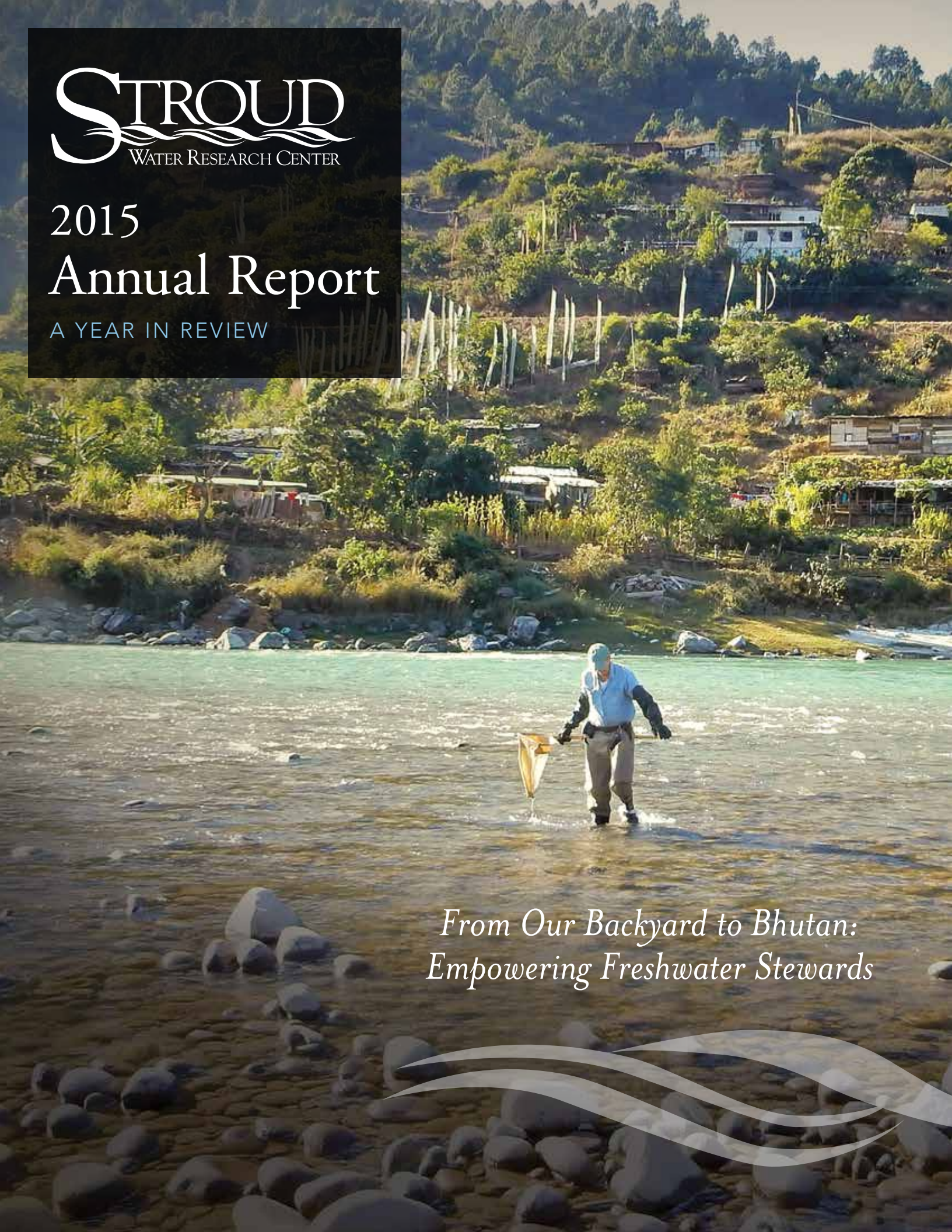


STROUD
WATER RESEARCH CENTER

2015 Annual Report

A YEAR IN REVIEW

From Our Backyard to Bhutan: Empowering Freshwater Stewards

AT A GLANCE

2015


A.

A | EDUCATION

In July, the education department hosted 400 advanced middle school students from across the U.S. through the ENVISON program to learn about science, technology, engineering, and stream ecology at the Stroud Center. *Photo: Kay Dixon*

B | RESEARCH

As part of a three-year project funded by the William Penn Foundation, Stroud Water Research Center and 45 other environmental organizations are collaborating to monitor, protect, and restore the Delaware River watershed. In 2015, Stroud Center scientists collected and analyzed chemistry and ecology data that will be valuable in developing and monitoring watershed restoration plans for targeted streams within the Delaware River Basin. *Photo: Jan Battle*


B.

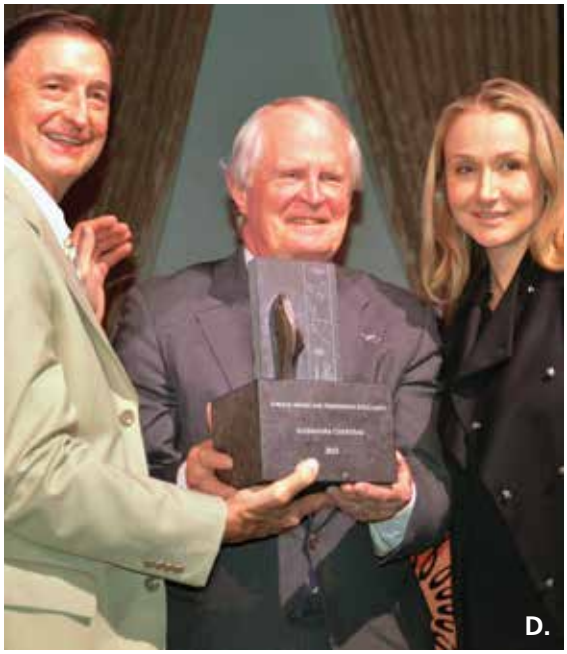
C | RESTORATION

As part of our watershed restoration efforts, we plant trees to filter pollutants before they enter streams, to reduce stormwater runoff and erosion, to provide shade for aquatic species, and to add valuable leaf litter and tree debris. In 2015, we planted 3,500 trees along streams and signed agreements with farmers to plant another 10,700 on more than 85 acres. *Photo: Stephanie Eisenbise*

D | THE WATER'S EDGE

Alexandra Cousteau, founder of Blue Legacy and granddaughter of Jacques Cousteau, received the 2015 Stroud Award for Freshwater Excellence at The Water's Edge gala on November 19 for her work in conservation and sustainable water management. *Photo: Yeda Arscott*


C.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E.

E | PRESENTATION

Stroud Center Director Bern Sweeney, Ph.D., traveled to Costa Rica in late January to discuss the importance of forest buffers for improving in-stream habitat and water quality in tropical ecosystems. The presentation, held at the Piro Biological Research Station, was organized by Osa Conservation and the Bobolink Foundation and was attended by leading conservation practitioners. Sweeney pointed to a new research finding that 100-foot forest buffers are needed to adequately protect streams. *Photo: Jim Palmer*

Cover photo: Mandy Cabot

MESSAGE
FROM THE DIRECTOR

Photo: Lisa Stroud

At Stroud Water Research Center, science is the foundation for all we do. But the information our research yields is of limited value unless it can be conveyed to others and put into action.

