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Change in Emphasis for Hydraulic Research at Bureau of Reclamation

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by

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CHANGE IN EMPHASIS FOR HYDRAULIC RESEARCH AT BUREAU OF RECLAMATION

Throughout its illustrious history, the Bureau of Reclamation has focused its efforts on creating a life-sustaining environment in the once-barren west. The bureau has constructed over 220 dams since it was established in 1902. Its hydraulic research, which started in the early 1930s, played a key role in developing innovative designs and establishing standards for dams and many other hydraulic structures. At first the bureau's hydraulic research dealt with dam structures such as spillways, outlet works, and their energy dissipators. Over time its research expanded to include hydraulic equipment and various conveyance systems for irrigation and municipal and industrial water supplies. This article describes the bureau's current research emphasis, which aims at using hydraulic structures to manage water resources in an environmentally, economically, and structurally sound manner.

The Bureau of Reclamation's hydraulic structures research in the period from 1930 through the 1970s resulted in world-class technological advancements in water-resource development, documented in publications such as *Design of Small Dams* (1960) and Engineering Monograph No. 25, "Hydraulic Design of Stilling Basins and Energy Dissipators" (1958). As public values have shifted from an emphasis on water resource development to management of western waters, the bureau's contemporary hydraulic research program has also changed. This evolution from water development to water management has led to an emphasis on technology innovation for protecting the public and existing infrastructure, encouraging water conservation, and emphasizing environmental restoration on regulated river systems. Much of the technology innovation is being performed at the Bureau of Reclamation Water Resources Research Laboratory (WRRL).

PROTECTING INFRASTRUCTURE: DAM SAFETY

The Bureau of Reclamation administers the Department of the Interior dam safety program, which involves, among other goals, the development of new technologies to cost-effectively solve dam safety problems. Inadequate spillway capacity is a primary reason for dam failure; therefore, the bureau's dam-safety research includes hydraulic investigation of alternative spillway designs, fuse plug concepts, and overtopping protection concepts. The safety improvements, innovative design concepts, and construction costs savings realized from this research have been significant.

Increased Spillway Capacity: Labyrinth Spillways

The Bureau of Reclamation has used labyrinth spillways on existing dams where the discharge capacity of a spillway is insufficient or where a reservoir must be enlarged. Research on the labyrinth spillway concept produced design criteria that were applied to augment the spillway capacity at Ute Dam on the Canadian River, New Mexico, and generated significant savings in field construction cost. Ute Dam labyrinth spillway was constructed for $10 million, a $24 million cost savings over the estimated $34 million cost for a traditional gated structure. Houston (1982) describes laboratory flume studies and a 1:80 scale model of the full labyrinth spillway shown in Fig. 1. The 9 m high, 14 cycle spillway had a length magnification ratio of 4 and a flow magnification ratio of 2.4.

Emergency Spillway Concepts: Fuse Plugs

Pugh (1984) defines a fuse plug as "an embankment d signed to wash out in a predictable and controlled mann when the capacity in excess of the normal capacity of t service spillway and outlet works is needed." A number laboratory embankments, 0.15 to 0.38 m high and 2.7 m lo at scales of 1:10 and 1:25, were tested in the WRRL to devel fuse plug spillway design criteria. Fig. 2 illustrates a typic laboratory fuse plug investigation. Fuse plug designs ha been selected for the dam safety corrective action plan for t Horseshoe and Bartlett Dams on the Verde River in Arizo The fuse plug for Bartlett Dam is designed with an erosic resistant invert and abutment structure and will pass 10,1 m^3/s. Three erodible embankment sections will operate in s quence. The Horseshoe Dam fuse plug is designed to pa 6,850 m^3/s through three 44–52 m long openings 6.0–7.9 high. The documented construction cost savings of $150–3 million on the recently upgraded Verde River dams are example of the significant benefits resulting from this hydra lic research of innovative alternatives to traditional spillw design.

