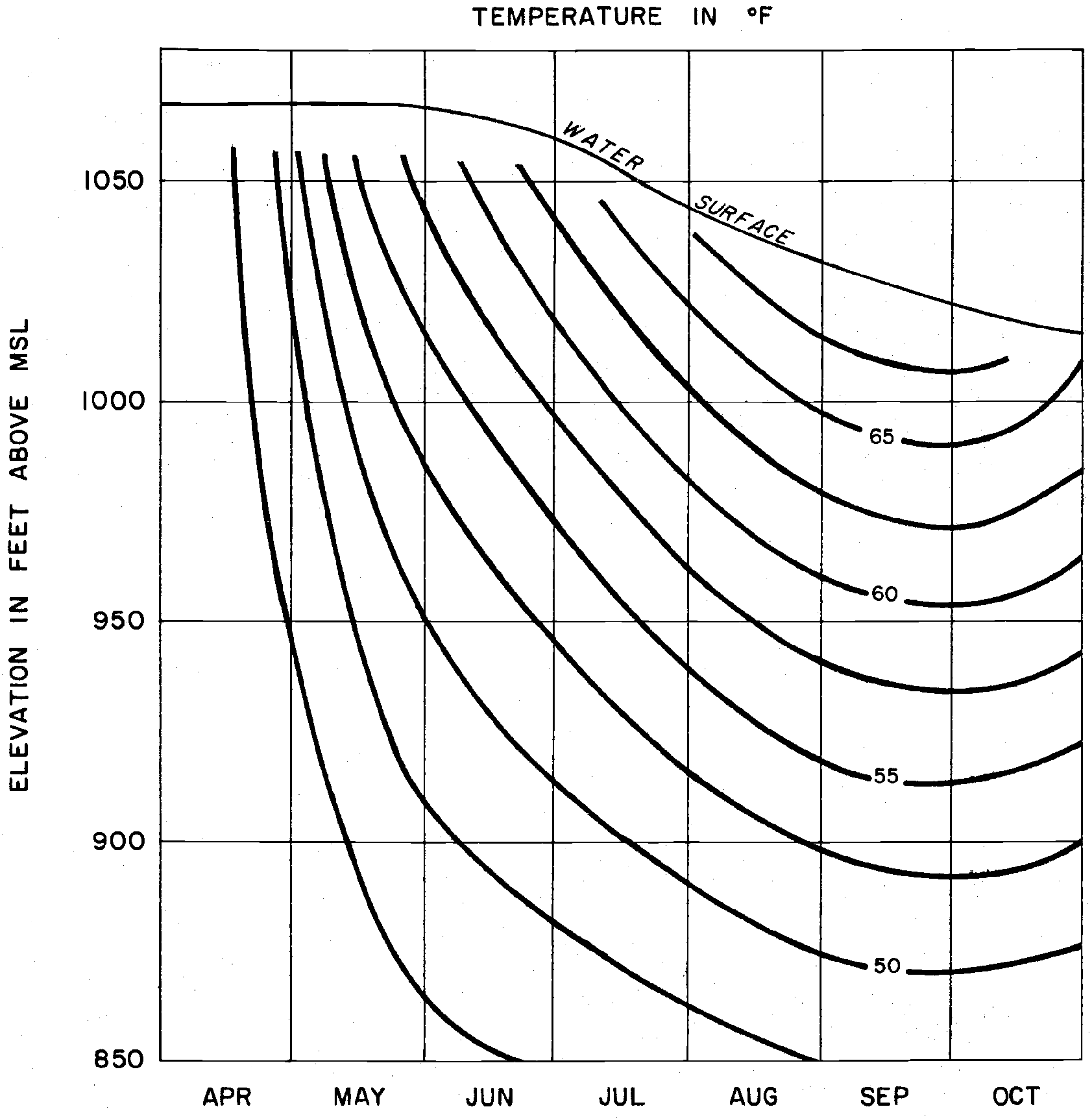


FIGURE 24. Monthly temperature distribution for the regulation shown in Table 12.

In view of the close resemblance between Hinkle and Galesville Reservoirs, the thermal behavior of the latter can be expected to apply to the former. However, release requirements for downstream temperature control will be less severe for Hinkle Reservoir because Calapooya Creek below the dam is less than one-half as long as Cow Creek below Galesville Reservoir.