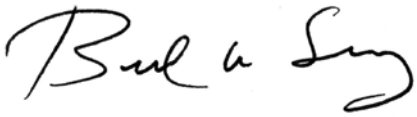
With fresh water at the heart of our mission, we connect research, education, and restoration across Stroud Center projects. From the familiar White Clay Creek in our own backyard to the remote Himalayan rivers of Bhutan and beyond, you'll find us working to ensure a brighter future for water quality and availability.

Indeed, our feature stories in this report span this continuum. You'll read about our low-cost, high-impact restoration philosophy and how we're empowering citizens and nations with the knowledge and tools to steward their freshwater resources.

At a time when specialization in sports, medicine, music, and most other fields is the hallmark of success, we have chosen a different path. We promote interconnectedness. By intentionally connecting research, education, and restoration — disciplines that have historically been greatly disconnected, especially in the world of watersheds — we believe we can make the greatest difference.

I hope you will continue to support our efforts, making the availability of clean fresh water a reality for you, your family, and all families worldwide.

Making every drop count,



RESEARCH

We specifically wanted to provide Bhutan with some new technologies that are low cost, precise, accurate, sustainable, and adaptable to their needs to help them monitor their own water quality.

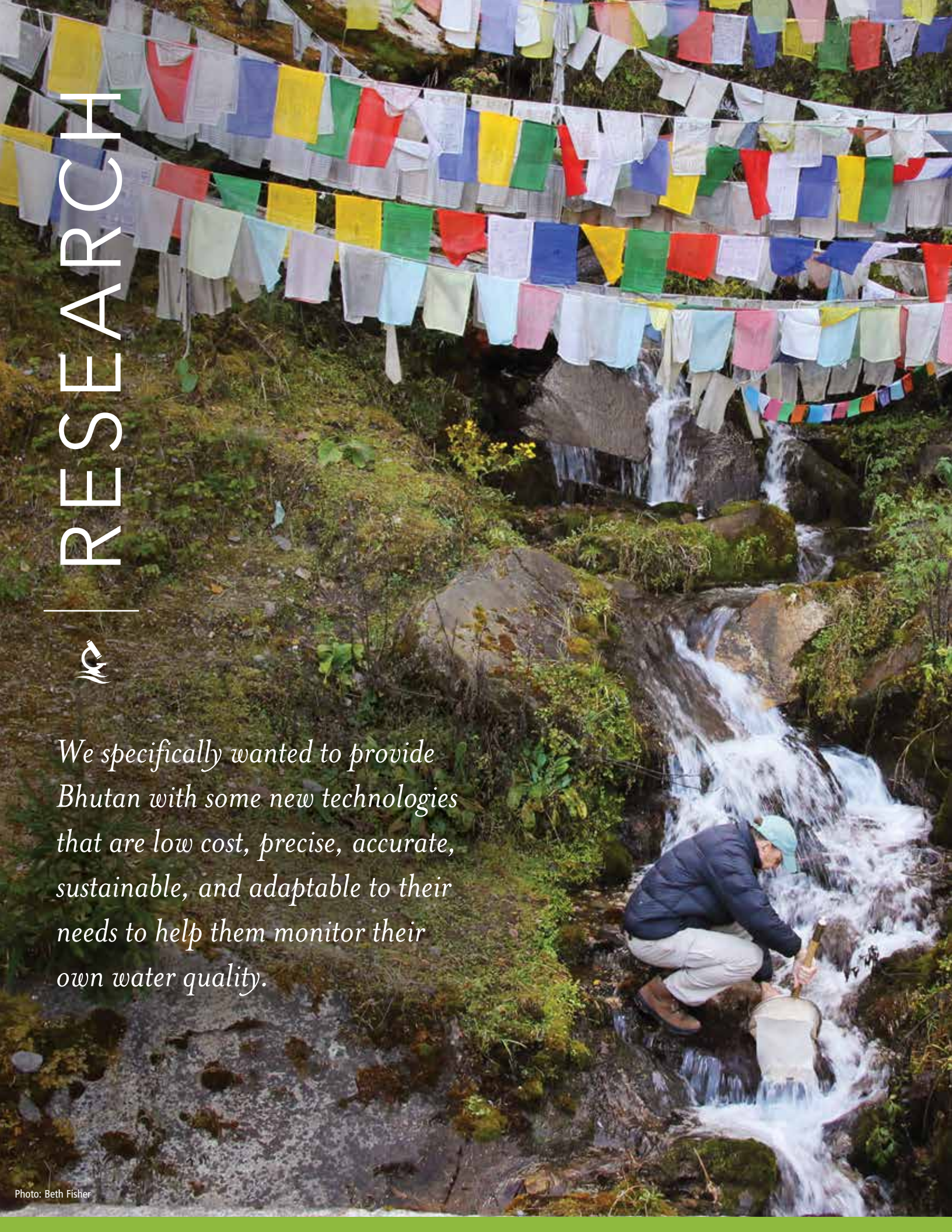


Photo: Beth Fisher

Bhutanese children play in a polluted stream, not realizing it is contaminated.
Photo: Bern Sweeney

Achieving Water-Quality Enlightenment in Bhutan

STROUD CENTER SCIENTISTS PROVIDE METHODS, EQUIPMENT, AND TRAINING TO HELP BHUTAN MONITOR WATER QUALITY

Within moments of collecting the first samples from streams below major population centers in the tiny Himalayan country of Bhutan, Stroud Water Research Center scientists realized the quality of the water was not as good as in upstream locations. This was probably due to human waste and, perhaps, chemical contaminants.

Child's Play and Polluted Water Do Not Mix

"One day," said Director Bernard Sweeney, Ph.D., "we were sampling a feeder stream in an urban center, wearing all our protective gear, when a bunch of kids came running down and began playing in the water." Sweeney snapped a picture on that November day in Bhutan, which he later shared with the secretary of the country's Ministry of Health.

"I told him the water quality of the stream those children were playing in was substantially degraded by nearby businesses and homes. There was clear indication of sewage contamination: counts of *E. coli* bacteria and total coliform bacteria were dangerously high. So those kids were at high risk of being exposed to pathogens and chemicals that could cause diseases, severe infections, and other health issues. In many areas, it appeared that wastewater was flowing right out in the open," said Sweeney. "Without treatment, such surface water certainly poses a human health risk."

Adding to the problem is that groundwater resources are difficult to tap into due to the country's mountainous geography. Therefore, the streams and rivers of Bhutan are an important source of drinking water for Bhutan as well as for nearby nations such as India.

In early November, Stroud Center scientists provided methods, equipment, and training to help develop Bhutan's ability to test and monitor the nation's water quality. The Stroud Center initiative was carried out in partnership with Waterkeeper Alliance, an international organization of more than 270 local Waterkeeper organizations protecting waterways across the globe, which now includes the Thimphu River Waterkeeper in Thimphu, Bhutan.

Bhutan has good infrastructure and data about water quantity, but not about water quality, Karma Dupchu acknowledged during a September visit to the Stroud Center. Dupchu is the chief hydrology officer at Bhutan's Ministry of Economic Affairs. The objective of the November trip was to provide Bhutan with a toolkit for monitoring both water quantity and quality, and to start what will become widespread citizen-science water-quality monitoring.

Four Methods for Examining Water Quality in the Thimphu River

WIRELESS SENSOR STATIONS

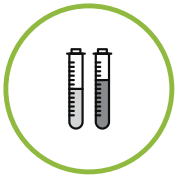
Solar-powered, continuously operating sensor stations measure the water's turbidity, electrical conductivity, temperature, and depth.