Concepts for Embankment: Overtopping Protection

Flood flow overtopping an embankment is considered u acceptable. However, hydraulic research in recent years h greatly advanced the concept of embankment protection sy tems, not only for low dams (under 15 m high), but now f high dams as well. Frizell et al. (1994) have reported on c operative research, funded by the Department of the Interi the Electric Power Research Institute, and Colorado State U versity, that has resulted in design criteria development f concrete step overlay protection for embankment dams. La oratory studies were completed at the WRRL, and tests we performed in a large-scale, outdoor overtopping facility at Co orado State University. The 1.5 m wide, 15 m high outdo test facility subjected tapered blocks to unit discharges as hi as 3.2 $m^3/s \cdot m$ (see Fig. 3). The 35 cm long, 5 cm high, a 60 cm wide blocks were placed in an overlapping pattern filter material. The blocks are designed to aspirate water fro the filter layer through small drainage slots formed in ea block. The block shapes developed through these studies ha

FIG. 1. 1:80 Scale Model of the 14 Cycle, 9 m High Ute Da Labyrinth Crest Discharging 15,500 m^3/s

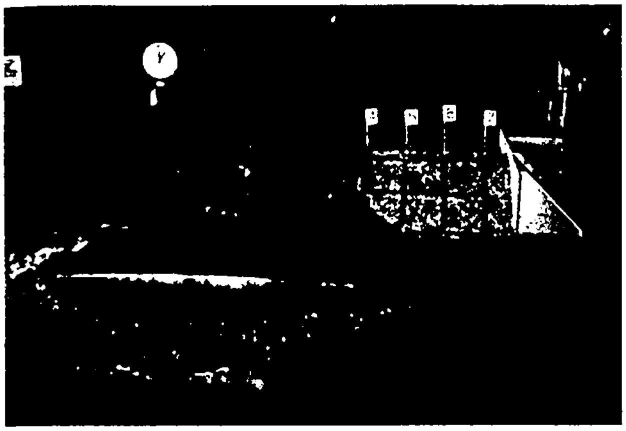

FIG. 2. Fuse-Plug Washout Process

FIG. 3. Flow Starting Down a 2:1 Slope of Blocks over 0.15 m of Gravel

been patented and are effective for a range of embankment slopes.

Evaluating Extent of Dam Foundation Erosion

Dam failure can occur when the foundation is undercut or the downstream slope is eroded, eventually causing slumping of the dam crest and failure by overtopping. There are numerous documented instances of extensive erosion damage to spillways, stilling basins, and riverbeds that threaten dam stability. Predicting flow patterns, velocity distributions, material erosion, and other factors of impinging jets in prototype situations is largely beyond the capability of conventional physical and numerical modeling techniques. The Bureau of Reclamation has entered into a multiyear cooperative research and development agreement to develop new technologies for predicting the extent of erosion and scour at dam foundations, specifically at the downstream toe and abutments of dams. The study approach couples hydraulics and geomechanical index concepts and will utilize a laboratory scale model as well as a near-prototype test facility to develop and evaluate a predictive numerical code to estimate the extent of dam foundation erosion. The variety of materials and material properties present in dam foundations indicates the need for an erodibility index, which is a product of mass strength, block size, interparticle strength, and relative orientation. The laboratory and near-prototype studies will scientifically investigate the erosion processes of jacking, dislodging, and transporting foundation material. The test results will provide reliable data to verify the numerical code for predicting the extent of dam foundation erosion.

ENVIRONMENTAL RESTORATION

Water development and environmental interests are striving to coexist, to provide today's society with a higher standard of living while fully protecting environmental resources. In recent years hydropower production and agricultural water supply have been cut back substantially in the U.S. to meet regulatory agency requirements. Rivers regulated for hydropower development, urban and agriculture water supply, and flood control are complicated systems; operational decisions must consider fish behavior and environmental resources as well as engineering design. A bioengineering focus has led to new, innovative concepts for using hydraulic structures to manage regulated aquatic ecosystems in the west. A look at fishery and stream restoration issues in the west illustrates these new technological approaches.

Reservoir Selective Withdrawal

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 river water temperatures during the late summer and fall incubation and rearing season. Water temperatures exceeding 12.0°C can cause significant egg mortality. During the late 1980s, the Bureau of Reclamation developed flexible curtain barriers to manage and control water-release temperatures for reservoirs on the Trinity and Sacramento Rivers.

A sophisticated temperature stratified test facility (9 m long, 9 m wide, and 2.4 m deep) was built at the WRRL to develop and test various temperature-control device concepts for reservoir release. A refrigeration system was used to create temperature profiles from 7°C to 24°C in the test facility. Scaling laws allowed appropriate simulation of water releases from temperature-stratified reservoirs in the model facility. Flow in reservoirs approaching the outlets is significantly affected by water density, directly related to temperature; therefore, it is important to properly simulate the water temperature in the laboratory model.