In the only regulation performed on Hinkle Reservoir, a high holdover storage was attempted for average meteorological conditions. Details of the regulation are given in Table 12, while the corresponding reservoir temperatures are illustrated in Figure 24. The regulation demonstrated that stream temperatures can be held below 70° F. under average meteorological conditions by utilizing little more than one-half of the storage capacity at full pool. Residual storage at the end of October was over 33,000 acre-feet.

Results of the foregoing regulation and the results of temperature analyses on Galesville Reservoir, indicate that Hinkle Reservoir is capable of holding temperatures in Calapooya below 70° F. for all years, including the maximum temperature year.

4. Umpqua River

Of the three proposed reservoirs, only Tiller Reservoir has the potential to influence temperatures in the main stem of the Umpqua River. Temperatures were therefore determined immediately below the confluence of North Umpqua River and South Umpqua River for each of the adopted releases from Tiller Reservoir. These temperatures, for certain releases, were noted to be slightly higher than those occurring without regulation. These increases occur when the increase in discharge of the South Umpqua River under regulation is not accompanied by a corresponding reduction in temperature at its mouth. A temperature analysis was also made for the main stem between the confluence and Elkton for the various releases from Tiller Reservoir. Maximum temperature values resulting from these analyses are graphically illustrated in Figures 25 through 29. The curves show that for all the adopted reservoir releases, stream temperatures higher than 70° F. will occur in July, August and September.

Results of the analyses indicate that stream regulation by the proposed reservoirs will have no material effect on the temeperature regime in the main stem of the Umpqua River.

