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Bureau of Reclamation

Managing Water in the American West

1999 US-JAPAN WORKSHOP ON WATERSHED MANAGEMENT

TOPIC 2: Reservoir Operation Methods for Sustaining Water Quality and Ecosystems

SUMMARY AND CASE STUDIES

U.S. BUREAU OF RECLAMATION

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Topic 2: Reservoir Operation Methods for Sustaining Water Quality and Ecosystems

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Introduction - As outlined in Reclamation's 1997 Strategic Plan, we have developed an increased emphasis on improved management and protection of water resources which is reflective of changing societal values and needs, greater environmental knowledge, and the natural evolution from a resource development focus. As a result, Reclamation projects are being planned, designed, constructed, and operated to preserve and enhance environmental resources while still meeting our client's water and power supply needs. Reclamation is concerned with reducing the water quality impacts of water resource projects. These impacts, on a site-specific basis, include increased salinity, gas supersaturation, selenium, sediment, low dissolved oxygen, and temperature, which in some cases contribute to fish and wildlife habitat degradation. It should be noted that the actions of other entities may affect Reclamation's ability to deliver a quality water supply.

Reclamation projects and management strategies strive for the appropriate balancing of all uses, including meeting water quality objectives, providing for instream flow needs, and conserving and enhancing fish and wildlife habitat and resources.

Water Quality -The quality of surface and ground water is critical to the economic and environmental health of the U.S. and must be protected from contamination. Our goals are to manage resources to protect and provide for safe and reliable water supplies of suitable quality for agricultural, domestic, municipal, industrial, fish and wildlife, and recreational purposes. Strategies we are employing to attain our goals are as follows:

- Develop and implement policies and procedures to better integrate surface and ground water quality objectives and standards into Reclamation's planning and management activities.
- Develop operational and structural modifications to improve water quality of releases from Reclamation reservoirs.
- Improve water quality modeling of our watersheds, reservoirs, and river systems.

Instream Flows- Reclamation understands that instream flows are integral to meeting water quality, fish and wildlife, and recreational objectives. Our goal is to operate Reclamation reservoirs to meet instream flow quantity and quality needs consistent with other project purposes. Strategies we are employing to attain our goal are as follows:

- Conduct detailed operational studies to identify flexibility in reservoir operations that would improve instream flows and modify operations as appropriate.
- Conduct research on cost-effective measures that could be implemented at Reclamation facilities to improve the quality of instream flows.
- Operate Reclamation projects in coordination with other projects and agencies to meet instream flow objectives.

Fish and Wildlife Resources - The responsible stewardship of natural resources entails conservation and enhancement of fish and wildlife resources in conjunction with the development and management of water and land resources. Our goal is to develop and manage Reclamation projects to conserve and, where appropriate, to enhance fish and wildlife habitat and populations. Strategies we are employing to attain our goal are as follows:

- Embody the value of fish and wildlife habitat and related resources in Reclamation's resource management and project operating plans.
- Complete and implement all fish and wildlife mitigation plans for Reclamation projects.
- Pursue innovative and cost effective approaches to enhancing fish and wildlife habitat on Reclamation projects.
- Pursue, in cooperation with Federal, State, and other interests, the objectives and regulatory requirements of the Endangered Species Act, Migratory Bird Act, Fish and Wildlife Coordination Act, and other pertinent acts as they relate to Reclamation projects.

Case Study: Glen Canyon Dam - Glen Canyon Dam, which is located on the Colorado River above one of the most scenic places on earth, the Grand Canyon. Glen Canyon Dam was constructed by Reclamation in the early 60's. The six powerplants generate approximately 6.7 billion kilowatt-hours of energy a year, worth $128 million. The problem was that impacts on the downstream environment in the Grand Canyon from constructing and operating this facility were not fully considered, such as the fact that the habitat of the endangered humpback chub was rapidly deteriorating. There were other considerations as well such as: water temperature, sediment transport, invasion of exotic species, and beach erosion along the river. This affected not only fish and wildlife, but also the recreation industry--whitewater rafting

In the early 1980's, scientists began studying the effects of Glen Canyon Dam to determine negative impacts. Reclamation completed an Environmental Impact Statement that proposed creative ways to operate the dam to preserve critical water conservation, generate power, and reduce impacts to the ecosystem. In March 1996, Interior Secretary Bruce Babbitt initiated an experimental flood from Glen Canyon Dam which mimicked the natural spring flooding that occurred prior to the dam's construction. This was the first time a dam had been operated solely for environmental benefit. The seven-day simulated spring flood had a number of positive environmental impacts on the Grand Canyon. The experiment was successful in restoring the natural Grand Canyon environment by rejuvenating beach and species habitat. The flood recreated natural sand beaches along the river, rejuvenated endangered fish spawning habitat, and reduced non-native, invasive plant growth.

