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THERMAL MODIFICATION OF RIVER WATER QUALITY

R. T. JASKE

APRIL 1968

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By

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Water Quality Systems Analysis System

Environmental and Radiological
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THERMAL MODIFICATION OF RIVER WATER QUALITY

R. T. Jaske

INTRODUCTION

During the past five years a great deal of attention has been focused on the general matter of thermal modifications of lakes and streams resulting from the activities of man in utilizing nature's abundance for his own purposes. Efforts at Hanford include extensive data summaries, advancements in water treatment, mathematical simulation of water quality, and pioneer efforts in the manipulation of the Columbia River in order to enhance water temperatures for the combined purposes of production increase and aid to anadromous fish.

In order to evaluate the results of this cooling program, a system of data collection points was installed (Figure 1), with particular emphasis on measurement accuracy. The resulting temperature data have been used to develop an environmental simulation model capable of predicting temperature and associated water quality variables to a high degree of accuracy. Although a flow-through model of this type is capable of great accuracy either in the prediction of future conditions or the creation of intermediate data from old records, it was thought advisable to conduct additional statistical analyses in order to support conclusions derived from the simulation model.

The availability of analytical techniques derived from applied physics research at the Pacific Northwest Laboratory (Battelle-Northwest) made it possible to utilize existing data in a form never before attempted. A computer method of least squares analyses (Code LEARN) has permitted the generation of a series of least squares fitted functional models which form the basis for the conclusions of this work.

