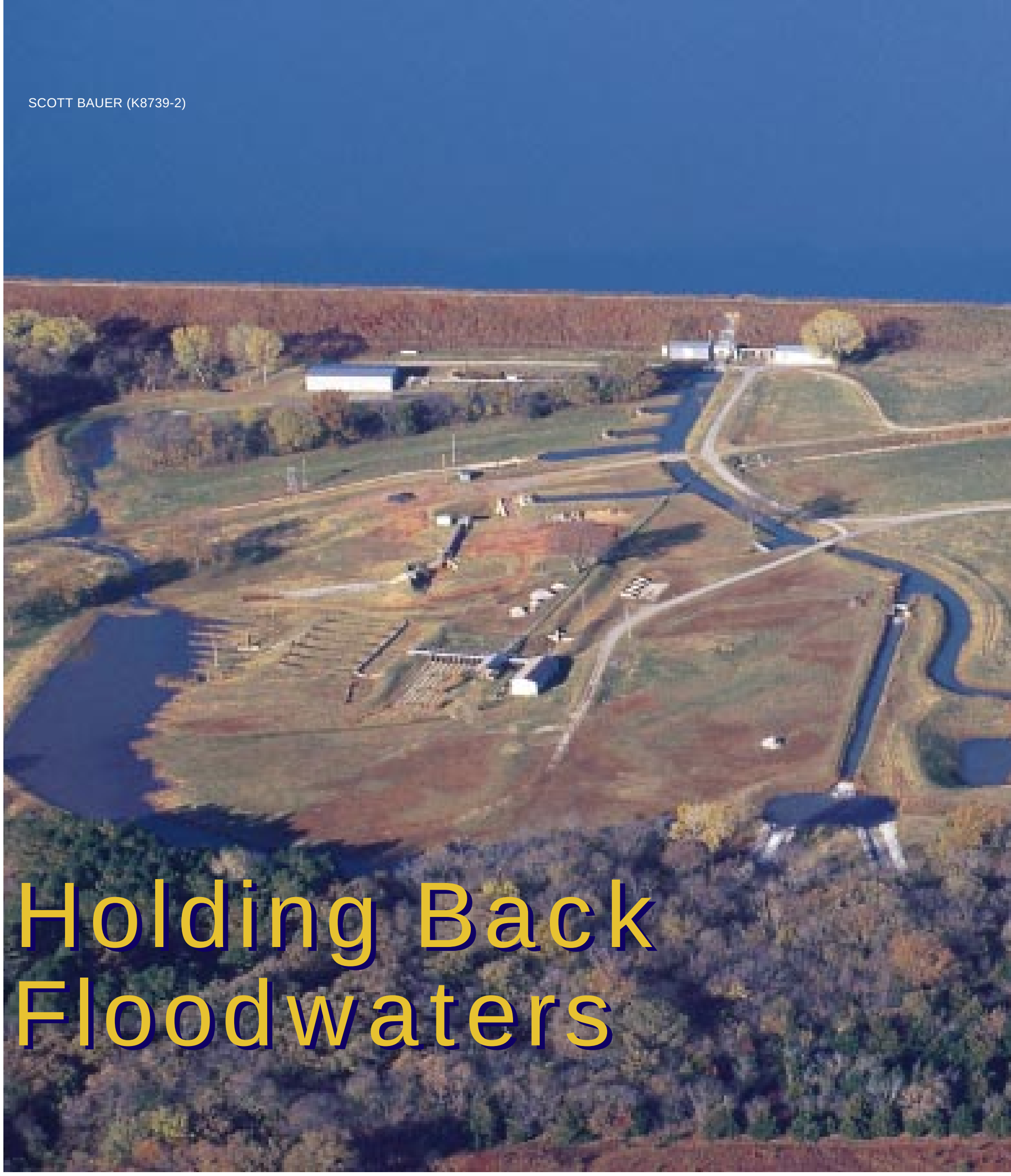


Holding Back Floodwaters

Aerial view of the ARS Hydraulic Engineering Research Laboratory facility with Lake Carl Blackwell in the background. An earthen dam running along the shoreline separates and protects the facility from the lake, which is at a higher elevation.

From a distance, the 50-acre ARS Hydraulic Engineering Research Laboratory in Stillwater, Oklahoma, looks more like an archeological excavation than a world-class research facility. The laboratory and its many outbuildings and grounds are covered with all types of hydraulic structures. Hydraulics is the science that deals with the motion of water and other liquids.

Recognized worldwide for modeling, designing, and engineering hydraulic structures for agriculture, the Stillwater facility today specializes in studying how water erodes spillways and forms gaps in earthen dam walls or embankments. The lab is set to play one of its greatest roles—assisting in the rehabilitation and revitalization of thousands of earthen dams in the United States.