Overall, the experiment provided Reclamation with a unique opportunity to test our ability to operate Glen Canyon Dam for environmental purposes. Ecologists now believe that controlled floods can be used for ecosystem management. Our work in the Grand Canyon ecosystem has served as a leading example for other federal projects involving environmental restoration. In addition, a multi-level intake structure is being designed to provide selective withdrawal capability at Glen Canyon Dam. These modifications will allow managers to meet temperature objectives in the Colorado River in an effort to create more habitat for the endangered humpback chub.

Some Case Studies from Reclamation's Proceedings from the Non-Point Source Water Quality PollutionConference, Portland, Oregon, September 2-4, 1998

Application of a Two-Dimensional Water Quality Model to Lake Powell by Dr. Robert George

The proposed temperature controls at Glen Canyon dam would be used to create more suitable temperature conditions for humpback chub while protecting the existing blue ribbon trout fishery immediately below Glen Canyon Dam. By coupling warmwater releases from the dam with downstream warming, the Colorado River near the Little Colorado River would reach suitable spawning temperatures for the humpback chub. Outflow and river temperature modeling studies conducted by Reclamation show that this is possible. It has also been proven to work well at Flaming Gorge Dam.

The BETTER model developed by the Tennessee Valley Authority (TVA) was applied to Lake Powell. Calibration was done for the years 1992 and 1993. The model was used to evaluate different operating scenarios and structural modifications to the dam to achieve warmer releases from the Glen Canyon dam. Changes in release quality and impacts to the reservoir were modeled to evaluated to determine which option would achieve increased downstream temperatures and minimize the impacts to the reservoir. The evaluations indicated that a withdrawal placed at elevation 3630 could be operated during months of June through September and could increase the release temperatures to about 15° C. instead of the current release temperatures of about 9°C.

Observations on the Inflow from Las Vegas Wash on Boulder Basin, Lake Mead by Dr. Chris Holdren

Lake Mead is a large mainstem Colorado River reservoir in the Mohave Desert, Arizona-Nevada. Its lower end is 15 km east of Las Vegas, Nevada. The Colorado River contributes about 98 percent of the annual inflow to Lake Mead; inflow via Las Vegas Wash, which receives all drainage from the Las Vegas Valley, provides the second highest volume of inflow to Lake Mead. The Las Vegas Wash drainage includes both non-point surface and groundwater discharges, and treated effluent from all Clark County and municipal wastewater treatment facilities.

Las Vegas Wash inflow enters Las Vegas Bay in Boulder Basin as a well-defined plume with a high dissolved solids concentration. As a result of its high density, the plume does not mix completely with the lake water and can be detected far into Boulder Basin. Nutrients, bacteria, turbidity and perchlorate are also concentrated in the influent plume. Boulder Basin serves as the primary source of drinking water for the Las Vegas Valley, which includes nearly 1.5 million people, and also provides water for 25 million people downstream. The subsurface municipal water intakes for the Southern Nevada Water District are located approximately 10 km downstream of the Las Vegas Wash inflow. As a result, the potential of the plume entering the lake from Las Vegas Wash to influence the drinking water intake is of great interest.

The current sampling program was initiated in 1990 to examine basic physical-chemical characteristics of Boulder Basin, as well as to examine lake productivity and characteristics of the plume entering the lake as a distinct flow from Las Vegas Wash. The paper will focus on results from 1998, including conductivity, nutrients, turbidity, bacteria, perchlorate, phytoplankton and zooplankton.

SUMMARY OF TWO-DIMENSIONAL WATER QUALITY MODELING OF CASCADE RESERVOIR by: Merlynn D. Bender, Technical Service Center, Land Suitability and Water Quality Group (D-8570) Denver, Colorado Telephone No. 303-445-2460

EXECUTIVE SUMMARY

The water quality and aquatic biological resources of Cascade Reservoir and its tributaries are being adversely impacted by point and nonpoint pollution sources, reservoir operations, and natural processes. Data indicate that Cascade Reservoir has surplus nutrients, extensive algal biomass, a decaying benthic layer, and is, consequently, eutrophic. To better understand the effects of external and internal nutrient and organic loadings and effects of reservoir operations on Cascade Reservoir, a two-dimensional Box Exchange, Transport, Temperature, and Ecology of a Reservoir (BETTER) model was assembled, calibrated, and used for sensitivity and management simulations. Using a two-dimensional array of longitudinal and vertical elements, the BETTER model calculates flow exchange, heat budget, and dissolved oxygen (DO). The model simulated Cascade Reservoir's warm surface layer and cold bottom water.

