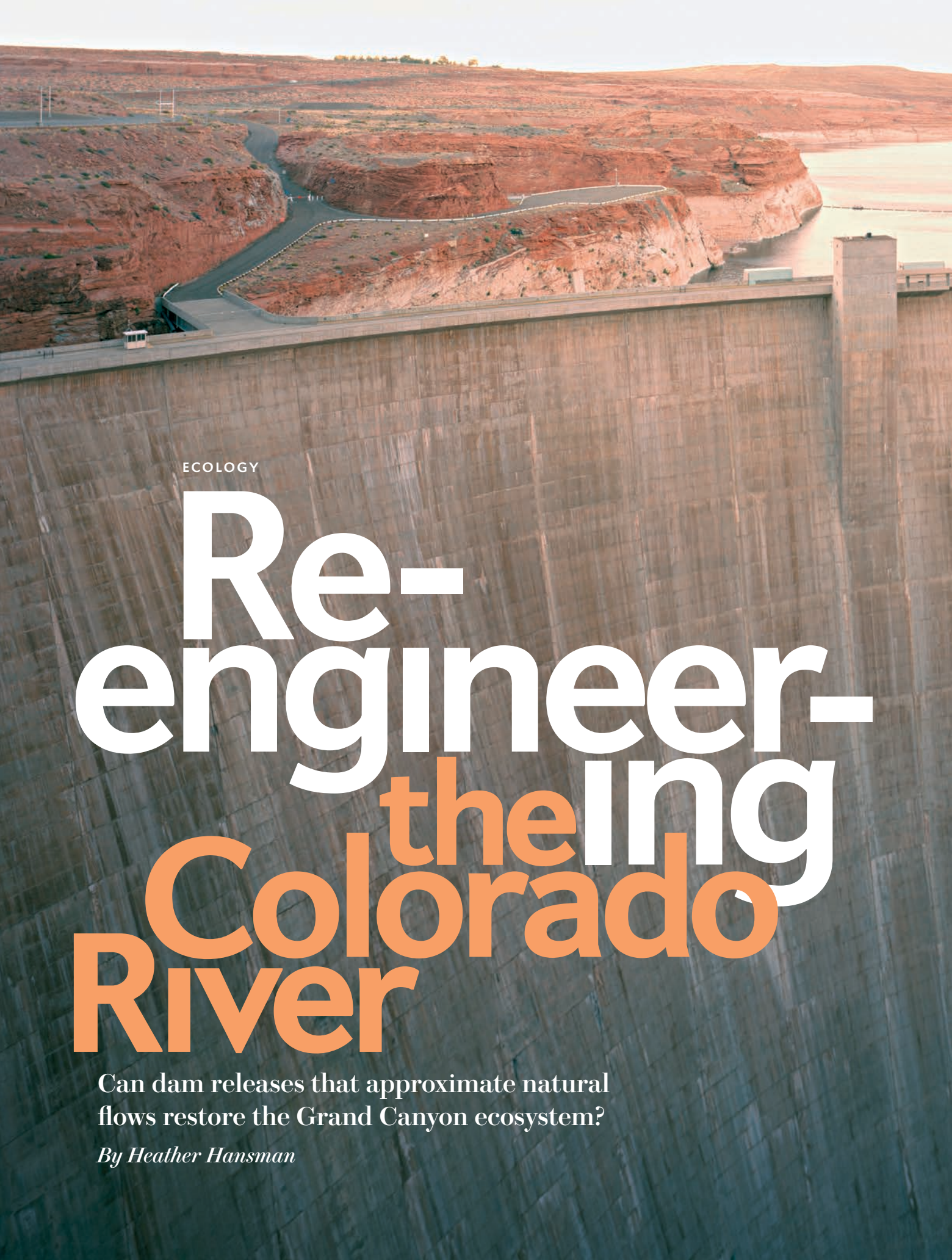

ECOLOGY

Re-engineering the Colorado River

Can dam releases that approximate natural flows restore the Grand Canyon ecosystem?

By Heather Hansman

THE GLEN CANYON DAM in Arizona creates hydropower by controlling releases from Lake Powell, the second largest reservior in the U.S.

