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HYDRAULIC PERFORMANCE OF A FLEXIBLE CURTAIN USED FOR SELECTIVE WITHDRAWAL: A PHYSICAL MODEL AND PROTOTYPE COMPARISON

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by

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Hydraulic Performance of a Flexible Curtain Used for Selective Withdrawal
A Physical Model and Prototype Comparison

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Abstract

Reclamation (U.S. Bureau of Reclamation) studied a 1:120 scale undistorted density stratified physical model to develop a lightweight flexible curtain barrier that would control the outflow temperatures from Lewiston Lake, California. The model scale was selected to allow study of a 3,000-ft length of reservoir. The reservoir topography in this reach substantially influences withdrawal layer characteristics and temperature profiles at the intake structures. Unfortunately, this scale yielded flow Reynolds numbers in the laminar to turbulent transitional range. Consequently, mixing and flow entrainment were underestimated in the model. Despite the scale effects, the model was a valuable qualitative tool for evaluating various curtain designs and hydraulic responses.

Based on model results, a 35-ft-deep, 1,000-ft-long curtain was developed which optimized curtain and topography interaction to yield the best possible release temperature control. The curtain was installed in August 1992. Initial field monitoring confirms that the design objectives were met.

This paper presents model and field observed performance with a discussion of model observations that influenced the final curtain design. The paper also interprets field performance and relates differences in model findings to scaling distortions.

Background

A value engineering study (USBR, 1990) identified flexible curtain(s) as a potential solution for reducing temperature of water released from Lewiston Lake. Biologists expect cooler outflows will enhance late summer spawning conditions for anadromous

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fish in the Sacramento and Trinity River Basins. Salmon populations in both rivers are in decline, which has been attributed in part to warm water releases associated with drought conditions. The Chinook salmon "winter run" on the Sacramento River has been listed as threatened under the Endangered Species Act. Likewise, the population of "spring run" salmon is also in decline and listing may result.

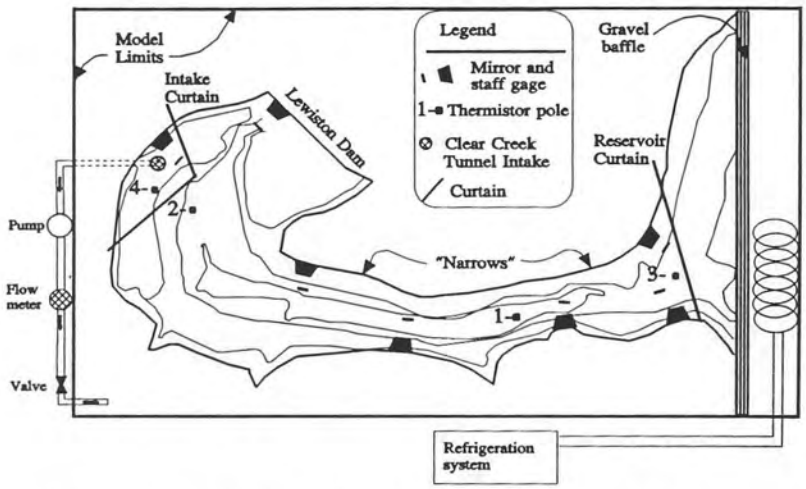

Figure 1. - Plan view of 1:120 scale hydraulic model of Lewiston Dam and reservoir.

Preliminary curtain designs were developed using selective withdrawal theory for submerged weirs developed by Bohan and Grace, 1973. Hydraulic performance of several curtain options with varying lengths and depths was examined theoretically prior to model testing. Curtain options which produced maximum cooling and were of reasonable length were chosen for model testing.

Physical Model Study

A 1:120 scale density stratified physical model was used to examine the effectiveness of flexible curtain structures to reduce water temperatures released through Clear Creek Tunnel and the Judge Francis Carr Powerplant (fig. 1). The scale was chosen to include, in a limited laboratory space, both potential curtain locations and topography that exerts a strong influence on withdrawal characteristics.

Unfortunately, the 1:120 scale model yielded flow Reynolds numbers in the laminar to turbulent transitional range, as a result, turbulent mixing and flow entrainment were

underestimated in the model. However, the model served as a qualitative tool for evaluating various curtain designs and hydraulic responses. This study included the following elements:

- **Baseline Withdrawal Characteristics** - This task included evaluating withdrawal layer thickness, velocity profiles at several cross sections, and modifications to density stratification.