Currently, cold bottom water is trapped behind sediment deposition in the inlet channel to the turbine intake. The heat budget includes drybulb (air) and dewpoint temperature, solar radiation, wind mixing, convective cooling, and inflow density distribution. The DO components include sediment oxygen demand (SOD); biochemical oxygen demand (BOD); ammonia; surface reaeration; and algal photosynthesis, respiration, and nutrient recycling. A seasonal DO pattern was simulated from ice-out to ice-up using a 12-hour (day and night) input-data time step. The North Fork Payette River, four tributaries, and local inflow to the surface layer were modeled.

The Cascade Reservoir model was calibrated with sparse data for years 1989, 1993, 1994, and 1995: 1989 was slightly below average inflow and followed a dry year; 1993 was slightly above average inflow and followed a dry year; 1994 was severely dry; and 1995 was wet. Model simulations indicated that SOD; anaerobic release of nutrients, which stimulates algal growth; and minimal flushing were the primary factors contributing to low DO in the reservoir. A simulated 50-percent reduction in nutrient and organic loading had minimal immediate effect on Cascade Reservoir. However, significant loading reductions over several years may improve Cascade Reservoir water quality. Simulated sealing of the sediments, cutting off anaerobic release of nutrients, and cutting sediment oxygen demand in half significantly improved reservoir water quality. However, the mechanism to seal the sediments was not identified or simulated directly.

Simulated aeration of releases improved release water quality. However, aeration of releases would not improve water quality upstream of Cascade Dam forebay. Simulations indicated several alternatives were technically infeasible. Simulated selective withdrawal of bottom waters via removal of sediment deposits just upstream of the turbine trashrack degraded reservoir water quality. Simulated selective withdrawal of surface waters via increased spillway discharge of surface waters had minimal effect on reservoir water quality. Sediment deposits in front of the turbine trashrack forces both turbine and spillway discharges to be withdrawn from the mixed surface layer. If the deposits were removed, modeling indicated that cold bottom waters would quickly be flushed out of the reservoir through the turbines and replaced with warmer water. The warmer water would increase decay of organics and anaerobic conditions. Water quality would be worse due to increased bottom temperature, even though more bottom waters would be flushed from the reservoir. Simulations that decreased the minimum pool resulted in more withdrawal from the surface, more flushing and turbulent mixing, and less volume with high DO and cold temperatures for trout refuge. These changes would result in release of supersaturated surface waters during spring, release of poor quality water during late spring and early summer due to flushing of the reservoir bottom water layers, and release of surface waters saturated with DO from algal photosynthesis during late summer and early autumn due to simulated earlier pool turnover. Winter water quality was not simulated. However, lower winter minimum pools would result in less mass of DO and, consequently, greater potential for winter kill of fish. Increasing the minimum pool is expected to increase the volume of water with high DO and cold temperatures for trout refuge, increase the total volume with poor water quality, and decrease winter kill of fish. Higher pools would lessen the ability to optimize releases for downstream uses, such as irrigation, downstream water quality, and salmon migration to the Pacific Ocean. Continuous release to improve flushing would drop pool water surface elevation.

Phosphorus, Blue-Green Algae, TMDL's, and Reservoir Transport Mechanisms, the Provo River Multiple Reservoir Phosphorus Waste Load Allocation Program by Jerry Miller

