RIVER REPLICATION

When applied to the small-scale physical modeling of rivers and streams, micromodeling can help engineers and other experts solve a variety of flow and sedimentation problems.

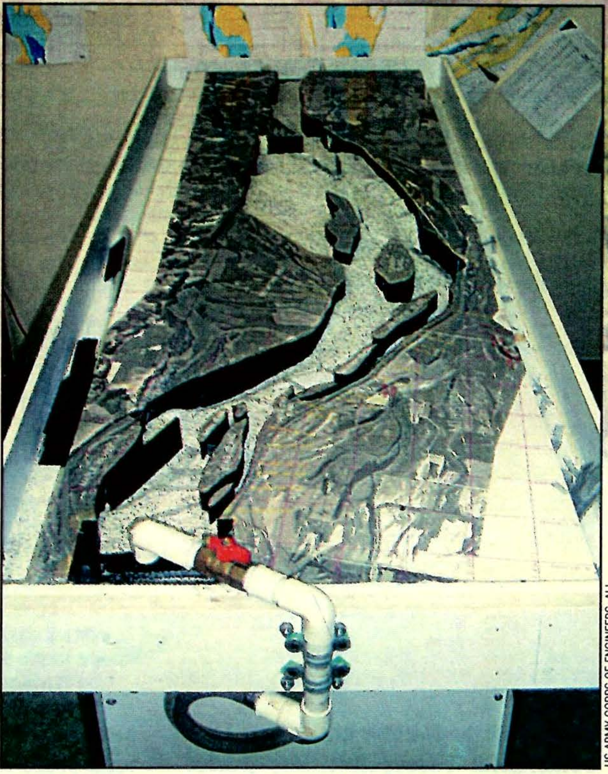
Rob Davinroy

Sedimentation, the interaction of flowing water and sediment, is a complex natural phenomenon that has plagued civil engineers since the beginning of modern civilization. Many notable scholars, including the famous geomorphologist Hans Einstein, have devoted their careers to the study of sediment transport. While research has yielded numerous empirical sediment load equations, the answers obtained from these equations vary considerably. A great deal of research is currently being devoted to this area and to the ultimate development of numerical three-dimensional (3-D) modeling tools.

In 1997 a U.S. patent was granted to the U.S. Army Corps of Engineers for a new applied engineering tool and methodology called micromodeling, which uses a small-scale physical model to simulate sediment conditions in rivers and streams. Since the introduction of micromodels in 1994 by the St. Louis District Corps of Engineers, the technology has been used to address a variety of sedimentation problems and issues, among them navigation design in the Mississippi River; restoration of side channels; bridge scour in rivers and streams; improvements to detrimental flow conditions at locks and dams; siltation at water supply intakes; and the effects of dredging.

Micromodeling was developed on the basis of years of observation and analysis of Mississippi River data, including hydrographic surveys, velocity data, ice photos, and channel sweep and multiswath bathymetry. Careful study of large physical sediment models used in Europe, Canada, and the United States also played an important part in the creating the technology. The goal was to develop a practical applied engineering tool that could supply realistic answers to sedimentation problems in a cost-effective and timely manner.

The same basic premise on which the majority of larger physical sediment



US ARMY CORPS OF ENGINEERS, ALL

TYPICAL SCALES *for micromodels have ranged between 1:15,000 and 1:600 horizontal and 1:1,200 and 1:100 vertical, with distortion ranging between 5 and 13. Distortion is necessary in most physical models to sufficiently move the sediment, inset. A micromodel was used in 1996 to develop fish and wildlife habitat in a side channel of the Mississippi called the Santa Fe Chute,* these pages.

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models operate—that small streams behave like large rivers—also informs micromodeling. The micromodel does not follow a stringent set of similitude laws; rather it focuses on the similarity between the response of the model bed and that of the bed or stream under study.