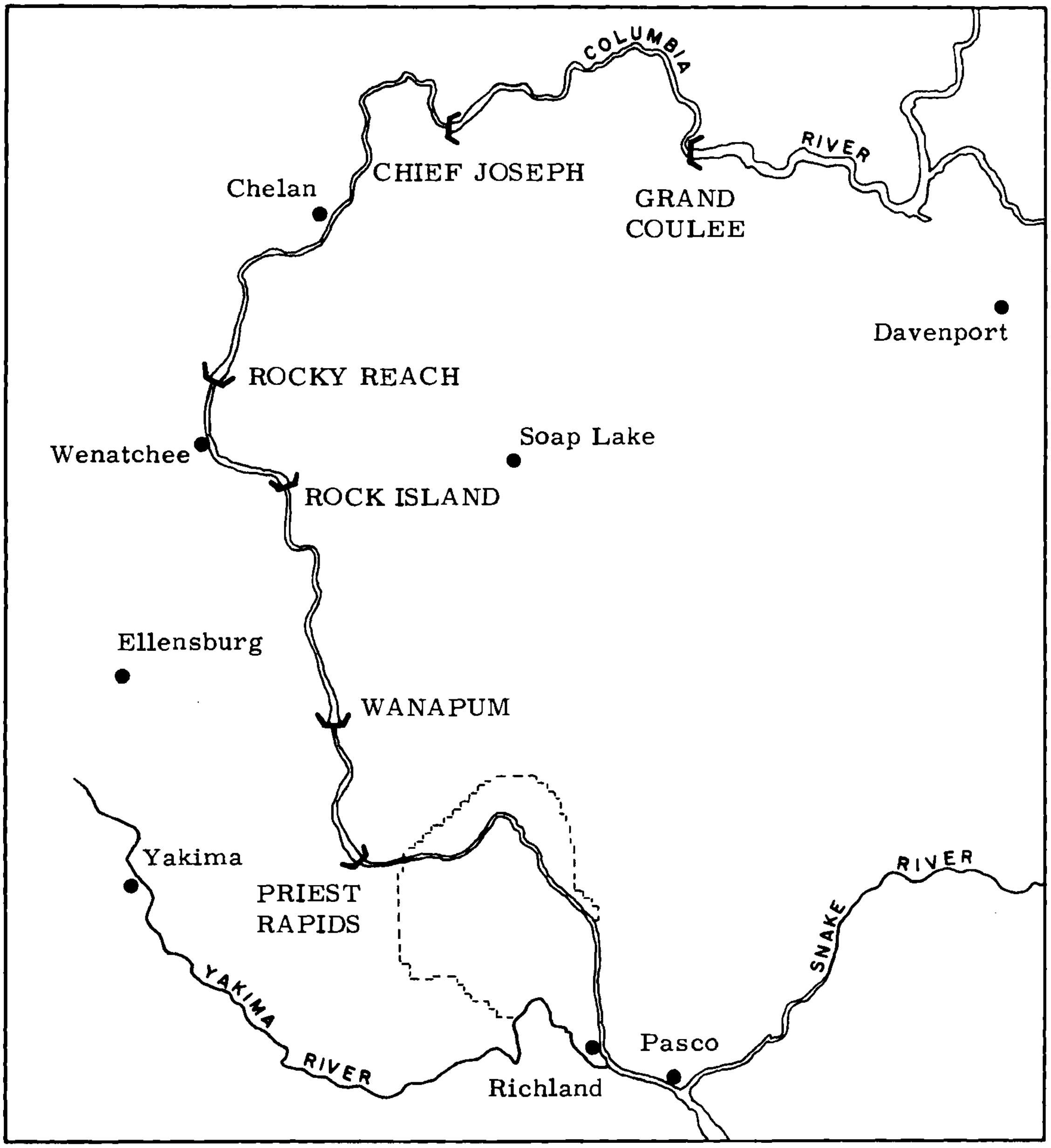

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FIGURE 1. Projects Used in The Study

DISCUSSION

In this case, the function T = A + B sin (Cd + D)* originally used in oceanography and described by Ward[1] was adopted because of the excellence of representation of annual temperature data afforded by its use. In the operations research supporting this study, the data points were grouped by year from January 1 through December 31 using 365 or 366 days per year as appropriate. The data were then analyzed by means of a nonlinear, maximum-likelihood, least-squares-fit routine capable of handling nonlinearities and saddle points reliably. This program, developed by the Applied Physics and Electronics Department of Pacific Northwest Laboratory is called program MISFIT-LEARN and can be conveniently adapted to a variety of computers such as the IBM 7090 or the larger Univac 1108. LEARN makes use of numeric rounding for accuracy, ill-conditioned matrix inversion logic, and statistical determination of saddle points on the parametric surface. In addition, it contains a two-stage recovery logic. If the usual first order approximation fails, the routine tries the second order terms of the multivariate Taylor expansion. Failing this, the routine branches into a series of approximations best described as "reverse and halve the last change" logic. The analysis of the data yields the best-fit parameters and, in addition, produces the root-mean-square error associated with that parameter estimate.

Also included as output is a series of graphs plotted by the Benson-Lehner plotter from magnetic tapes generated by the computer. These plots include the observed data, the calculated curve, and another pair of curves of ± one standard deviation on each side of the calculated curve. Examples of these plots are shown in Figures 2, 3, and 4.[2]