Blue-green algal blooms were adversely impacting Deer Creek Reservoir and impairing drinking water quality to the major Salt Lake City/Provo metropolitan area. Copper sulfate treatment was attempted for over 2 decades to control the algae, but with little success. Reclamation's plans to build an additional dam 11 miles upstream had major limnological and water quality ramifications. Some empirical models suggested that at least an 80% phosphorus reduction would be required to significantly improve the water quality in Deer Creek Reservoir. A phosphorus wasteload allocation program for the river basin was proposed as early as 1976-78. There appeared to be no way to implement a meaningful phosphorus wasteload allocation program unless the problem could be divided in half with the proposed upstream dam retaining at least 50% of the inflowing phosphorus. A phosphorus fate and transport conceptual model, internal loading parameters, and phosphorus/algal bloom model were developed initially t o determine that a phosphorus wasteload allocation program in the watershed would produce a benefit in Jordanelle Reservoir. A watershed phosphorus wasteload allocation program was designed jointly by Reclamation, the State of Utah, and local agencies. Jordanelle Dam was designed with a selective level outlet works to control temperature, phosphorus, and plankton releases as part of an overall river basin phosphorus waste load allocation. A new non-discharging wastewater treatment plant was built in Heber Valley between the two reservoirs. Dairies, erosion control, county zoning with a master plan, fish hatcheries, agricultural, construction, and other non-point source controls were implemented. To date the total phosphorus reductions to Deer Creek Reservoir amount to about 50%. Even before Jordanelle Reservoir began filling the blue-green algal blooms long dominating summer/fall periods in Deer Creek Reservoir were greatly curtailed. Modeling of the Jordanelle Temperature and phosphorus released and transport to Deer Creek Reservoir are ongoing to further improve the water quality. Combined with new water treatment plants and the watershed cleanwater action plan, drinking water, aesthetics, fisheries, and recreation have been significantly improved. Understanding internal reservoir nutrient recycling, and transport was critical to determining how to implement a watershed clean water action plan that would produce the results desired.

Selenium Clean-up at the Stewart Lake Waterfowl Management Area in Eastern Utah by Delbert Smith

Selenium in irrigation return flows from adjacent irrigated land is entering the Stewart lake Waterfowl Management Area, a large wetland connected to the Green River, during the runoff season. The selenium is contaminating bottom sediments and is causing damage to fish and wildlife resources in Stewart lake, its outlet channel, and in the mixing zone in the Green River. Construction activities have been underway at Stewart Lake to address hazards to the endangered fish as well as aquatic birds that frequent the wetland. As a means of improving habitat for endangered fish and reducing water quality problems associated with irrigation drainage, the Bureau of Reclamation has modified the hydraulics of Stewart Lake. This modification will allow the lake to be periodically flushed with Green River flows during runoff and also during low flow periods in the fall. The end goal is to maintain low selenium concentrations in the wetland. This will provide high quality waterfowl habitat as well as nursery habitat to the endangered razorback suckers in the spring and summer

Fate and Transport of Mercury in the Lake Owyhee Watershed, Southeastern Oregon by Doug Craft

Lake Owyhee, first filled in 1933, is the largest reservoir in Oregon (12,700 acres/5160 ha) and is located in Malheur County in the semi-arid southeastern region of the state. The Owyhee River and its tributaries drain a large watershed area (around 11,200 mi2) that extends into Nevada and southwestern Idaho. The watershed is mostly sagebrush and wheatgrass rangeland, with geology comprised primarily of igneous volcanic rocks with intrusive granitic rocks at higher elevations. The volcanic geology of the watershed contains many localized natural sources of mercury, present as near surface cinnabar, hydrothermal ore bodies, and tuffaceous olivine deposits; and elevated mercury concentrations have been observed in volcanic rock located near Lake Owyhee. Mining and amalgamation recovery of gold and silver around Delamar-Silver City, Idaho, area also released significant quantities of mercury (up to 76 lbs/day from 1860 to 1920) into the Jordan Creek sub- basin. The specific and diffuse sources of mercury in the watershed have caused public health concern arising from mercury bioaccumulation in watershed fish. The Oregon Health Division has issued fish consumption advisories for lake Owyhee and several tributaries of the Owyhee River because of high observed concentrations of mercury in fish tissues. This investigation, which started in spring of 1996, has been collecting and analyzing reservoir water, reservoir sediments, and suspended sediment samples to determine fate and transport of mercury and methylmercury in Lake Owyhee, and to provide a better understanding of the chemistry and water quality processes in this reservoir. Data collected to date suggest that suspended sediments are the primary transport vector for mercury into Lake Owyhee, with greatest loading occuring during spring runoff. Another related study will attempt to identify localized mercury-containing mineral deposits in the watershed using NASA-JPL AVIRS (Airborne Visible and Infrared Imaging Spectrometer) images and USGS spectral matching software to identify and map Cinnabar, and other mercury mineral weathering products, as well as mercury minerals associated with hydrothermal activity in the watershed.