Typical scales for micromodels have ranged between 1:15,000 and 1:600 horizontal and between 1:1,200 and 1:100 vertical. Micromodel distortion has ranged between 5 and 13. Distortion is necessary in most physical models to sufficiently move the sediment. The scales are usually chosen on the basis of the scale of the particular river or stream under study, as well as the economics and practicality of containing the micromodel within the boundaries of a tabletop flume.

The first step is to create a scaled-down physical replica of the river or stream under study. For this task, engineers have some interesting modern-day composites at their disposal: lightweight plastic sediment; miniature, galvanized steel mesh structures; and oil-based clay for fixed and removable boundaries. A 3-D replica of the existing boundaries is first constructed by affixing detailed, high-resolution, georeferenced photographic maps to molded polystyrene and acrylic to form what is called a model insert. This insert, which represents the existing configuration or planform of the river or stream, is placed within a tabletop hydraulic flume. Plastic sediment is added, and any additional structures are carefully configured and set in their proper position using a 3-D digitizer.

The micromodels are made to behave like the actual river or stream through an empirical calibration or replication process. Water flow and sediment loads are first simulated on the model through a computer-controlled operation system, with bed forms such as point bars, scour holes, and crossings left to develop naturally within the physical channel boundaries of the inserts. Further adjustments to the micromodel slope, sediment load, discharge hydrograph, and entrance and exit boundary conditions will eventually cause the micromodel to reproduce a bed response similar to that of the actual river or stream under study.

Once the engineers achieve this replication, they can use the micromodel to make qualitative assessments about the effect of prospective design alternatives. They can realign channels or install such additional structures as dikes and underwater weirs within the micromodel. Through computer software, users of micromodels can adjust the discharge and corresponding sediment load at any time during the simulation by a simple click of the mouse.

Controlled automation and highly accurate measurement devices are the keys to this technology. The micromodels use integrated process control valves and durable centrifugal pumps to emulate a repeatable discharge/sediment response through the model channels. They are engineered to automatically run hydrographic simulations over any given time sequence.

An important feature of micromodeling is its dynamic sediment and flow equilibrium, which is obtained by a simple but clever reservoir and sediment filter chamber system contained under the tabletop model. The equilibrium of the model—the constant balance of sediment and flow entering and exiting the model—is needed to compare present and future conditions. The computer software is designed to coordinate the amount of water discharged into the micromodel with the sediment load. The automated system allows the user to return the micromodel to its initial condition after each design is studied, allowing an accurate comparison of alternatives.

To gauge the micromodel's bed response, a 3-D laser scanner is used to collect model bed bathymetry measurements. After each hydrographic simulation, the scanner collects hundreds of thousands of points over the bed of the model with tremendous speed and precision. The data are then processed, converted into real-world coordinates, and used to create high-resolution, colorized bathymetric maps. These maps are compared with the bathymetric field maps, hydrographic range surveys, channel sweep surveys, or multibeam surveys that were obtained from the actual river or stream.

Once engineers achieve calibration or replication in the tabletop model, they establish a base condition that will be used to compare all future design alternatives. A team of biologists, for example, might want to test the effects of removing a rock dike closure structure from the river, or a landowner might want to know the effects of a proposed dike design. Each of these alternatives could be implemented within the micromodel and simulated hydrographically on the computer. The resulting bed response would then be collected with the laser and compared with the base condition.

An unexpected benefit of micromodeling is that the technology has brought together a variety of specialists who until just a few years ago would have worked separately. "Engineers, biologists, riverboat pilots, landowners, recreation users, or anyone else who has a stake in the river or stream can now see almost instantaneously how their imposed plans will adversely or positively affect downstream conditions several miles away," says Butch Atwood, a fisheries biologist for the Illinois Department of Natural Resources.