- **Intake Curtain No. 1, Option 1** - Evaluated a 1,200-ft-long, 30-ft-deep curtain around the Clear Creek Tunnel intake.

- **Intake Curtain No. 1, Option 2** - Evaluated a 1,200-ft-long, 40-ft-deep curtain around the Clear Creek Tunnel intake.

- **Reservoir Curtain** - Evaluated a 720-ft-long, 30-ft-deep curtain upstream from the "narrows."

- **Combinations** - Evaluated simultaneous use of Curtain no. 1, Option 2, with the reservoir curtain.

Reservoir Stratification - Stratified density profiles in the model were created by floating a warm water layer above a cold water layer. This filling technique resulted in a stratified temperature profile similar to that which forms in Lewiston Lake.

Model Operation - After reservoir stratification was established, tests were started by withdrawal of a constant flow rate through the Clear Creek Tunnel intake. Model replacement water was supplied from the cold water reservoir, simulating the cold water available from the hypolimnion (cooler bottom stratum).

A typical test length was 2 or 3 hours (22 to 33 hours - prototype), which allowed a quasi-steady-state condition to be established. A true steady-state condition could not be established because the finite epilimnion (warm surface stratum) in the model reservoir eroded slowly as the test progressed.

Testing and Data Acquisition - Testing and data acquisition for this model study included measuring temperature profiles at three locations for baseline conditions, and a fourth location was added for curtain tests (fig. 1). Temperature data were also collected in the intake structure to measure average withdrawal temperatures. Mirrors, dye, and staff gages were used for flow visualization and to estimate the withdrawal layer thickness.

Model Results - In general, model data indicated that both the reservoir and intake curtains were effective in cooling intake temperatures when compared to the baseline condition. The 40-ft-deep intake curtain was most effective at cooling withdrawal temperatures for discharges less than 1,000 ft^3/s. The reservoir curtain was more effective for discharges ranging from 2,500 to 4,000 ft^3/s. Data analyses indicated that the intake curtain was ineffective at high discharges because of warming caused by

mixing as cooler water passed through the "narrows"- a restricted portion of the reservoir (fig. 1). Mixing primarily occurs in the shear zone which develops between the withdrawal layer and the warm water wedge which forms behind the curtain. Turbulent mixing also occurs as the flow accelerates through the reduced cross section in the "narrows."

Locating the reservoir curtain upstream from the "narrows" reduced the shear zone mixing because of lower curtain approach velocities. Likewise, warming caused by mixing in the "narrows" was reduced by isolating this mixing zone from the main reservoir body, which effectively limited the available warm water. For the reservoir and discharge conditions observed in the physical model, the reservoir curtain reduced water temperatures released from Lewiston Lake to the Clear Creek Tunnel by 2.5 °F.

Withdrawal characteristics of the Clear Creek Tunnel intake were evaluated with simultaneous use of the intake and reservoir curtains. This configuration provided the highest performance for a range of operational discharges of 1,000 to 4,000 ft^3/s. The intake curtain supplies release temperature control at low discharges, and the reservoir curtain provides release temperature control at higher discharges.

Because turbulent mixing was expected to be greater in the prototype, it was concluded that mixing in the "narrows" would severely limit the intake curtain's effectiveness in reducing withdrawal temperatures. Because the reservoir curtain effectively blocks warmer water from replacing surface withdrawals, the downstream pool should approach a constant temperature. Consequently, the intake curtain's effectiveness would be limited especially during extended periods of powerplant operation. Therefore, it was decided that only the reservoir curtain would be recommended for installation.

Lewiston Lake Prototype Curtains

During the recent California drought, Sacramento River temperatures were approaching critical levels with respect to sustaining viable spawning and rearing habitat for threatened salmon populations. As a result, any decrease in river water temperatures, which would lower the salmon mortality rate, was aggressively pursued. In an effort to cool river temperatures, power releases were bypassed through low reservoir outlets at Shasta and Trinity Dams (Trinity discharges into Lewiston Lake) resulting in lost power revenues which totaled $10 million in 1992.

Reclamation constructed and installed an 830-ft-long reservoir curtain (temperature control curtain) in Lewiston Lake in August 1992. The curtain was installed near the reservoir curtain location identified by the physical model studies.

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 hatchery desired both warmer and cooler water depending on the season and fish requirements. Therefore, a curtain was designed which could skim warmer water or

underdraw cooler water depending on whether the curtain was in the sunken or floating position, respectively.

