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A SECOND FORECAST OF TEMPERATURE CONDITIONS IN THE BROWNLEE RESERVOIR AND IN THE SNAKE RIVER BELOW BROWNLEE DAM

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ABSTRACT

A graph is presented which shows the average annual temperature depth profile which has been computed and estimated for the Brownlee Reservoir. Forecast computations and estimations are for a median river flow year. The graph also contains forecasts of the annual temperature cycle for the Snake River below Brownlee Dam.

INTRODUCTION

The present forecast of temperature conditions in the Brownlee Reservoir is based on principles of continuity. The amount of water and heat entering and leaving the reservoir during each five day period from 15 February to 30 September has been strictly accounted for in the determination. For the rest of the year, temperatures have been estimated on the basis of continuity and mean temperatures in the nearby Owyhee Reservoir.

This forecast should supersede the one made in Technical Report No. 1 of this series. It should be considered as a "best estimate" at this time based on presently available methods and data. However, future forecasts will probably not differ greatly for the mean temperature distribution of the surface 70 feet or for downstream temperatures during the period 1 January through September. This covers the critical, warm, mid-summer part of the year.

Less than 6% of the volume of the reservoir, when full, is stored below the 1800 foot elevation. This small amount of water may be greatly changed by relatively small changes in the over-all flow pattern in the reservoir. For this reason, the actual temperature for any given time may vary considerably from that forecast. Examination of similar bottom waters for Roosevelt Lake, behind Grand Coulee Dam, show large annual variations exceeding 12°F (August 1943, 43.1°; August 1944, 56.2°.)

The temperatures which are forecast for fall are estimated, There are some indications that the estimates presented for any given time in the fall may be closer to minimum temperatures rather than mean or maximum temperatures.

HEAT BUDGET

The heat budget for the reservoir has been computed based on U.S. Weather Bureau Data. Methods used are described in Jacobs, 1951; Anderson and Saur, 1950; Anderson, 1952; and Burt, 1954. An endeavor was made to compute the long term mean annual cycle of the rate of heat entry or loss through the reservoir water surface. Exact details of the computation are beyond the scope of this report. All computations and methods used are on file at Oregon State College where the author will be glad to explain the system to any interested individuals.

The results of the heat budget computations are in the form of the number of cubic feet of water that will be heated or cooled by 1°F during each five-day period of the year. The combined processes of evaporation, conduction, long wave back-radiation, and absorption of short wave solar radiation are considered. The changing area of the reservoir with time as its volume changes is also considered in the calculations.