* A = model mean, B = computed extreme, C = daily shift, D = peak shift

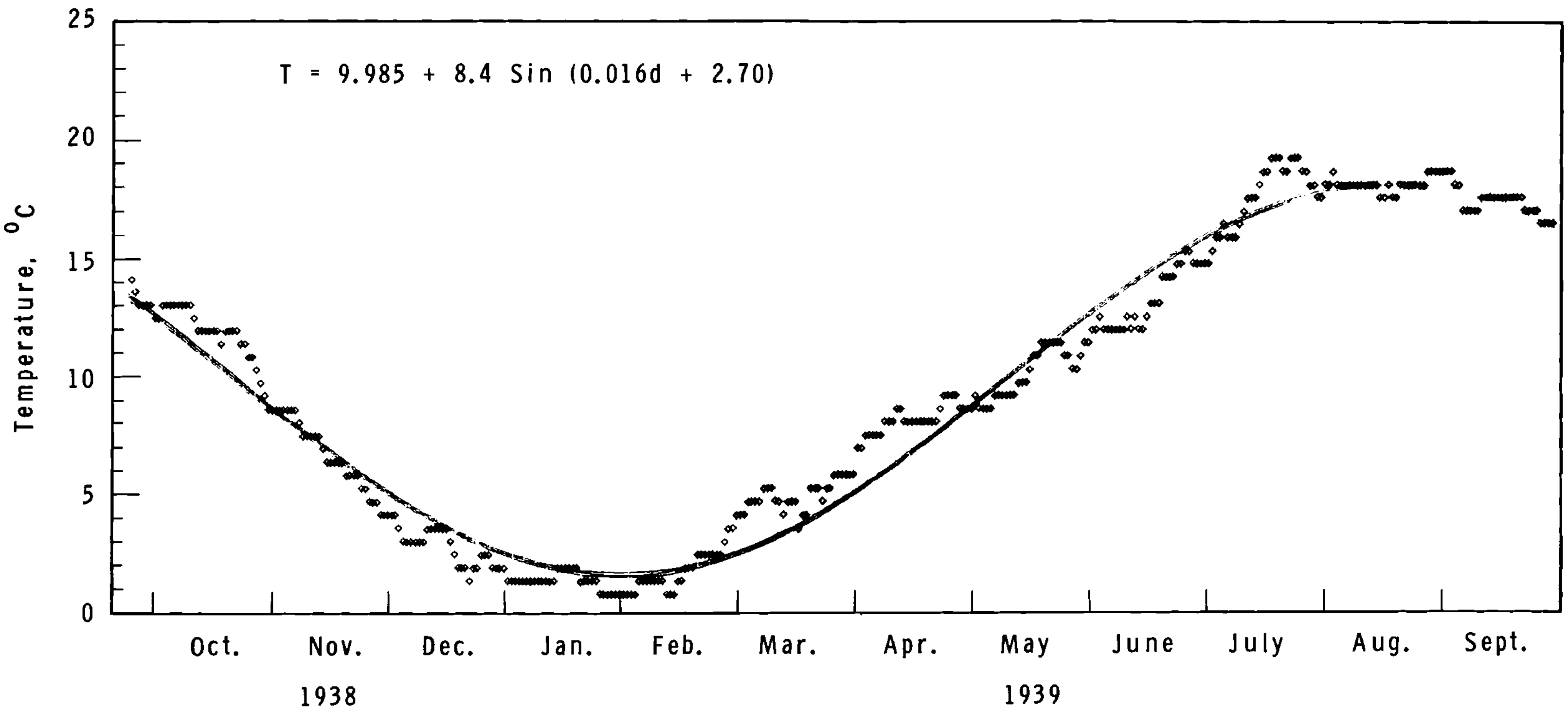

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FIGURE 2. Rocky Reach - U.S.G.S. Year 1938-39

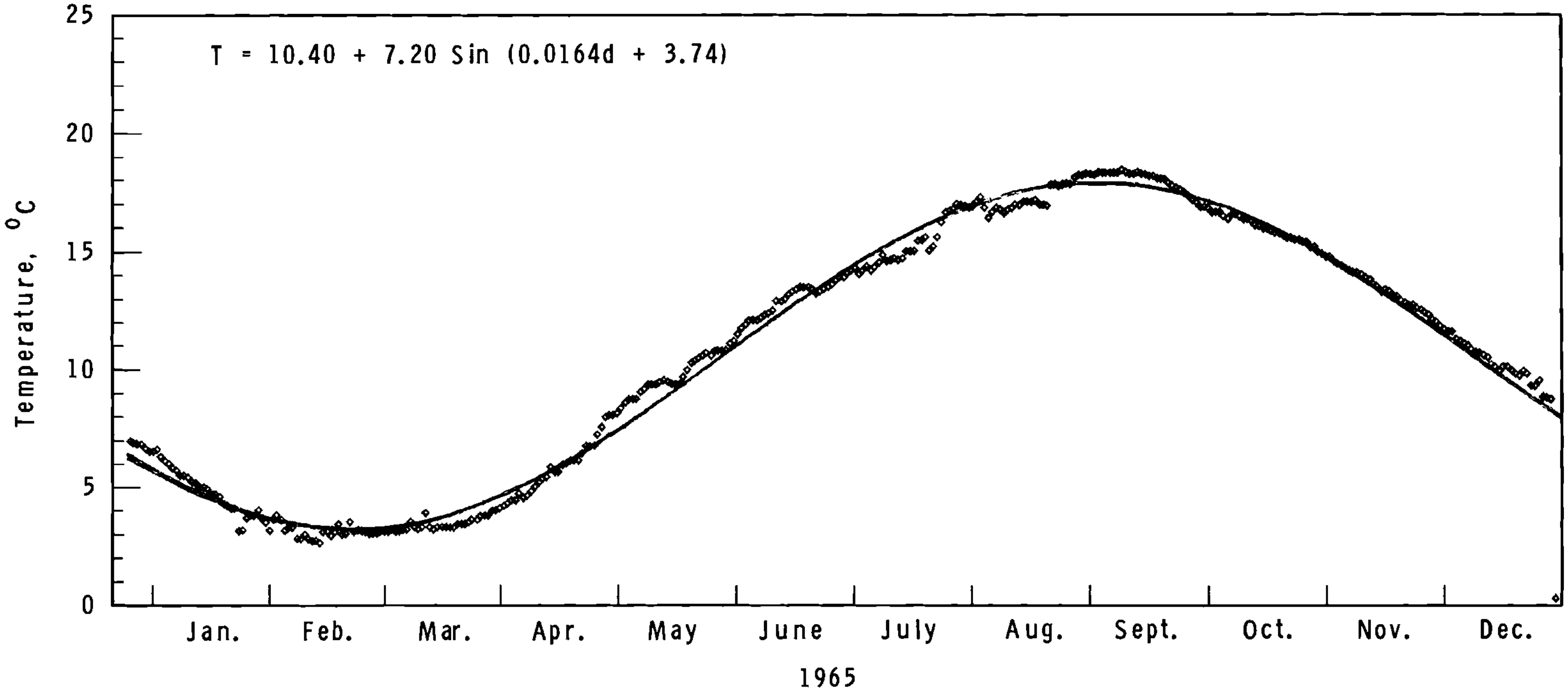

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FIGURE 3. Grand Coulee - Calendar 1965 Water Temperatures