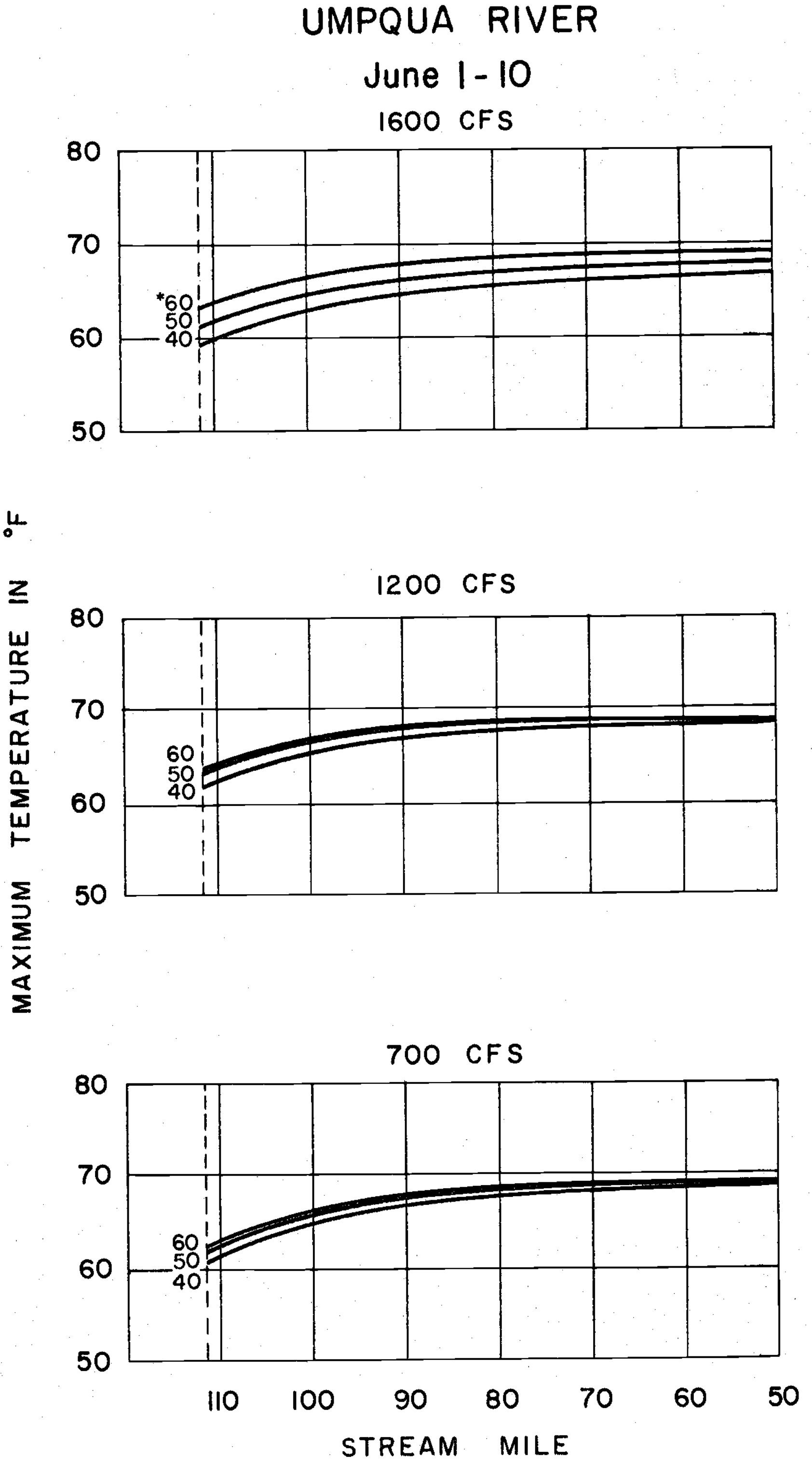


FIGURE 25. Maximum stream temperatures for indicated releases from Tiller Reservoir.

* Release temperature.

