USE OF LAKE ROOSEVELT STORAGE TO LOWER RIVER TEMPERATURES

By

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BACKGROUND

The reduction of river temperatures below Grand Coulee Dam by storing hot surface layers and releasing colder bottom water is, as far as is known, the only such operation for industrial purposes. This use was first conceived in late 1948 during an examination of the possible use of Grand Coulee Dam for flood control. The late Frank Banks had in his files thermoclines of Lake Roosevelt at the Dam from 1942 to that date which were used at that time to determine if flood control would cause harmful expansion stresses. These thermoclines showed that a large amount of colder water persisted in the bottom levels of Lake Roosevelt throughout the warm weather period. The difference in temperature from year to year varied between top and bottom from 8 to 20 degrees F.

In subsequent years, the feasibility of using the colder water for river cooling was reviewed several times. In 1958 when Columbia water temperatures reached an all-time high, it became economically justifiable to overcome the river temperature increment resulting from Lake Roosevelt surface spill by arranging for special releases of colder water from the lower levels.

By that time, the use of special cold water releases from reservoirs on other rivers in order to decrease trout mortality had been successful. Confirming studies of this method of cooling had been made at the Friant Dam and Folsom Dams. The California State Fish and Game Division is now successfully operating a fish hatchery with cooled water from Friant Dam. Since then, the Bureau of Reclamation has designed cold water outlets from lower levels of the Whiskeytown and Trinity Dams of the Trinity Project in California.

DESCRIPTION OF DAM AND LAKE

Grand Coulee Dam (Plate 1), the world's largest concrete structure, is 4173 feet long, weighs 22,000,000 tons and stands 550 feet above granite bedrock. It rises 370 feet above the river, and the spillway section is capped by 11 drum gates 28 by 135 feet.

1/ Hanford Atomic Products Operation, General Electric Company, Richland, Washington.