COMPUTATION

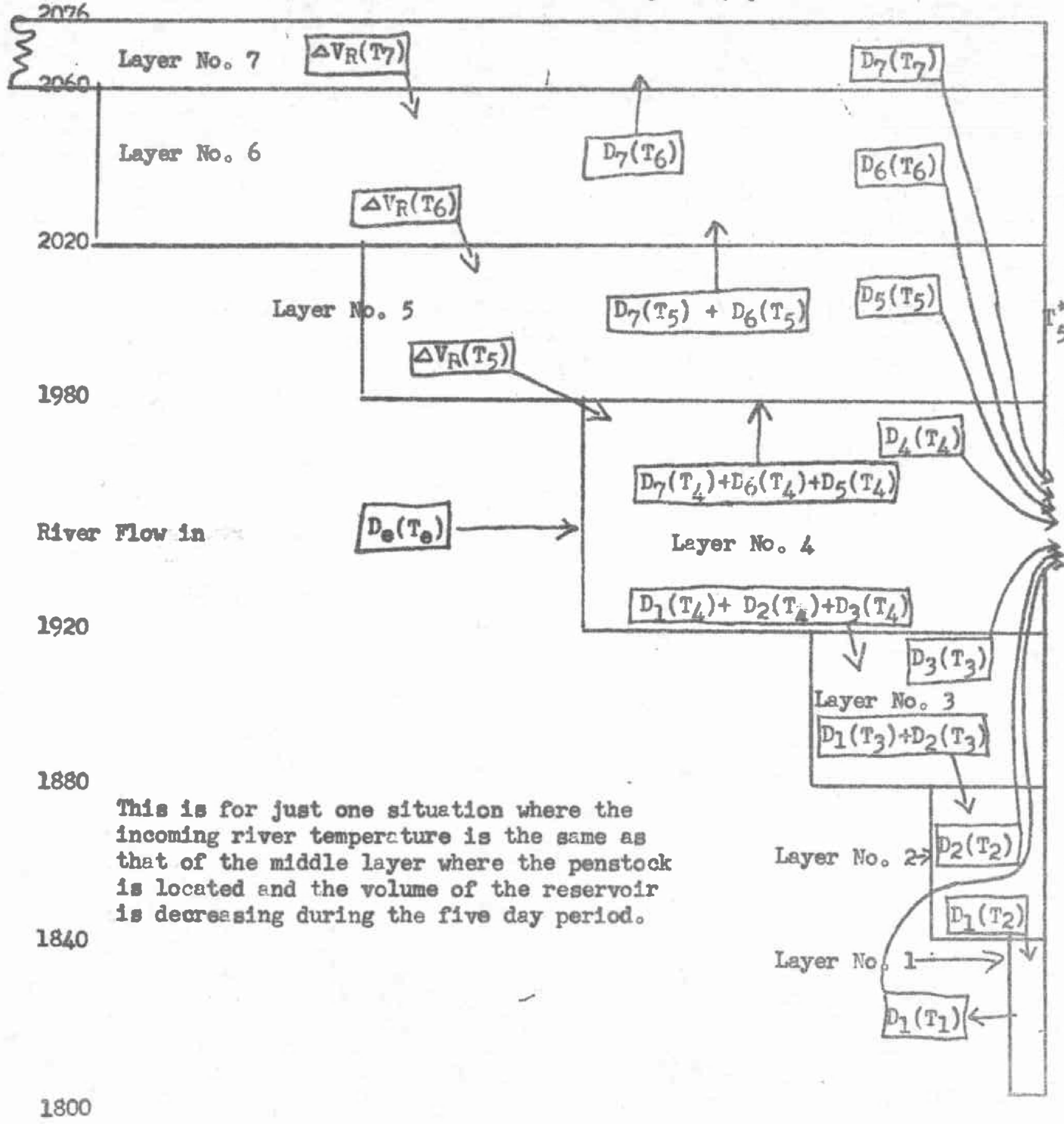
The reservoir has been divided into seven layers for purposes of computation. As a first approximation, the temperature in each layer is considered to be homogenous at the beginning and at the end of each five-day period of the year.

The amount of heat and water in each layer and changes in heat and water are treated in the same manner as money in a bank account. The accounting period is 1/6 of a month, or five days. The heat involved in any transaction is considered proportional to the temperature times the amount of water involved. During each five-day period, some water leaves each layer to form part of the water discharged through the dam. The increment discharged takes its heat and temperature with it. At the same time, the water discharged from each layer must be replaced during the five days under consideration by water at a different temperature from other layers or from inflowing river water. The inflowing river water must enter the layer with temperature close to that which it has or the layer with a temperature above it so that all lighter water is displaced upwards. Two other processes also occur during each five days. First, the reservoir may be changing volume and this must be accounted for. Then, the heat budget at the surface results in heating or cooling the surface layer or layers by the amount computed in the heat budget for the five-day period under consideration.

The process of computation began for February 15 with the whole reservoir filled with 39° water. Computations were then made for each layer for each five-day period from February 15 through September 30. The starting temperature and the temperatures of the inflowing river water were taken from the three-year mean annual temperature cycle for all available data from thermograph records for Oxbow and below Swan Falls.

The details of the computation are given below with a diagram to illustrate the processes involved.

Elevation — Movement of water during 5 day period — Temperature at end of 5 day period



This is for just one situation where the incoming river temperature is the same as that of the middle layer where the penstock is located and the volume of the reservoir is decreasing during the five day period.

$$T_7^* = \frac{(V_7-D_7-\Delta V_R)T_7+D_7T_6}{V_7-\Delta V_R}$$

$$T_6^* = \frac{(V_6-D_6-D_7-\Delta V_R)T_6+(D_6+D_7)T_5+\Delta V_R T_7}{V_6}$$

$$T_5^* = \frac{(V_5-D_5-D_6-D_7-\Delta V_R)T_5+(D_5+D_6+D_7)T_4+\Delta V_R T_6}{V_5}$$

