Experimental Flooding in Grand Canyon

Scientists monitor a controlled deluge that was staged in the early spring of 1996 solely for the benefit of the environment in and around the Colorado River

by Michael P. Collier, Robert H. Webb and Edmund D. Andrews

For more than three decades, Glen Canyon Dam has impounded the flow of the Colorado River above Grand Canyon, the vast winding chasm in America's southwestern desert that ranks as one of the wonders of the natural world. Although many people recognized that damming the flow would destroy the river upstream, few anticipated that there might be serious environmental consequences downstream. But over the years, scientists, government officials and professional river guides have become increasingly aware of troubling changes within Grand Canyon.

These alterations have occurred because the dam replaced the Colorado's natural pattern of forceful summer flooding with a gentle daily ebb and flow dictated entirely by the electrical power demands of distant cities. The dam thus eliminated the normal seasonal variation in river flow and ended the immense floods that had annually washed through the canyon. Although these floods had lasted only a few weeks of the year, they had been the principal force

sculpting the river corridor. The floodwaters routinely stripped all but the highest vegetation from the channel banks, deposited sandbars and plucked boulders out of rapids. After Glen Canyon Dam went into service, exotic flora encroached, sandbars disappeared and boulder piles clogged the main channel.

So as dozens of scientific observers (including the three of us) made ready, the secretary of the interior, Bruce Babbitt, launched a bold experiment in environmental restoration at 6:20 A.M. on March 26, 1996, opening the first of four giant "jet tubes" at Glen Canyon Dam. Over the next nine hours, the other three tubes and the eight hydroelectric turbines added to the torrent, which grew to 1,270 cubic meters per second—a discharge 50 percent greater than the maximum flow through the turbines alone. As the surge of water mounted, the surface of the river rose five meters higher than usual. In all, 900 million cubic meters of water coursed through the canyon during the weeklong experiment. Never before had an intentional flood been released specifically for environmental benefit, and we were eager to help assess the results.

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A Changed River

Along with many other scientists who monitored the experimental flooding, we have been aware that conditions in the canyon had been evolving dramatically since Glen Canyon Dam began operations in 1963. After construction of the dam, virtually all sediment coming from upstream was trapped above the dam, in the newly created Lake Powell, and most sandy beaches in Grand Canyon began slowly but steadily to vanish. By the time the test flood was planned, some rapids in the river had become so obstructed by coarse debris swept down from side canyons that particular stretches had become extremely difficult to navigate. The bridled river did not have sufficient power to clear away the boulder-filled deposits. Many people familiar with the canyon had also observed dramatic alterations to the vegetation since the dam was built. Native coyote willow, as well as exotic tamarisk, camelthorn and even bermuda grass, took root on beaches that had previously been bare. Mature mesquite trees growing at the old high waterline began to die.

But not all changes brought about by the damming of the river were obviously undesirable. Trout—which did not live there before in the relatively warm, turbid waters of the free-running river—flourished in the cold, clear water below the dam. Stabilization of flow favored trees and shrubs on the riverside, which provided new homes for some endangered birds. The green ribbon of new vegetation made the once barren canyon appear more hospitable to other kinds of wildlife as well—and to countless campers who traveled the river for recreation.

Indeed, the many beneficial changes to the canyon ecosystem may have diverted attention from some of the more disturbing trends. It was not until 1983 that many scientists and environmentalists took full notice of the important role that floods originally played in shaping the canyon. In June of that year, a sudden melting of the winter snowpack rapidly filled Lake Powell and forced the operators of Glen Canyon Dam to release water at a rate of 2,750 cubic meters per second. This flow was far smaller than some recorded flood episodes, but it still constituted a momentous event.

This emergency release in 1983 required the first use of the "spillways"—giant drain tunnels carved into the walls of Glen Canyon alongside the dam. The operators of the dam had at first been dismayed—and then gravely concerned—to see the outflow turn red as swiftly moving water plucked first concrete and then great blocks of sandstone from the spillway tunnels. Some feared that destruction of the spillways could catastrophically undermine the dam. Fortunately, the crisis passed, and engineers were able to redesign the spillways to minimize "cavitation." This phenomenon (formation of a partial vacuum within a moving liquid) had sucked material from the tunnel walls and caused them to erode with startling speed.