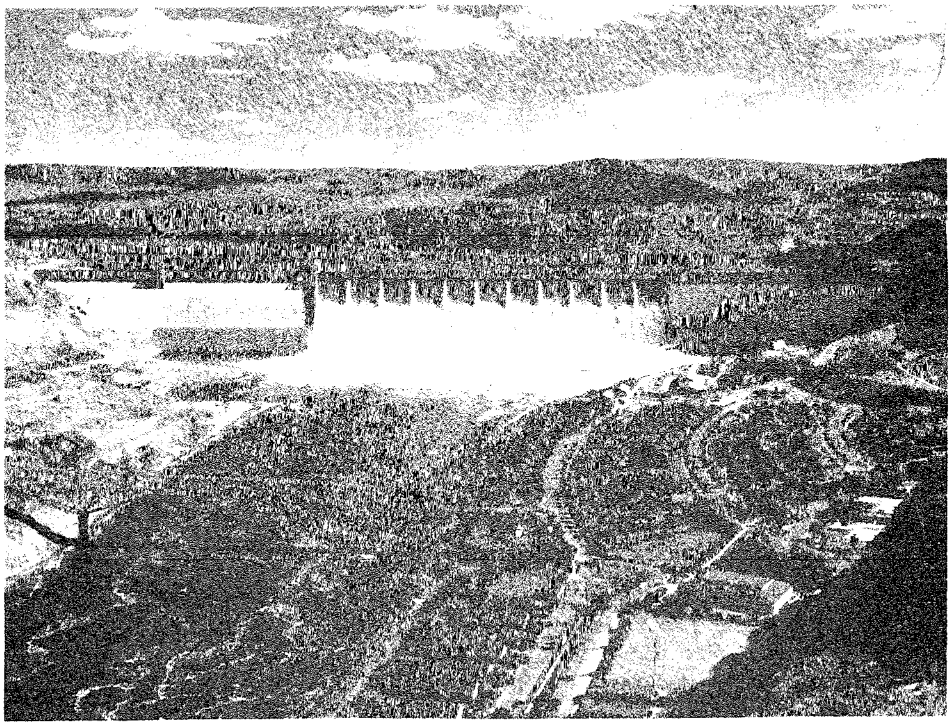

Plate 1

Bureau of Reclamation-Official Photo

GRAND COULEE - LOOKING EAST

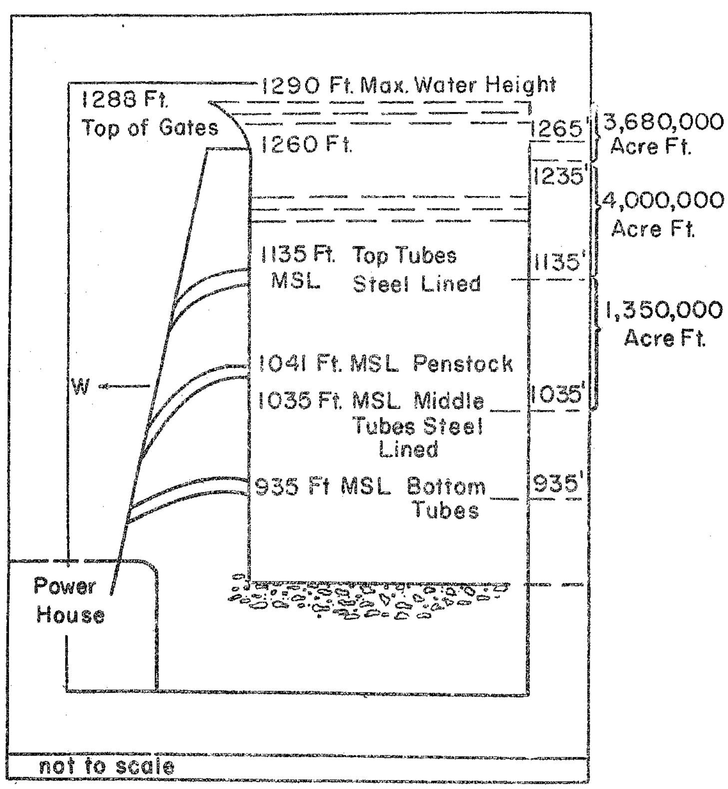

Plate 2

Through the spillway section (Plate 2) are three rows of outlet tubes, each 8-1/2 feet in diameter. The centerlines of the tube rows are at nominal elevations of 935, 1035 and 1135 feet. The top two rows are steel lined. The closed gate top is at a level of 1288 feet m.s.l. Eighteen penstocks 18 feet in diameter deliver water to the main turbines. Three 6 foot diameter penstocks feed the house turbines. The center line of the inlet of these tubes is 1041 feet m.s.l.

The total storage of Lake Roosevelt is 9,600,000 acre feet with nearly 9,000,000 above the 1035 foot level. Lake levels at the dam are controlled to not exceed 1290 feet. A canadian Treaty condition requires that the lake at the British Columbia border will not exceed former normal flood levels. The Grand Coulee gates when closed allow about 22,000 cfs of the warmer water to spill when the lake level is at 1290 feet. Flashboards to raise the gates 2 feet have been provided and will be used when economically feasible to prevent this spill, thereby retaining the head for greater Coulee generation and storing additional water for later generation at Coulee and ownstream plants.

Each year since 1948, Lake Roosevelt has been drafted during the spring months to permit extra storage for flood control. By early July, the lake is full (elevation 1288 to 1290 feet), and spill over the gates continues until the lake inflow equals the discharge required for generation and pumping which is usually by the middle of September.

Six irrigation pumps (Plate 3) discharging to the Banks Lake head works at an elevation of 1565 feet, remove up to 10,000 cfs of warmer water from the 1195 foot level. Generation of the electricity used to operate the pumps adds to the release of cold water and storage of an equivalent amount of warm water.

Lake Roosevelt (Plate 4) is fed at the northern-most point by discharge from the Lower Arrow and Kootenay Lakes and the discharge of the Pend Oreille River. About 50 miles west of Grand Coulee Dam the Spokane River enters the lake.

The summer water temperature below the Arrow Lakes at Castelgar ranges from 15 to 20 degrees C. Temperatures at Brilliant Dam on the Kootenay range from 17 to 21 degrees C and on the Pend Oreille below Waneta Dam from 22 to 24 degrees C. The Spokane River peak temperature is 21 to 23 degrees C.

Halfway between the Canadian border and Coulee Dam, surface temperatures at Gifford Ferry reach 24 degrees C in some years and from the ferry 40 miles west of Coulee to the dam, readings of near 24 degrees C occur often.