"The 3,000-acre Lake Carl Blackwell located next to the laboratory provides the water used for simulating and testing hydraulic structures," says the ARS laboratory's research leader Darrel M. Temple. "The facilities are ample for conducting full-size prototype tests of many hydraulic structures, like full-scale vegetated channels."

Such a readily available and abundant water supply allows the laboratory's scientists to generate the high waterflow rates—up to 130 cubic feet per second—needed to simulate the forces that cause holes to form in earthen spillways and embankments.

"The laboratory's unique topography and proximity to the lake make it possible to deliver these high rates of waterflow," he says.

Water used for experiments can be diverted to the outdoor laboratory or to one of three buildings where the ARS scientists model and test hydraulic structures.

"Designs for hydraulic structures are typically tested in one of the buildings that have various-sized channels," he says. "After we fine-tune the scale model indoors, we often build and test it outdoors under conditions that more closely match field conditions."

Of current concern to the Stillwater lab are the nation's earthen dams. America's countryside is dotted with these small dams. These earthen dams protect the watershed. Many supply water to municipalities. They also prevent floods; provide water for irrigation, recreation, fish and wildlife habitats, and groundwater recharge; and improve water quality.

"Each year," says Temple, "these reservoirs provide Americans with more than $800 million in benefits."

Dams store and trap sediment and prevent excess runoff from damaging land downstream. As dams age, they can fill up with sediment and become unsound structurally, says Temple, who has spent 23 years as an ARS hydraulic engineer working at the Stillwater laboratory.

Temple says, "Many of the more than 10,000 flood-control structures in the United States were designed to have a 50-year service life. About two-thirds of them were designed before 1962 to protect communities and rural lands downstream."

Today, these upstream flood-control dams are in urgent need of revitalization and rehabilitation. Over the next 10 years, more than a thousand will need significant repairs and modification. Temple

says that "many no longer work as efficiently as they should. That's mainly because of aging, sediment filling, and changes in what the land has been used for. These conditions could not have been anticipated during design and construction."

SITES Software Program

The expertise and database amassed by the ARS laboratory over its 60 years of research are needed to rehabilitate these dams. And USDA's Natural Resources Conservation Service (NRCS) will work cooperatively with the Stillwater lab to develop technologies for rehabilitating and revitalizing the dams.

The software program documenting these technologies is called SITES (not an acronym). "SITES combines the principles of geology, hydrology, soil science, and physics to predict the performance of spillways—both principal and auxiliary," says Temple.

"The current software program predicts how an earthen spillway will perform and evaluates its potential for failure. Future versions will incorporate current research that will predict the damage that results from embankment overtopping. The likelihood of an earthen dam failing will be determined from the erosion that occurs on the downstream face of the dam."

Adding to the urgency of this problem is the increased risk to life and property from changes in upstream and downstream land use since the dams were constructed.

"When these dams were built, most of the surrounding areas were rural," he says. "As communities expanded and homes were built in known flood plains, the system of reservoir dams—originally intended to protect crops and farmland—now safeguards houses, property, and lives."

A High Price To Pay

When dams fail, land is often devastated, homes and roads can be destroyed, and people can die.

Temple remembers one example of dam failure that occurred in May 1983 at Black Creek in Mississippi. The dam failed because of erosion in the emergency spillway. The flood that caused the failure was generated by heavy rainstorms that dumped 14 inches of water on the watershed.

"The spillway was originally 5 feet deep and 100 feet wide. The reservoir was full of water before the dam failed. After the spillway breached, it was about 190 feet wide and 40 feet deep. The reservoir drained, releasing 4,500 acre-feet of water at a peak rate of 9,000 to 12,000 cubic feet per second to the downstream flood plain," says Temple.

He adds, "Luckily, no homes were immediately downstream of the reservoir. No loss of life occurred. However, the water and sediment released caused substantial damage downstream."

A county bridge about 1-1/2 miles downstream washed out, and the roadway was severely damaged. Two downstream ditch bank levees were breached. The water caused massive erosion and sediment deposits in agricultural fields.