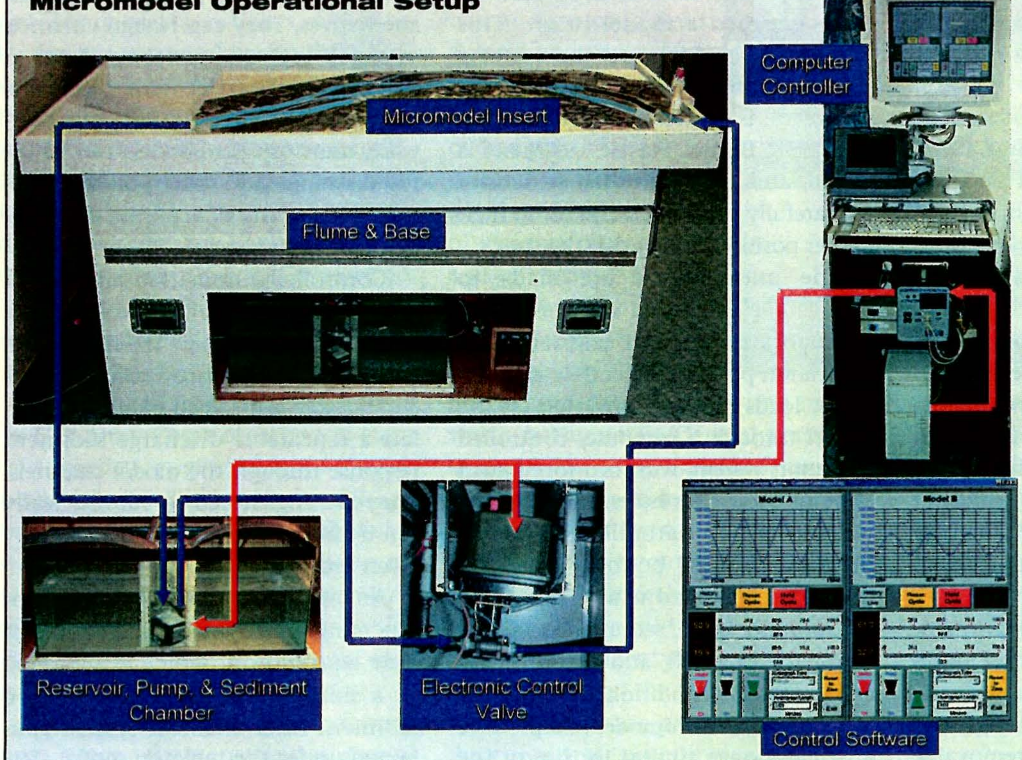
In 1997 a group of engineers, river pilots, lockmasters, and biologists constructed a micromodel at the Applied River Engineering Center in St. Louis to examine the causes of a navigation problem that historically has beset Lock and Dam No. 24, on the upper Mississippi River near Clarksville, Missouri. Between 1980 and 1995, more than 40 barge accidents occurred at the lock and dam. In most cases, barge tows approaching the lock chamber would encounter severe crosscurrents leading into the adjacent dam. Some tows became so misaligned with the lock chamber that barges would break apart, endangering not only the cargo but the crew as well. Barges have also crashed into the dam's adjacent tainter gates, causing significant structural damage. The incidents prompted the barge industry to add a helper boat in the early 1980s to aid tows entering the lock chamber.