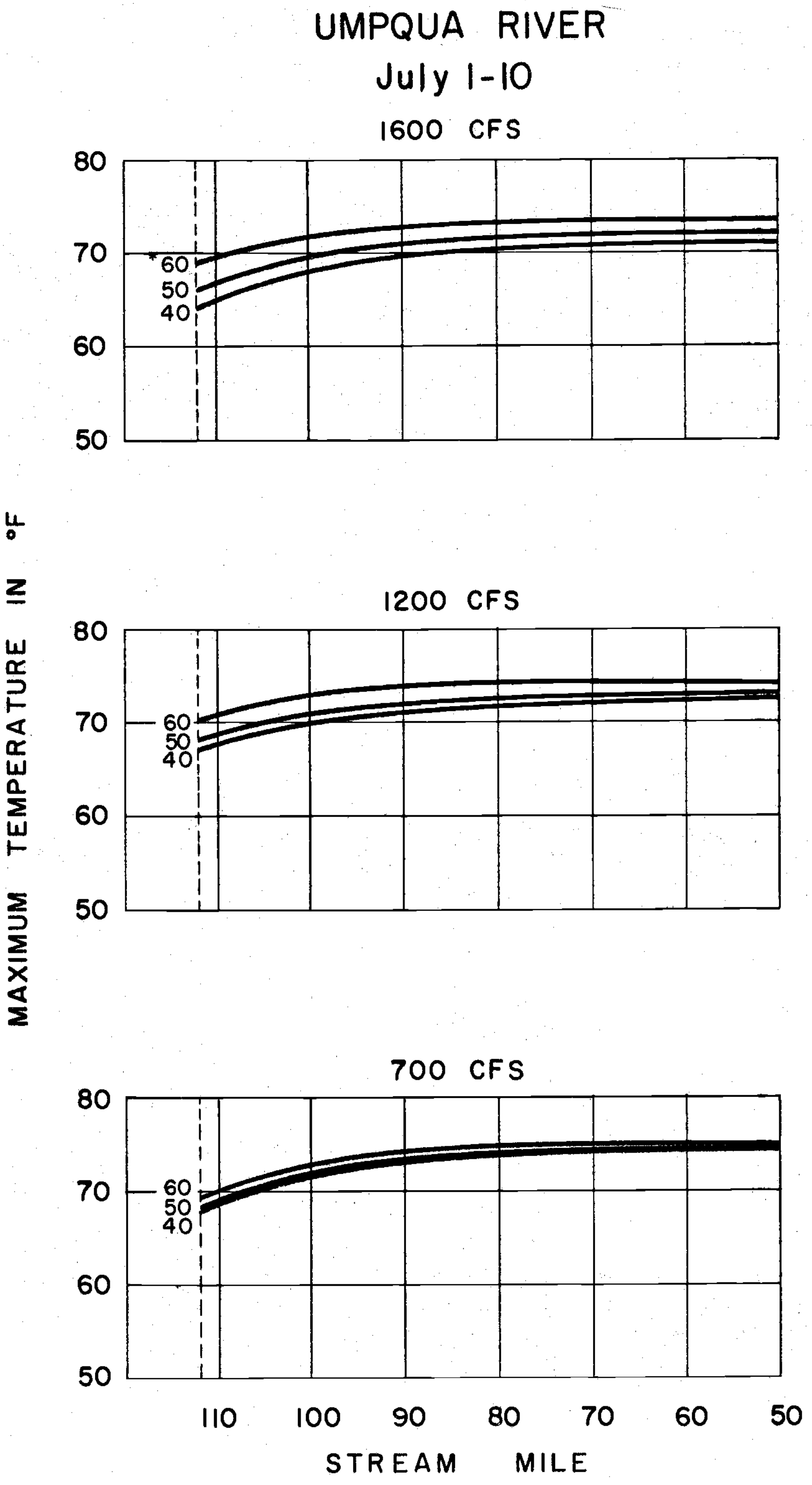


FIGURE 26. Maximum stream temperatures for indicated releases from Tiller Reservoir.

* Release temperature.

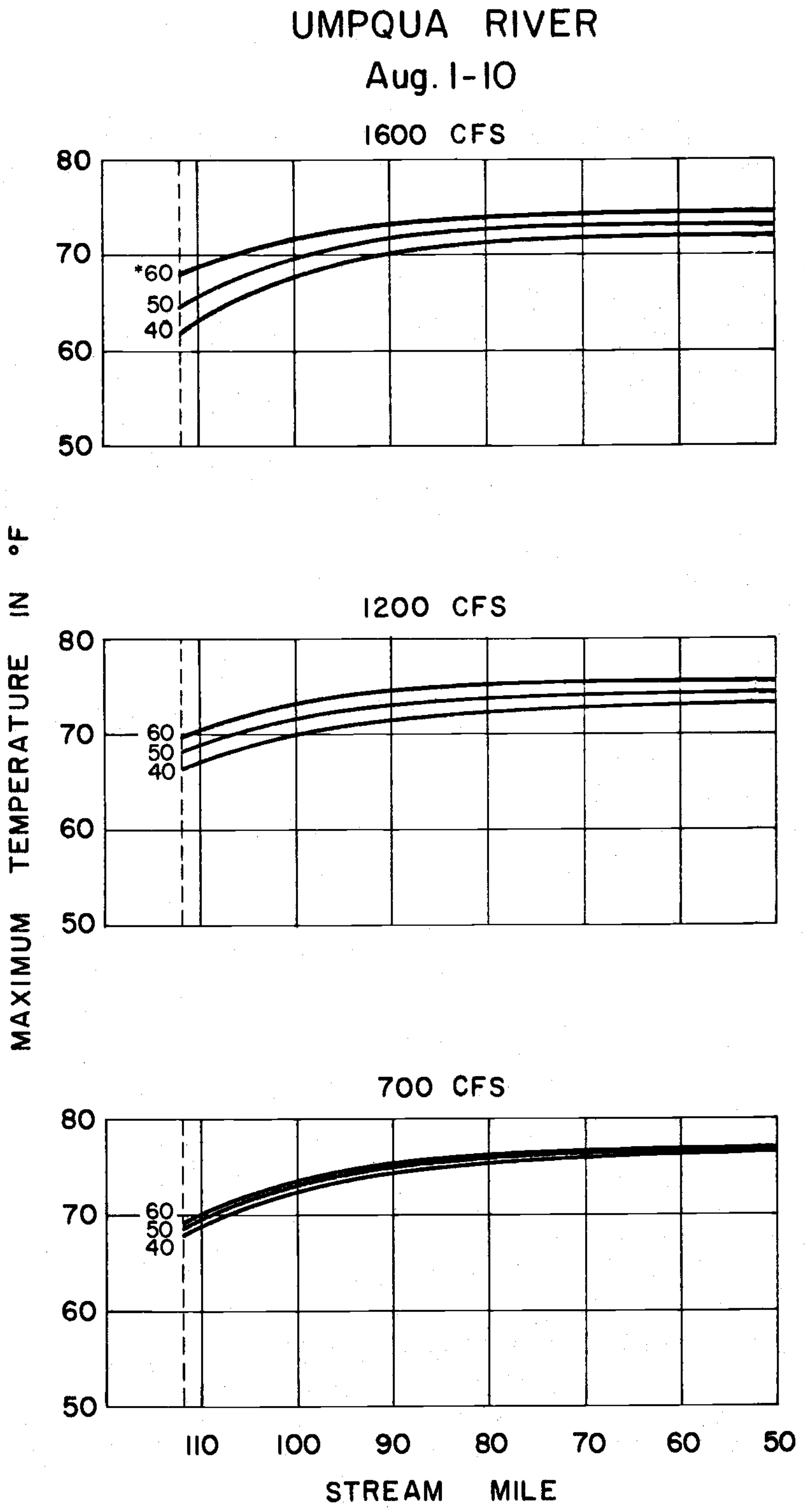


FIGURE 27. Maximum stream temperatures for indicated releases from Tiller Reservoir.

