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SIMULATION OF THE EFFECTS OF HANFORD
AT THE WASHINGTON-OREGON BORDER

R. T. Jaske
D. G. Daniels

July 1970

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AT THE WASHINGTON-OREGON BORDER

R. T. Jaske
D. G. Daniels

Water and Land Resources Department
Environmental and Life Sciences Division

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R. T. Jaske and D. G. Daniels

ABSTRACT

A series of transects taken in the summer and fall of 1969 at the Oregon and Washington border are used as the basis for checking the accuracy of the COLHEAT simulation model and the extent of stratification and mixing which occurs in the reservoir under conditions where solar thermal input is at a maximum. The model is then used to estimate the extent to which heat additions at the Hanford Plant (Columbia River Mile 382) persist to the Washington-Oregon border (River Mile 308) under a range of statistically determined extreme and normal conditions expected after completion of the Columbia Treaty dams in 1975. The results show that 65% or more of the incremental addition to the temperature of the Columbia River between Priest Rapids dam and Richland is dissipated in the reach under study. The remaining 35% is only weakly related to the weather in terms of yearly variations. The study suggests the practicability of using computer simulation as the basis for management of stream standards using in situ stream conditions as the basis of the judgment.

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SIMULATION OF THE EFFECTS OF HANFORD
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INTRODUCTION

Since passage of the Federal Water Quality Act (1965), legislative actions and executive orders culminating in the Water and Environmental Quality Improvement Act of 1970 have required improved knowledge of the fate of effluents discharged from the operating Hanford reactors. The thermal aspects of these releases have been further placed under Washington State standards subject to review by the Federal Water Quality Administration. Standards for the intrastate section of the Columbia River have been issued by Washington, and both Oregon and Washington have placed numerical values on the permissible alteration of the river temperature for interstate reaches of the River. Because these reaches are navigable, special consideration is being placed on the review of these numerical values by the Federal government and, as a result of the most recent legislation, additional guidelines or numerical limits for the navigable portions of the Columbia River under Federal jurisdiction are expected to be issued.

A question has always existed as to the extent of attenuation of temperature differentials imposed on the Columbia River as a result of operations at Hanford as the flow of the stream passes from intra- to interstate jurisdiction. At present, the intrastate standards of the State of Washington allow a larger numerical temperature modification in comparison to the 2 °F limit set by the State of Oregon. The purpose of this report is to demonstrate the extent to which Hanford effluent makes a contribution to temperature modifications of the Columbia River at the Washington-Oregon

border and to test the reliability of the demonstration with field measurements and other tests of the computer simulation model. The situation is further complicated by the inflow from the Snake River which at times differs considerably in temperature from the Columbia. Because the temperature differentials of interest to this study cannot be directly measured, resort is made to the simulation of the incremental effects in a river simulation model which is tested for overall accuracy on real data. This model is used first to simulate the Columbia River from Priest Rapids to the Washington-Oregon border with Hanford heat effects and then without the Hanford heat effects. Then the increment of heat introduced by the Hanford operation can be deduced and conclusions can be drawn from the numerical results.

This procedure was carried out for the investigation reported. The accuracy of the data used to support the analysis is generally quite good and all instruments used in the investigation are carefully calibrated to better than ± 0.10 °C. It has been determined that the mean error from instrument to mean river sample is less than 0.20 °C for the thermograph stations used to test and verify the COLHEAT model. Data obtained in the transects in the McNary Reservoir represent best effort measurements which could be obtained by single point samples from a research vessel. The conditions for the performance of the simulation represent acceptable high quality research techniques which would be used in day-to-day monitoring of the conditions of the Columbia River by regulatory agencies.