A model scale of 1:72 was used to simulate a 91 m deep, 396 m long flexible curtain to control releases through the power plant at Shasta Dam. The curtain could be lowered away from the reservoir surface to permit withdrawal of warm surface water or could be raised 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 to and field experience in using underwater curtains of this size prompted the decision to use a more traditional steel structure. The steel structure installed on Shasta Dam in 1996 will extend 15.2 m out into the reservoir, run 122 m horizontally, and

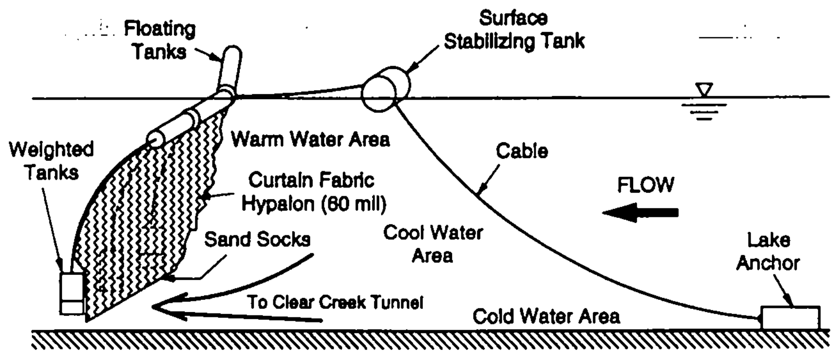

FIG. 4. Lewiston Lake Temperature-Control Curtain

extend as deep as 107 m into the deepest part of the reservoir, permitting access to near-bottom cold water. Construction costs for the steel structure are estimated to be four times the cost of a flexible reservoir curtain.

The 1988–1992 drought in northern California resulted in limited volumes of stored cold water deep in reservoirs. Because of the urgent need to reduce reservoir outflow temperatures, the bureau initiated an active research program to study and install temperatures-control curtains in shallower waters, such as Lewiston Lake. Two curtains were designed and installed in Lewiston Lake in August 1992. The primary (reservoir) curtain, shown in Fig. 4, was designed to hold back the warm water while colder water traveled under the curtain and was released through Clear Creek Tunnel into 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 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 1–1.5°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 multiagency effort, two additional flexible curtains were laboratory tested, designed, and installed in Whiskeytown Lake in 1993. The use of these new temperature control technologies will ensure continued hydropower production at Shasta Dam, increase the selective withdrawal capability within the Sacramento River basin, and provide improved management by selective withdrawal of the limited cold water in Shasta Lake.

Fish Passage

Considerable effort has been placed on improving fish passage technologies in recent years, including new designs for fishways, improved spawning facilities, fish barriers with associated bypass designs for canals, and various screening and fish behavioral control concepts. Most recently, efforts have centered on returning the Sacramento River near Red Bluff Diversion Dam to a run-of-river condition by raising the dam gates. Several alternatives are being studied to improve the fishery.

One alternative, proposed by Liston and Johnson (1992), is to evaluate the feasibility of replacing the diversion dam with a pumping station utilizing fish-friendly pumps. The plant would deliver 76.5 m^3/s, with a lift of 4.3 m to the Tehama Colusa Canal, while incurring minimal fish mortality. Every effort would be made to minimize fish entrainment at the pump intakes. Construction of a pilot pumping plant, which pumps up to 9.5 m^3/s, was completed in the spring of 1995. It is designed to evaluate and monitor the mechanical performance of two fish-friendly pump concepts as well as evaluate fishery issues associated with pumping. A screw-centrifugal (helical) pump (Fig. 5) and an Archimedes screw pump (Fig. 6) are being evaluated. Two 3.0 m diameter, 8.0 m long Archimedes pumps, placed on a 38° angle, deliver a total of 4.5 m^3/s at a rotational speed of 28 rpm. One 1.2 m helical pump delivers 5.0 m^3/s at 400 to 600 rpm. Fishery and mechanical issues will be evaluated over several years at the research pumping plant before construction of a larger, permanent pumping plant.

Stream Restoration

The Bureau of Reclamation water development projects have altered the character of rivers and watersheds. We now refer to these systems as regulated aquatic ecosystems. Restoring a watershed or ecosystem damaged by physical alterations to the natural flow regime requires multidisciplinary re-