CONTROL OPERATIONS

Spill control for river cooling was initiated in 1958, a record hot weather and hot water year for the Columbia Basin. The plan for that year was to attempt to minimize the daily peak temperature by so timing the hours of release of the colder water so as to pass the Hanford plant during the hours of maximum solar heating. Although fairly successful, the subsequent addition of new dams between Grand Coulee and the Hanford plant has made flow timing too variable during the critical months to be dependable. In subsequent years, we have attempted to minimize river temperatures continuously during control periods by storing as much of the hot surface layer as possible.

In order to hold the surface spill to a minimum, extra electrical generation has been assigned to Coulee by Bonneville Power Administration, all possible irrigation pumps have been operated, and the bypass tubes at the 1035 foot level have been opened when necessary. These tubes remain open until total inflow drops to the point where surcharge would be reduced if they were not closed. Extra generation is continued as long as there is sufficient inflow. Extra irrigation pumps are shut off as Banks Lake approaches the 1565 foot level.

Control was started each year when there was -

1) an optimum spill for control, and

2) weather forecasts and prior experience indicated that higher river temperatures could be expected.

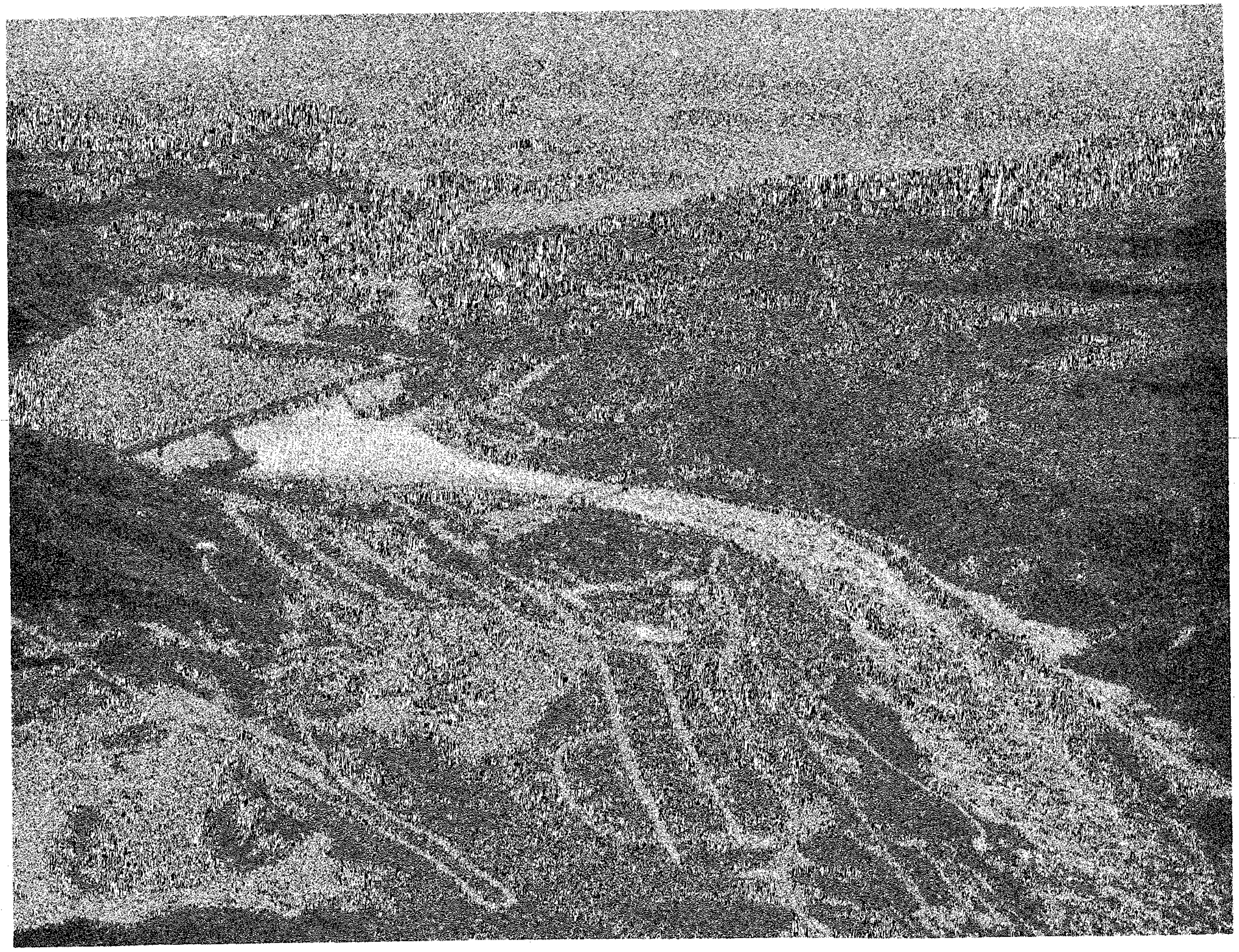

Plate 3 Bureau of Reclamation-Official Photo

AEC-GE RICHLAND, WASH.

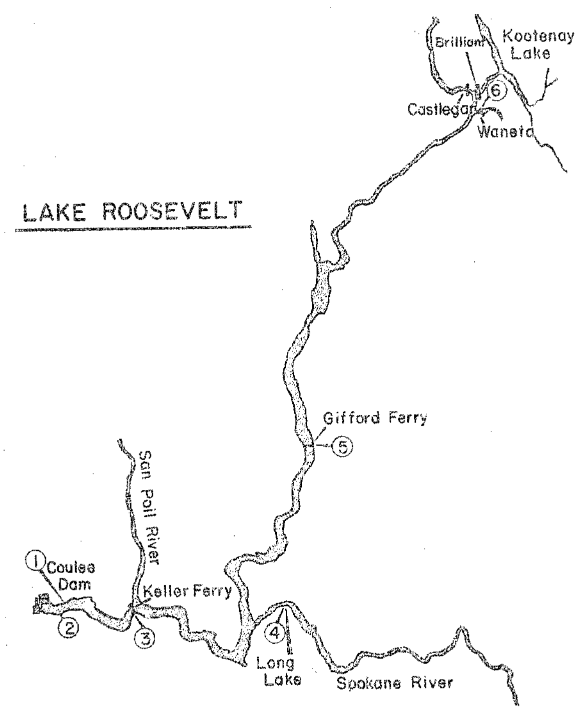

Plate 4