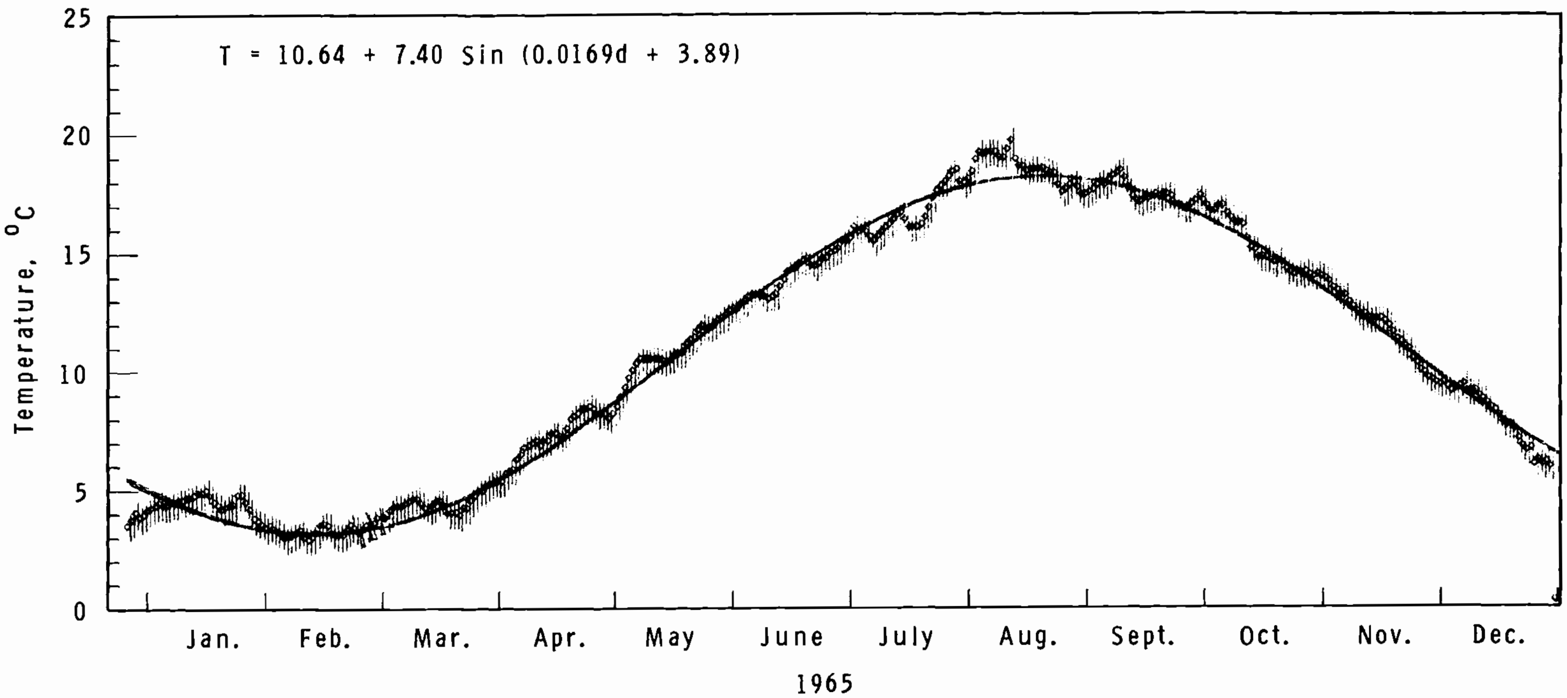

FIGURE 4

PRIEST RAPID GAGE

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FIGURE 4. Priest Rapids Gage - Calendar 1965 Water Temperatures

If a function of the form $T = A + B \sin (Cd + D)$ is fitted to annual temperature data, then $C \approx 2\pi/365.25 \approx 0.017$. As an added check on the goodness of fit, this parameter was allowed to vary in each case in order to see what value the computer would calculate. Table I shows a series of values of all four parameters for a series of data points from the International Border to Bonneville Dam for the Calendar Year 1966.