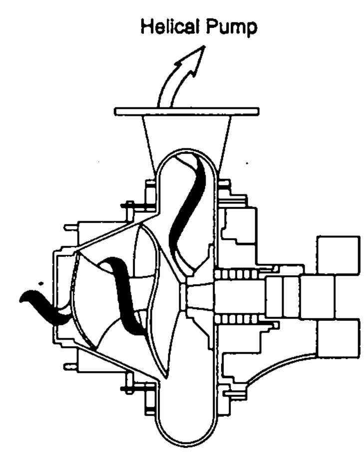

FIG. 5. Schematic of Helical Pump

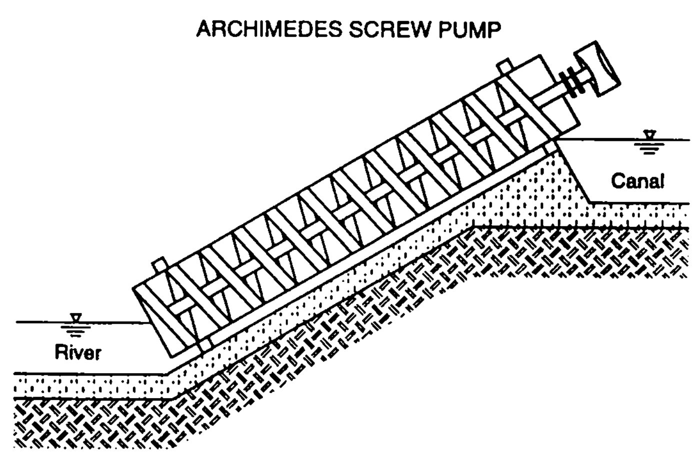

FIG. 6. Schematic of Archimedes Pump

search involving engineers, biologists, geomorphologists, and the public.

Muddy Creek, near Great Falls, Montana, is an example of the Bureau of Reclamation's stream restoration efforts. This creek has been drastically altered by irrigation return flows. Muddy Creek experienced flows of 12.3×10^6 m^3/year before irrigation. The creek now sustains runoff of 98.7×10^6 m^3/year. A 15 m incised channel has been carved in the glacially deposited silty soil since the early 1900s. Active measures to restore stream gradient and reduce erosion are now under way in a cooperative project involving the Bureau of Reclamation, the Natural Resources Conservation Service, and the local irrigation district. The erosion control demonstration project includes 19 rock ramps and three barbs placed along a 6.6 km reach of the creek in 1994 to control 8.2 m of stream gradient. The demonstration project will look at long-term performance of the in-place technology as monitoring programs track stream response in the short and long term.

Environmentally Acceptable Lubricants

Hydropower stations have historically used oil and grease for lubrication. Some of this grease inevitably enters the water, creating a source of contamination of potable water and aquatic habitat. Blum (1994) describes a test apparatus developed by the WRRL specifically to test the mechanical performance of environmentally safe greases for wicket-gate bushing applications. A 1:4 scale model of a prototype wicket gate at Mt. Elbert Power Plant, Colorado, was enclosed in a rectangular conduit, and flow through the facility was scaled to represent flow through one wicket-gate passage. A computer-controlled, motor-driven operator was used to cycle the gate through a model test time of 20 hours. Strain gauges measured changes in torque as the gate was exposed to 1,370 opening and closing cycles. As a result of these tests, the bureau was able to identify several environmentally safe lubricants, which meet both water quality standards and mechanical performance requirements.

Water-Quality Improvement: Dissolved Gases

Hydraulic structures often dramatically affect water quality and aquatic life by changing the spatial and temporal distribution of dissolved gases within reservoirs and natural streams. The Bureau of Reclamation is conducting research to address problems of both nitrogen supersaturation and reduced dissolved oxygen concentrations downstream of energy dissipation structures and power plants.

Spillways and outlet works associated with hydraulic structures affect the dissolved gas content of the released flow. Depending on the structure and local conditions, there may be positive or negative effects on water quality. Releases may aerate flows depleted in dissolved gas, create supersaturated dissolved gas levels, or reduce supersaturated levels in the flow. Johnson (1975) presents an analysis to predict the effect of a wide variety of hydraulic structures on the dissolved gas content of the flow.

The Tennessee Valley Authority (TVA) has led efforts in recent years to improve dissolved oxygen conditions in reservoirs and downstream of power-plants (Bohac and Ruane 1990). The Bureau of Reclamation has cooperated with the TVA and the U.S. Army Corps of Engineers to develop autoventing turbine technologies that use aeration of power plant flows to improve dissolved oxygen concentrations of power plant releases. Reclamation has also retrofitted turbines at Deer Creek Power Plant on the Provo River, Utah, to improved dissolved oxygen concentrations through turbine aeration (Wahl 1995).

ONGOING EFFORTS

There are numerous practical problems associated with hydraulic structures on water resource projects that will motivate applied hydraulic research in the future. Water use, of necessity, requires continued use of hydraulic structures to effectively manage water resources. Some of the Bureau of Reclamation's past successes in water resource development have produced new problems in water management as societal values have changed. The challenge is to keep hydraulic research contemporary by clearly identifying the problems and working as partners with the social and scientific communities to develop holistic solutions.

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