The downstream effects of the 1983 flood also took others by surprise. When the waters receded from the flooded banks, scientists and guides familiar with the river were stunned to see many of the formerly shrunken beaches blanketed with fresh sand. The flood had killed some exotic vegetation that had grown artificially lush and had also partially restored riverine animal habitats in many spots. Had several years of ordinary dam operations followed, many people would have hailed the 1983 flood for improving conditions in the canyon. Instead runoff in the Colorado River basin during the next three years remained quite high, and the operators of Glen Canyon Dam were forced to release huge amounts—an average of 23 billion cubic meters of water every year. Flows commonly reached 1,270 cubic meters per second, for at least brief periods, each

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JETS OF WATER (*opposite page*) emerge during the experimental flood from four steel drainpipes built into the base of Glen Canyon Dam (*right*). The water stored in the adjacent reservoir, Lake Powell, can also flow through the hydroelectric turbines situated underneath the dam or, if there is urgent need to lower the lake, through the two "spillway tunnels" carved into the canyon walls (*visible at right, below the dam*).

year through 1986. The beaches that had been built up in 1983 soon washed away. A single flood, it seemed, could create beaches; frequently repeated floods could destroy them.

Time for Another Flood?

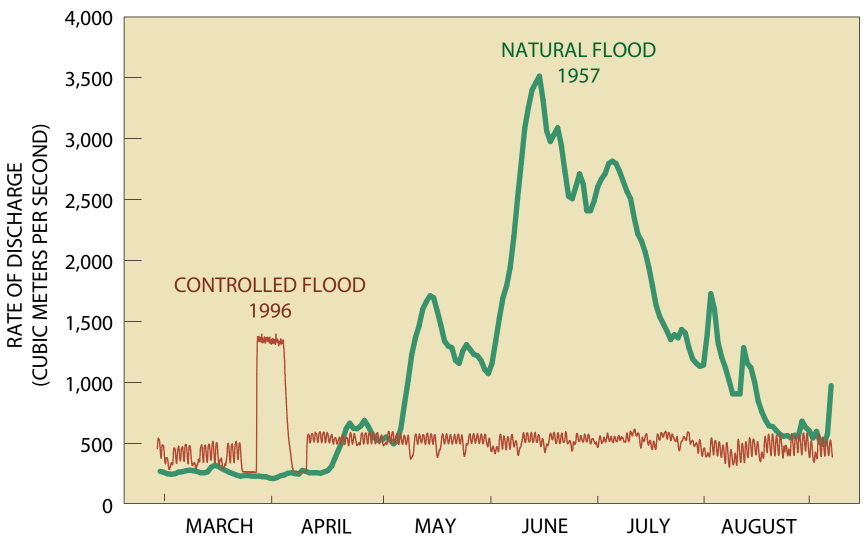
As scientists learned more about risks and benefits of flooding in the canyon, many of those interested in the fate of the river began to recognize the need to restore flooding of some type. Most geologists who had studied the movement of sediment by the Colorado River were convinced that an artificial flood would benefit the canyon, and they began championing that idea within the scientific community in 1991. But during discussions, some biologists worried aloud that a flood would jeopardize the gains that had been made within the canyon by several endangered species. A few geologists, too, were concerned that the beaches nearest Glen Canyon Dam might be inadvertently washed away. And anthropologists working in the canyon expressed concern that new flooding would accelerate erosion and threaten the integrity of archaeological sites next to the river.

Yet the overall sentiment was that purposeful flooding would be more beneficial than harmful and should be arranged. By 1993 the murmurs in favor of a flood had turned to shouts. Some of the loudest voices came from river guides who were being forced to find camping sites on smaller and smaller beaches—despite the fact that millions of metric tons of sand were reaching the Colorado every year by way of its two main tributaries below the dam, the Paria and Little Colorado rivers. Under the normal operating regime of Glen Canyon Dam, only 450,000 metric tons of this sand wash downstream and out of Grand Canyon. So sand was filling the canyon, but it was not accumulating on the banks. Rather it was settling out of sight on the bottom of the river.

Along with others at the U.S. Geological Survey (USGS) and the Bureau of Reclamation's Glen Canyon Environmental Studies program, we were certain that a flood would stir up these deposits and drape them along the banks, just as the river had done before the dam had reined it in. But what sort of flood would be most appropriate? The people debating that question agreed that the best time of year for an initial test would be during a narrow window in late March, when fish were least likely to be spawning and troublesome tamarisk plants would not yet be able to germinate. A date at that time would also assure that most bald eagles and waterfowl that had wintered in the canyon would have already left. Still, the optimum choice for the size of the flood remained elusive.

