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USE OF TEMPERATURE CONTROL CURTAINS TO MODIFY RESERVOIR RELEASE TEMPERATURES

by

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Abstract

Reclamation (U.S. Bureau of Reclamation) has constructed four temperature control curtains to reduce release water temperature at structures in the Sacramento and Trinity River drainages in northern California. Curtains can provide selective withdrawal at intake structures, control topography induced mixing, and control interfacial shear mixing associated with plunging density currents entering reservoirs. Comprehensive field monitoring has been conducted to measure curtain performance characteristics. Monitoring included extensive temperature profiling, and velocity profiling using an ADCP (acoustic Doppler current profiler). This paper presents and summarizes performance data collected near curtains in Lewiston and Whiskeytown Reservoirs.

Background

Increased water temperatures, especially during drought years, are one of many threats to endangered salmon species in the Sacramento River. As a result, much effort has been expended to lower river temperatures. A value engineering study (Reclamation, 1990) identified temperature control curtains as a potential alternative for reducing temperature of water released from Trinity Dam and routed through Lewiston and Whiskeytown Reservoirs into the Sacramento River. Fisheries biologists expect cooler releases will enhance late summer and fall salmon spawning and rearing conditions. As a result, Reclamation engineers developed lightweight and flexible curtain structures fabricated from nylon-reinforced rubber for installation in Lewiston and Whiskeytown Reservoirs.

Central Valley Project - Shasta and Trinity Division

Water from the Trinity River Basin is diverted to the Sacramento River Basin through two tunnels and three reservoirs. Trinity River water is diverted from Lewiston Reservoir through Clear Creek Tunnel to the Carr Powerplant and into Whiskeytown

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Reservoir. From there, water flows through the reservoir and into the Spring Creek Tunnel and through Spring Creek Powerplant. Spring Creek Powerplant releases water into Keswick Reservoir where it combines with water released from Shasta Dam. Water released from Keswick Dam enters into the Sacramento River. Over the course of this diversion and prior to curtain installation it was not uncommon for water temperatures to rise 5-7 °C.

Applications

Four temperature control curtains, two in Lewiston Reservoir and two in Whiskeytown Reservoir, were installed in 1992 and 1993, respectively. At Lewiston, a 250-meter-long, 11-meter-deep curtain is suspended from flotation tanks and is secured in place by a cable and anchor system. This curtain was designed to block warm, surface water from entering the Clear Creek Tunnel intake. As a result, cold water from the bottom of the reservoir is diverted into Whiskeytown Reservoir. In addition to the reservoir curtain, a second curtain funded by the California Department of Fish and Game was installed surrounding the Lewiston Fish Hatchery intake structure. The fish hatchery desired both warmer and cooler water depending on the season and fish rearing requirements. Therefore, a curtain (90-meter-long and 14-meter-deep) was designed which could skim warmer water or underdraw cooler water depending on whether the curtain was in a sunken or floating position.

Ideally, cold water diverted from Lewiston is to be routed through the Whiskeytown's hypolimnion (deep, cold water layer) to the Spring Creek Conduit intake. To optimize this diversion, two curtains were installed in Whiskeytown Reservoir. The tailrace curtain (180-meter-long and 12-meter-deep) was installed to force cold water from Carr Powerplant into Whiskeytown's hypolimnion while limiting mixing with the epilimnion (warm surface water). This curtain restrains the epilimnion from moving upstream toward Carr powerplant. With the tailrace curtain in-place mixing is reduced where the cold density current plunges into the hypolimnion. The second curtain, a 730-meter-long, 30-meter-deep, surface-suspended curtain surrounds the Spring Creek Tunnel intake. This curtain, like the Lewiston curtain, was designed to retain warm surface water while allowing only cold water withdrawal. A more detailed description of these four curtains is presented by Johnson, et al., 1993.

Temperature Monitoring - An extensive temperature monitoring program has been conducted for several years. Monitoring was required to assure compliance with maximum allowable Sacramento River temperatures as specified by several regulatory agencies. Additional temperature profiling stations were installed near the curtains to gather data necessary to evaluate their performance.

Velocity Profiles - Velocity profiles were measured upstream and downstream from the curtains to evaluate the selective withdrawal and hydrodynamic performance. In the future, velocity profile data will be used to incorporate curtains into reservoir operation models. Hourly velocity profiles were collected using two upward looking, narrow-band ADCP's placed on the reservoir bottom. ADCP data were collected upstream of the Lewiston curtain and downstream of the Carr tailrace curtain. ADCP data were collected in a cooperative effort with USGS's Sacramento District Office.