ON WEEKDAY EVENINGS, MILLIONS of workers return to their homes across the American Southwest and turn on their air conditioners, microwaves and televisions. From Tucson to Burbank, power needs surge. Meeting this demand begins at 5 or 6 A.M. inside the Glen Canyon Dam, the chip of concrete that plugs the Colorado River just above the Grand Canyon. At noon, an average peak of 14,000 cubic feet of water per second is churned through eight turbines, then released.

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Artificial tides oscillate downstream where the canyon gorge is steep and narrow for more than 200 miles, sluffing the sandstone banks and sluicing fish out of eddies. These flows are calculated and controlled at all times by the U.S. Bureau of Reclamation, sometimes doubling in volume as the water moves downstream. Raft guides who lead trips down the Colorado know to stake their boats high and leave lots of rope for them to float, so that they do not get stranded in the morning as the levels go down overnight. The river, they know, is constantly changing.

If you were boating or fishing on the Colorado in the summer of 2018, however, you might have noticed that days passed without any tides at all. In a rare opportunity for scientists who are trying to better understand the river ecosystem, the Bureau of Reclamation was releasing steady flows of 8,000 cubic feet per second through summer weekends. Aquatic biologist Ted Kennedy and his team from the Grand Canyon Monitoring and Research Center (GCMRC) wanted to see if holding the river at a consistent level would aid the struggling native bug population, 85 percent of which lay their eggs in the intertidal zone. Those eggs can get wet, but they cannot get dry; eggs laid at high tides desiccate within an hour of the water dropping.

Bugs might seem like a lowly thing to focus on. But they form the basis of a complex food web. When their numbers drop, that reduction affects species, such as bats and endangered Humpback Chub, that feed on them. In a national park held up as an iconic wild, Kennedy and his team are trying to figure out why, according to their research published in 2016 in *BioScience,* the Grand Canyon section of the Colorado has among the lowest insect diversity in the country. "There are more bugs in the Detroit River," says Jeff Muehlbauer, a biologist in Kennedy's laboratory.

Last summer the researchers were testing whether adjusting dam releases so that the Colorado runs closer to its natural course might help insect populations recover. In those tests they artificially created the kind of flow patterns that allowed life to flourish before the dam went in—without removing the dam itself.

Nearly forty million people depend on the Colorado for the necessities of daily life, including electricity, tap water, and irrigating 10 percent of land used for U.S. food production. Ever since Glen Canyon Dam opened in 1963, the river has been engineered to accommodate these demands. Doing so changed the the ecosystem balance, which was dependent on ingredients such as sediment, snowmelt and seasonal flows. For more than than 30 years researchers have been trying to figure out how to help the ecosystem coexist with human needs, and they are finally beginning to test some solutions. By working out an experimental flow schedule that minimally impacted power generation, the 2018 bug tests marked one of the first times that dam operations were adjusted for species health in the Grand Canyon.

Meanwhile, though, the river is dwindling. The Colorado River Basin has been in a drought for almost two decades; 2018 was the third-driest year ever recorded. Since 2000, ambient temperatures in the basin have been 1.6 degrees Fahrenheit warmer than 20th-century averages, and researchers predict they will reach up to 9.5 degrees F hotter still by 2100. The effects of climate change could decrease river flow by as much as half by the end of the century. With earlier snow melt and more evaporation, the Bureau of Reclamation has predicted that it may have to cut the amount of water it sends downstream for the first time—as soon as 2020. That will stress every part of the system, from hydropower and city water supplies to native fish populations. It will also mean less room for experimental flows, a tool the scientists think is critical for understanding how to protect the canyon.

IN BRIEF

Nearly forty million people rely on the Colorado River for water and power, and its flow is engineered to maximize those resources. But the ever changing releases from the Glen Canyon Dam have harmed the Grand Canyon ecosystem.

In 2018 researchers tested consistent dam releases that allowed the river to run more "naturally." They are trying to understand how to bring back native insect populations—and restore ecosystem health—without disrupting energy production.

But as the result of climate change, decreased snowfall and increased evaporation mean there is less water available for experimental flows. As new research informs management of the Colorado River, the Western U.S. is preparing for water cutbacks.

PRECEDING PAGES: MICHAEL HALL *Getty Images*

The insect research is a meaningful step toward sustaining the river for habitat as well as humans. It also runs straight into a core conflict between science and Colorado River policy: scientists want the flexibility to experiment, whereas power and water managers want stability. As the Colorado dries up, this conflict will intensify. And yet if Kennedy and others can show that changing the flow can bring back insect populations, it could make ecosystem health a bigger priority for those who manage the most used river in the West.