One reason for that difficulty was that the quantity of sand moved by a river varies quite strongly with the rate of discharge: when the discharge rate doubles, the flux of sand increases eightfold. Consequently, for a given flood volume, more sand will be stirred up and deposited on the banks by a large flood that runs for a short time than by a lesser flood of longer duration. One of us (Andrews) argued for a release at the rate of 1,500 cubic meters per second, which would have been close to two thirds the size of the typical annual flood before the dam was built. After all, if the goal was to restore a critical natural process, why not try roughly to approximate that level?

But there was an important logistical constraint: flows greater than 1,270 cubic meters per second through the dam would require the use of the spillways. Despite having made repairs and improvements, officials at the Bureau of Reclamation were reluctant to risk repetition of the frightening experience of 1983. Restricting the flood to 1,270 cubic meters per second would also minimize the threat to an endangered species of snail that lived near the dam. Most proponents of flooding felt that this level was a reasonable compromise. They



SOURCE: Robert H. Webb

JENNIFER C. CHRISTIANSEN


MICHAEL P. COLLIER

DISCHARGE of water during the experimental flood of 1996 may have appeared extremely powerful (*photograph*), but the flow maintained for that one week is dwarfed by natural events of the past, such as the flood of 1957 (*chart*), which endured for much of the spring and summer.

agreed that the flood would last one week—enough time to redistribute a considerable amount of sand but not so long as to deplete all sand reserves at the bottom of the river.

On the eve of the test, our biggest fear was that the water would not have the power needed to build sizable beaches. But John C. Schmidt, a geologist at Utah State University who had also favored the flooding experiment, had a bigger concern. He worried that something might unexpectedly go wrong: Would scientists in their arrogance ruin what was left of the heart of Grand Canyon?

On a Rising Tide

On March 26 the flood began on schedule. The waters of the river rose and raced down the canyon. On signal, scientists from the USGS released 30 kilograms of a nontoxic fluorescent dye into the river a short distance downstream from the dam. They used the chemical to track the velocity of the water by measuring the arrival of this dye at six sites spaced throughout the canyon, where they had placed sensitive fluorometers. A numerical model developed by researchers at the USGS accurately predicted the progress of the flood. The model and measurements showed that the floodwaters accelerated as they ran through the canyon, pushing riverwater so far ahead that the first crest reached Lake Mead at the downstream end of the canyon almost a day before the actual waters of the flood arrived.

On its way west to Lake Mead, the flood reshaped many parts of the river. For example, at a stretch of rapids called