Control operations were coordinated with dam maintenance and load assignments.

Thermoclines were taken at the dam at intervals of a week or ten days to determine the effects of the program on lake temperatures and provide an estimate of the cooling potential remaining.

RESULTS OF PROGRAM

The temperatures of the mixed discharges (Plate 5) were substantially reduced in each of the control years.

PLATE V

CALCULATED REDUCTION IN RIVER TEMPERATURE

	1958	1959	1960
August 1st.	1.1	---	1.0
August 7th.	1.3	1.0	1.6
August 15th.	.7	1.6	2.4
September 1st.	.5	.9	1.1
September 7th.	---	.5	.8
September 15th.	---	1.7	.4
September 30th.	---	.4	1.2
Maximum	1.5	1.7	2.7
6 Hour Peak	3.5		

During 1958, the object was only to reduce the diurnal peak , since we did not know for how long a period the temperature differential could be maintained with the additional water release. Reductions at Coulee, therefore, varied during the day. The maximum effective average daily reduction amounted to 1.5 degree C in 1958.

The object since 1958 has been to reduce average daily river temperatures. The 1959 reduction on the maximum day was 1.7 degree C. In 1960 the maximum daily temperature decrease was 2.7 degrees C. Temperature benefits were calculated by determining the difference in heat content of the total outflow with and without control and dividing by the total flow.

Control periods varied with the need and the amount of available water.

1958 - started control July 25, 1958 - ended August 24, 1958.

1959 - started control August 7, 1959 - ended September 9, 1959.

1960 - started control August 1, 1960 - ended October 12, 1960.