INSECT SAMPLING

Some species of insects, like stoneflies and mayflies, are highly sensitive to water pollution and are valuable indicators of water quality.

MICROBIOLOGICAL SAMPLING

Simple, inexpensive test kits monitor *E. coli* and coliform bacteria.



PHYSIOCHEMICAL SAMPLING

An open-source color analyzer used in conjunction with an aquarium water-quality test kit evaluates nutrient levels.

Drinking Water Must Be Boiled or Bottled

Bhutan currently has limited infrastructure for treating wastewater or purifying tap water. Its people are advised to generally boil tap water or drink bottled water, said Sweeney. Bhutan's Ministry of Health is responsible and concerned about the country's lack of access to safe drinking water.

"They already know that people can get sick by drinking contaminated water. One concern that we tried to emphasize was that people can also get sick by just going into a contaminated stream. But we didn't go there to simply raise awareness. We wanted to give them tools and information they can use to work towards solutions," Sweeney stated.

The scientists launched their Bhutan expedition with two goals in mind. First, they sought to learn about the unique, steep-gradient river systems. Second, they wanted to help expand and improve the national monitoring program with a twofold approach using open-source sensors and citizen scientists to sustain freshwater resources far into the future.

Sweeney said, "We specifically wanted to provide Bhutan with some new technologies that are low cost, precise, accurate, sustainable, and adaptable to their needs to help them monitor their own water quality."

Bhutanese citizens practiced insect sampling as a method for monitoring water quality in their local streams and rivers.
Photo: Mandy Cabot

The team sampled 18 stream and river sites in the Bhutanese districts of Paro, Thimphu, and Punakha. They followed the river reaches from their nearly pristine headwaters in the heavily forested, high mountain ranges through the lower-lying farming regions, small towns, and big cities. They found substantial degradation in the cities.

Sensors Never Sleep

The scientists deployed three solar-powered, continuously operating sensor stations on the Thimphu River, upstream and downstream from the capital. The sensors measured the water's turbidity, electrical conductivity, temperature, and depth.

They purchased SIM cards, typically used for cell phones, to make the wireless sensors function as mini-communication stations. They then installed the sensor stations side by side in collaboration with Bhutanese government officials and scientists as well as with the Thimphu River Waterkeeper.

"Within half an hour of installation, we could see the data streaming in real time from the river sensors to the Internet and onto our computers and smartphones," said Sweeney.

Later, Anthony Aufdenkampe, Ph.D., the Stroud Center's organic geochemist, and Beth Fisher, a doctoral candidate from the University of Minnesota, taught the Bhutanese officials, scientists, and the Thimphu River waterkeepers how each component of the low-cost sensors could be adapted so the extent of the monitoring system could be expanded in the future.

Low-Cost, Accurate Tests Identify *E. coli* and Coliform Bacteria

The team brought simple, inexpensive test kits to monitor *E. coli* and coliform bacteria that cost only about $1.80 per

test. A small amount of test water is pipetted onto the surface of a "test well" containing substrate for growing bacteria. It is then incubated for 24 hours at 35 degrees Celsius. During the incubation period, bacteria colonies acquire color-coding. *E. coli* colonies show up as blue dots with gas bubbles; coliform colonies display as red dots.

"If you don't have access to electricity, it's possible to incubate the samples out in the field by placing the test kit close to your body under your shirt to maintain the proper test temperature. It's a citizen-science protocol that will soon be rolled out by the Bhutan Ministry of Health," said Sweeney. However, to process large numbers of samples at the correct temperature, the team purchased chicken-egg incubators and left them behind for the Bhutanese Waterkeeper to use.

Looking for Nutrients — But Not the Yummy Kind

Working in a makeshift hotel room laboratory, Stroud Center scientists tested an open-source color analyzer and used it with an aquarium water-quality test kit to evaluate levels of ammonia, nitrite, nitrate, and phosphorus in water samples.

"These important chemical components help tell us the extent of human influence on the stream. Typically, to measure such chemicals accurately requires sending your water samples out to a laboratory. But that's expensive and time-consuming," said Sweeney. Aquarium test kits look for the same chemicals by producing a specific color related to the quantity of each nutrient.

Visual test results can be subjective, so Aufdenkampe worked with Stroud Center team members Sara Damiano and Steve Hicks to discover an accurate open-source instrument for measuring color that costs about $100. The combination of methods they found for measuring nutrients are readily available, easy to learn, surprisingly accurate, and only cost a few pennies per sample.

"We also gave instructions for the color readers to the Bhutanese collaborators so they could adapt the instruments to measure other water-quality parameters, including turbidity. They were really very excited about it," said Sweeney.

Aquatic Bugs Tell Tales All Around the World

The researchers were pretty confident that insect sampling would be a valuable water-quality indicator in Bhutan as it is elsewhere in North and South America and in Europe.

"However, we didn't know if the same major groups of aquatic insects that indicate good and bad water quality elsewhere would be the same groups here in Bhutan," said Sweeney. "For example, stoneflies are one of the most sensitive groups to water pollution in North America. But there are parts of the world where there aren't many stoneflies because they just didn't disperse widely enough over geologic time. But they've gotten to Bhutan. So when we got to the cleanest of rivers, there were lots of them, and they became sparse or nonexistent in rivers receiving a lot of contamination." He added, "This was further confirmation that the use of insect sampling for water-quality analysis works well globally."

Sweeney said the team is excited that the methodologies they used to test water quality worked well and that they were able to deliver methods of measuring water quality that were not only accurate but also low in cost. "Eventually, some of these methods will be very useful to help Bhutan provide a sustainable source of clean water to the public," he said.

Dressed in traditional Bhutanese gho and kira, (from left) Sharon Khan from the Waterkeeper Alliance, Mandy Cabot, Peter Kjellerup, Bern Sweeney, Lisa Stroud, Dixon Stroud, Beth Fisher, and Anthony Aufdenkampe were invited to be special guests at the king's birthday dinner celebration.

EDUCATION

"When citizens better understand and take an active role within their watersheds, the opportunity for conservation and restoration is significant."

— TARA MUENZ, STROUD WATER RESEARCH CENTER

Photo: Osa Conservation

Preserving Eden

CREATING WATERSHED MONITORS IN COSTA RICA'S BIOLOGICALLY RICH OSA PENINSULA

In a remote corner of southwestern Costa Rica lives 2.5 percent of Earth's biodiversity. The Osa Peninsula, surrounded by the Pacific Ocean to the west and the Pavon Bay to the east, makes up less than a thousandth of a percent of the total surface area of the entire planet. It's vibrant, lush, and largely unspoiled by development. A tropical paradise. A modern Eden.

Teeming with beautiful rivers, lakes, wetlands, and estuaries, this tiny peninsula is home to some of the world's most pristine waters. And yet, like those in any other area of the world, these waters need protecting to ensure a sustainable freshwater future. The way to do that, says Tara Muenz, the assistant director of education at the Stroud Center, is through citizen empowerment.

Empowering Freshwater Stewards

"When citizens better understand and take an active role within their watersheds, the opportunity for conservation and restoration is significant," Muenz says, her eyes bright with enthusiasm. "As educators and scientists, we serve as guides for freshwater stewardship. We conduct the research to learn what makes streams and rivers healthy. We then put that research into action. We share our findings with others and initiate our own restoration projects. The next big step is to empower citizens to monitor and protect their own water sources, and much of this comes from the wisdom they obtain through experiences such as water-quality monitoring."

