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INNOVATIVE SELECTIVE WITHDRAWAL TECHNOLOGIES PROVIDE OPERATIONAL FLEXIBILITY FOR TAILWATER FISH HABITAT IMPROVEMENT AT POWER STATIONS

by

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INNOVATIVE SELECTIVE WITHDRAWAL TECHNOLOGIES PROVIDE OPERATIONAL FLEXIBILITY FOR TAILWATER FISH HABITAT IMPROVEMENT AT POWER STATIONS

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INTRODUCTION

Water managers, including hydro-electric operators, are increasingly working to bring reservoir release temperatures into conformance with water quality standards and fish habitat objectives. During periods of power generation, reservoir stratification often results in release temperatures which cause excessive stress to successful fish reproduction (too warm) or are detrimental to fish growth efficiency (too cold). Constant low temperatures (below 10 °C) can suppress species diversity and production of invertebrates. For new dams, multi-level intake towers or inclined conduits provide selective withdrawal capabilities to prevent temperature stress to the tailwater fish habitat. The cost for these traditional selective withdrawal structures are prohibitive for existing structures where innovative retrofits may provide the operational flexibility needed to meet fish habitat objectives.

Reclamation hydraulic engineers and fishery biologists are cooperating in developing hydraulic concepts and biological criteria to effectively address tailwater fish habitat issues at power stations. Mathematical models are used to develop reservoir operational schemes using various temperature control devices (TCD). Such TCD concepts are complex and require evaluation of intake coefficients, headloss, density influences, withdrawal layer thickness, vertical mixing and flow entrainment. The three-dimensional flow characteristics in near-field situations are best addressed using laboratory physical models, preferably density stratified physical models. Table 1 summarizes several Reclamation sites where innovative selective withdrawal technologies have provided tailwater fish habitat improvement without curtailing power production.

SHASTA AND TRINITY RIVER DIVISIONS

A recent example of intensive research and demonstration into retrofit selective withdrawal systems has occurred in northern California. The winter run Chinook Salmon population in the Sacramento River has declined over the past two decades. A contributing cause of this decline is thought to be the mortality of eggs and fry caused by elevated water temperatures during the late summer and fall incubation and rearing season. Fishery experts estimate that water temperatures exceeding 12.0 °C can cause significant egg mortality. For the past several years the water temperature in the Upper Sacramento River in California (figure 1) has been cooled by releasing the deep cold water from Trinity and Shasta Dams through the low outlets works, bypassing the power penstock intakes which are located too high in the reservoir. This temperature control operation resulted in losses of $10 million in power revenue in 1992. Reclamation initiated studies in the late 1980's to develop flexible curtain barriers to manage and control reservoir release water temperatures for structures in the Trinity and Sacramento River drainages.

A sophisticated temperature stratified test facility (9-meters by 9-meters by 2.4-meters deep) was built in Reclamation's Water Resources Research Laboratory (WRRL) in Denver, Colorado, to develop and test various temperature control device concepts for reservoir release. A refrigeration system is used to create temperature profiles in the range from 7 °C to 24 °C in the laboratory facility. Scaling laws allow research engineers to simulate releases from temperature stratified reservoirs in the model facility. Flow in reservoirs approaching the outlets is greatly affected by water density which is directly related to temperature; therefore, it is important to properly simulate the water temperature in the laboratory test facility.

The first flexible curtain concept evaluated in the laboratory facility used a model scale of 1:72 and simulated a large flexible curtain to control temperature release through the powerplant at Shasta Dam. An adjustable curtain concept was developed where the curtain was placed vertically in the reservoir and could be lowered from the reservoir surface to withdraw warm surface water or could be raised off of the reservoir bottom to access the cold bottom water. The proposed large curtain at Shasta Dam, up to 91-meters deep and 396-meters long, would