* Release temperature.

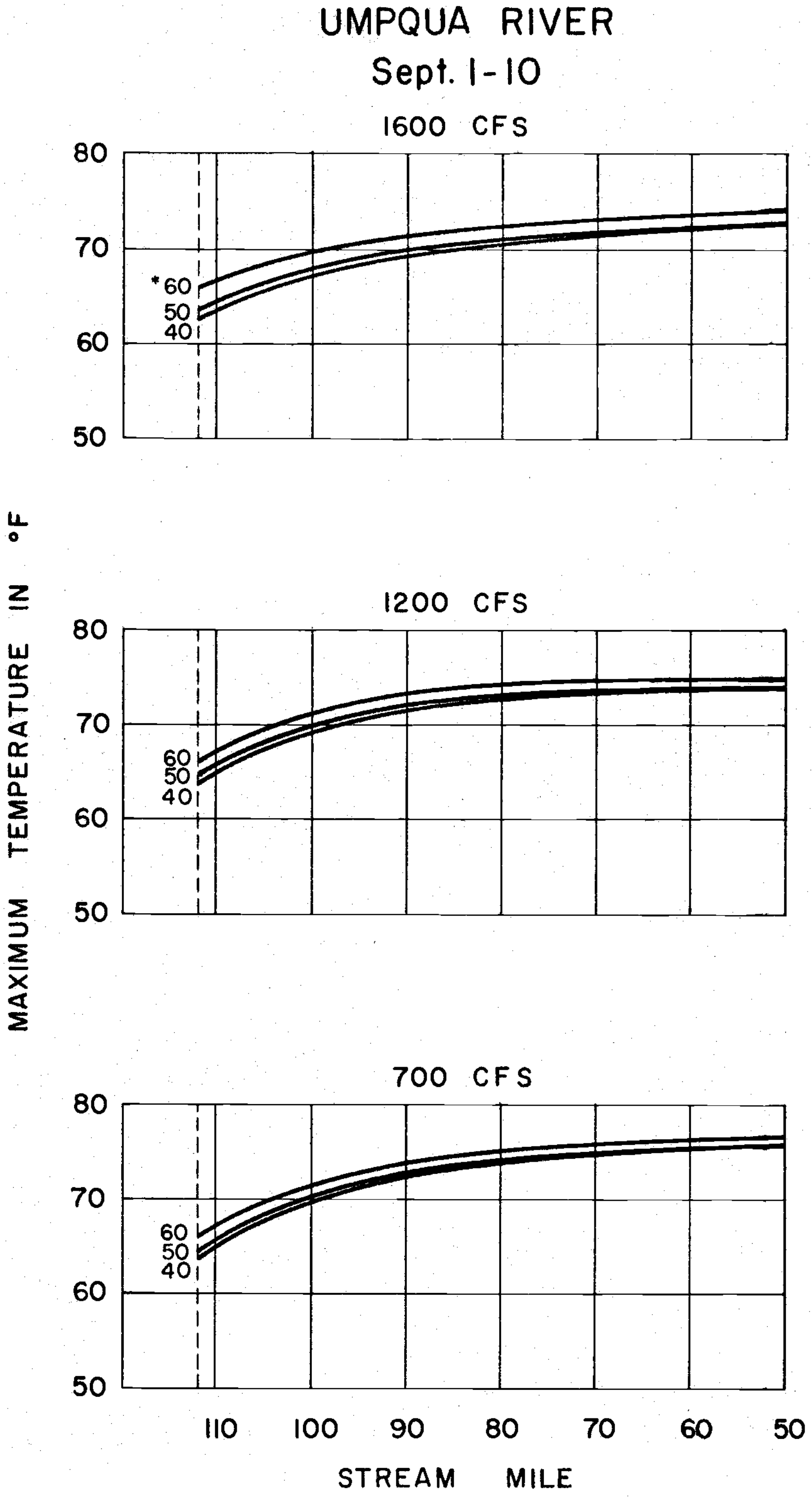


FIGURE 28. Maximum stream temperatures for indicated releases from Tiller Reservoir.