Ríos Saludables de Osa, or Healthy Waters of Osa, was created to empower the citizens of Costa Rica to ensure healthy freshwater legacies for the Osa Peninsula. With funding through the Blue Moon Foundation, Osa Conservation (a nonprofit dedicated to protecting the Osa Peninsula's biodiversity) partnered with Stroud Water Research Center, Allegheny College, and Georgia Adopt-A-Stream to launch the effort in the fall of 2014. Today, Ríos Saludables de Osa is fully operational and composed of volunteer community members and schools who work together to monitor the river and coastal water quality of the Osa Peninsula.

With that vision in mind, Muenz, along with Jim Palmer, Ph.D., science director of Osa Conservation, journeyed to the natural wonderland of Costa Rica's Osa Peninsula in October of 2014. Once there, they spent the next two weeks showing community members, including local teachers and employees from environmental nonprofits and national parks, how to successfully monitor their waterways and how to train others to monitor them too.

Rising at 5 a.m., the team was greeted each morning by the sun's early light and the low, hollow calls of howler monkeys. They stayed in rustic cabins at the Piro Biological Research Station and slept under mosquito nets. Every wild sound and smell enveloped them. After breakfast in the solar-powered main campus, Muenz met with Osa Conservation staff to go over the day's training workshops.

Training Water-Quality Monitors and Their Trainers

"The first avenue we thought to take," says Muenz, "was to get schools and teachers

A new Ríos Saludables de Osa trainer sifts through a leaf pack sample. *Photo: Tara Muenz*

"THIS PROGRAM OFFERS ME THE OPPORTUNITY TO ADD MY PART FOR A HEALTHY ENVIRONMENT." – RÍOS SALUDABLES DE OSA VOLUNTEER

involved because they have the connections to reach whole communities."

Muenz and Palmer have worked with thousands of volunteers and multiple watershed groups to protect their watersheds, and so they had lots of ideas for teaching tools the volunteers could use to train fellow community members. "The best approach is to give them as many real examples and experiences as possible, and that means getting right in the river to use the monitoring equipment, getting their hands wet, walking through each step, addressing questions as they come up, and processing the results with an immediate discussion so they gain confidence in the process from beginning to end.

"The dissolved oxygen test is typically the most difficult to master, as it involves many different stages and steps, but it's one of the most important parameters to measure because it is a great indicator of a stream's overall health and ability to sustain aquatic life. So we demonstrate how it's done first and then have the volunteers follow the instructions on their own to see if they get the same result."

Muenz and Palmer also created bilingual manuals and data sheets for the program, as well as a manual to guide the trainers through instructing others how to monitor water quality. "Seeing the trainers use the Spanish-translated materials, from the data forms to the testing directions to the PowerPoints, was exciting, and we hope all the time devoted to translating these tools will be utilized across Costa Rica and Central America."

Over the last year, the Stroud Center has assisted in the development of a website, riossaludablesdeosa.org, and an online publicly accessible database on CitSci.org, where the volunteers and Osa Conservation can communicate and share data. Since Ríos Saludables de Osa's inception, data from more than 81 sites have been added to the database. The data encompass more than 260 observations and 3,950 measurements. Nineteen core sites are being monitored by 12 Ríos Saludables de Osa volunteer groups on an ongoing basis.

When asked why he got involved, one volunteer responded, "This program offers me the opportunity to add my part for a healthy environment."*

Volunteers can choose from different levels of involvement. At the foundational level, new volunteers work with Osa

**Translated from Spanish.*

Conservation to select sites to monitor for a core set of water-quality tests on a monthly, quarterly, or sometimes annual basis. Water quality may be monitored through visual surveys and metrics for water chemistry, bacteria (*E. coli*), and aquatic species like fish and insects.

See How It Grows

Individuals or teams who want to be more involved may choose to partner with a local school or become a leader of the community to organize events promoting clean water and watershed stewardship.

Going forward, Osa Conservation staff will continue to serve as guides for watershed stewardship in the field, working with Ríos Saludables de Osa volunteers to promote the goals of the organization and organize monitoring efforts.

"Ríos Saludables de Osa is proof that one person can make a difference," says Muenz. "One person's passion and care for the earth can and does inspire others. We're seeing that happen."

Tabea Zimmerman of Osa Conservation says, "In the short time that I have been working with Ríos Saludables, the program has strengthened its relationships with citizen scientist groups and local schools and expanded to new groups. We held a very successful workshop at Piro Station in mid-December, in which we trained 14 community members on visual, chemical, bacterial, and biological-monitoring protocols. Many of these were returning volunteers who have expressed interest in taking Ríos Saludables de Osa into their schools and also assisting in training additional community volunteers. ... I believe this program has immense potential."

Clockwise from left: The biologically diverse Osa Peninsula is home to beautiful birds, insects, fish, and other wildlife (photo by Dave Montgomery); Escuela Amapola, a potential partner school; a damselfly; a group of new Ríos Saludables de Osa trainers; participants learned how to conduct a dissolved oxygen test.

Photos (all except noted): Tara Muenz

"RÍOS SALUDABLES DE OSA IS PROOF THAT ONE PERSON CAN MAKE A DIFFERENCE. ... ONE PERSON'S PASSION AND CARE FOR THE EARTH CAN AND DOES INSPIRE OTHERS. WE'RE SEEING THAT HAPPEN."

– TARA MUENZ, ASSISTANT DIRECTOR OF EDUCATION, STROUD WATER RESEARCH CENTER

RESTORATION

Healthy streams begin on land. So too does the work of the Watershed Restoration Group.