$$T_4^* = \frac{D_eT_e+\Delta V_R(T_5)+(V_4-D_x)T_4}{V_4}$$

$D_x(T_x)$ where $T_x = \frac{1}{\sum D_i} \sum_{i=1}^{i=7} D_i T_i$

$$T_3^* = \frac{(V_3-D_1-D_2-D_3)T_3+(D_1+D_2+D_3)T_4}{V_3}$$

$$T_2^* = \frac{(V_2-D_1-D_2)T_2=(D_1+D_2)T_3}{V_2}$$

$$T_1^* = \frac{(V_1-D_1)T_1+D_1T_2}{V_1}$$

The middle, or fourth layer, is 60 feet thick. It brackets the penstock by 16 feet on the under side and 20 feet on the top. Layers 3, 2, and 1 beneath layer 4 are 40 feet thick. Layers 5 and 6 above it are also 40 feet thick. Layer 7 is 17 feet thick when the reservoir is filled. As the surface elevation decreases, layer 7 decreases to 0 thickness and disappears. Layer 6 becomes the top layer with decreasing thickness as the elevation drops from 2060 to 2020 feet. Between 1980 and 2020, layer 5 is the top layer, and at minimum pool of 1976, layer 4 is the top layer.

The table below gives the following information for each layer:

Layer No.	Thickness of Layer in Feet	Elevation Feet	Volume of Layer 10^9 Cu. Ft.	% of Draw	Volume of Draw
7	17	2060-2076	$10.01=V_7$	7.9	D_7
6	40	2020-2060	$18.30=V_6$	10.3	D_6
5	40	1980-2020	$13.29=V_5$	18.2	D_5
4	60	1920-1980	$13.29=V_4$	50.0	D_4
3	40	1880-1920	$4.57=V_3$	10.3	D_3
2	40	1840-1880	$2.18=V_2$	2.7	D_2
1	40	1800-1840	$.65=V_1$	.6	D_1

1. The number assigned to each layer from 1 on the bottom to 7 on top.
2. The thickness of each layer, in feet, when the reservoir is full. Only the top layer at any given time is thinner than the thickness listed.
3. The elevation above sea level of the top and bottom of each layer.
4. The volume of each layer in billions of cubic feet when the reservoir is full. At other times, the volume of all layers except the top and missing layers is the same as that listed. The symbol V_i refers to the volume of the ith layer at any given time.

5. The per cent of the water running through the penstock which has been assumed to be drawn from each layer when the reservoir is full. It will be discussed below how these percentages are changed at other times.
6. The symbol D_i refers to the number of cubic feet of water which is assumed to flow out through the penstock from the ith layer during any given five-day period.

When the reservoir is full, it is assumed that 50% of the outflow water will be drawn from the main thick layer, number 4. The draw from each of the other layers is assumed to be inversely proportional to the vertical distance from the center of that layer to the level of the center of the penstock.

Waters from the middle layer, number 4, will be moving relatively rapidly in a horizontal direction toward the penstock entrance. A second assumption on the per cent of the total which leaves each layer is based on the idea that entrainment from each layer is proportional to the area of that layer which is exposed to the shear from above or from below from the rapidly moving main layer. The ratio of proportionality has a value of less than one for the relatively small mean areas of layers 1, 2, and 3, and the maximum value of one for layers 5, 6, and 7 above the main layer. The per cent of draw figures listed in the table are based on these two assumptions.

When the reservoir is drawn down, it is assumed that the draw from the surface layer will decrease directly as its depth decreases. This leaves more water to be drawn from the other layers which is assigned to each layer in proportion to the amount drawn from the individual layers when the reservoir is full.

After layer 7 is gone, layer 6 becomes the top layer. Further decrease in volume of the reservoir eventually results in layer 5 and layer 4 in turn becoming the top layer. On filling, the reverse occurs with layers 4, 5, 6, and 7 in turn becoming the top layers.

The general method which has been developed may be applied to any set of conditions which may occur in the reservoir. For purposes of illustration, one set of conditions has been selected for illustration which will be considered in detail. These conditions are listed below:

1. It is assumed that the reservoir is full at the beginning of the five-day period under consideration. However, the elevation of the reservoir decreases during the five-day period by such an amount that the total volume of the reservoir is changed by an amount of ΔV_R billion cubic feet during the five-day period.

2. During the five-day period, the temperature of the incoming river water, T_e, is the same as the temperature of layer 4. Therefore, the incoming river water is assumed to flow into layer 4 during the whole of the five-day period.

The movement of water during the five-day period taken as an example and the method of computing the temperature at the end of the five-day period are illustrated on the first figure.

Each layer is shown in schematic form. The areas of the rectangle representing the layers are proportional to the volume of the layers. The temperatures of the layers at the beginning of the period are, respectively, T_1, T_2, T_3, T_4, T_5, T_6, and T_7.