Lewiston Reservoir Curtain Performance - Figure 1 presents hourly operations and outflow temperature data collected in the Clear Creek Tunnel intake. These data demonstrate the curtain's effectiveness in reducing the water temperature entering the intake. For similar operational conditions the average temperatures released through Carr Powerplant were reduced by about 1.4 °C after the curtain installation. 1.4 °C may appear to be a small improvement, but given the weak temperature stratification in Lewiston Reservoir 1.4 °C is a significant improvement.

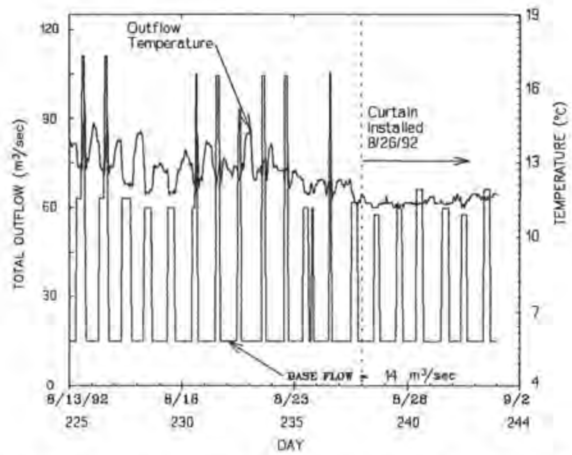

Figure 1. - Lewiston Lake outflows and hourly temperature data collected in the Clear Creek Tunnel intake structure during August 1992. Peaks in outflow represent Carr Powerplant operation.

Figure 2 illustrates the curtain's performance for three types of power operations at Trinity Powerplant in August 1994: 1) during days 220 through 227 the flows through the reservoir are baseload power operations at 90 m^3/s; 2) days 228 through 242 had peaking power operations with one turbine on continuously at 50 m^3/s and peaking was performed with the second turbine operating for 10 to 12 hours for a total flow of 100 m^3/s; 3) days 243 through 260 had peaking operations between no-flow and peaking with one and occasionally two turbines operating for 10 to 12 hours. A comparison of reservoir inflow and outflow temperatures indicates that there is consistent 1.9 °C temperature gain through the reservoir for days 220 through 242 regardless of the two types of operations. However, when operations were changed on day 242 a steady increase in outflow temperature was observed. After day 252 the temperature gain through Lewiston Reservoir had stabilized at 3.6 °C. This additional 1.7 °C temperature gain occurs because warm water accumulates upstream and downstream from the curtain during no-

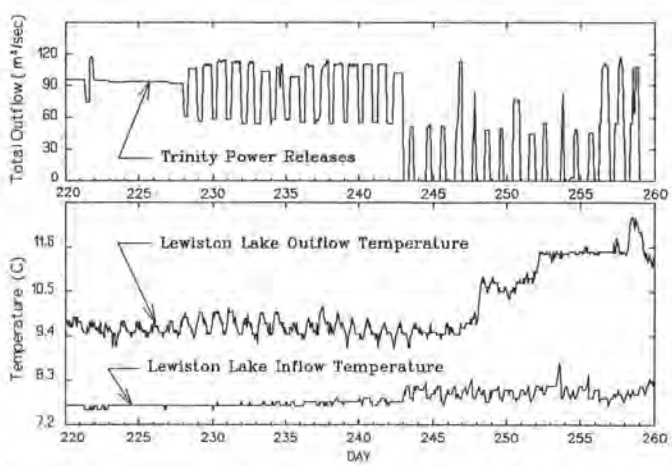

Figure 2 - Lewiston Reservoir inflows along with inflow and outflow temperatures illustrate the temperature gain of water diverted through the reservoir during mid-August 1994.

flow periods, and warm water is released during peaking operations. In addition, about 0.3 °C temperature gain can be attributed to increasing inflow temperatures. As a result of this significant temperature gain, we concluded that strictly peaking operation (both turbines on or off) should be avoided during periods when release temperature restrictions are in effect. Lastly, based on observations of a similar 1992 data set (fig. 1) it is reasonable to conclude that an additional 1.4 °C increase in release temperatures would occur if the curtain was removed.

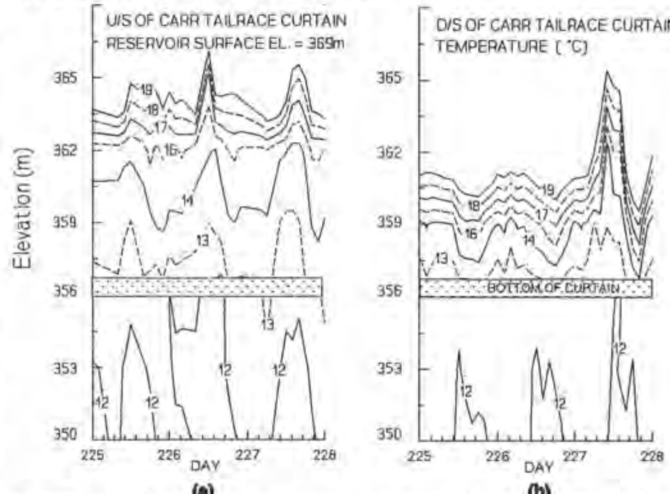

Figure 3 - Isotherm plots for locations (a) upstream and (b) downstream of the Carr tailrace curtain. These plots illustrate the difference in reservoir stratification across the curtain.