OBSERVATIONS ON LAKE ROOSEVELT TEMPERATURE DISTRIBUTION (Plates 6-11)

During the months of July, August, and sometimes early September, the temperature of the top layers of the reservoir increases, the top 1 to 10 feet eventually reaching temperatures of 21 to 26 degrees C. Major temperature changes can occur from day-to-day in the surface layers of the lake, in addition to the normal diurnal variation observed

TEMPERATURE LAKE ROOSEVELT-1948

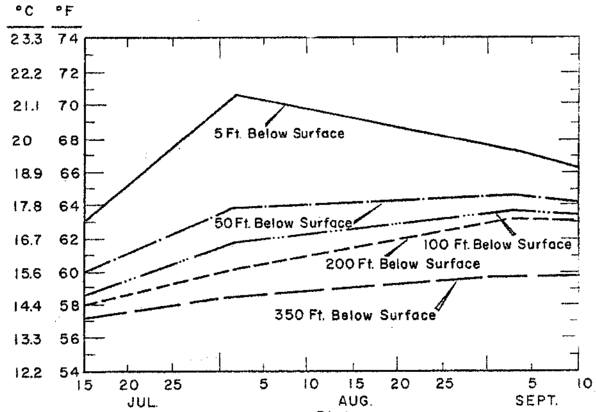

Plate 6

TEMPERATURE LAKE ROOSEVELT-1949

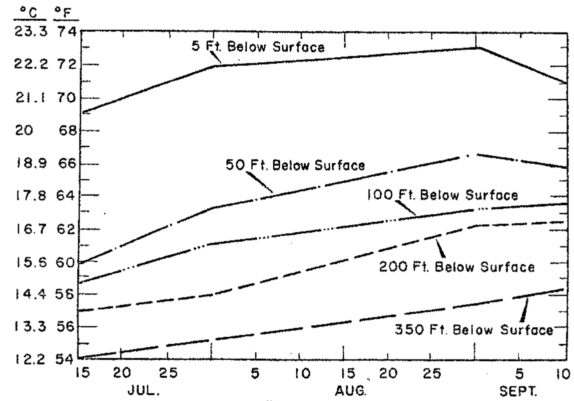

Plate No. 7

TEMPERATURE LAKE ROOSEVELT-1951

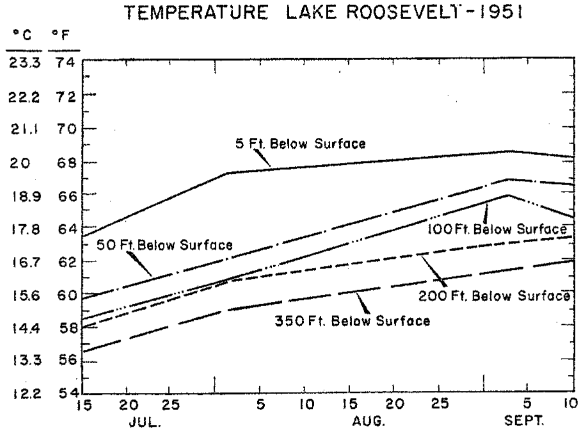

Plate 8

TEMPERATURE LAKE ROOSEVELT-1958

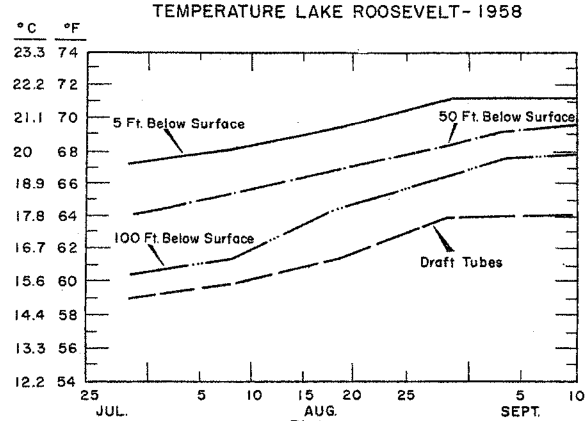

Plate 9

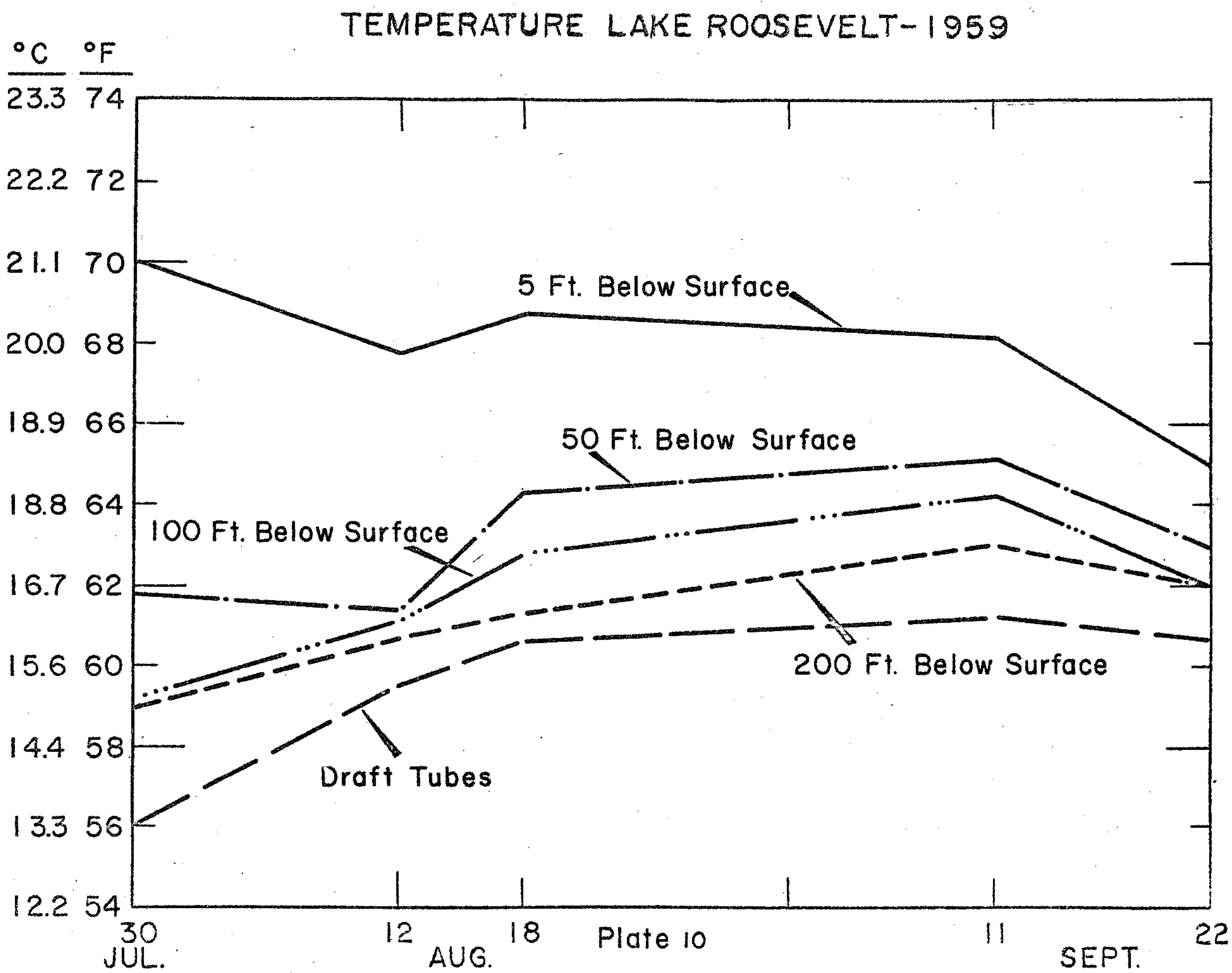

Plate 10

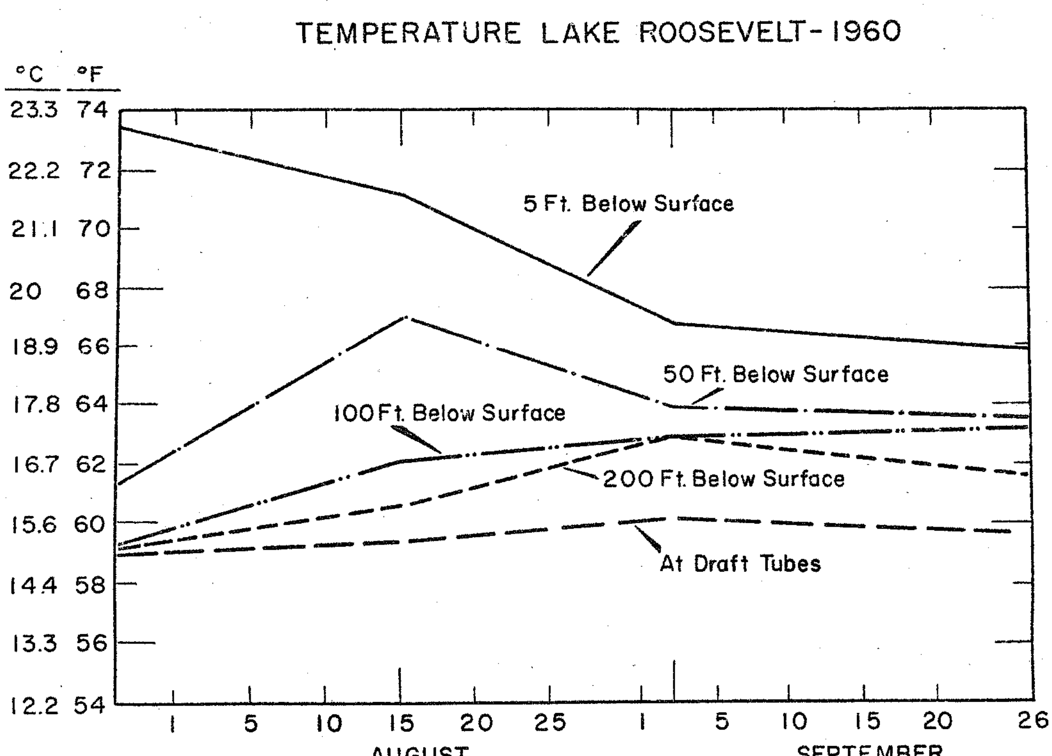

Plate 11

in the first foot. Calm bright days cause excessive concentration of heat, and surface temperatures rise. Cloudy days cause surface temperatures to fall, as does rainfall generally. High winds of extended duration cause mixing of the top levels; the effects may be observed at 10 to 20 foot depths or even deeper. There is considerable evidence of lateral stratification, as if the lake and river were composed of several small streams within the larger. At times, temperatures at a given point may vary by a degree within a few minutes.