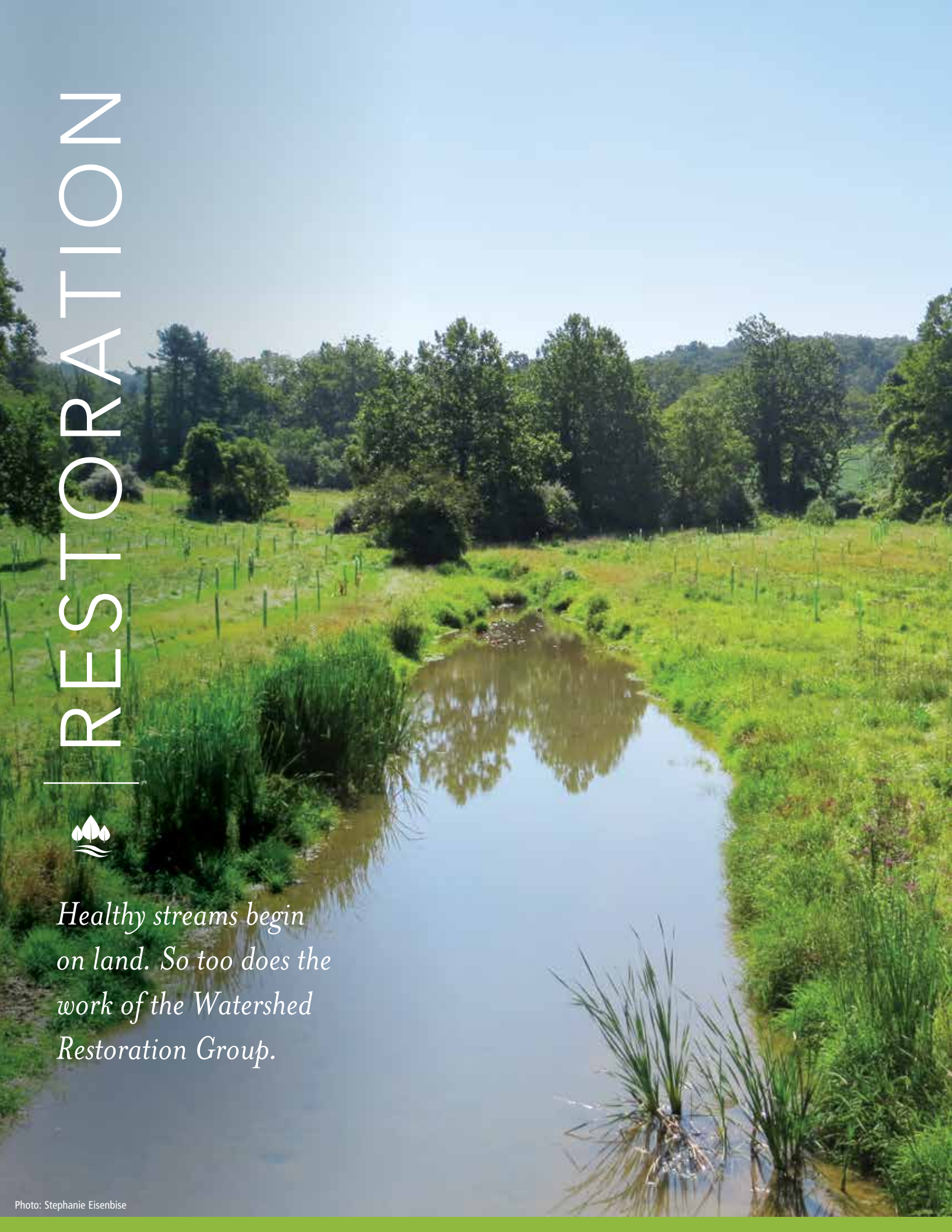


Photo: Stephanie Eisenbise

Working Lands, Clean Water

SCIENCE-BASED RESTORATION AT THE STROUD CENTER

The nation's waterways look a lot better since the passage of the Clean Water Act in 1972. Rivers no longer catch on fire. Fish kills are less common. Yet more than half of the river and stream miles in the United States are in poor condition, according to the Environmental Protection Agency. As such, they no longer support healthy aquatic communities. And they pose threats to human health as well, for polluted waters can be unsafe for swimming and fishing.

"There's more work to be done," says Matt Ehrhart, Stroud Water Research Center's director of watershed restoration, "and we need to rely on a variety of best management practices to address a problem of this scale."

But if there's one watershed restoration tool that stands out, it's trees. Specifically, trees planted along streambanks.

Harnessing the Power of Trees

The Stroud Center has been studying the potential power of trees to improve stream health for decades. Experimental tree plantings have been a part of that research for nearly as long.

"Long before we launched the Watershed Restoration Group, we were restoring streams as research projects so we could determine what really worked and what did not," says Director Bern Sweeney, Ph.D. "Restoration has been a natural outgrowth of research."

A forest buffer planted last May (pictured left) is improving biodiversity and pollinator habitat for this York County crop farm. Before the planting (pictured above), fish and other aquatic species were less protected from the sun's heat. As the trees mature, they will enhance in-stream habitat by providing shade and contributing leaf litter and woody debris to the stream.
Photo: Stephanie Eisenbise

At the Stroud Center, restoration strategies follow science. And while Ehrhart and his team look to science for guidance, the scientists look to nature.

In a research paper published in 1992, Sweeney declared, "The quality of streamside forests" is likely the "single most important factor altered by humans that affects the structure and function, and ultimately water quality, of the streams providing water to coastal embayments."

Today, Sweeney says, "Over the years, we've observed the return of stream health in response to the planting of forest buffers in many locations. We've documented improved temperature, chemistry, and biodiversity."

The robust body of research shows that forest buffers allow a stream channel to develop a more complex and suitable aquatic habitat for trout and other native freshwater species. Trees shade out grasses, whose fibrous but shallow roots gather sediment and build streambanks inward, thus narrowing the channel. Wider, shallower, and more stable stream channels

Healthy Streams Begin on Land

REDUCE RUNOFF

Since much of the sediment and nutrient runoff that reaches streams comes from farms, best management practices such as cover crops and no-till farming are needed. Farm animals should be moved away from streams.

LEAVE WOODY DEBRIS

Trees that fall into stream channels leave large branches, trunks, and root systems that become in-stream wood features. These form vital habitats and improve water flow and channel conditions.

PLANT TREES

To adequately protect streams, streamside forests should be at least 100 feet wide.

Photos (from left): Stephanie Eisenbise, David Wise, and Jerry Scott

within forests mean greater bottom surface area for supporting the stream's ecosystem, which is vital to retaining, processing, and transforming pollutants.

When streambanks are reforested, water temperatures and light levels return to more natural levels. Tree litter feeds many species of macroinvertebrates, bacteria, and fungi. Tree roots protect banks and encourage undercuts, where trout like to be. With all these benefits and more, forested streams provide more ecosystem services per unit length than streams flowing through open lawns and pastures.

So healthy streams need trees. But trees need space, and lots of it — at least 100 feet to be exact. Sweeney and collaborating scientist Denis Newbold, Ph.D., published their findings related to buffer width: To adequately protect freshwater ecosystems from human activities, streams need forest buffers that are at least 100 feet wide. Of course, the wider the buffer, the better.

And then there's time. John Jackson, Ph.D., head of the Entomology Group, has led long-term research studies — decades long, in fact — showing that, given enough time and the right conditions, streams can heal themselves without expensive, highly engineered interventions that need ongoing maintenance. When streams become healthier, they process pollutants more efficiently. They become better water-treatment systems.

The Watershed Restoration Group springs into action. Ehrhart and his team — David Wise, Lamonte Garber, and Stephanie Eisenbise — build relationships with landowners and coordinate the funding and technical assistance to implement low-tech, low-cost, and low-maintenance best management practices like forest buffers. "Our approach is low tech, but it's supported by high-tech science," says Ehrhart.

Jackson says, "Reduce runoff. That's the first step." Since much of the sediment and nutrient runoff that reaches streams comes from farms, best management practices such as cover crops and no-till farming are needed. Farm animals should be moved away from streams. After that, he says, "Don't let any remaining runoff reach the stream."

For streamside forests to effectively protect streams from residual runoff, however, coordination is key. Jackson says, "We know that you can't only work with half the landowners along a stream. Every mile counts." Starting in 1999, his team set up four experimental watersheds in Lancaster County, Pennsylvania. Two were restored. For one of the streams, only half of the landowners participated. For the other, minimal best management practices were implemented (although, they were state-of-the-art at the time). During the next fifteen years, the more-restored stream improved, but not enough at that point in time. The stream with only half of the landowners participating did not improve at all. "We have two key barometers for determining whether streams are healthy or not healthy: macroinvertebrate populations and water chemistry. That's the gold standard. We looked at both. And we discovered it's not enough for half the landowners to participate, and it's not enough if minimal best management practices are implemented. Restoration needs to be comprehensive, and it needs time."