SUMMARY AND CONCLUSIONS

This report is an estimate of the residual thermal effects of the operation of the Hanford plant at the Washington-Oregon border. The effects were calculated using the COLHEAT digital simulation model and the principle of superposition to

determine both the numerical values of the remaining temperature differences and the extent to which these differences are affected by weather conditions and inlet water temperatures. Case examples for the post-Columbia Treaty Dam conditions were used based on the work performed for the Portland General Electric Company.⁽¹⁾ These case examples show that in all but the high temperature case, temperatures at the Washington-Oregon border will be below the 20 °C upper permissible limit for thermal discharges. The reference study determined that the high temperature case was a 1 in 20-year event. In view of generally decreasing world atmospheric temperatures, it appears proper to speculate that the 1958 extreme may not be exceeded again in this century. The results of this study show that a fraction of the temperature rise measured at Richland varying from 0.1 to 0.4 remains at the Washington-Oregon border and that this temperature increment is essentially independent of the weather conditions at that point. Other studies have also pointed out the numerical values of temperature increment remaining at Bonneville Dam.⁽²⁾ As a general conclusion it can be stated that temperature differentials represented by differences between Priest Rapids and Richland resulting from the operation of the Hanford reactors make a relatively small, but significant contribution to temperatures in the Columbia River as far downstream as Bonneville Dam.

The following specific statements appear to apply:

- 1) The maximum predicted water temperatures expected to exist at the Washington-Oregon border under post-Columbia Treaty operation which would occur from a repetition of the operation of Hanford reactors at power levels actually achieved during Calendar Year 1969 would be as follows:

High temperature year:	Probability 1/20	21 °C
Low temperature year:	Probability 1/20	18.1 °C
Normal temperature year:		19.6 °C

- 2) River temperature modifications introduced by natural environmental effects and operation of reactors at 1969 power levels would be approximately 65% dissipated at the Washington-Oregon border. The extent of this dissipation is nearly independent of Priest Rapids water temperature and weather conditions affecting the Columbia River between Priest Rapids and the Washington-Oregon border. The numerical values of the remaining increment range from essentially zero to a momentary high of 0.5 °C, the average being 0.20 °C for the April through October period used in this study.
- 3) On the basis of the transects taken in the summer and fall of 1969 and using water temperature as a tracer, the McNary Reservoir at the Washington-Oregon border is sufficiently well mixed that a single point monitoring station could be appropriately located for the purpose of thermal auditing at that point. Such stratification as exists is very weak, and the isotherms appear to be more subject to modification by flow conditions of the Snake and the Columbia than by heat transfer across the water surface in the reservoir. The study suggests that on the basis of the samples collected, and previous transects made before 1962 (Soldat et al., unpublished), it appears that the day-to-day peaking operations of Ice Harbor Dam in relation to Columbia River peaking operations may bear as important a relationship in creating patches of warmer and cooler water within the reservoir flow system as residual Hanford effects. Additional study is needed to verify this conclusively.

- 4) The good simulations achieved using the COLHEAT digital simulation and the method of superposition show another example of the practical uses for simulation models. Simulation models of this type used by regulatory agencies can assist in adjudicating conflicting requirements and present possibilities for realistic abatement plans using in situ stream conditions as the basis for decisions.

SIMULATION AND MODEL VERIFICATION

The model used in this study to predict the effects of the Hanford reactors on the Columbia River temperatures was the COLHEAT digital simulation developed at Battelle-Northwest and originally described in a publication by Jaske and Spurgeon.⁽²⁾

Initially a simulation was made on the Columbia River for calendar year 1969 from Priest Rapids to Umatilla, Oregon. Actual Hanford heat discharges were advected into the river. The observed temperatures and flows at Priest Rapids and Ice Harbor were used as boundary conditions together with Hanford weather data which includes daily total solar radiation, daily average air temperature, wet bulb temperature, wind speed, and cloud cover.

The COLHEAT model ordinarily uses a small incremental surface temperature bias to account for boundary effects. In this case, no surface temperature correction was made between Priest Rapids and Richland since the river is well mixed and no warm surface film of water is present in this reach of river. For this condition, the conductivity coefficient* was raised to 0.012 Btu/(ft² mi in Hg °F) for this reach to help account for added conductive heat transfer across the water surface. Between Richland and Umatilla, a surface

* See Appendix for explanation of conductivity coefficient.

temperature correction* was made in the form of a sine function which increased the surface temperature by as much as 1.5 °C in September and the conductivity coefficient was lowered to 0.006 Btu/(ft² mi in Hg °F) a normal value for the conductivity coefficient, to account for the lesser conductive heat transfer across the water surface in McNary Reservoir.