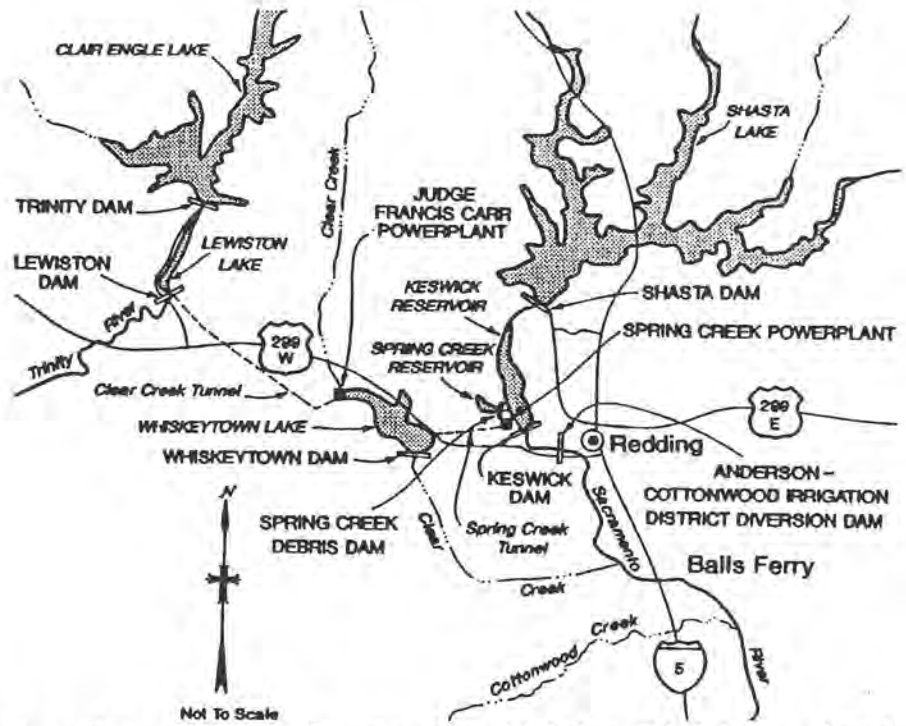

Figure 1. - Location Map - Shasta and Trinity Divisions, Central Valley Project, California.

have used nearly 1.2 hectares of 32-mil Hypalon reinforced with nylon. Estimated construction costs were one-quarter to one-third the cost of traditional selective withdrawal intakes. However, lack of historical reference and field experience using underwater curtains of this size prompted the decision to use a "more traditional" steel shutter structure similar to the Flaming Gorge Dam TCD. The rigid steel structure will attach to the upstream face of the dam and enclose all five power intakes. A low-level intake structure "elephant trunk" attaches to the structure and extends an additional 49 meters into the deeper part of the reservoir permitting access to near-bottom cold water.

The recent drought (1988-1992) in northern California resulted in limited volumes of stored cold water deep in reservoirs. Because of the urgent need to reduce reservoir outflow temperatures, Reclamation initiated an aggressive research program to study and install temperature control curtains in more shallow waters, such as those present at Lewiston Dam. Two curtains were designed and installed in Lewiston Lake in August 1992. The primary (reservoir) curtain, figure 2, was designed to hold back the warm surface water while accessing the colder water and release it to Clear Creek Tunnel and, in turn, to the lower Sacramento River basin.

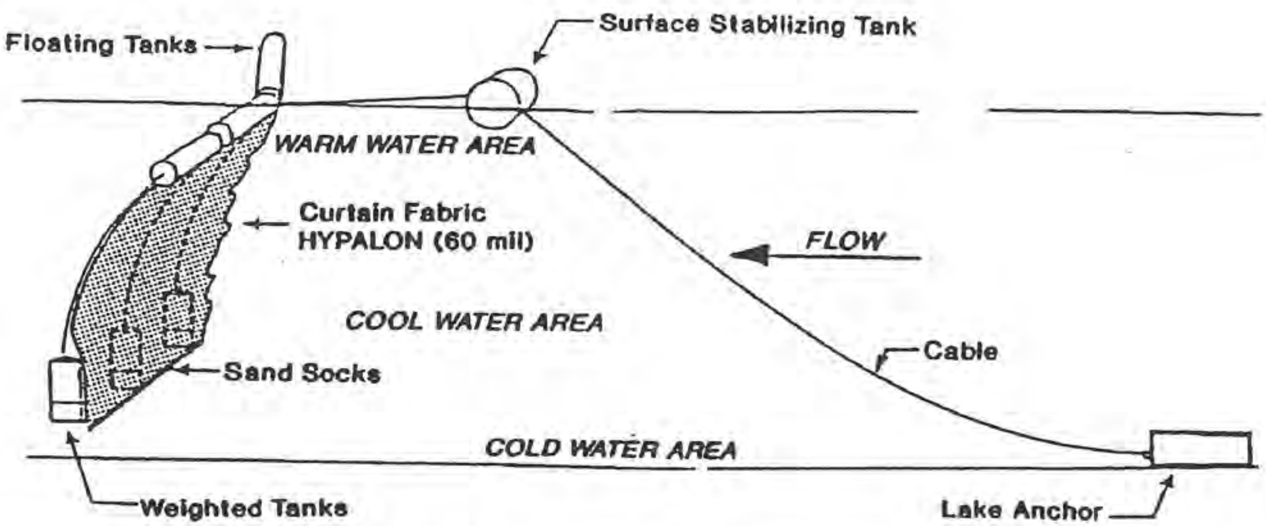

Figure 2. - Illustration of the Lewiston Lake Temperature Control Curtain.