Construction - Total time for engineering, procurement, fabrication, and installation was 5 months. GSE Construction of Livermore, California, began subcontract work in June 1992. By August 26, 1992, the 830-ft-long reservoir curtain was operational. Two weeks later, the 300-ft-long hatchery curtain was operational; this smaller curtain was completely assembled and installed in 7 working days. The costs for the reservoir curtain and hatchery curtain were $650,000 and $150,000, respectively.

Curtain Performance - A cooperative temperature monitoring program was implemented by Reclamation, U.S. Fish and Wildlife Service, and the California Department of Fish and Game. Temperature profiles were measured upstream and downstream from the reservoir curtain site for pre- and post-curtain conditions. Figure 2 represents typical data sets. The pre-curtain profiles are nearly identical, but the post-curtain profiles indicate a substantial modification to the reservoir stratification. For post-curtain conditions the downstream temperature profile is nearly vertical except for surface warming, whereas the upstream temperature profile is 1 °F and 4.5 °F warmer for elevations 1875 and 1895, respectively. Notice that the temperatures below the curtain's bottom edge are unchanged, which indicates that the withdrawal layer does not extend significantly upward into the thermocline (intermediate stratum with large temperature gradient).

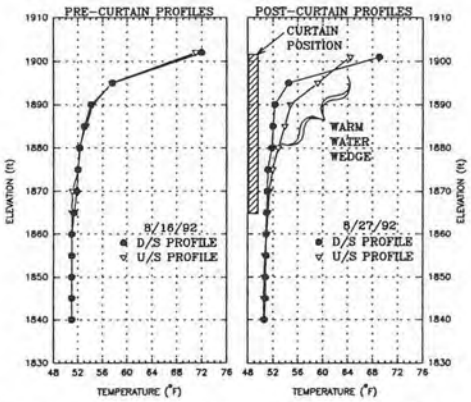

Figure 2. - Temperature profile comparison for pre- and post-curtain conditions. *Profiles were measured for similar powerplant operation schedules.*

Figure 3 presents hourly temperature data collected from the Clear Creek Tunnel intake, which supplies water to Judge Francis Carr Powerplant. These data demonstrate the reservoir curtain's effectiveness in reducing the water temperature entering the intake. For similar operational conditions (flow, period, and time of day), the average temperatures released through the Carr Powerplant were reduced by about 2.5 °F. This result corresponds well to the reservoir and discharge conditions observed in the physical model, where the reservoir curtain reduced water temperature released through the Clear Creek Tunnel by about 2.5 °F. This relatively small cooling is in part caused by the weak temperature stratification in Lewiston Lake. Even though 2.5 °F may appear to be a limited improvement, Sacramento River temperatures were approaching critical levels with respect to sustaining viable spawning and rearing habitat for threatened

salmon populations. As a result, all possible efforts to reduce late summer river temperatures are being pursued.

Conclusions

Flexible curtain barriers have been successfully employed to provide selective withdrawal at Lewiston Lake, California.

A density stratified physical model was used to develop an effective temperature control curtain. The curtains rapidly modified reservoir temperature profiles and Lewiston Lake release temperatures were reduced by 2.5 °F. Curtains were a relatively inexpensive alternative to a more traditional selective withdrawal structure. Two curtains were designed, constructed, and installed in five months. The construction and installation costs for both curtains totaled $800,000.

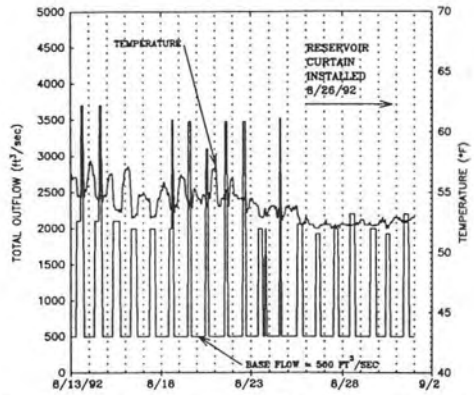

Figure 3. - Lewiston Lake Outflows and hourly temperature data collected in the Clear Creek Tunnel intake structure. *Peaks in outflow represent Carr Powerplant operation.*

In a continuing multi-agency effort, two additional flexible curtains are being designed for Whiskeytown Lake, California (Johnson, et al., 1993). These curtains will further improve the selective withdrawal capability within the Sacramento River basin.

References

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Unit Conversions	To convert	To	Multiply by
	ft	cm	30.45
	ft^3/s	l/s	28.3
	°F	C	5/9*(°F-32)