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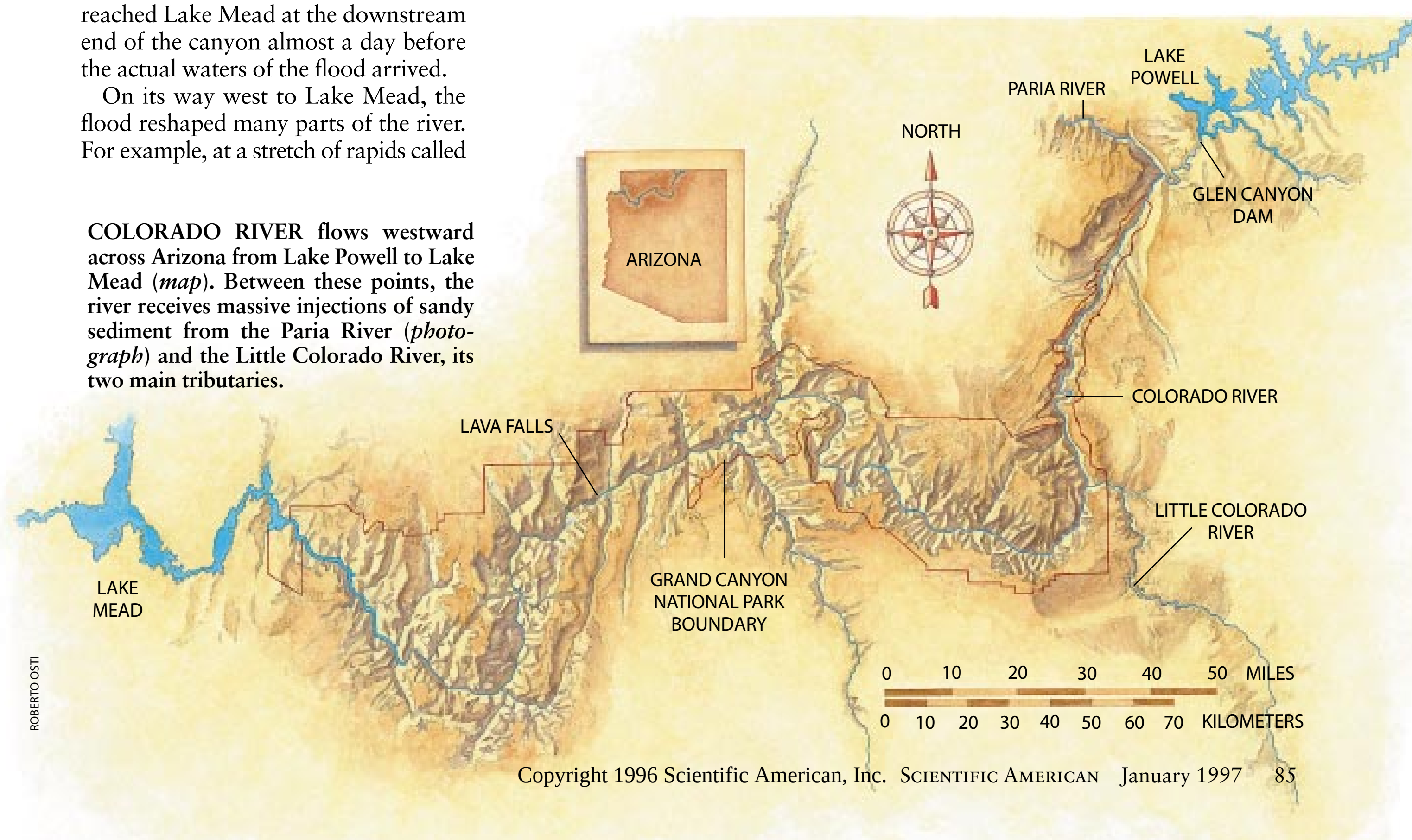
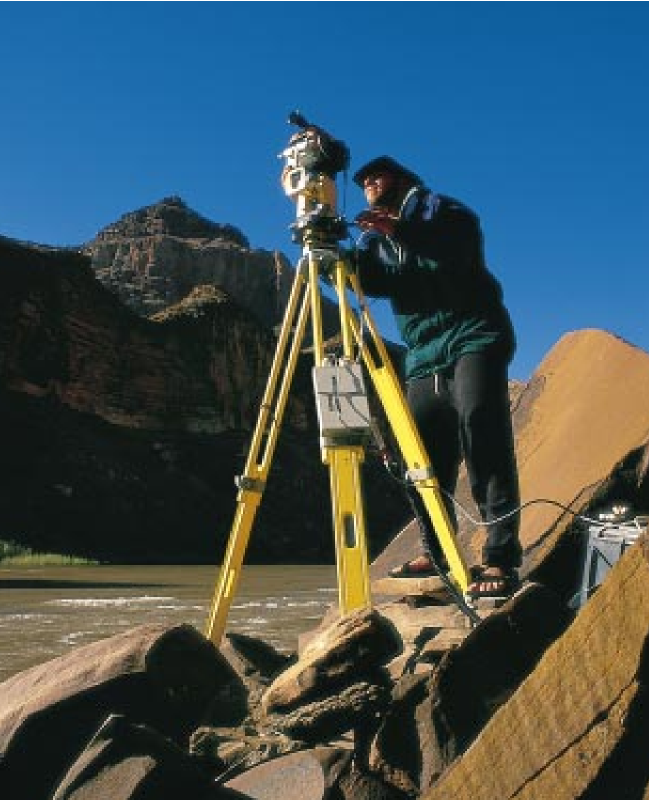


ROBERTO OSTI

COLORADO RIVER flows westward across Arizona from Lake Powell to Lake Mead (*map*). Between these points, the river receives massive injections of sandy sediment from the Paria River (*photograph*) and the Little Colorado River, its two main tributaries.