Normally the surface temperature of Lake Roosevelt begins to cool near the middle of September and by October 5, the entire body is near the temperature of the draft tubes. The reduction of surface temperatures is rapid and this rapid decrease continues until almost all of the upper 50 feet is at the same temperature. The daily drop is often 2 to 4 degrees C in the early cooling period. By October 5, colder inflow from Canada causes draft tube temperatures to fall and by November 1, the entire lake is cooler than it was at the time cooling control was started. Cooling continues at about 3 degrees C per month and in March, the entire body is usually between 2 and 3 degrees C. Winter lake temperatures do not appears to be changing as a result of the control program.

The spring runoff increases upper level temperatures. If runoff is normal, very little of the stored cold water is released other than by generation; if there is an early high runoff or flood potential, however, much of the cold water is lost for temperature control due to dumping of water through the spill tubes to lower the reservoir level. In 1948, due to flood conditions, all levels of the lake had near the same temperature, 14 degrees C on July 4. This same year the temperature five feet below the surface was 21.5 degrees C, but the temperature at the draft tube level was only 15.3 degrees C. In 1961, on July 13, temperatures were 14.5 degrees C at draft tube level and 22 degrees C at the five foot elevation.

In 1948, by August 3, with no outlet tube use, hot water storage (temperatures above 18 degrees C) had filled the top 45 feet of the lake. In 1961, by August 4, with outlet tube use for flood control, hot water storage (temperatures above 18 degrees C) had filled the top 110 feet of the lake.

Plat 12 shows temperature differentials for selected dates of several years. Parallel variations of surface and sub-surface temperatures were indicated for similar flow years even though actual temperatures vary from year-to-year.

PLATE 12

THERMOCLINE COMPARISON °C

		July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 10
1948	5 Ft. Below Surface	17.2	21.4	20.8	19.8	19.0
(Flood)	Draft Tubes	14.2	15.4	16.0	16.8	16.7
	Difference	3.0	6.0	4.8	3.0	2.3
	5 Ft. Below Surface	20.6	22.2	22.5	22.8	21.7
1949	Draft Tubes	13.5	13.8	15.1	16.1	16.2
	Difference	7.1	8.4	7.4	6.7	5.5
	5 Ft. Below Surface	17.6	19.7	20.0	20.3	20.2
1951	Draft Tubes	13.6	15.7	16.3	17.0	17.3
	Difference	4.0	4.0	3.7	3.3	2.9
	5 Ft. Below Surface	*19.0	19.7	20.6	21.7	21.7
1958	Draft Tubes	14.4	14.9	16.1	17.8	17.9
	Difference	4.6	4.8	4.5	3.9	3.8
	5 Ft. Below Surface	*21.1	21.0	20.1	20.2	20.1
1959	Draft Tubes	13.3	13.4	15.6	16.0	16.2