TABLE I. Values for CY 1966

	A, Annual Average °C	Computed Extreme-B-°C	Daily Shift-C Radians	Peak Shift-D Radians
International Border	9.29	6.67	0.017	4.15
Grand Coulee	10.40	6.49	0.0165	3.67
Rocky Reach	10.44	6.53	0.0163	3.80
Priest Rapids	10.65	6.63	0.0166	3.95
Richland	12.04	6.24	0.0163	4.04
McNary Dam	12.21	7.16	0.0165	4.09
Bonneville Dam	11.93	7.20	0.0164	4.17

Computations made during the most recent fiscal year support the conclusions of a preliminary study.[2] Least-squares-fitted models have been generated for all of the major projects for which data have been collected over several years. These include the following:

a) Bonneville Dan 1939-1966
b) McNary Dam 1951-1966
c) Ice Harbor Dam 1964-1966
d) Richland Ferry 1963-1966
e) Priest Rapids 1961-1966
f) Rock Island-Rocky Reach 1934-1966
g) Grand Coulee 1963-1966
h) International Border 1966

TABLE II. Comparison of Trends

	Upper Extreme-Mean-°C	Mean-°C	Lower Extreme-Mean-°C
Rock Island	18.0	10.6	2.9
	σ = 0.95	σ = 0.65	σ = 0.94
Bonneville	19.0	11.4	3.8
	σ = 0.88	σ = 0.81	σ = 1.06

Several of the trends observed in comparing the results of extended analyses are of great significance in understanding the overall effects of the combined construction of dams and other industrial plants involving thermal waste discharges. A careful review of the data in Figure 5 which compares the values computed for the A (annual average) and B (computed extreme) terms yields the following observations (see Table II also):

1) The annual mean temperature computed for Rock Island-Rocky Reach for the period 1934 to present shows a slight increase of about 0.2 to 0.4 °C. This is about one-half of a standard deviation for the period stated. The annual mean computed for Bonneville during the period 1939 to present shows a lesser overall effect and appears to reflect a definite downturn for the period 1960 to present, after the peak of 1958. The relationship between the computed means for the two data sets shows a significant departure for the period 1944 to 1948 and again 1950 to present. It is apparent that some external influence between these dam locations is adding heat to the river.

2) The computed upper and lower extremes with the exception of 1948, the flood year, show a close relationship and consistently rise and fall together. The two groups of data tend to separate in the case of the upper extreme by values about equal to the separation of the means,