PHOTOGRAPHS BY MICHAEL P. COLLIER

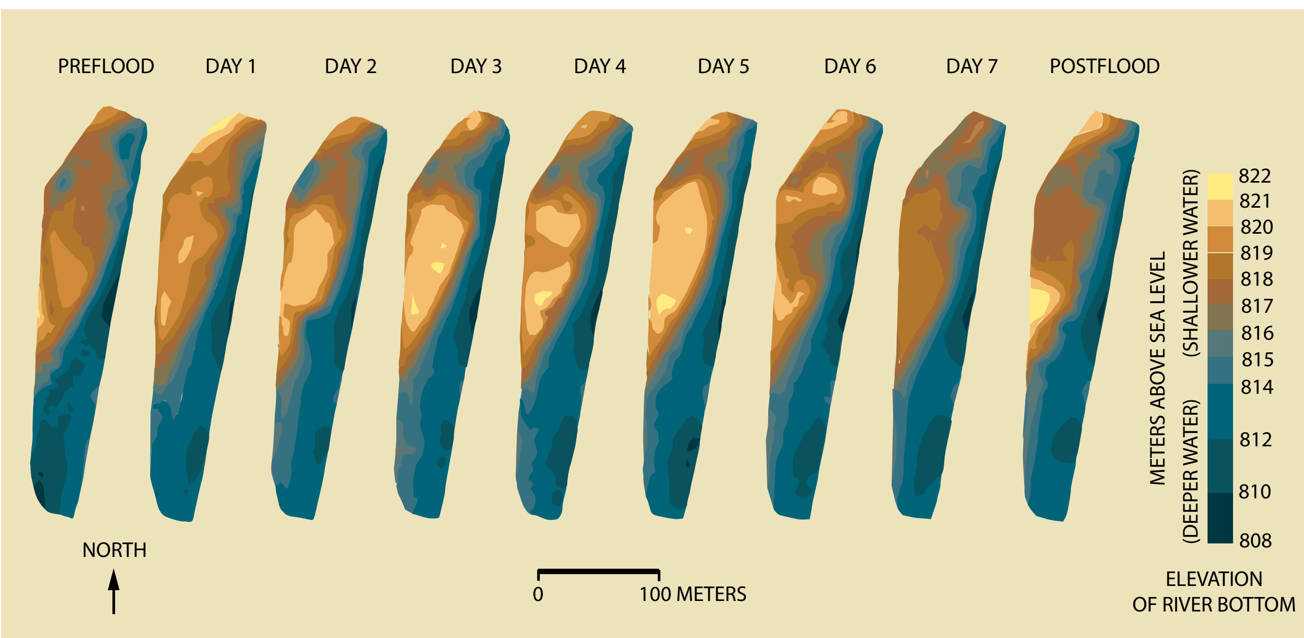
Lava Falls, about 300 kilometers below the dam, the river rose against a fan-shaped bank of loose mud and boulders that had been formed one year earlier after a debris flow roared down a small side canyon. The material deposited by that cascade of rock and mud had narrowed the Colorado—normally 50 meters wide there—by almost 20 meters. Although some geologists had previously concluded that very large floods would be required to clean out such constrictions, we believed this flood would be sufficient to do the job.

And so we were quite pleased to see just how effective the experimental flood proved. As discharge of the river surpassed 850 cubic meters per second at Lava Falls on March 27, the energized water quickly cut through the new debris fan, reducing its size by one third. We studied that event by placing radio transmitters in 10 large stones positioned originally near the top of the rapids. Despite their considerable size (up to 0.75 meter across), all 10 rocks traveled downstream during the flood. Using directional antennas, we subsequently located eight of the boulders. The great stones had moved, on average, 230 meters.

Besides tracking boulders at Lava Falls, we worked with several colleagues to measure the deposition of sand at some other key locales. For those studies, we chose five eddies—places where the river widens abruptly, and water swirls upstream near the banks. Employing laser tracking equipment and a small boat equipped with a sonar depth finder, we charted the sandy bottom during the flood. The results were quite surprising. We found that a great deal of sand accumulated in the first 36 to 48 hours. But as the influx of sand slowed, the bottom of the eddy began to lose sand back into the main channel.

This behavior initially puzzled us, but after we examined the measurements more carefully, we realized that much of the sediment had originally settled above its so-called angle of repose, an unstable configuration that resulted in some newly deposited sand slumping

SAND DEPOSITION within an eddy, a place where water swirls in the upstream direction near the banks, raised the bed of the river along one margin (*tan areas in diagrams*) in the first days of the flood. Later during the flood, much of that sand escaped back into the main channel (*blue areas in diagrams*). To collect this record of sediment accumulation and removal, a boat fitted with an acoustic echo sounder (*photograph at left*) measured the depth of the water, and surveying equipment on land tracked the position of the boat (*photograph at top*).