Calculated daily average water temperatures were output and compared with observed values at Richland and Umatilla. These simulation results are shown in Figures 1 and 2, respectively. Calculated daily average water temperatures were also output at the Washington-Oregon border and compared with the averages of seven transects taken at the border during summer and fall of 1969. These results are compared in Figure 3 and the transects are shown in Figures 4 through 10. It can be seen that good simulation has been obtained at these three locations and thus the model is calculating reasonable results.

BASIS FOR CASES EXAMINED

A set of hypothetical cases was constructed from a study completed under Contract AT(45-1)-1831 for the Portland General Electric Company.⁽¹⁾ In this study the temperature effects of Mica and Arrow Dams on the Columbia River, Duncan Dam on the Duncan River, Libby Dam on the Kootenay River, and the installation of the Third Power House at Grand Coulee have been estimated using a linear program model developed at Battelle-Northwest and a modified flow record generated jointly by the Bonneville Power Administration and the U.S. Army Corps of Engineers.

This linear program model generated a synthetic temperature record below Grand Coulee from 1929 through 1957 for post-Canadian dam conditions. The 95% confidence envelope was

* See Appendix for explanation of surface temperature correction function.

FIGURE 1. Comparison of Richland (River Mile 338.0) Calculated and Observed Temperatures (1969) (These include the effects of production reactor operations)

FIGURE 2. Comparison of Umatilla (River Mile 290.5) Calculated and Observed Temperatures (1969)

FIGURE 3. Washington-Oregon Border Calculated Temperatures Compared with the Averages of Seven Temperature Transects (River Mile 309.3)

FIGURE 4. Temperature Transect at the Washington-Oregon Border, August 13, 1969 (River Mile 309.3)
(Temperatures indicated are in °C.)

FIGURE 5. Temperature Transect at the Washington-Oregon Border,
August 15, 1969 (River Mile 309.3)
(Temperatures indicated are in °C.)

FIGURE 6. Temperature Transect at the Washington-Oregon Border, August 20, 1969 (River Mile 309.3) (Temperatures indicated are in °C.)

FIGURE 7. Temperature Transect at the Washington-Oregon Border, August 22, 1969 (River Mile 309.3)
(Temperatures indicated are in °C.)

FIGURE 8. Temperature Transect at the Washington-Oregon Border,
August 25, 1969 (River Mile 309.3)
(Temperatures indicated are in °C.)

FIGURE 9. Temperature Transect at the Washington-Oregon Border,
November 21, 1969 (River Mile 309.3)
(Temperatures indicated are in °C.)

FIGURE 10. Temperature Transect at the Washington-Oregon Border,
November 28, 1969 (River Mile 309.3)
(Temperatures indicated are in °C.)

established assuming the synthetic temperature record to be normally distributed. The results of this analysis are summarized in Tables 1 and 2 and the extreme and average temperatures below Grand Coulee are plotted in Figure 11.

TRANSPORTING THE POST-CANADIAN DAM TEMPERATURE ENVELOPE TO THE WASHINGTON-OREGON BORDER

Initially a simulation was made from Grand Coulee to Priest Rapids using actual 1965 water temperatures and flows at Grand Coulee and 1965 Hanford weather data. A plot of the observed and calculated temperatures at Priest Rapids is shown in Figure 12 and indicates that the model is calculating reasonable results.

The results of a statistical analysis of post-Canadian dam water temperatures and flows below Grand Coulee, Trinidad, Washington air temperatures, water temperatures and flows below Ice Harbor on the Snake River, and Hanford air temperatures performed in the Portland General Electric Company study are summarized below. The interested reader should refer to that study for detail.

- 1) Generally speaking, no correlation between meteorology and water temperature below Grand Coulee exists for mean monthly temperature sets.
- 2) Generally speaking, no correlation between the air temperature measured at Trinidad, Washington and the modified hydrology below Grand Coulee exists for mean monthly temperature sets.
- 3) Generally speaking, no correlation between water temperature and hydrology below Grand Coulee exists for mean monthly temperature sets.
- 4) A strong correlation between Snake River flows and Columbia River flows exists for mean monthly flow sets.