The Watershed Restoration Group builds relationships with farmers and landowners with the goal of increasing participation and, in turn, the number of stream miles restored. In 2015, the group's efforts yielded 3,500 trees planted along streams and signed agreements with farmers to plant another 10,700 on more than 85 acres. They also coordinate funding and technical assistance to implement best management practices on farmland that surrounds streams and buffers.

Stroud Center scientists know that healthy streams begin on the land. If the forests, farmland, floodplains, and developed areas in a watershed are healthy, the streams and rivers will be too. Ehrhart says, "That understanding is the guiding principal of our restoration philosophy."

The Future of Watershed Restoration

Melinda Daniels, Ph.D., who leads the Fluvial Geomorphology Group, studies another key role played by streamside forests: the contribution trees make when they fall into the stream channel and become in-stream wood features, often called "woody debris." As trees shed limbs or fall wholesale into the stream, they add large branches, trunks, and root systems to the stream channel. Rarely moving far downstream, this in-stream wood forms vital habitats and improves water flow and channel conditions.

"With guidance from Melinda, we're considering how adding wood to streams could be more integral to our restoration activities," says Ehrhart.

But healthy streams need more than trees along their banks — what scientists call the riparian zone — they also need well-managed upland areas to reduce stormwater runoff. During Hurricane Irene in 2012, Anthony Aufdendampe, Ph.D., head of the Organic Geochemistry Group, observed one forested stream that piqued his curiosity. Boulton Run in Chester County, Pennsylvania, flows through a dense and mature forest, but the upland area is dominated by traditional row-crop agriculture. That summer, as Hurricane Irene's cascading rains led to destructive flooding across the East Coast, Boulton Run's protective forest buffer was no match for the 100-year storm event. Aufdenkampe recalls, "The water generated from the upland area just ripped through the forested riparian zone of the stream." There was substantial runoff generated from this upland area, and it carried valuable topsoil from the upland into the stream. The mighty force of all that water eroded the stream bottom and its banks. "It just goes to show that a whole-watershed approach to restoring streams is really important." Riparian forests, he says, play a significant role in stream health, but they should be accompanied by best management practices throughout the entire watershed to have the greatest impact.

"As we learn more through scientific study, our restoration activities evolve," Sweeney says. Future restoration work may include more best management practices not yet conceived. Aufdenkampe, for example, is interested in carbon sequestration and how healthier soils may be able to address not only stream degradation but also related issues such as greenhouse gases and climate change.

"Our education programs and public outreach reflect what we learn through scientific study," says Sweeney. "And our restoration efforts do too; they are designed to enhance the water-treatment functions of streams to the greatest extent possible, and to enhance what nature is ready to provide us, if the right conditions are set in motion."

Research Projects

Note: Stroud Water Research Center scientists and staff are indicated in bold.

American Chestnut Foundation Leaf Feeding Study 2015–2016

Funded by: The American Chestnut Foundation

In an effort to restore chestnut trees to watersheds, blight-resistant varieties of American Chestnut have been developed over the last several years. This study uses the growth and survivorship of aquatic insects to test for differences in palatability and nutrition of leaves from wild-type American Chestnut, Chinese Chestnut, hybrid Chestnut (American x Chinese), and three transgenic American Chestnut types.

Principal Investigators: Bernard W. Sweeney and **John K. Jackson**

Brandywine Stream Stewards: Community Action in Support of Healthy Waters

Funded by: William Penn Foundation

The Stream Stewards Program, centered on 1,100 acres of open space in the First State National Historical Park, engages the community and targets youth from Wilmington in a sustainable, citizen-science program. It contributes to land and water management through monitoring water resources and education programs that lead to conservation action. Another goal of the program is to create a replicable citizen-science model that develops a committed and active constituency for watershed protection.

Principal Investigators: John K. Jackson and **Matthew J. Ehrhart**

Collaborators: Jinjun Kan, **Melinda D. Daniels**, **David B. Arscott**, and **Anthony K. Aufdenkampe**; The Nature Conservancy – Delaware Chapter

Characterizing Stream Connections and Physical, Chemical, Biological Influences on Downstream Navigable Waters

Funded by: U.S. Department of Justice

Drs. Dow and Arscott provided scientific expert services for the U.S. Dept. of Justice in the matter of *Foster et al. v. EPA et al.*, No. 2:12-cv-16744 (S.D.W.V.). The scope of work was to characterize and provide testimony on the physical, biological, and chemical relationships between certain headwater streams located in Wood County, West Virginia, and downstream waters connecting to the Little Kanawha River and eventually to the Ohio River.

Principal Investigator: David B. Arscott

Collaborator: Charles L. Dow

Brook trout hatched from these eggs will be released into a local stream.
Photo: Tara Muenz

Christina River Basin Critical Zone Observatory (CRB-CZO): Quantifying Carbon Sequestration Resulting From Human-Induced Erosion

Funded by: National Science Foundation EAR 0724971 and 1331856

The study aims to determine whether large-scale, human-induced soil erosion might transport, bury, and sequester carbon in floodplain and coastal sediments, modifying greenhouse gas emissions from the landscape.

Principal Investigators: Anthony K. Aufdenkampe and **Louis A. Kaplan**; Jim Pizzuto and Holly Michael (University of Delaware); Kyungsoo Yoo (University of Minnesota)

Collaborators: Jinjun Kan, **Melinda D. Daniels**, **David B. Arscott**, **Charles L. Dow**, and **Susan E. Gill**; Rolf Aalto (University of Exeter, United Kingdom); Lee Slater (Rutgers University); Rodrigo Vargas, Clara Chan and Donald L. Sparks (University of Delaware)

CNH: Coupled Climate, Cultivation, and Culture in the Great Plains: Understanding Water Supply and Water Quality in a Fragile Landscape

Funded by: National Science Foundation

This collaborative project develops a model to predict the potential impact of climate variability, climate change, land use, and human activity on water resources across decades and centuries in the Central Great Plains of North America. It also identifies the most effective strategies to achieve sustainability and optimize policy.

Principal Investigator: Melinda D. Daniels

Collaborators: Marcellus Caldas, Jessica Heirr-Stamm, Jason Bergtold, Aleksy Sheshukov, Martha Mather, and David Haukos (Kansas State University)

Collaborative Research: Coupled Geochemical and Geobiological Characterization of Dissolved Organic Matter Oxidation to Carbon

Funded by: National Science Foundation

As microbes process dissolved organic matter (DOM) from leaves that fall into streams, they release CO_2 into the atmosphere. Scientists are studying stream networks from two different climatic regions to identify which molecules release high rates of CO_2 into the atmosphere from streams and rivers.

Principal Investigator: Louis A. Kaplan

Collaborators: Rose Cory (University of Michigan); Patrick Hatcher (Old Dominion University)

Delaware River Watershed Initiative — Monitoring, Evaluation, Scientific Support, and Capacity Building for Watershed Protection and Restoration Projects — Entomological and Fish Collections

Funded by: Academy of Natural Sciences of Drexel University (ANSDU) and William Penn Foundation

This project collected and interpreted data on macroinvertebrate specimens from 38 stream sites to provide a baseline for restoration projects funded by the William Penn Foundation in its efforts to restore and protect water quality in the Delaware River Basin.