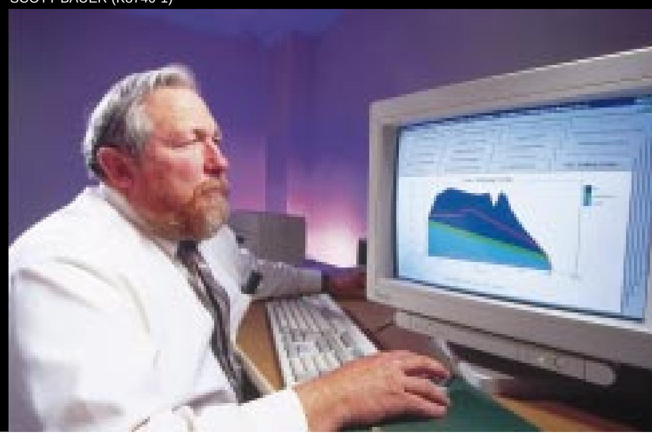
"If a breaching like this occurred today in a reservoir where housing had encroached on the downstream flood plain, loss of life would be likely," he says.

SCOTT BAUER (K8735-3)

▲ **This rock chute safely transfers runoff to a lower elevation. Near the top of the loose-rock structure, agricultural engineer Kem Kadavy (left) and hydraulic engineer Kerry Robinson monitor its performance.**

▼ **Research leader Darrel Temple examines graphic output from SITES, a software program used for predicting the performance of spillways and designing new structures.**

SCOTT BAUER (K8740-1)



SCOTT BAUER (K8736-2)

"The Mississippi dam failure drives home the point that dams are a vital part of our nation's infrastructure, like roads, bridges, and sewage-treatment plants," says ARS hydraulic engineer Gregory J. Hanson, who has worked for 15 years at the Stillwater laboratory. "An estimated $8.5 billion infrastructure in 1997 dollars has been developed in the form of these earthen dam structures," he says.

"As ARS scientists, we work closely with and respond to the needs of NRCS nationally," Temple says. "The SITES software project is the most recent example of this cooperation and response."

Developed from both ARS laboratory studies and field data, the SITES software now provides engineers with a tool for analyzing and predicting the performance of vegetated earth spillways like those used on many watershed flood-control reservoirs.

"SITES is a model used for designing new structures or for analyzing how existing structures perform," he says. "The model considers how runoff from rainstorms affects the structures and the performance and failure potential for vegetated spillways. Future refinements will allow us to evaluate performance and failure potential for dams overtopped by extreme flood flows."

How SITES Works

The SITES software evaluates spillway surface and subsurface conditions and determines the location and nature of the erosion posing the greatest risk of failure.

"New technology is incorporated into the model, such as the use of an index—called a headcut erodibility index—to describe the resistance of the exposed geologic materials to erosive attack during the latter stage of the erosion process," says Temple.

The SITES software also uses mathematical curves for calculating waterflow rates of vegetated auxiliary spillways. These curves take into consideration the flow-retarding effects of vegetation in the spillway.

"These capabilities place the SITES software on the leading edge of technology of earth spillway design and analysis," he says.

"The spillway erosion prediction portion of SITES is based, in part, on data cooperatively obtained by the long-term joint effort of ARS and NRCS," says ARS hydraulic engineer Kerry M. Robinson. He has worked at the Stillwater laboratory for 17 years.

Started in 1983, the SITES project was aimed at gathering data from field spillways that had significant waterflow or damage or both. At the same time, ARS scientists at the Stillwater laboratory began large-scale lab and field studies to examine the processes associated with the erosion and overtopping of earthen spillways.

▲ A low-drop grade-control structure is used to stabilize the stream or channel bed where an abrupt drop is needed. Here, agricultural engineer Kem Kadavy (left) and hydraulic engineer Kerry Robinson measure bed profiles in riprap (loose rock) upstream in a scaled-down model of the structure.

▼ Hydraulic engineer Greg Hanson conducts a jet test to evaluate soil erodibility.

SCOTT BAUER (K8738-1)

SCOTT BAUER (K8733-2)

▲ Kem Kadavy observes the hydraulic performance of a model of a principal spillway inlet tower. The tower is a scaled-down version of what will be built under a dam in Mississippi. Water from above moves through the tower down to a pipe outlet. Air is added to create bubbles to study water movement.

"The SITES water resources site analysis software, released by NRCS in early 1997, significantly changed that agency's approach to analyzing spillways," says Temple.

"We're presently refining the hydrologic criteria—the quantity of rainfall used for dam and spillway design—for use with this software."

Since SITE's 1997 release, the two federal agencies have been cooperating with Kansas State University, Manhattan, to simplify how the model can be applied. An advanced graphic program assists users in applying the model by guiding them through the needed model inputs and graphically displaying the results of computations on the monitor of the computer.

"For example," Temple says, "if a user changes the width of the spillway, the impact of that change will automatically show up in other aspects of design and performance—sort of a ripple effect."

He says, "This will allow the user to conveniently compare and contrast the technical implications of various design alternatives. It includes display screens for data entry and for both text and graphical output."