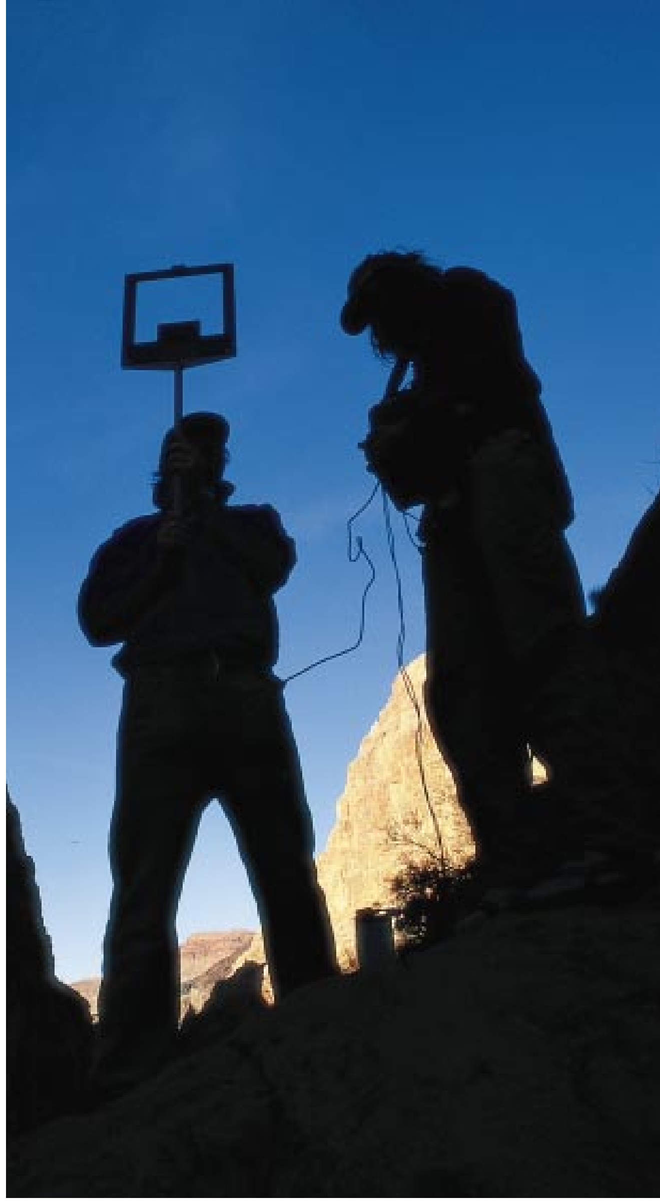


JENNIFER C. CHRISTIANSEN; SOURCE: CHRISTOPHER E. JOHNSTON back into the main channel. Still, we found that the overall amount of sand after the flood had increased in all five places we mapped.

Many other scientists made important observations during the course of the flood. Near the lower end of Grand Canyon, our colleague J. Dungan Smith measured the velocity of the river and concentration of sediment held in suspension by the turbulent water. His goal is to compare the quantity of sediment washed out of the canyon during the flood with the amount normally delivered into the canyon by the Paria and Little Colorado rivers. Smith is still analyzing his data, but he should soon be able to predict how often floods could be staged without depleting the existing sand reserve.

Several other scientists took special interest in the movement of sand. Using optical sensors and sonar equipment borrowed from his oceanographer colleagues at the USGS, David M. Rubin studied the sediment concentration of water entering an eddy and characterized the fine-scale patterns in the deposition of this sand. Working at the same site, Jon M. Nelson documented the curious behavior of swirling vortices that form in a line where the main downstream current rushes past a slower, upstream-flowing eddy. Nelson observed that as the main current pushes these vortices downstream, the vortices tip over, because flow is slowed near the channel bottom where friction is greatest. In this canted position, he reasoned, the vortices should then act to sweep sediment out of the main current and into the eddy.

But sediment came and went within the eddy at rates far greater than anticipated. With a sinking feeling, Rubin and Nelson watched as $70,000 worth of borrowed equipment was first buried, then excavated and finally carried away by the water. They were fortunate enough to have collected sufficient data to show that the vortex "sediment pump" operated as they had predicted. So their ideas withstood the test flood, even though much of their equipment did not.