Principal Investigator: John K. Jackson

Collaborators: Roland Wall, Stefanie A. Kroll, Richard J. Horwitz, Jerry V. Mead, Donald F. Charles, and David J. Velinsky (Academy of Natural Sciences of Drexel University)

Delaware River Watershed Initiative — Protecting and Restoring Places of Ecological Significance (Brandywine-Christina and Middle Schuylkill Clusters)

Funded by: William Penn Foundation

Professional and volunteer monitoring of chemistry, macroinvertebrates, and fish to support restoration and protection efforts represent an invaluable (and often neglected) tool to evaluate short- and long-term progress toward

conservation priorities and goals. This project develops and implements restoration and protection plans for targeted watersheds in the Brandywine-Christina and Middle Schuylkill clusters in the Delaware River Basin.

Principal Investigators: John K. Jackson, Matthew J. Ehrhart, Bernard W. Sweeney, William Eldridge, and **Susan E. Gill**

Collaborators: Berks Conservancy; Brandywine Conservancy; Brandywine Valley Association; Natural Lands Trust; Partnership for the Delaware Estuary; The Nature Conservancy of Delaware; University of Delaware

Delaware River Watershed Initiative — Protecting and Restoring Places of Ecological Significance (Schuylkill Highlands Cluster)

Funded by: Green Valleys Watershed Association and William Penn Foundation

In collaboration with the Stroud Center's cluster partners, this project monitored macroinvertebrates to establish a water-quality baseline at 10–16 selected sites associated with protection and restoration efforts for targeted watersheds in the Schuylkill Highlands cluster (i.e., Pigeon Run and French, Pickering, and Hay creeks) in the Delaware River Basin.

Principal Investigator: John K. Jackson

Collaborators: Tara Muenz; Green Valleys Watershed Association; Natural Land Trust; French and Pickering Creeks Conservation Trust; Partnership for the Delaware Estuary; Audubon Pennsylvania

Developing a Community Information Model and Supporting Software to Extend Interoperability of Sensor- and Sample-Based Earth Observations

Funded by: National Science Foundation EAR 1224638

This EAR Geoinformatics Program grant supported a project to develop the Observations Data Model version 2 (https://github.com/ODM2) and related software to enable interoperability of Earth observations derived from sensors and samples that span discrete data and informatics initiatives for multiple communities. This information model is now at the foundation of the BiG CZ Project software and the emerging Citizen Science data portal newly funded by William Penn Foundation.

Principal Investigator: Jeffrey Horsburgh (Utah State University)

Collaborators: Anthony K. Aufdenkampe; Ilya Zaslavsky (University of California, San Diego); Kerstin Lehnert (Columbia University); Emilio Mayorga (University of Washington)

Developing a Water Atlas for the ACOSA Region of Costa Rica

Funded by: Blue Moon Fund

Stroud Center biologists are working with researchers and managers in the ACOSA region of southwestern Costa Rica to collect and disseminate information on streams and rivers to a variety of community stakeholders. The two-year project, which started in 2013, includes (1) education programs to teach school students, researchers, and other citizens about stream health and monitoring protocols; (2) professional surveys conducted by Stroud Center biologists; (3) and development of an online water atlas to store, visualize, and share data among government managers and scientists, nongovernmental organizations, and citizens.

Principal Investigator: William H. Eldridge

Collaborators: Bernard W. Sweeney, David B. Arscott, and **Tara Muenz**

Ecotoxicity Study for Mayflies Exposed to Elevated Concentrations of Chloride

Funded by: Pennsylvania Department of Environmental Protection

Chloride concentrations in surface waters have been increasing over the last several decades at multiple locations throughout the United States. Sources include wastewater treatment plants; wastewaters from some agricultural, industrial, and oil and gas production activities; and road runoff following applications of deicing products. At times, it appears that ambient chloride concentrations now reach levels that may have a negative effect on aquatic organisms. This project measures lethal and nonlethal responses of six mayfly species exposed to elevated chloride concentrations in water from three Exceptional Value streams in Pennsylvania as well as in White Clay Creek at the Stroud Center.

Principal Investigators: John K. Jackson and **David H. Funk**

Stroud Center entomologist John Jackson, Ph.D., leads a group of international visitors on a tour of White Clay Creek. *Photo: Beverly Payton*

Ecotoxicity Study for Mayflies Exposed to Elevated Concentrations of Sulfate

Funded by: Pennsylvania Department of Environmental Protection

Across the United States, sulfate concentrations tend to be elevated in areas where acid rain or coal mining is present. This project measures lethal and nonlethal responses of six mayfly species exposed to elevated sulfate concentrations in water from three Exceptional Value streams in Pennsylvania as well as in White Clay Creek at the Stroud Center.

Principal Investigators: John K. Jackson and **David H. Funk**

Evaluating Potential Impacts on Groundwater of Passive Composting of Spent Mushroom Substrate According to Best Practices Guidelines

Funded by: Stroud Water Research Center and American Mushroom Institute

By installing monitoring wells for groundwater, soil-water samplers, and probes to measure the conductivity in soil and groundwater, researchers are testing whether PA DEP guidelines for passive composting of spent mushroom substrate are protecting groundwater.

Principal Investigator: Louis A. Kaplan

Improving Stream Water Quality and Reducing Runoff by Improving Farm Soil Health Through Permanent Cover Cropping

Funded by: U.S. Department of Agriculture

Scientists are studying how soil structure and soil ecosystem health improve on a farm field over a three-year period after shifting from conventional tillage practices to cover cropping. They are also quantifying changes in the amount of water, sediment, and nutrient runoff that result from the shift to cover cropping. At the conclusion of the project, watershed scaling models will be used to promote cover crops as a best management practice for mitigating pollution of streams and downstream estuaries.

Principal Investigator: Bernard W. Sweeney

Collaborators: Matthew J. Ehrhart, Anthony K. Aufdenkampe, and **David B. Arscott**

Stroud Center researchers enjoy local field work on a beautiful day. *Photo: Jan Battle*

Installation and Maintenance Services for Two Wireless Stream Monitoring Stations Measuring Conductivity, Temperature, Depth, and Turbidity for London Grove Township, Pa.

Funded by: London Grove Township

Stroud Center staff installed and maintained two real-time stations for monitoring water quality in a tributary of the East Branch of White Clay Creek to measure stream water level, temperature, specific conductivity, and turbidity in the creek. The object was to monitor the creek between two points (approximately 1 kilometer apart) to determine the extent of changes in water quality that may be related to land-use differences between the sensor stations.

Principal Investigator: Anthony K. Aufdenkampe

Integrated Data Management System for Critical Zone Observatories

Funded by: National Science Foundation EAR 1332257

The objective of the project is to develop a comprehensive, integrated data-management system for the Critical Zone Observatory (CZO) program, called CZOData. The project's first goal is to support, empower, and broaden the impact of CZO science. The second is to maximize the return on investment of the CZO program by transforming capabilities to easily share, integrate, analyze, and preserve the wide range of multidisciplinary data generated within and across CZOs.

Principal Investigator: Anthony K. Aufdenkampe

Collaborators: Ilya Zaslavsky (University of California, San Diego); Kerstin Lehnert (Columbia University); Jeffrey Horsburgh (Utah State University); Emilio Mayorga (University of Washington)

Integration of Physiological, Life-History, and Macro-Ecological Approaches for Understanding Thermal Limitation in Aquatic Insects: Implications for Freshwater Biodiversity in a Warming World

Funded by: National Science Foundation

In this project, we test the hypothesis that temperature limits the distributions of aquatic insects through its effect on resource allocation, and that warming decreases egg production by shunting energy to other metabolic processes.