TABLE 1. Synthetic Monthly Mean Discharge Temperatures Below Grand Coulee Dam

Year	May		June		July		Aug.		Sept.		High		Low	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
1929	27	-2.2	29	-4.4	24	-4.8	6	-3.4	24	-5.7	24	6	24	-5.7
1930	28	-2.7	20	-3.5	29	-6.8	22	-5.3	20	-4.8	20	22	20	-4.8
1931	20	-1.8	21	-3.5	28	-5.9	13	-4.1	3	-2.8	3	13	3	-2.8
1932	10	-1.4	18	-3.4	14	-3.1	26	-5.7	25	-5.7	25	26	25	-5.7
1933	18	-1.7	1	-1.9	2	-1.5	1	+1.2	5	-3.0	5	1	5	-3.0
1934	15	-1.5	12	-3.4	25	-4.8	15	-4.3	21	-5.0	21	15	21	-5.0
1935	21	-1.8	22	-3.5	9	-2.8	19	-4.8	15	-4.1	15	19	15	-4.1
1936	25	-2.1	24	-3.6	11	-2.9	20	-4.9	26	-5.7	26	20	26	-5.7
1937	16	-1.6	9	-2.6	21	-4.0	10	-4.0	14	-4.0	14	10	14	-4.0
1938	4	-1.1	27	-3.8	8	-2.4	14	-4.1	16	-4.1	16	14	16	-4.1
1939	22	-1.9	12	-2.7	22	-4.2	27	-5.7	27	-5.7	27	27	27	-5.7
1940	11	-1.4	13	-2.9	26	-4.9	11	-4.0	22	-5.0	22	11	22	-5.0
1941	17	-1.6	5	-2.0	23	-4.6	28	-5.8	12	-3.9	12	28	12	-3.9
1942	9	-1.3	14	-3.0	15	-3.2	29	-6.5	2	-5.9	2	29	2	-5.9
1943	8	-1.3	8	-2.4	3	-1.7	2	-0.5	17	-4.3	17	2	17	-4.3
1944	29	-3.3	28	-3.9	20	-3.9	23	-5.3	4	-3.9	4	23	4	-3.9
1945	5	-1.2	2	-1.9	10	-2.8	7	-3.4	7	-3.2	7	7	7	-3.2
1946	7	-1.3	25	-3.7	19	-3.8	24	-5.3	18	-4.6	18	24	18	-4.6
1947	19	-1.7	9	-2.6	27	-4.9	16	-4.3	9	-4.6	9	16	9	-4.6
1948	6	-1.2	10	-3.1	2	-3.0	2	-3.7	12	-2.9	12	2	12	-2.9
1949	12	-1.4	3	-1.9	17	-3.3	9	-3.2	18	-7.8	18	9	18	-7.8
1950	13	-1.4	26	-3.7	4	-1.7	5	-4.0	29	-3.2	29	5	29	-3.2
1951	3	-1.0	4	-1.9	5	-1.9	21	-5.1	8	-3.6	8	21	8	-3.6
1952	2	-0.8	6	-2.0	13	-3.0	25	-5.3	11	-5.1	11	6	11	-5.1
1953	26	-2.1	23	-3.5	6	-1.9	3	-2.2	23	-3.5	23	3	23	-3.5
1954	14	-1.5	11	-2.6	1	-0.8	18	-4.7	10	-2.0	10	18	10	-2.0
1955	23	-1.9	17	-3.3	18	-3.6	17	-4.3	6	-3.0	6	17	6	-3.0
1956	1	-0.7	15	-3.0	16	-3.2	8	-3.6	9	-3.3	9	8	9	-3.3
1957	24	-2.0	7	-2.1	7	-2.0	4	-2.3	1	-1.3	1	4	1	-1.3

TABLE 2. Grand Coulee Dam Outflow, Post-Canadian Dam, Kcfs
(Ref. Bonneville Power Administration)