Spring Creek Debris Dam / Iron Mountain Mine by Kerry Rae, Haz Waste Coord., MP

Iron Mountain Mine (IMM) is located approximately 9 miles northwest of Redding, California, and was listed on the National Priorities List in 1983. Prior to commencement of remedial activities, IMM was the largest point source discharging to surface waters in the country, according to EPA, where average metal discharges totaled over one ton of toxic metals per day. The IMM Superfund Site has been defined to include the inactive mines on Iron Mountain, the tailings piles, and other areas where hazardous substances released from the mines have come to be located in the watershed, including the waters and sediments of Reclamation's Spring Creek Reservoir and the Spring Creek Arm of Keswick Reservoir. Spring Creek is a tributary to the Sacramento River, and flows into Keswick Reservoir approximately one mile upstream from Keswick Dam. Reclamation constructed the Spring Creek Debris Dam (SCDD) in 1963 for two purposes: 1) to meter acid mine drainage (AMD) laden with heavy metals into the Sacramento River in a manner protective of the fisheries, 2) to protect the tailrace of the Spring Creek Powerplant from the heavy sediment loads carried by Spring Creek. The winter run chinook salmon, an endangered species, spawns in the Sacramento River downstream from Keswick Dam, as does the threatened Central Valley steelhead. Two other chinook salmon runs have also been proposed for listing as threatened or endangered and are impacted by the toxic metals emanating from IMM.

During heavy storm events, Spring Creek Reservoir can fill quickly if Sacramento River flows are not adequate to allow large volumes of AMD to be metered from SCDD. At times, this results in uncontrolled spills from SCDD, which in past years have resulted in fish kills in the Sacramento River. Historically, Reclamation has provided releases of water from Shasta Reservoir to dilute toxic metal concentrations in Keswick Reservoir. EPA's Records of Decision for the IMM Superfund Site have selected construction of clean water diversions around mining areas, an enlargement of SCDD that is now unlikely to occur, construction of a treatment plant, capping and cleanup of waste piles, and construction of a small debris dam on a tributary draining part of the mine site. Reclamation has been involved in the design and construction of most of the remedial actions.

My discussion will include information about how Reclamation has managed operations of both

Spring Creek Debris Dam and Spring Creek Powerplant to protect the Sacramento River ecosystem, how those operations tie into EPA's remedial plans for IMM, how Reclamation monitors water quality to make operational decisions for SCDD, and studies being conducted on toxic sediments which have come to be located both in Spring Creek Reservoir and the Spring Creek Arm of Keswick Reservoir.

Artificial Wetlands Within a Multi-Use City Park by Steve Muth

The Boulder City Wetlands Park started with Bureau of Reclamation's (BOR) need to develop habitat for Threatened and Endangered (T&E) Species as part of its T&E Recovery Program. Discussions with Nevada Department of Wildlife also identified a desire to establish a stream and pond type environment for other species listed by the state to be protected. In addition, BOR's Wetlands program cooperates with wastewater treatment operators such as Boulder City, NV to reuse treated wastewater for wetlands development. After numerous discussions among these three agencies the idea of a multi-purpose wetlands park emerged with most of the goals of all agencies being met or exceeded. The 50 acre Park located within the city limits is nearing completion with all major construction finished. The Park includes 4, one acre ponds, an artificial (constructed) stream averaging 5 foot wide, 1 foot depth and 2,200 feet in length. The water after running through the wetlands will be used to irrigate an adjacent cemetery. Both the ponds and the stream are planted with a variety of wetlands plants and will serve as rearing areas for T&E fish. Additionally, the Park contains an interpretive trail within the wetlands area and four softball and volleyball fields adjacent to the wetlands. University of Nevada Las Vegas under contract with the BOR is monitoring water quality and razorback sucker (one of the target T&E species) growth. An outdoor education program at the wetlands has also been established by UNLV and BOR under the GLOBE program. This program funded by National Oceanic and Atmospheric Administration provides a web site for displaying environmental data collected by students from the local schools. Construction at the wetlands is 85% completed. Pending approval of NPDES permit, effluent from the city will be blended with raw Lake Mead water as the wetlands permanent water supply. Water leaving the wetlands will be used for irrigation at the nearby Veterans Cemetery. Total construction cost to date is approximately 1.5 million dollars, Reclamation's contribution is 500,000 dollars.