SCIENTIFIC STUDIES carried out during the experimental flood included documentation of fine-scale patterns of sand deposition using plaster molds (*bottom right*), time-lapse videography of the floodwaters (*bottom left*) and measurement, by means of a directional antenna (*top right*), of the displacement of boulders that were fitted with radio transmitters.

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As expected, a good deal of the newly deposited sand quickly eroded, but months later much of it still remained at those sites monitored by scientists—and at many other places as well. During the summer of 1996, many longtime observers believed the Colorado River had taken on something of its original appearance. Those impressions echoed the more careful assessment of Lisa H. Kearsley, a biologist working for the Bureau of Reclamation. She tracked the fate of almost 100 beaches throughout the canyon and concluded that 10 percent of them were diminished by the flood, whereas 50 percent were augmented, and the remainder were unaffected. Six months after the flood, she found that much sand had slipped back into the river, but there was still more beach area than before.

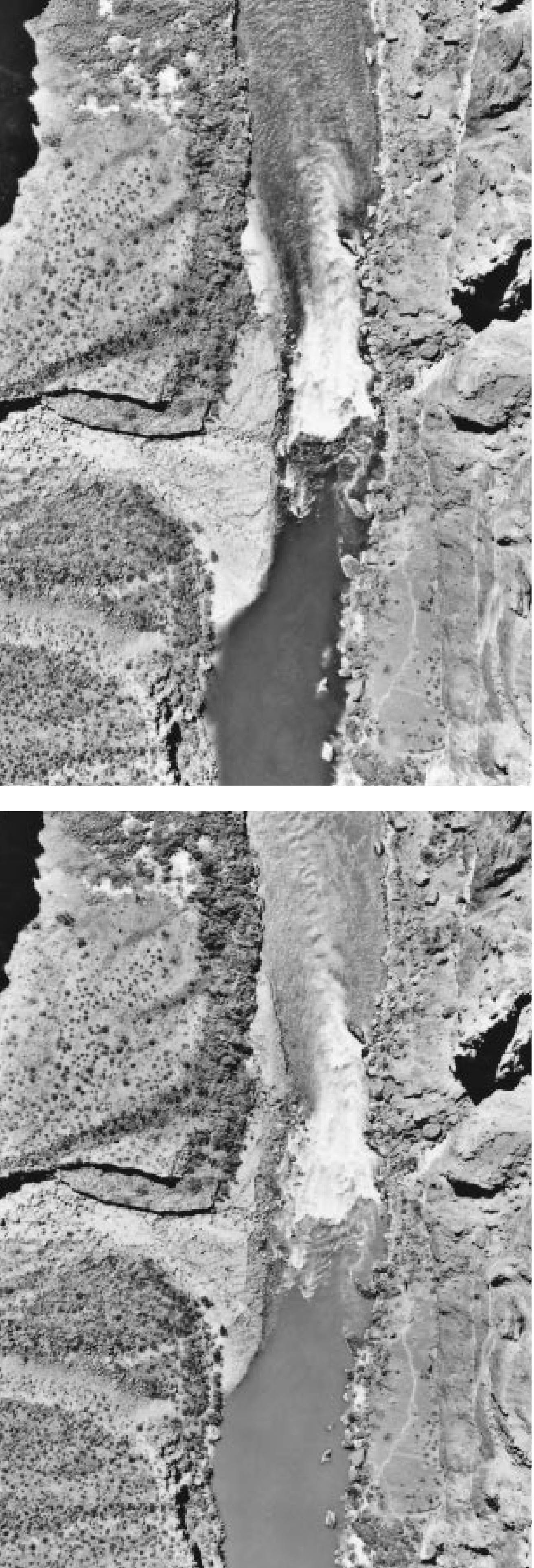
The expanded beaches should please campers in years to come, but scientists are also anxious to know how the flood might have affected many less vocal residents of the canyon. Because the earlier unintentional flood of 1983 had hurt the trout fishery, some biologists were particularly concerned that the experimental flood of 1996 would wash many fish far downstream. To find out, biologists stationed below Lava Falls during the experimental flood placed nets in the river. These scientists captured a few more trout than they would have otherwise done, but their tests did not show any flushing of native fishes, whose ancestors had, after all, survived many larger natural floods. The biologists surmised that the native species (and most of the trout) must have quickly retreated to protected areas along the riverbank. Other investigators determined that the floodwaters had hardly disturbed the ubiquitous cladophora algae and associated invertebrates, which constitute an important source of food for fish.