		July 15	Aug. 1	Aug. 15	Sept. 1	Sept. 10
1959	Difference	7.8	7.6	4.5	4.2	3.9
	5 Ft. Below Surface	*23.0	22.7	21.8	19.8	19.5
1960	Draft Tubes	15.3	15.7	15.9	16.3	16.2
	Difference	7.7	7.0	5.9	3.5	3.3
	5 Ft. Below Surface	22.6	25.0	24.0	22.5	21.4
1961	Draft Tubes	14.6	17.3	17.5	18.1	18.4
	Difference	8.0	7.7	6.5	4.4	3.0

* Calculated Data

We have attempted, without much success, to correlate changes in the temperature profile with calculated changes in the heat budget, using the same methods as in the Lake Hefner and Lake Mead studies. A much more extensive program than we have been able to support for collection of field data would be required for such a correlation, including incoming stream temperature profiles, underground water flow and temperatures and local meteorological data. For our purposes, it has not been necessary to pursue such a broad program, although more complete temperature traverses above the dam would be useful for evaluation and control of special releases. The use of recording thermometers for a continuous record at selected points is being considered.

CONSIDERATIONS IN CONTROL PLANNING

If special releases from Lake Roosevelt are to be successfully used to minimize downstream river temperatures, several things must be considered before and during the operation.

1. There must be enough temperature differential between surface and draft tube elevations to make control worthwhile.

2. The total average spill must be large enough to permit sufficient diversion to provide effective cooling.

3. There must be enough outlet tubes operable on the 1035 foot level to provide for warm water storage during the cooling program.

4. The amount of discharge from reservoirs above Lake Roosevelt must be within total control limits at Coulee.

5. Unusual storage and releases on other reservoirs must be small enough so as not to upset the program.

6. Operations should be planned to provide control throughout the expected peak river temperature period.

To achieve effective control, there must be continuing long-range planning and coordination of the operation with the many agencies involved. For example, when there is early spill through the tubes for flood control, less colder water is available for later river cooling. Arrangements must be made for maximum pumping of irrigation water to Banks Lake. Possible maintenance programs that the various dam operators might be considering must be reviewed for possible interference with the program.

Maximum generation loads are arranged for with the Bonneville Power Administration. Even with this, generation loads drop just before midnight and low loads hold till near 8:00 AM. During this time, extra outlets may have to be opened or other arrangements made. The installation of flashboards, in addition to conserving water for generation, is useful in preventing the spill of hot surface water when the discharge drops to a point where fluctuations in generation would cause interim spilling.

It is essential before control starts that arrangements be made with those who will supply needed information. Current suppliers of data include many private citizens as well as water plant operators and dam operators.

CONCLUSION

The successful operation of our program for the last four years shows that by adequate planning and control of special water releases, the effects of hot surface spill from dam reservoirs can be at least partially alleviated. We feel that not only has the Hanford Plant benefited, as well as other industries using river water for cooling, but that there has also been some benefit to the downstream fish population. It is recognized that in many reservoirs where surface spill does not normally occur during the warm water period of the year, these benefits are, so to speak, built in. Nevertheless, there are other dams in existence where a similar program would provide similar results. Certainly in the planning of new dam construction, the possibilities of such a program should be evaluated and facilities provided where justified.

ACKNOWLEDGMENT

Full credit must be given for the success of this program to employees of the U. S. Bureau of Reclamation and the Bonneville Power Administration who have given outstanding cooperation in translating this program into effective action, as well as contributing useful ideas and information.

REFERENCES

1. "Water Loss Investigations: Lake Hefner Studies, Technical Report," U. S. Geological Survey Professional Paper No. 269, 1954.

2. Anderson, E. R., and Pritchard, D. W., "Final Report: Physical Limnology of Lake Mead," U. S. Navy Electronics Laboratory, 1951.

3. Dugan, H. P., U. S. Bureau of Reclamation - Private communication (1960).