The second curtain was designed to provide temperature control for water supplied to a nearby fish hatchery. Laboratory results indicated the reservoir curtain would reduce the water temperatures released from Lewiston Lake to the Clear Creek Tunnel by about 1.5 °C. Actual temperature measurements made at the Clear Creek Tunnel intake after the August 1992 installation of the curtain showed a 1 to 1.5 °C temperature reduction. Although seemingly a small change in temperature, every degree of reduction can significantly decrease the salmon egg mortality rate.

In a continuing multi-agency effort, two additional flexible curtains were laboratory tested, designed, and installed in Whiskeytown Lake, California, in 1993. The use of this new temperature curtain technology, as well as the steel shutter structure at Shasta Dam, will increase the selective withdrawal capability within the Sacramento River basin and provide improved management by selective withdrawal of the limited cold water resource in the reservoirs.

HUNGRY HORSE DAM

Releases from the large Hungry Horse Dam hydropower facility located near Kalispell, Montana, do not currently conform to the water quality standards for new projects. Release temperatures are lower than acceptable for optimum fish growth efficiency in the downstream river channel. Presently, the penstock configuration only permits cold water releases located in the lower portion (hypolimnion) of the reservoir. During power peaking operation, these cold water releases cause excessive stress to aquatic life.

Retrofit concepts, using an adjustable semi-cylindrical bulkhead within the power intake trashrack structures, were tested in a 1:18 scale laboratory model at Reclamation's WRRL. The adjustable bulkheads block deep cold water entry to the penstocks and permit withdrawal of reservoir water from within the epilimnion and thermocline regions, which contain higher temperature water. It is expected that the design will provide the operational flexibility to raise the release temperatures by up to 5 °C.

FLAMING GORGE DAM

In 1978, 16 years after Flaming Gorge Dam was constructed, the penstock inlets were modified with a large steel shutter structure to permit selective withdrawal. Prior to the modification, the tailwater temperatures exceeded 7 °C for only 3.5 months, reaching a high of only 9 °C. After the modification the tailwaters exceeded 7 °C for over 6 months and ranged from 10 to 14 °C for approximately 4.5 months. The annual fish production increased threefold after the retrofit selective withdrawal structure became operational.

CONCLUSIONS

Scaled temperature stratified laboratory models, coupled with reservoir and river computer models, were used to effectively develop temperature control devices for five Reclamation dams. These innovative selective withdrawal technologies are providing cost-effective temperature control alternatives for fish habitat improvement at power stations. Reclamation continues to gather field data to further evaluate and fine-tune in real-time the operation of these temperature control devices.

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Table 1. - Summary table - retrofit selective withdrawal technologies at Reclamation's power stations.

Power Station (constructed)	Fish	Problem	Retrofit	Approximate cost	Temperature improvement	Model scale	Maximum discharge (m^3/s)	Power (MW)
Shasta Dam (1945)	Four species Chinook Salmon	Winter - too cold Summer - too warm (high and low level withdrawal needed)	Steel shutter structure attached to dam (76 m x 91 m x 15 m) (1995)	$64 M	1-5 °C	1:72	498	540
Lewiston Dam (1963)	Four species Chinook Salmon							0.35
	Steelhead Trout	Winter - too cold Summer - too warm (high and low level withdrawal needed)	**Hatchery Intake** Curtain 91 m x 11 m (1992)	$150 K	3-4 °C	No physical model	1.5	
		Too warm (low level withdrawal needed)	**Carr Powerplant** Curtain 253 m x 9 m (1992)	$600 K	1-1.5 °C	1:120	100	
Whiskeytown Dam (1963)	Four species Chinook Salmon							
		Too warm (low level withdrawal needed)	**Spring Creek Powerplant** Intake Curtain 731 m x 30 m (1993)	$1.8 M	1-2 °C	No physical model	100	150
		Too warm (low level withdrawal needed)	**Carr Powerplant** Curtain 243 m x 9 m (1993)	$500 K	1-2 °C	1:72	100	140
Hungry Horse Dam (1953)	Bull Trout	Too cold (high-level withdrawal needed)	Semi-cylindrical bulkhead inside trashrack structure (13 m R - 61-m high) (1996)	$6.3 M	5 °C	1:18	350	428
Flaming Gorge Dam (1962)	Trout	Too cold (high-level withdrawal needed)	Steel selective withdrawal structure on face of dam (10 m x 10 m x 67 m) (1978)	$4.6 M	8 °C	No physical model	120	108