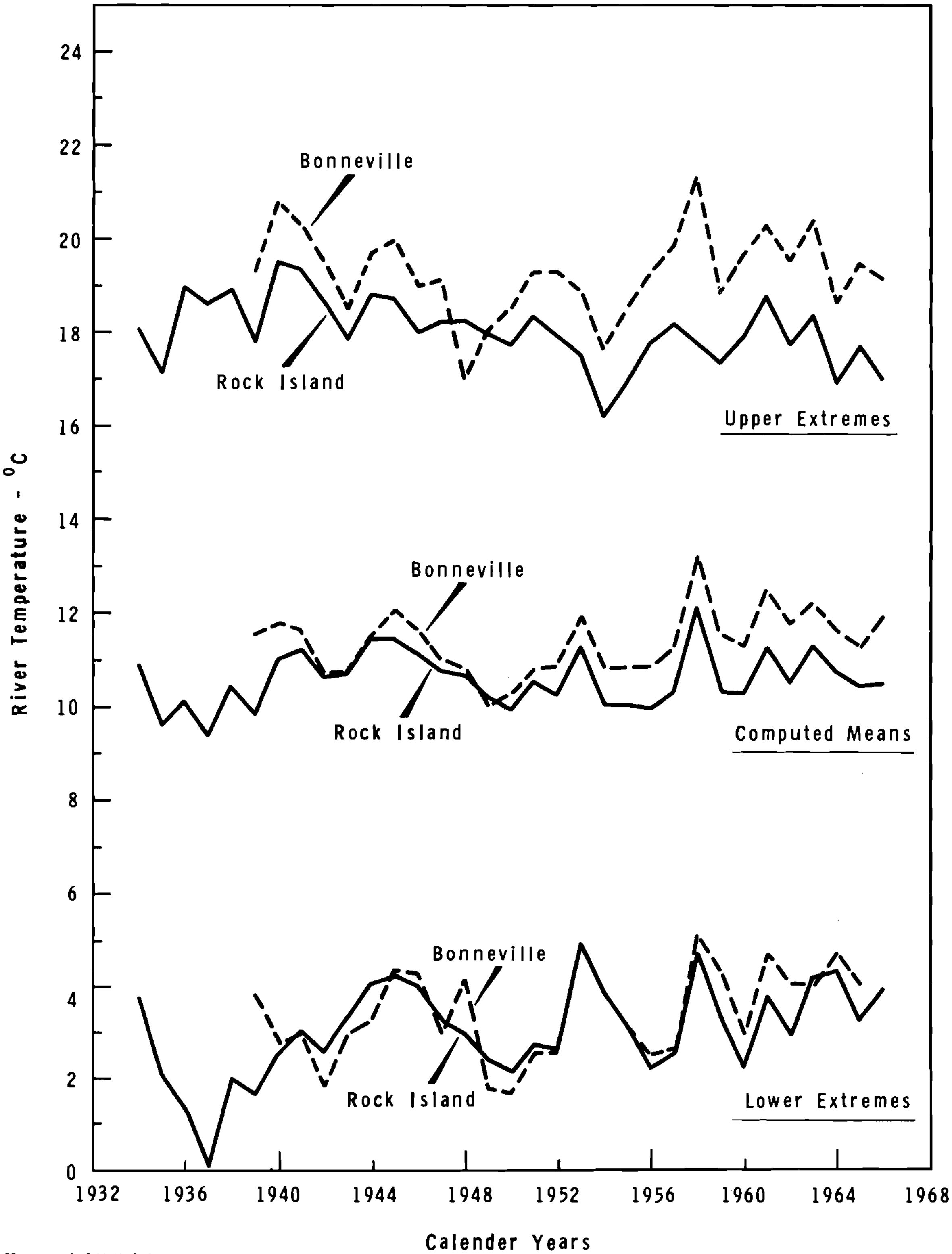

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FIGURE 5. Computed Temperature Trends, 1938-1966

while the upper extreme of Rock Island continues a steady decrease. During the recent period of 1960 to present both the upper and lower extremes show a sharp tendency to converge on the mean. Again, it is plain that a strong influence has affected the historic trend and sharply reduced the departure from the mean. This timing coincides with the period of greatest dam building activity in the upper Columbia.

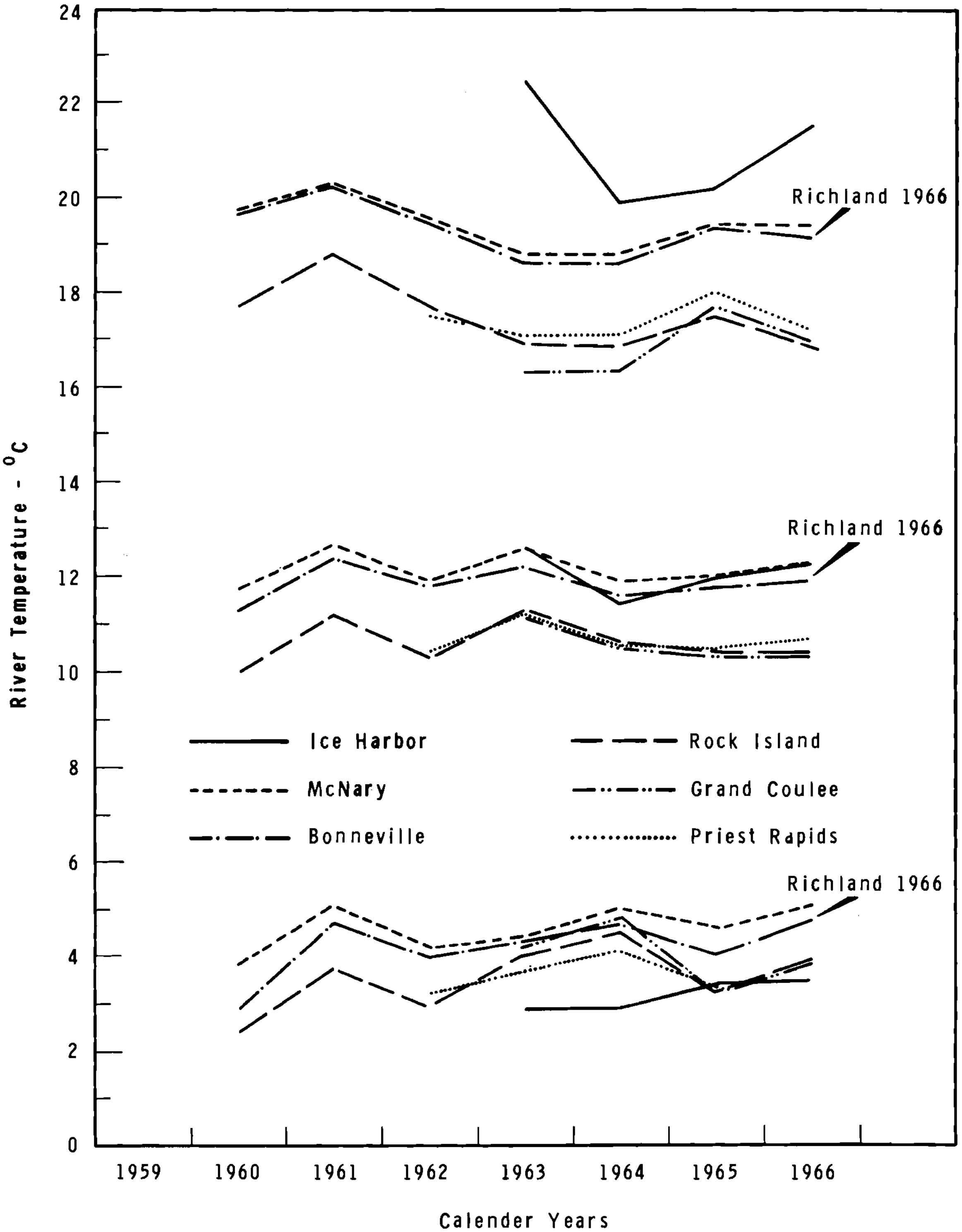
In order to more fully understand the fine structure involved in these differences, additional runs were made in order to add the effects of intermediate projects. Figure 6 illustrates the computed parameters for six projects for which data are available since 1961. Inspection of these data yields further observations:

1) The values for the means and the extremes fall into distinct groups, those above the Hanford Project and those below it. Further, the mean values for Ice Harbor are essentially equal to the McNary values and could not account for more than a fraction of the difference between the upper and lower sets because of the greatly lesser flow of the Snake River.

2) The values of the means for the period 1960 to present show no significant trend or departure from the group response to individual yearly weather patterns.

3) The upper and lower extremes for both project sets show a common convergence toward the mean. This is more pronounced for the upstream locations than those downstream indicating that a nonweather related influence is overriding the average convergence to a slight extent.

4) The upper and lower computed extremes for the Snake River, a more natural stream at this stage in time, are significantly higher and lower than the Columbia River group and similar to the historic values for Bonneville before the erection of Grand Coulee Dam.



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<u>FIGURE 6</u>. *Comparative Trends, 1960-1966*

5) The data for the projects up-river from Hanford have closely related values with a tendency for a slight reduction in values of the extremes. On the other hand, the McNary and Bonneville data groups show effects peculiar to a cooling trend with the Bonneville Project showing significant lower values for both the annual mean and the lower extremes.

Since these two data groupings would tend to create the impression that the erection of the Columbia River Dams have had little or no effect on the water temperature, reference to Figure 7 is necessary to complete the analysis of trends. Figure 7 indicates:

1) A sharp and permanent change in the timing of the peak temperature at Rock Island commencing with the filling of Lake Roosevelt in 1941-1942. The permanent change amounts to about 30 days, the average transport time for the mean annual flow through Lake Roosevelt.

2) This sharp and permanent shift is also observed at Bonneville Dam although to a lesser extent. The two projects reveal surprisingly similar shifts in response to annual weather cycles. While the Rock Island peak has stabilized at about September 20, the Bonneville peak has continued to occur later and later as longer and longer flow times result from the addition of upstream projects. The close relationship of McNary and Bonneville indicate little or no cooling takes place in the reach between these projects.

3) The values for the Priest Rapids Project closely resemble peak temperature patterns for Rock Island. The date differences of about 7 to 10 days appear to be related to the travel time through Wanapum and Priest Rapids reservoirs in about the same manner as Grand Coulee.

4) All projects have strong indications of responding in unison to regional weather influences. For example, all