But the effects on other components of the local biota are still a matter of intense debate. Lawrence E. Stevens, a biologist with the Bureau of Reclamation, has studied the river for 25 years as an entire suite of animals—some endangered—migrated into the canyon and survived in the artificial environment created by Glen Canyon Dam. He is concerned that intentional flooding may threaten the existence of some species protected by the Endangered Species Act, such as the humpback chub (a fish), the southwestern Willow Flycatcher (a bird) or the Kanab ambersnail. But we would argue that floods were part of the natural cycle of the Colorado River in the past, and many species, both common and endangered, have adapted to this process as long as there has been a Grand Canyon—for about five million years. Restoration of flooding may be detrimental to some organisms, but we and many of our colleagues hypothesize that in the long run a collection more resembling the native fauna will return.

Epilogue

Did the flood work? It deposited significant amounts of sand above the normal high-water line and rejuvenated some backwater habitats important to spawning fish. The flood widened the two largest rapids on the river. Archaeological sites along the edge of the river were neither helped nor hurt by the high water; most of the encroaching vegetation was similarly unaffected.

So in our view the environmental benefits outweighed any damage. But one needs to consider other costs as well. Five months after the flood, David A. Harpman, an economist with the Bureau of Reclamation, was analyzing factors that bear on the final price tag. Because power had been continuously generated during the flood even at times when demand was low, and because the huge quantity of water sent through jet tubes produced no electricity at all, he



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GLEN CANYON ENVIRONMENTAL STUDIES

LAVA FALLS, a stretch of rapids in the Colorado, was narrowed by coarse, rocky material that had washed down a side canyon and spread into a fan-shaped deposit. An aerial photograph taken before the flood (*top left*) shows an obvious constriction in the river. A matching photograph taken after the flood (*bottom left*) reveals that much of the debris has been cleared away.

REJUVENATED BEACHES, such as the one enjoyed by these kayakers, signal that the flood restored habitats along the river's edge to a more natural configuration. Such changes should, for example, benefit native fish, which spawn in the shallows.

estimates that the Bureau of Reclamation has foregone about $1.8 million in lost revenue (about 1 percent of the total yearly income from the sale of electricity). Add to this expense the price of the scientific studies, and the total cost of the experiment almost doubles.

Because similar expenditures will be incurred during future floods, the Bureau of Reclamation will want to know precisely how big and how often floods will be needed to support the environment. The answers are far from clear. All scientists involved agree that a future flood need not last seven days. Smith believes Grand Canyon beaches can be improved by floods staged perhaps every year, as long as incoming sediment from the Paria and Little Colorado rivers is at least as great as the amount of sediment carried out of the canyon during a flood. One of us (Webb) argues for an initial release of as much as 2,800 cubic meters per second to scour debris fans, followed by an immediate drop to more moderate beach-building levels. Andrews emphasizes that under any scenario, artificial floods should be made to vary in magnitude from year to year, the better to mimic natural variability.

Will there be more floods? Probably—both in Grand Canyon and elsewhere. We have studied several other American rivers controlled by dams, and they, too, would benefit from periodic floods. So the ideas and instrumentation developed by scientists working within Grand Canyon during the 1996 experimental flood could soon help restore natural conditions within and around many other rivers across the nation and, perhaps, throughout the world.

The Authors

MICHAEL P. COLLIER, ROBERT H. WEBB and EDMUND D. ANDREWS have long cherished the splendor of Grand Canyon. Collier, who considers himself a writer and photographer rather than a true scientist, also maintains an active medical practice in Flagstaff, Ariz. He earned a master's degree in geology from Stanford University in 1978 and worked for six years as a river guide in Grand Canyon before he began collaborating with U.S. Geological Survey scientists. Webb received a doctorate from the University of Arizona in 1985 and then joined the staff of the USGS as a hydrologist. Since 1989 he has also taught at the University of Arizona. Andrews worked as a river guide in Grand Canyon from 1969 to 1974. Three years later he earned a doctorate from the University of California, Berkeley, and has since done research for the USGS in its water resources division. Andrews also maintains an ongoing affiliation with the University of Colorado at Boulder.

Further Reading

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