* Release temperature.

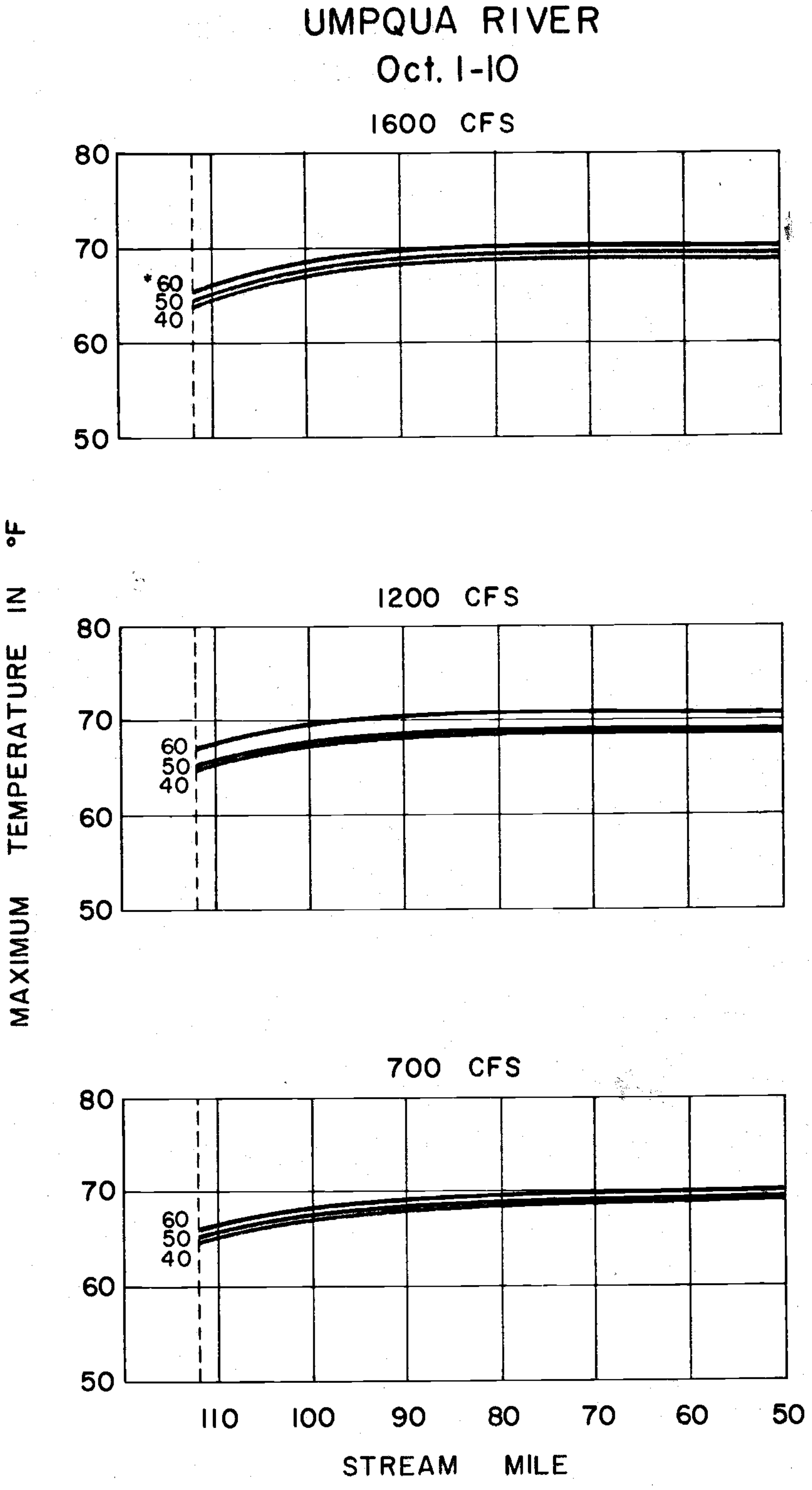
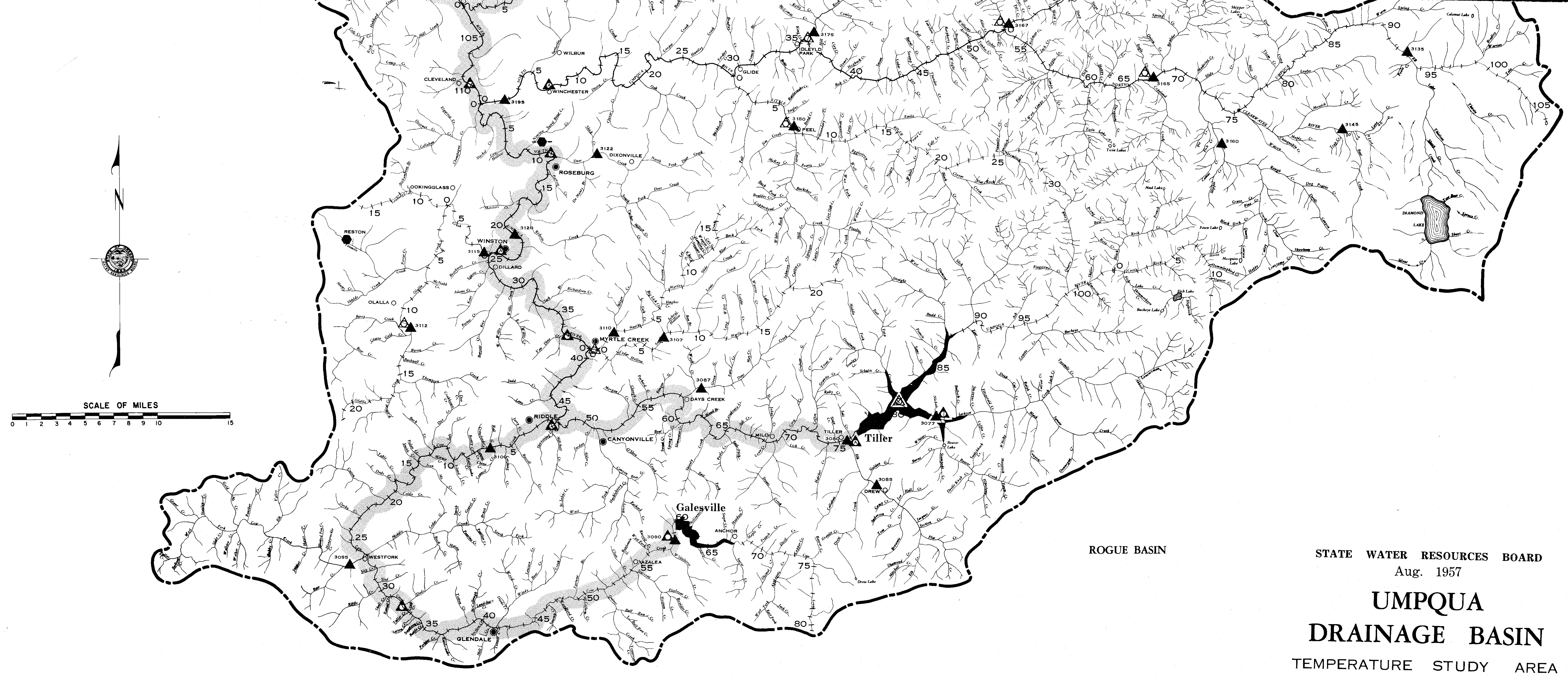


FIGURE 29. Maximum stream temperatures for indicated releases from Tiller Reservoir.

* Release temperature.


LEGEND
1964
3000▲ Stream Gaging Station
Water Temperature Station-active
Water Temperature Station-inactive
Water and Air Temperature Station
Climatological Station (precipitation only)
Climatological Station (precipitation and air temp.)
Reservoir Site
Stream Segment Studied
MID COAST BASIN
WILLAMETTE BASIN
COOS-COQUILLE BASIN
PACIFIC OCEAN
N
WINCHESTER BAY
REEDSPORT
GARDINER
SCOTTSBURG
ELKTON
DRAIN
ANLAUF
YONCALLA
ELKHEAD
GUNTER
KELLOGG
TYEE
ASH
LOON LAKE
OAKLAND
SUTHERLIN
NONPAREIL
Hinkle
3210
3220
3207



STATE WATER RESOURCES BOARD
Aug. 1957

UMPQUA DRAINAGE BASIN

TEMPERATURE STUDY AREA
FILE NO. 16.7016
PLATE I

Numbers on streams indicate miles above mouth