Whiskeytown Reservoir Curtain Performance - Figure 3 illustrates how the tailrace curtain modifies the reservoir stratification. The temperature profiles collected upstream from the curtain (fig. 3a) indicate a weak thermocline, a relatively shallow epilimnion, fluctuations of underflow water temperatures, and diurnal fluctuations in epilimnion and thermocline temperatures. The isotherm plots of downstream temperatures (fig. 3b) indicate a stronger thermocline, a thicker epilimnion, reduced diurnal fluctuations, and slight warming of water passing under the curtain. The warming is probably generated by interfacial shear mixing. A review of pre-curtain temperature data identified 3.6 °C of warming in this same reach. Likewise, an analysis of temperatures measured between Carr Powerplant and the tailrace curtain indicated the inflow water warms 2.5 °C because of mixing between the powerplant and the tailrace curtain. Water leaking through a boat passage in the curtain has been identified as a large source of warm water. Alternative methods of boat passage which minimize leakage are currently being studied.

Figure 4 presents some typical reservoir operations (fig. 4a) and ADCP data (fig. 4b). Figure 4 illustrates how the velocity profiles downstream from the tailrace curtain change with peaking power operations. It is interesting how the velocities decrease to nearly zero at the curtain bottom when flows are reduced to 50 m^3/s. This indicates that the curtain no longer controls the underflow at this discharge, and flow passes the curtain as a density current. However, at flows of 90 m^3/s, curtain control is established and underflow velocities as high as 100 mm/sec extend into the thermocline (El. 359) where limited mixing with warmer water occurs. These flow conditions were confirmed by field observations that the curtain was heavily loaded during midday (high flows) and was slack during the early morning (low flows).

A comparison of pre- and post-curtain temperature profile data for Whiskeytown Reservoir for similar August power operations in 1988 and 1994 indicates that with the two temperature control curtains installed the epilimnion is warmer and the hypolimnion is slightly cooler. In addition, the average temperature gain of water routed through Whiskeytown Reservoir in August 1988 was 3.3 °C, while in August 1994 gains were 2.1 °C. These results are as expected because less warm water is being released from the reservoir.

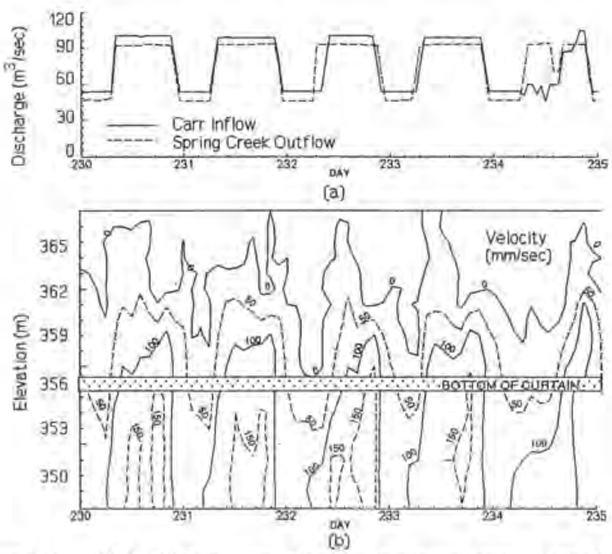

Figure 4 - (a) Whiskeytown Reservoir operations - baseload for one turbine and peaking the second turbine. (b) ADCP isovel data collected below the Carr tailrace curtain. Both plots are for the same 5 days in August 1994.

Conclusions

- Temperature control curtains allow project operators to manage power generation releases while controlling release water temperatures. Curtains have substantial economic advantages when compared to traditional selective withdrawal structures.

- In Lewiston Reservoir, peaking power operations result in a 1.6 °C temperature gain in water routed through the reservoir. As a result, two-unit peaking operations should be avoided for Carr Powerplant during periods when release temperature restrictions are in effect.

- For similar power operations, average temperature gain of water routed through Whiskeytown Reservoir in August 1988 (pre-curtain) was 1.2 °C higher than the curtain-controlled temperature gains measured in August 1994.

- ADCP data were useful in determining how powerplant operations affect temperature control curtain performance.

References

Johnson, P., T. Vermeyen, and G. O'Haver, *Use of Flexible Curtains to Control Reservoir Release Temperatures: Physical Model and Field Prototype Observations*, Proceedings of the 1993 USCOLD Annual Meeting, Chattanooga, Tennessee, May 1993.

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