<u>Year</u>	<u>April</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>August</u>	<u>September</u>	<u>October</u>
1929	84	54	35	72	92	87	81
1930	64	61	67	88	93	90	82
1931	71	62	88	97	93	84	82
1932	75	95	125	130	97	89	88
1933	125	90	199	177	125	99	95
1934	180	243	188	116	94	93	79
1935	127	98	101	116	90	90	83
1936	86	133	104	111	93	88	83
1937	65	71	47	81	91	88	82
1938	109	164	112	103	88	90	80
1939	111	96	106	85	91	90	84
1940	119	94	72	88	89	90	82
1941	96	65	60	87	90	82	78
1942	102	87	76	107	98	88	83
1943	120	169	130	119	94	79	74
1944	73	66	63	83	89	82	79
1945	73	71	73	73	89	85	83
1946	115	151	139	151	85	89	72
1947	105	160	153	159	83	87	102
1948	110	195	265	171	113	93	77
1949	98	146	96	67	85	85	73
1950	100	154	189	245	109	90	88
1951	135	220	176	208	105	90	96
1952	98	180	111	139	84	85	81
1953	105	101	167	124	100	86	78
1954	106	156	166	286	158	118	86
1955	93	81	131	191	106	84	88
1956	199	245	211	170	97	86	79
1957	100	136	146	113	88	85	73
Mean	105	126	124	131	97	88.5	82.4
σ	35	55.4	55.0	53.4	15.1	16.0	21.2

FIGURE 11. Predicted Outlet Temperature Envelope from Grand Coulee Dam After the Construction of the Canadian Dams (From Report to Portland General Electric, June 18, 1969)

FIGURE 12. Comparison of Measured Versus Simulated Temperatures at Priest Rapids Dam (1965) (From Report to Portland Electric, June 18, 1969)

- 5) A strong correlation between Snake River temperatures and Hanford meteorology exists for annual average temperature sets.

CASES EXAMINED

Three basic cases were examined in this study. All cases used average flows at Grand Coulee based on Bonneville Power Administration predictions for modified flows under post-Canadian dam conditions and average Snake River temperatures and flows based on 1963 through 1969 data at Ice Harbor. The average Snake River temperatures and flows were used because it was felt that not enough data were available to perform a statistical analysis on the Snake River characteristics at Ice Harbor. Initially runs made from Grand Coulee to Priest Rapids for the Portland General Electric study were utilized. The calculated temperatures at Priest Rapids are shown in Figure 13. These temperatures calculated at Priest Rapids were input and run from Priest Rapids to the Washington-Oregon border. The cases used were as follows:

Case 1 (High Extreme)

A hypothetical case was constructed using average calculated water temperatures at Grand Coulee for post-Canadian dam conditions and 1958 Hanford weather. The anticipated occurrence is less than 1 in 20 years.

Case 2 (Average Case)

A hypothetical average case was constructed using average calculated water temperatures at Grand Coulee for post-Canadian dam conditions and average Hanford weather based on records from 1955 through 1967.

FIGURE 13. Predicted Temperature Envelope at Priest Rapids Dam After the Construction of the Canadian Dams (From Report to Portland General Electric, June 18, 1969)

Case 3 (Low Extreme)

A hypothetical case was constructed using low calculated water temperatures at Grand Coulee for post-Canadian dam conditions and 1964 Hanford weather. The anticipated occurrence is less than 1 in 20 years.

For all three cases two runs were made. In the first, 1969 Hanford reactor heat was advected into the system and daily average water temperatures were calculated at the Washington-Oregon border. In the second, no Hanford heat was advected and daily average temperatures were calculated at the same location. Then the daily average temperature difference, or temperature excess, between the run with advected heat and the run without advected heat was calculated to indicate the amount of Hanford heat still present in the Columbia River at the Washington-Oregon border. Plots of these temperature excesses, together with plots of water temperatures calculated with 1969 Hanford heat advected are shown in Figures 14, 15, and 16 for the high average, and low cases, respectively.

FIGURE 14. Calculated Water Temperatures with Hanford Heat at the Washington-Oregon Border and Calculated Temperature Excesses at Richland and the Washington-Oregon Border for the High Extreme (River Mile 309.3)

FIGURE 15. Calculated Water Temperatures with Hanford Heat at the Washington-Oregon Border and Calculated Temperature Excesses at Richland and the Washington-Oregon Border for the Average Conditions (River Mile 309.3)

FIGURE 16. Calculated Water Temperatures with Hanford Heat at the Washington-Oregon Border and Calculated Temperature Excesses at Richland and the Washington-Oregon Border for the Low Extreme (River Mile 309.3)

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The authors wish to thank Mildred O. Synoground for her diligent assistance in assembling all the computer runs and plotting much of the calculated and observed temperature data during the study period.