A volume of water D_1 at a temperature T_1 leaves layer one to form part of the discharge. This same volume of water, D_1, at a temperature

T_2 moves down from layer 2 to layer 1 to replace the discharged water. The temperature at the end of the five-day period, T_1^*, is computed from the lower equation shown on the diagram. Layer 2 discharges a volume of water D_2 at a temperature T_2. It receives water from layer 3 to replace that discharged, as well as that moved from layer 1 to replace the discharge from layer 1. Thus, a volume of water, D_1, at a temperature of T_3 plus a volume of water D_2 at T_3 moves down from layer 3 to layer 2. The temperature of layer 2_2 at the end of the five-day period is then computed by use of the equation to the right of layer number 2 on the diagram.

Similar manipulations are made on layer 3, 5, 6, and 7. Each manipulation is illustrated on the diagram. The discharge temperature, T_x, is computed by simply adding the volume of water discharged from each layer, D_i, times the temperature of the water discharged from each layer, T_i, and dividing by the amount discharged during the five-day period.

The change in volume during the five-day period is accounted for by moving ΔV_R at T_7 from layer 7 to layer 6. In turn, the same volume at T_6 is moved from layer 6 to layer 5 and at T_5 from layer 5 to layer 4.

The volume flowing in from the river, D_e, at T_e has flowed into layer 4 to replace the water discharged from layer 4 and the water which moved upward and downward from layer 4 to replace the discharge from all of the other layers.

After the above manipulations have been carried out for each layer for the five-day period, an addition or subtraction of heat from the sun and atmosphere must be made to the top layer. The amount added or subtracted is determined from the heat budget study. This added or subtracted increment of heat is used to change the temperature of the top layer.

If the amount of heat during the five-day period is large, and the top layer is thin, then the top 2 layers are considered as one. This is accomplished by theoretically mixing the 2 layers together at the end of the five-day period and computing a composite temperature for the combined layers. Whenever the top layer becomes colder than the next layer below, the 2 top layers are similarily mixed together, and a temperature is computed for the 2 layers together.

The set of manipulations illustrated on the figure is adjusted to fit particular conditions during each five-day period. For example, if the reservoir is filling, the change in volume, (ΔV_R), is moved upward from layer to layer rather than downward.

If the temperature of the river flowing in at the top of the reservoir is different from the main layer, 4, then the entering water must mix with the layer with the closest temperature. Thus, during the year the inflowing river water may mix with the water in any layer, depending on the relative temperatures of the layers and the temperature of the inflowing water. One extreme case occurs when the inflowing water is colder than any of the water in the reservoir. In this situation, layers 1 and 2 are completely replaced by the inflowing water each five days, along with a part of layer number 3. The water in layer 1 at the beginning of the five-day period is partly discharged (D_1) and the rest moved up to layer 3 The same thing occurs to the water in layer number 2 as well as the part of the water in layer number 3.

The system of computation worked well until the end of September. Predicted surface temperatures agreed well with long-term mean surface temperatures for nearby Owyhee Reservoir. After September, the results of the computation indicated that successive approximation techniques are needed to continue. This work, which may take considerable time, was postponed in order to make the first computations immediately available.