THE LAW OF THE RIVER

AS SOON AS THE PENSTOCKS CLOSED on the Glen Canyon Dam in 1966, it became clear that the fragile, federally protected downstream ecosystem of the Grand Canyon National Park was unexpectedly altered. Inconsistent, sediment-depleted flows scoured sandbars, a significant habitat structure for native plants such as coyote willow and arrowweed. The clear, 48-degree-F water, released from the depths of Lake Powell, stressed endangered fish, which were adapted to silty, 80-degree-F flows. Very little was known about the interconnectedness of such elements before the dam went in, so these changes came to bear without forethought for the consequences.

It was not until 1989, after scientific evidence from an initial 1982 assessment and under pressure from both the public and agencies such as the National Park Service, that the secretary of the interior asked for the first Environmental Impact Statement on the dam. The results, finalized in 1995, confirmed that endangered species and valuable resources were being affected, but the Department of the Interior did not have enough data to quantify how much things were changing. Information found during that investigated sparked the 1992 Grand Canyon Protection Act, which required the Bureau of Reclamation to maintain both hydropower and natural habitat while managing the dam.

To uphold the act, in 1996 the Bureau of Reclamation formed a federal advisory committee to guide dam operations. Called the adaptive management program (AMP), it is made up of 25 stakeholders who represent groups that have legal rights to the water or depend on the canyon economically. They include the Hualapai Tribe, whose reservation runs 108 miles along the river and Grand Canyon; Western Area Power, which provides power to customers in 15 states; and the tourism industry, which brings $938 million to the local economy. Adaptive management, a term coined by fish biologists in Canada in the 1970s, is the practice of changing management decisions based on ongoing research. In other words, it is learning by doing. The Glen Canyon AMP was the first time that adaptive management had been applied to a federal project with so many stakeholders.

Exactly how the dam, drought and other variables stress the Colorado River ecosystem had long been poorly understood. Shifts in water temperature, flood timing, sediment suspension, chemical composition and species diversity all respond to one another. “You can’t pull one string and not expect it to change,” Kennedy says. So, in 1995, as part of the AMP, the U.S. Geological Survey created the Grand Canyon Monitoring and Research Center to investigate those impacts and serve as the sole science voice among its powerful group.

Under the aegis of the USGS, the geologists, hydrologists, biologists, ecologists and other scientists of the GCMRC monitor the river and advise the AMP. During the past two decades the researchers have built a longitudinal data set to establish a baseline of life in the canyon. They devised experiments to explore declining fish populations and disappearing sandbars—all, ideally, without cutting into the needs of the other stakeholders. “Nobody had done ecosystem science and looked at the management of a dam before,” says Dave Wegner, a former Bureau of Reclamation ecologist who set up the GCMRC at its outset. “We were making it up as we went.”

It is easier to flexibly manage an ecosystem in the single-species fisheries where adaptive management was first conceived. In a nonlinear system as complex as the Colorado River, this iterative strategy is also a tension point—especially when any tweaks require consensus among 25 competing values. “We change something we can control, and then two things we can’t control very quickly change,” says geologist Ted Melis, deputy director of the Southwest Biological Science Center, which oversees the GCMRC. For instance, the GCMRC is currently trying to unpack a 1,000 percent increase in populations of predatory, nonnative brown trout since 2012. The spike happened at the same time as experimental high flows that were designed to build sandbars. But that is the point of adaptive management, Melis says: learning from the ecosystem shifts and responding to them.

LOOK TO THE BUGS

IN NOVEMBER 2017, several months before the weekend bug flow experiment began in the Grand Canyon, I joined Muehlbauer and David Goodenough, another researcher in Kennedy’s lab, to collect monthly samples of insect populations on the shore and in the river. If the GCMRC scientists can understand what is triggering the bug die-offs, they can explicitly show how factors such as flow and food webs are related—and why they must be considered in any management strategy for a rapidly changing future.

Kennedy has been studying Grand Canyon insects since 2002. He thinks that hydropeaking—that is, spiking flows up and down for power needs—is part of why scientists see minimal numbers of

Map by Mapping Specialists

midges and almost no mayfly, stonefly or caddisfly, all of which are prevalent on other Western rivers and were likely once abundant on the Colorado. His team modeled how insect egg-laying cycles responded to hydropeaking, and in 2016 the researchers released a paper hypothesizing that limiting the artificial tides created by dam releases—for even just for two days in a row—would give bugs enough time to reproduce. Now Kennedy and his team are racing to test whether adjusting the flow toward a more natural state will restore and protect the Grand Canyon ecosystem in an increasingly drought-strapped, human-impacted river.