Reservoir Selective Withdrawal by Tracy Vermeyen

The winter-run Chinook salmon population in the Sacramento River, California, 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. Water temperatures exceeding 12.0 degrees C can cause significant egg mortality. Reclamation's hydraulic research in the late 1980's developed 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-m by 9-m by 2.4-m deep) was built in Reclamation's WRRL to develop and test various temperature control device concepts for reservoir release. A refrigeration system was used to create temperature profiles in the range from 7 degrees C to 24 degrees C in the facility. Scaling laws allow research engineers to simulate releases from temperature-stratified reservoirs in the model facility. Flow in reservoirs approaching the outlets is significantly 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.

A model scale of 1:72 was used to simulate a 91-m-deep and 396-m-long, flexible curtain to control releases through the powerplant at Shasta Dam. The curtain could be lowered from the reservoir surface to permit withdrawal of warm surface water or could be raised off the bottom to access the cold bottom water. The 1.2-hectare curtain was to be made of 32-mil Hypalon reinforced with nylon. Lack of historic reference and field experience using underwater curtains of this size prompted the decision to use a "more traditional" steel structure. The steel structure to be installed on Shasta Dam in 1996 will extend 15.2 m out into the reservoir, run 122 m horizontally and plunge as deep as 107 m into the deeper part of the reservoir permitting access to near-bottom cold water. Field construction costs for the steel structure are estimated to be four times the cost of a flexible reservoir curtain.

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 Lake. Two curtains were designed and installed in Lewiston Lake in August 1992. The primary (reservoir) curtain, figure 1, was designed to hold back the warm water while colder water was released through Clear Creek Tunnel to the Sacramento River.

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 degrees C. Actual temperature measurements made at Clear Creek Tunnel intake after the August 1992 installation of the curtain showed a 1 to 1.5 degrees C temperature reduction, Vermeyen and Johnson (1993). Although this seems a small change in temperature, every degree 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 in 1993. The use of this new temperature control 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. Table 1 summarizes retrofit selective withdrawal structure technologies used at five Reclamation power stations.

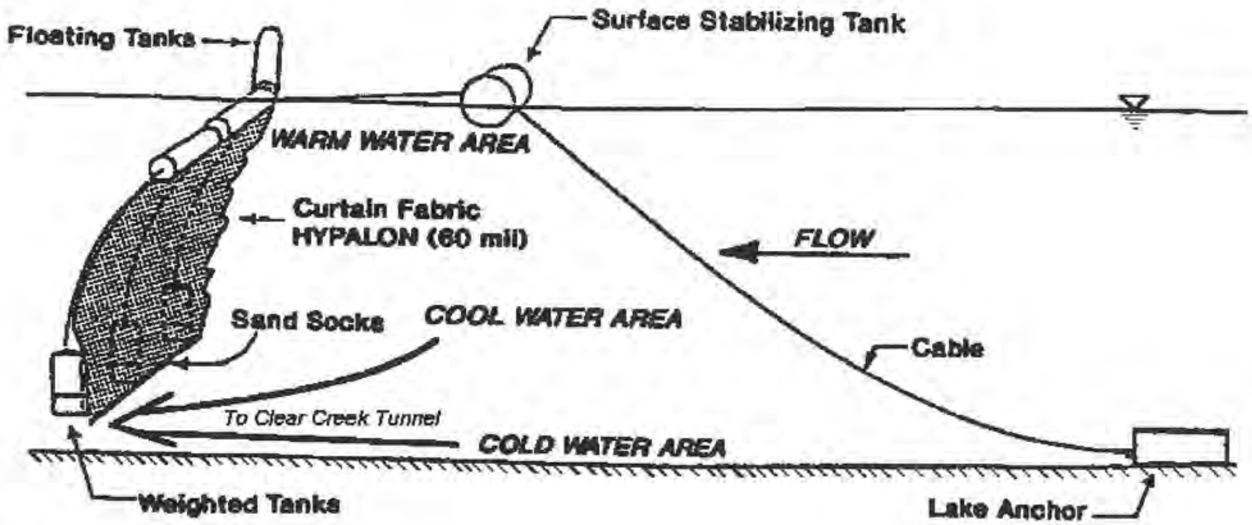

Figure 2. Schematic of temperature control curtain components.

Power Station (year constructed)	Fish species	Problem	Retrofit	Approximate cost	Actual 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 (Projected)	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 (Projected)	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

Table 1. Summary of retrofit selective withdrawal structures installed at several of Reclamation's Dams.

Vermeyen, T. B., and P. L. Johnson, (1993), "Hydraulic Performance of a Flexible Curtain Used for Selective Withdrawal - A Physical Model and Prototype Comparison," Proceedings ASCE National Hydraulic Engineering Conference.