At the present time, this enhancement—or interface—applies only to a reservoir site or existing structure with relatively simple upstream watershed conditions. Work is currently under way to expand the interface to include more complex watersheds with other reservoirs farther upstream.

"We expect to have this expanded version available by late 2000," Temple says. "The first test version of the model will be completed by February 2000.

"Research efforts are in progress to expand the SITES technology to allow users to model earthen embankments to determine what conditions will cause them to fail. Aging of these dams, combined with increasing population densities and increased environmental concerns, will generate many challenges for each of us involved in this effort."—By **Hank Becker,** ARS.

This research is part of Water Quality and Management, an ARS National Program (#201) described on the World Wide Web at http://www.nps.ars.usda.gov/programs/nrsas.htm.

Darrel M. Temple, Gregory J. Hanson, and Kerry M. Robinson are in the USDA-ARS Hydraulic Engineering Research Laboratory, 1301 N. Western St., Stillwater, OK 74075-2714; phone (405) 624-4135, ext. 226/223/225, fax (405) 624-4136, e-mail dtemple@pswcrl.ars.usda.gov ghanson@pswcrl.ars.usda.gov krobinson@pswcrl.ars.usda.gov.

More information about SITES can be obtained on the World Wide Web at http://www.wcc.nrcs.usda.gov/water/quality/common/sites/sites.html. ◆

SCOTT BAUER (K8735-2)

This step baffle trash rack on the spillway inlet of Boomer Lake prevents floating debris from plugging the inlet by forcing the water to enter upwards through baffles. Water entering the trash rack flows through the principal spillway conduit to the stream channel downstream of the dam.

So Many Structures, So Many Needs

Scientists at the ARS Hydraulic Engineering Research Laboratory, Stillwater, Oklahoma, look at water in terms of physics and math. The concepts and principles they have developed over the last 60 years have become the standards for the best design for safe, economical, and lasting hydraulic structures and channels for agriculture that are in harmony with nature.

"In the United States, USDA's Natural Resources Conservation Service has assisted in constructing tens of thousands of these hydraulic structures, based on the procedures developed at the ARS lab," says ARS hydraulic engineer Gregory J. Hanson.

One area of specialization is grass-lined waterways—natural alternatives to concrete and rock and other materials considered by some to be ugly and costly—for draining terraced agricultural lands. Hanson says the laboratory's worldwide leadership in designing vegetation-lined waterways is a lasting legacy.

"These vegetation-lined waterways are used today to safely convey runoff from more than 3 million acres through 500,000 miles of waterways," he says. "Many were built by NRCS. The grassed-waterway design procedures developed by ARS are virtually the only reliable ones available, originating from a solid experimental background."

The grassed-waterway design procedures are the result of a series of tests on vegetated channels. "Among other things, these tests accounted for resistance to waterflow caused by vegetation and the geometry of the channel. Engineers worldwide rely on these studies when they design vegetated channels," he says.

Hundreds of tests on the hydraulic performance of structures and channels have been performed at the Stillwater lab. Some better known products resulting from these tests and the team effort of USDA's agencies include design criteria for energy-dissipating structures, such as

- **stilling basins,** which slow down the flow velocity and reduce the erosive action of water
- **plunge pools,** which dissipate the erosive energy of falling water
- **hood inlets,** which allow a pipe to convey water more efficiently
- **step baffle trash racks,** which allow water to drain from a reservoir and which don't get plugged with floating debris
- **flow-measurement flumes,** which accurately determine the rate of waterflow
- **rock chutes,** which are loose rock structures that safely transfer water to lower elevations (photo on page 6).

"This is just a partial list of the many hydraulic structures studied and developed here," Hanson says.

Hanson's colleague, ARS hydraulic engineer Kerry M. Robinson recently tested a hydraulic model of a new water supply dam. It uses roller-compacted concrete for a structure being built near Randleman, North Carolina.

"With this design, the auxiliary spillway can be placed over the dam, with a stepped surface on the downstream side of the dam. The stepped surface decreases the velocity of water and reduces the energy of the flowing water as it goes over the spillway," he says.

Design modifications resulting from Robinson's study saved about $2 million on this project.

Besides structures, Hanson and colleagues have developed a circular jet test that uses a patented device to directly measure soil erodibility by water in the field or laboratory (photo on page 7).

"The device uses a jet of water to form a cavity in the soil," he says. "The soil's resistance to erosion is calculated from the difference between the original and the eroded soil profile. This difference is expressed as a jet index."

The jet device can measure the erosion potential of a soil in vegetated channels, road embankments, dams, spillways, and construction sites.

The device has been field and lab tested on several soils at various rates of waterflow. It was developed in conjunction with the SITES software for analyzing earth spillways.—By **Hank Becker,** ARS. ◆