The authors are also grateful to the Portland General Electric Company for permission to use the material which was abstracted from their report of June, 1969. Copies of the original should be requested from L. E. Hodel, Portland General Electric Company, 621 S. W. Alder Street, Portland, Oregon 97205.

APPENDIXCONDUCTIVITY COEFFICIENT

Sensible heat is conducted to or from a body of water whenever a temperature difference exists between the air and water. The amount of heat transported depends on the temperature differential between the air and water and on the wind speed at the interface. Since the evaporation energy also depends on these factors, the ratio proposed by I. S. Bowen⁽³⁾ can be used to evaluate the ratio of conducted heat energy to evaporation energy. The Bowen ratio may be expressed as

$$R = \frac{Q_h}{Q_e} = C_1 \left(\frac{t_a - t_w}{e_a - e_w} \right) \frac{P}{1000} \quad (1)$$

where

- Q_h = conducted heat energy
- Q_e = evaporation energy
- C_1 = an empirical constant
 $\approx 0.061 \text{ } ^\circ\text{C}^{-1}$ when temperatures are in $^\circ\text{C}$
- t_a = air temperature
- t_w = water surface temperature
- e_a = vapor pressure of air, in. Hg
- e_w = vapor pressure of water, in. Hg
- P = atmospheric pressure, in. Hg.

Anderson⁽⁴⁾ obtained an empirical equation for daily evaporation which best fit his data

$$Q_e = \lambda C_2 U (e_w - e_a) \quad (2)$$

where

- λ = latent heat of evaporation
- C_2 = an empirical constant
 $= 0.00177 \text{ lb}/(\text{ft}^2 \text{ mi mb}).$

Substituting Equation (2) into Equation (1) regrouping, and converting units

$$Q_h = 2.953 \times 10^{-5} C_1 C_2 \lambda U P (t_a - t_w) \quad (5)$$

where units are

$$Q_h = \text{Btu}/(\text{ft}^2/\text{hr})$$

$$\lambda = \text{Btu}/\text{lb}$$

$$U = \text{mi}/\text{hr}$$

$$P = \text{in. Hg}$$

$$t_a, t_w = ^\circ\text{F.}$$

Substituting values for C_1 , C_2 , and λ yields

$$Q_h = k U P (t_a - t_w) \quad (4)$$

where the conductivity coefficient, k , is

$$k = 0.004665 \text{ Btu}/(\text{ft}^2 \text{ mi in Hg } ^\circ\text{F})$$

According to Anderson this value of the conductivity coefficient should apply to lakes. In order to obtain good simulation for fast moving rivers this coefficient must be increased by a factor of nearly three. For example, during August 1966 when the Hanford reactors were shut down because of a strike, field data indicated that the conductivity coefficient was of the order of $0.012 \text{ Btu}/(\text{ft}^2 \text{ mi in Hg } ^\circ\text{F})$ to account for the $3/4^\circ\text{C}$ rise in water temperature between Priest Rapids and Richland.

SURFACE TEMPERATURE CORRECTION FUNCTION

Temperature profile data taken in reservoirs on the Columbia River indicate a pronounced warm surface film ($\ll 1\text{cm}$) of water which may be of the order of 1.5°C warmer than water in the hypolimnion in early September. In order to account for the differences in evaporation and conduction caused by this warm surface film, a surface temperature correction function is added to the average calculated water temperature within each river section. This function is of the form

$$TSA = S [1 + \sin (wD + \phi)] \quad (5)$$

where

TSA = surface temperature correction

S = one-half the maximum TSA

= 0.75 °C

w = frequency

= $2\pi/365$

ϕ = phase lag

= 3.65 radians

D = day of year.

This function has a minimum of 0 °C about March 3 and a maximum of 1.5 °C about September 1.

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