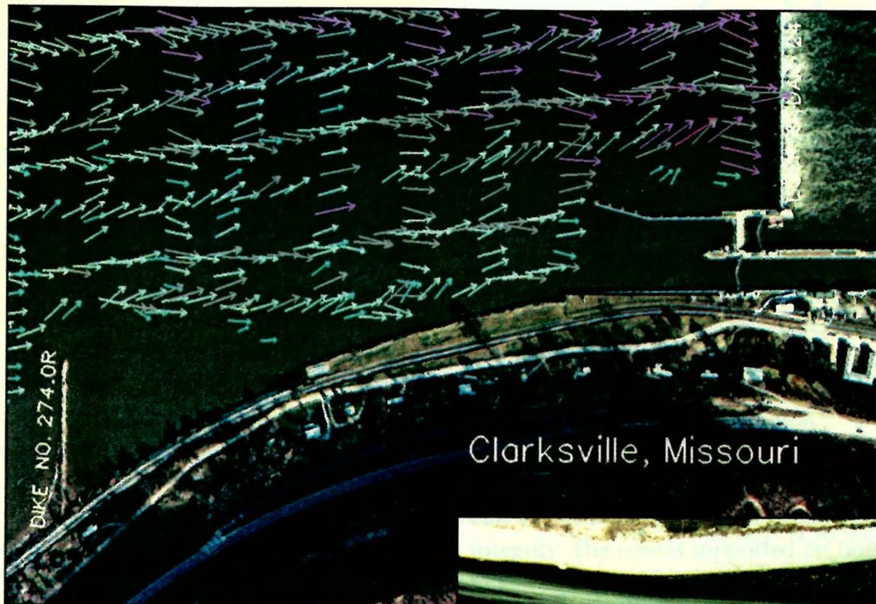
Prior to building a model, engineers collected velocity vector data in the Mississippi River to determine where and why the crosscurrents existed. An acoustic Doppler profiler, combined with photographic remote sensing of suspended sediment, enabled the engineers to determine that a rock bluff protruding into the river channel was causing the crosscurrents to occur approximately 600 ft (182 m) upstream of the dam.

A micromodel was created using the collected velocity data and hydrographic surveys from the Mississippi River. The research team studied 30 structural alternatives. The most effective and economical design called for the installation of four underwater weirs in the navigation channel, as well as the extension of an existing dike. The micromodel showed that this plan would abate the crosscurrent pattern developed off the upstream bluff and significantly improve navigation conditions at the lock.

"The micromodel enabled

Micromodel Operational Setup





AN AERIAL *shot of the upper Mississippi River near Lock and Dam No. 24 with superimposed computerized vectors showed that a protruding rock bluff was causing crosscurrents that interfered with barge navigation,* left. *Flow visualization showed that a dike extension and four underwater weirs in the navigation channel could moderate the currents,* below.

towboat pilots to gain a clear understanding of the proposed changes to flow patterns from the design alternatives," says Tommy Seals, the chairman of the River Industry Action Committee in St. Louis. "The model also allowed pilots and port captains to test their own ideas and supply their particular insights to the engineers while observing the model."

The dike extension was placed in the river in 1998, and the underwater weir construction is planned for 2000. Immediately after the dike extension was installed, pilots and lock personnel noted a marked improvement in the currents. Flow conditions have improved so much that many tows are now navigating into the lock without a helper boat.

Micromodeling was also used in 1996 by a team of engineers and biologists from the Corps of Engineers, the U.S. Fish and Wildlife Service, the Missouri Department of Conservation, and the Illinois Department of Natural Resources. In this case, a model was used to develop fish and wildlife habitat in a side channel of the Mississippi referred to as the Sante Fe Chute without adversely affecting depths in the adjacent navigation channel.

The team used a micromodel to determine the sensitivity of flow and sediment distribution in the river. Team members learned that forcing more flow down the side not only compromised the adjacent navigation channel, but also brought more sediment into the side channel. "Seeing the impacts occur in the model made me much more comfortable than having an engineer merely tell me what the impacts would be," says Joyce Collins, a fisheries biologist for the U.S. Fish and Wildlife Service.

After numerous design tests conducted in the micromodel, the team agreed to construct nine alternating dikes in the side channel. According to the model, the strategically placed dikes would generate a sinuous flow pattern down the side channel, which would create small scour holes at the end of each dike. Scour holes are desirable because they create flow and depth diversity, which encourages wildlife.

Three years after the dikes were constructed in the Santa Fe Chute, field bathymetry shows that the river's actual response is very similar to that predicted by the model. The program's success has spawned several more environmental side channel studies on the Mississippi River, in addition to some construction.

Additional research is currently being conducted by the Corps of Engineers to study the full range of potential applications of micromodeling. So far the technology has been used primarily in studies for the federal government. Despite its limited use, each new micromodeling project helps bridge the gap between sedimentation theory and practice and facilitates a better relationship between engineers and other parties concerned with the quality of our streams and rivers. ▼

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