It is only recently that such an experiment could take place. In 2016, because both science and statutory responsibilities (such as additions to the endangered species list) had changed, the Bureau of Reclamation and the National Park Service revised the original Environmental Impact Statement to allow for a broader range of experimental flows. The 2018 bug flow is the first test the GCMRC has tried within the new legal framework. It is timely work in the context of a global problem: a 2017 paper in *PLOS ONE* found that in Germany, flying insect populations have plummeted by 75 percent since 1990. The authors, led by Caspar A. Hallmann of Radboud University in the Netherlands, warned this drop would have cascading impacts on pollination and nutrient cycles across Europe—a scenario already playing out on the Colorado.

On a chilly November dawn, the researchers and I left the GCMRC offices in Flagstaff, Ariz., and drove down to Lees Ferry boat ramp, which is 16 miles below the Glen Canyon Dam. In a jet boat named *Quicksilver,* we zipped up the black glass of the river toward the dam, then turned downstream into the throat of the Grand Canyon. Muehlbauer and Goodenough set four sticky traps—back-to-back petri dishes lined with adhesive and glued to aluminum stakes—at monitoring points approximately every mile to catch adult invertebrates. We passed through 21 miles of the canyon, taking drag samples of what is suspended in the water column to see how bug density and species diversity changed the farther we got from the dam.

There were almost no bugs on the river. None in our teeth or our eyes as we motored downstream. Nothing biting when we pulled up in tamarisk bushes to collect the sticky traps. When Muehlbauer pulled a sample stake and looked inside the petri dish, he was underwhelmed. "Oh, my God, David," he said, eye rolling toward Goodenough. "We caught … midges!"

Later, they sorted through the samples in the lab, pulling out chironomine bodies with tweezers and tallying the different species, painstakingly adding to a 22-year record of the individual bug totals along the river. Kennedy hopes the data from the controlled flows during the summer of 2018 will reveal how the physical processes of dam releases impact the bugs. The researchers are worried that climate change, among other factors, is altering conditions faster than they can study them. But if they can show that engineering the river to run more naturally makes the entire ecosystem more sustainable, the GCMRC can push back against new projects that threaten to divert even more water from the Colorado.

Take the Lake Powell Pipeline, for example. It would remove 86,249 acre-feet of water every year from Lake Powell—the man-made reservoir behind the Glen Canyon Dam—and divert it to two growing counties in southern Utah. The pipeline was first proposed in 2006 by the Utah Division of Water Resources, and in September 2018 the *Federal Energy Regulatory Commission* agreed to license the hydroelectric portion of the project. As expanding communities try to claim every drop of water they are legally allotted, Kennedy is looking at how bugs are tied to the rest of the river system—and demonstrate how the AMP can manage for both in the face of less water coming downstream.

A HOTTER, DRIER FUTURE

GIVING SCIENTISTS A VOICE in water management has led to new insights about how the Colorado River reservoirs are suffering from climate change. Much of the news is alarming. A 2017 study published in *Water Resources Research* by climate scientists Brad Udall of Colorado State University and Jonathan Overpeck, then at the University of Arizona, found that average Colorado River flows in the 21st century were 19 percent lower than in the 20th. They predicted flows could drop by up to 55 percent by 2100 as a result of the effects of global warming. "If you've been paying attention, especially in the past two or three years, you should be frightened right now," Udall says, referring to how soon there might not be enough water to meet legal and environmental needs. In the Bureau of Reclamation's yearly water tally, which ends in September, the amount of water that flowed into the Colorado River Basin in 2018 was only 43 percent of the historical average.

The scientists want to present reasons for amending flows in the name of nature before it is too late to avoid ecosystem collapse.

There is also problematic math at Lake Powell. Because the Colorado's water is allocated down to virtually the last drop, the lake level is crucial to a 1922 legal compact that guarantees 8.23 million acre-feet of water will flow past Lees Ferry every year. The Bureau of Reclamation built reservoirs—including Powell—starting in the 1950s. But these storage systems only work if they are replenished. Lake Powell is considered "full" at 3,700 feet above sea level; the last time that happened was 1986. In 2002, the driest year on record, only 3.8 million acre-feet flowed into Powell from upstream on the Colorado. Because Lake Powell's entire purpose is to keep the downstream water supply consistent even when it does not rain or snow, the legally obligated 8.23 million acre-feet still went out.