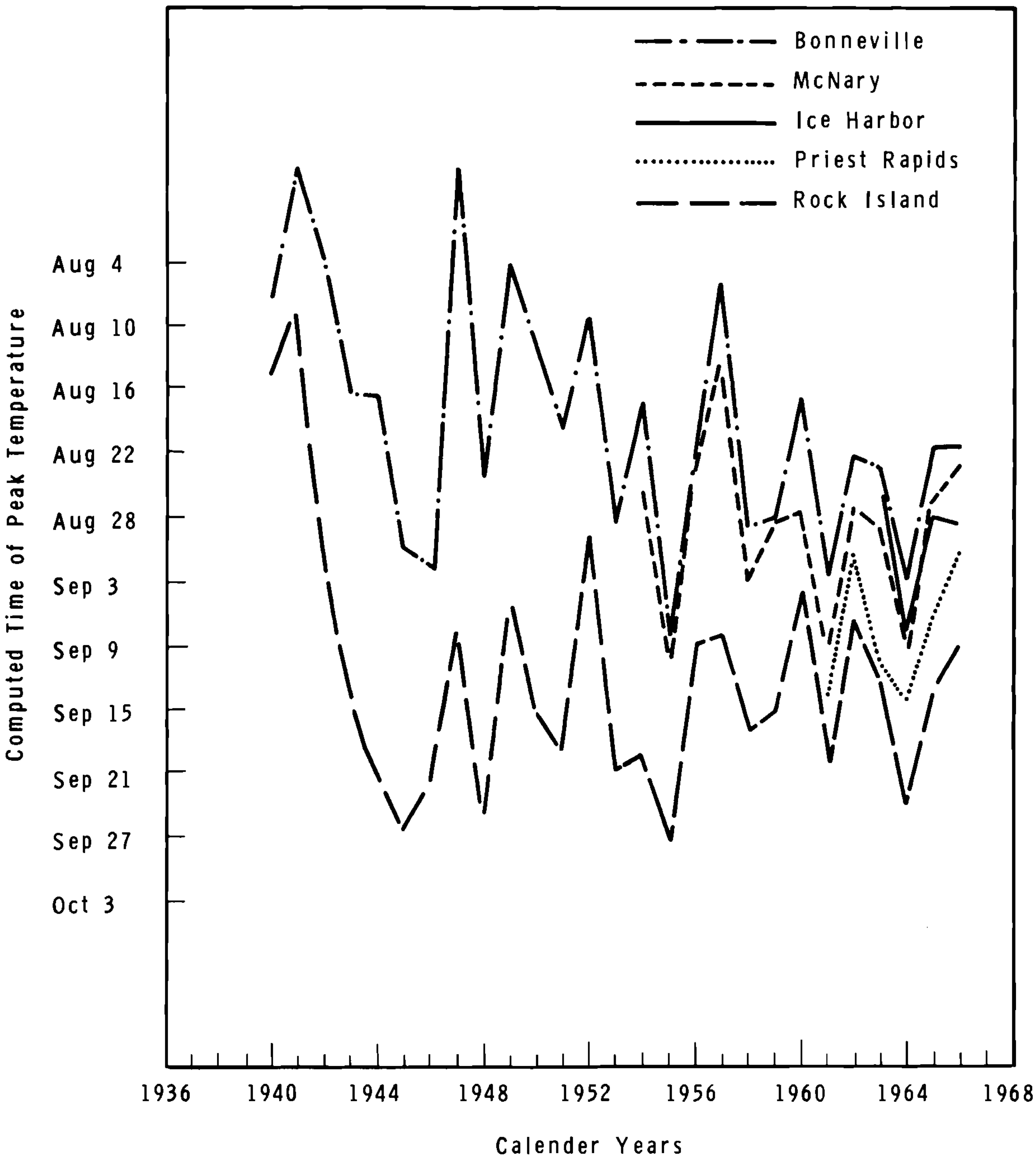

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FIGURE 7. Computed Peak Arrival Dates, 1940-1966

projects show early peak arrivals on high temperature years. Clearly, regional influences beyond the scope of man's activity affect all water temperatures to a surprisingly similar extent, even in unconnected portions of streams.

CONCLUSIONS

On the basis of the observations detailed in the discussion, and other previous observations reported in published work,[3,4] the following conclusions regarding the temperatures of the Columbia River Basin within the continental United States appear appropriate.

1) The erection of hydraulic power dams and reservoirs on the Columbia River has had only a nominal effect on the annual mean temperature of the entire system. This effect is less than 1 °C over the 30-year period 1936 to 1966. The extent of this change could easily be attributable to long-term weather changes due to causes beyond the scope of this study.

2) The erection of these projects has significantly altered the timing of the annual temperature and has to a limited extent, altered the seasonal extremes. Where annual peak temperatures in the natural, undeveloped river once occurred in mid-August, the construction of reservoirs has altered the timing about in proportion to the increased travel time through the system. The persistence of this effect verifies the prediction of high thermal inertia for lakes and streams which has been observed previously.[3] Thus, the moving of a relatively identical annual cycle laterally on the time scale creates the appearance of warmer water in later fall months and leads to the conclusion by relatively uninformed observers that dam construction is heating the river system. In actuality, the reservoir tends to slightly cool the river in more

cases than not, and the net effect is the time displacement of a relatively identical thermodynamic history. This is especially true for systems with large reservoir to mean-flow ratios.

3) This review provides further confirmation of previous published work(3) that in the reach between Grand Coulee and the Hanford plant 65 to 85% of a one degree change in river temperature at the upper location persists to the lower one. Roughly, this relationship can be expected to apply as well to the entire main stem down to the estuary. There is indication that the artificial change of temperature for any reason in a major stream such as the Columbia will persist for extended periods of time and correspondingly of dimension.

4) The erection of the Canadian dams on the Columbia River headwater streams can be expected to have considerable effect on the annual temperature cycle of the Columbia River throughout its entire length. On the basis of the observations in this study, it appears that additional delays of from 20 to 40 days will result from the upstream impoundments and that there may be some reduction of critical summer and fall water temperatures resulting from the exposure of water to increasingly out of phase air temperature conditions.

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