RESULTS

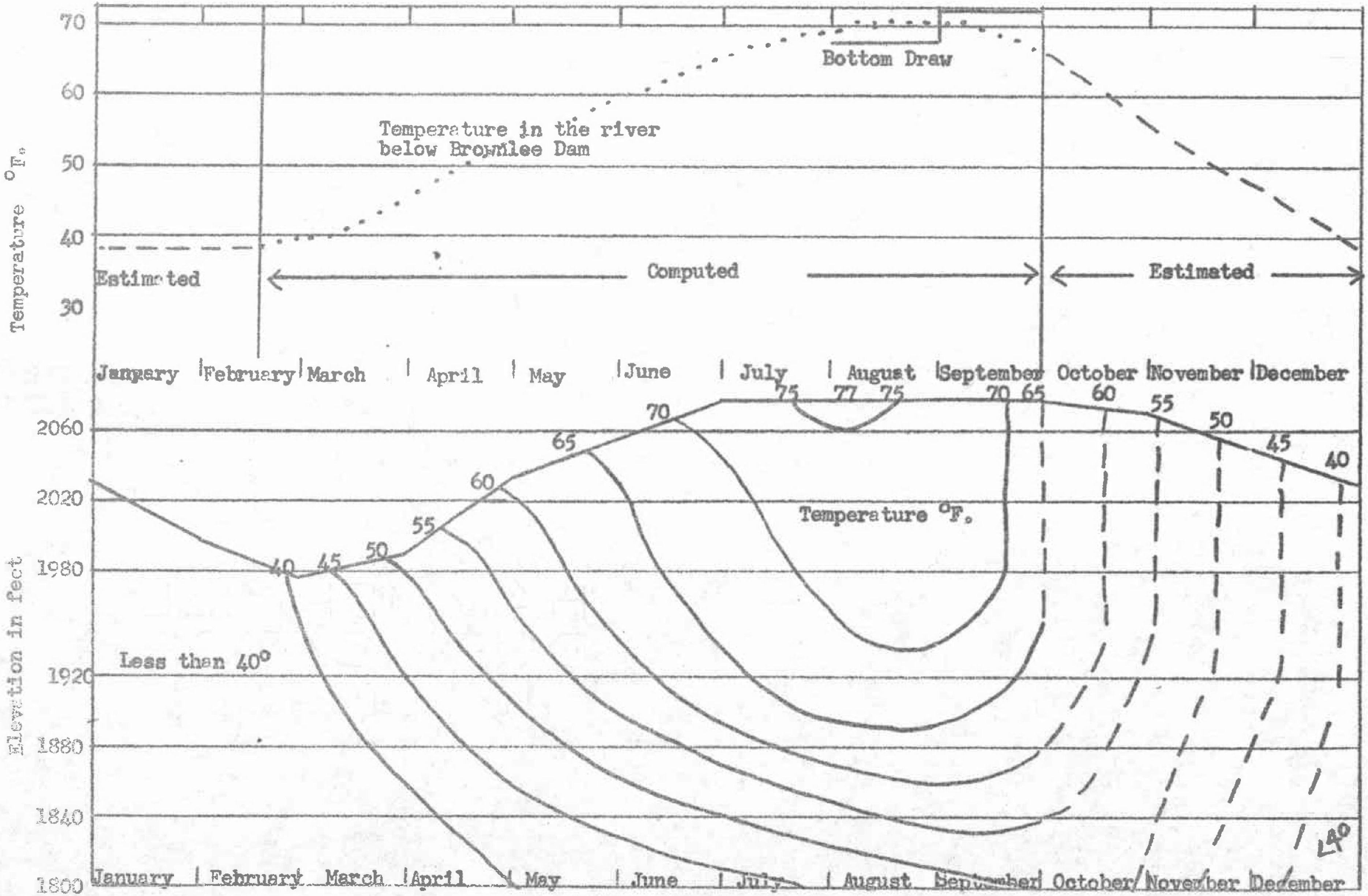
The results of the computations were plotted on annual graph paper and smooth curves drawn through the values to give a mean annual temperature cycle for the reservoir. This is shown on the lower half of the next diagram. The solid lines are based on the computations. The dashed lines for the rest of the year are estimates based on continuity and what occurs in the fall in nearby Owyhee Reservoir.

Computed discharge temperatures are plotted on the top half of the diagram for the period of February 15 through September 30. Discharge temperatures are estimated for the rest of the year.

DRAW FROM THE BOTTOM

In discussion of the temperature problem in Brownlee Reservoir with interested biologists, it appeared that too much credit has been given to possible cooling from bottom waters. In the above analysis a varying percentage of water has been taken from each bottom layer to cool the water leaving the reservoir. This water was replaced by warmer water from above or from incoming water.

As of 1 August, it appears from the figure that an abundance of cool water from below the penstock level has not been utilized. How much cooling potential does this water represent? Assume that all water below 1920 feet is mixed together and then drawn off in six equal increments. One increment is drawn for each five day period during August. In addition,



ESTIMATED MEAN ANNUAL WATER TEMPERATURE FOR BROWNLEE RESERVOIR MEDIAN TO HIGH FLOW YEAR assume that no water is drawn from the warmer surface layers above 1980 feet. That is, the remaining exhaust water is all taken from the main layer bracketing the penstock. The result is discharge water for the whole month with a temperature of 67.50°F. This is shown by the horizontal line on the top of the figure. Now all the cold water is gone! It has been replaced by warmer water from above and warmer water coming into the reservoir. The September discharge water then must have a mean temperature of 72°F. This is illustrated by the solid line on the upper part of the diagram.

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