There is a fundamental flaw in this logic. The compact water was allocated based on calculations done by the Bureau of Reclamation in the early 1900s, the wettest recorded period in measured history, which concluded that 18 million acre-feet of water flowed through the river basin every year. Data collected from USGS river gauges installed at Lees Ferry in 1922 have showed that average yearly flows are actually 14.8 million. Because the compact is federal law, the 8.23 million acre-feet of downstream obligations still stand. Water managers call this a structural defi-

CLIMATE CHANGE is accelerating a nearly 20-year drought at Lake Powell; the first-ever cutbacks to downsteam water allotments could occur as soon 2020.

ADRIA PHOTOGRAPHY *Getty Images*

cit, and it means that if every state claims its entire share—a near-future scenario thanks to projects like the Lake Powell Pipeline—there will not be enough to go around.

The accelerating drought has become so threatening that in 2018, seven "basin states" drafted contingency plans. Each state outlined how much of their allocated compact water they would leave in reservoirs if Lake Powell's level hits 3,525 feet above sea level, which is just high enough to maintain power production at the dam. (In November 2018 Powell was at 3,588 feet.) Interim guidelines were put forward in 2007, but this official step marked the first time since the compact was signed nearly 100 years ago that the basin states made a legally enforceable plan for a drier future. Finally, policy is starting to reflect science.

This shrinking volume of water also makes experimentation more difficult to pull off. "Everything we do within the adaptive management program has to work within the annual volume of release," says Katrina Grantz, Upper Colorado region chief of the AMP. The GCMRC researchers have considered any reasonable options that would increase the supply. One long-standing and controversial idea is to remove the Glen Canyon Dam altogether, then store the reservoir's water in Lake Mead to minimize evaporation. But so far neither science nor policy supports removal. A 2016 white paper from John C. Schmidt, a geomorphologist at Utah State University and a former head of the GCMRC, found that any water savings from consolidating reservoirs would be less than 1 percent of the average inflow. It is impossible to untangle the human uses of the river without upending life in the Southwest, Schmidt explains. "Sometimes we are agreeing to compromise the environmental health of the rivers to provide utilitarian benefits," he says.

RACING TO ADAPT

AS AN IMPENDING WATER CRISIS DAWNS, the GCMRC scientists are trying to experiment as much as possible. They want to present concrete reasons for amending flows in the name of nature before it is too late to avoid ecosystem collapse. In Kennedy's "encouraging" preliminary results from the bug flows, he says his team saw more than twice as much larval emergence in May 2018 as they have in any month they have monitored over the past seven years. On these "bug flow weekends," the team found millions of rinds of spaghettilike midge egg casings on the banks. Arizona Game and Fish Department's creel survey reported that fishing catch rates were up, and anecdotally, river runners and fly-fishing guides complained that it was buggier than usual. "These findings are a powerful reminder that flows really do matter," Kennedy says.

This success represents a promising step toward increased experimentation and variable flows on the Colorado River. Kennedy hopes it convinces the AMP to greenlight another year or two of bug flows. But it could have wider implications, too. The AMP is starting to become a global model for managing dam operations while balancing the competing demands of ecosystems, energy and irrigation. Over the past 20 years Melis says hydrologists and engineers from planned dams in the Brazilian Amazon—as well as researchers from Japan, China, Canada and other Bureau of Reclamation projects in the U.S.—have come to Arizona to learn from and share information with the AMP.

The collaborative, long-term thinking of adaptive management can seem idealistic. Melis refers to a "potpourri" of resources the scientists must consider as they try to find the connections that will restore ecosystem health. But in the changed and changing Colorado River system, there is plenty that still feels wild, even if it will take precise management to keep it seemingly so.

When Muehlbauer, Goodenough and I come back to the boat launch after a day of collecting bug samples, the late November sun is casting shadows on the canyon walls. The temperature is rapidly dropping. We are the only humans around as bats circle and click in the coming dark. But far down the grid, people across the Southwest are coming home from work and turning on their lights. The river has come up to meet them. SA

MORE TO EXPLORE

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