Principal Investigators: Bernard W. Sweeney, **John K. Jackson**, and **David H. Funk**

Collaborators: David B. Buchwalter (North Carolina State University); Charles P. Hawkins (Utah State University); Goggy Davidowitz (University of Arizona)

Land Use Effects on Stream Thermal Regime

Funded by: USDA Forest Service

Stream temperatures are dramatically affected by land use in the watershed and riparian zone. In this project, we measure stream temperatures throughout a series of small watersheds with land use ranging from very urbanized to completely forested to develop a predictive model of stream temperature changes.

Principal Investigators: Melinda D. Daniels and **Valérie Ouellet**

Large Runoff Flux and Transformation of Particulate Nitrogen (PN) Following Large, Intense Storms: A Critical but Unexplored Component of N Cycling in Watersheds

Funded by: U.S. Department of Agriculture

Particulate nitrogen (PN) in stormwater runoff can increase dramatically with large storms, thus constituting a significant component of nitrogen cycling in watersheds. In this project, Stroud Center scientists apply a novel combination of approaches to monitor the flux and transformations of PN. The goal is to produce a comprehensive model for PN fate and transport in watersheds, especially in agroecosystems subject to climate variability.

Principal Investigator: Jinjun Kan

Collaborators: Shreeram Inamdar and Rodrigo Vargas (University of Delaware)

Long-Term Research in Environmental Biology (LTREB): Trajectory for the Recovery of Stream Ecosystem Structure and Function During Reforestation

Funded by: National Science Foundation DEB 1052716

Stream restoration in the United States is a multibillion-dollar industry, but long-term monitoring of its effectiveness is virtually nonexistent. Stroud Center scientists initiated a study to follow restoration within White Clay Creek that involves the reforestation of meadows or pastures with native deciduous trees and the removal of invasive plant species. As the planted forest matures, researchers will characterize the changes in the aquatic biological communities and their associated activity. Teachers will be trained in the use of long-term environmental data as a means to enhance math skills, analytical abilities, and environmental knowledge of both students and teachers.

Principal Investigators: Bernard W. Sweeney, **Anthony K. Aufdenkampe**, **John K. Jackson**, **Jinjun Kan**, and **Melinda Daniels**

Collaborators: J. Denis Newbold, **David B. Arscott**, **Charles L. Dow**, **Susan E. Gill**, **Tara Muenz**, **Louis A. Kaplan**, and **William H. Eldridge**

Macroinvertebrate Monitoring at Sites in White Clay Creek, Pa., Flint River, Ga., Mississippi River, Mo., Susquehanna River, Pa., and Delaware River, Pa.

Funded by: Various public and private sources

These projects use aquatic macroinvertebrates such as mayflies, stoneflies, and caddisflies to provide assessments of current water quality in these streams and rivers. Where long-term data are available, the most recent conditions are interpreted with the invaluable perspective of conditions observed 5, 10, 20, or 30 years ago.

Principal Investigators: John K. Jackson and **Bernard W. Sweeney**

Metaecosystems and the Upstream Legacy: Influence of Dissolved Organic Matter on the Structure and Function of Streambed Bacterial Communities

Funded by: National Science Foundation DEB 1120717

Investigators explore how the quality of organic molecules changes with distance downstream and how those changes influence the composition of the communities of streambed microbes using that food resource. The research goals include advancing knowledge of stream ecosystems across drainage networks and forging a broad model of stream ecosystems in the global carbon cycle.

Principal Investigators: Louis A. Kaplan, Jinjun Kan, **Susan E. Gill**, **Tara Muenz,** and **Jennifer J. Mosher**; Robert H. Findlay (University of Alabama)

Collaborator: David C. Richardson (SUNY New Paltz)

Microbial Fuel Cell Project

Funded by: TE Connectivity

This project is testing sediment microbial fuel cells (MFCs) as a source of clean, sustainable, environmentally friendly energy. The study uses MFCs to power a Christmas tree as an example of its applicability.

Principal Investigator: Jinjun Kan

Microbial Population Dynamics of Periphyton Biofilms in White Clay Creek

Funded by: Stroud Water Research Center

Starting in the summer of 2011, Stroud Center scientists deployed glass slides into three reaches of White Clay Creek with distinct streamside land uses: mature forest, restored but immature forest, and meadow from upstream to downstream; microbial biofilms colonized the glass slides. Molecular DNA fingerprints of small subunit ribosomal RNA genes demonstrated spatial and temporal variations of biofilm population structures on both natural surface and glass slides. Comparing the results from other projects, the Stroud Center found that the surfaces on which microorganisms grow may be one of the most important environmental drivers for the growth of microorganisms.

Principal Investigator: Jinjun Kan

Model My Watershed — Delaware River Basin

Funded by: William Penn Foundation

This project expands the Model My Watershed application to the entire Delaware River Basin and supports restoration efforts funded by the William Penn Foundation. This application will provide higher-resolution modeling for developing effective restoration plans in targeted watersheds. The models that are integrated into this application include stormwater runoff, water-quality modeling (for nutrients, pathogens, and sediments), and terrain analysis.

Principal Investigators: Anthony K. Aufdenkampe and **Susan E. Gill**

Collaborators: Robert Cheetham (Azavea, Inc.); Emilio Mayorga (University of Washington); David Tarboton (Utah State University)

Parthenogenesis (Virgin Reproduction), Hybridization, and Life History Plasticity in Mayflies

Funded by: Stroud Water Research Center

Stroud Water Research Center's multiyear focus on the mayfly *Centroptilum triangulifer* has been expanded to include a number of mayfly species in White Clay Creek as well as in streams throughout eastern North America. This effort has increased our understanding of virgin reproduction and hybridization in mayflies, confirmed the biological integrity of species that are morphologically cryptic (i.e., those that are genetically distinct but morphological keys currently give them the same name), and led to the development of valuable laboratory techniques for mating and rearing aquatic insects.

Principal Investigators: David H. Funk, **Bernard W. Sweeney**, and **John K. Jackson**

Pathogen and Water-Quality Monitoring at White Clay Creek

Funded by: United Water Delaware and Suez Environment

As part of a plan to meet new drinking water regulations, United Water Delaware (UWDE) applied best management practices at several dairy farms in the White Clay Creek and Red Clay Creek watersheds to reduce pathogen loadings upstream of its Stanton plant. Stroud Center scientists are monitoring water quality near and below these farms to help UWDE determine how the best management practices influence levels of pathogens in White Clay Creek. Specifically, baseflow and storm samples are collected to quantify physical, chemical, and biological water quality. Biological sampling includes analyses for *Cryptosporidium*, *Giardia*, and coliform bacteria.

Principal Investigators: Jinjun Kan and **David B. Arscott**

Collaborators: John K. Jackson; Kristen Jellison (Lehigh University); John Dyksen (United Water Delaware)

Physical, Chemical, and Biological Monitoring of Streams in the Runnymede Sanctuary, Chester County, Pa.

Funded by: Runnymede Sanctuary

Runnymede Sanctuary streams were sampled to (1) assess their water quality relative to other streams in the region, (2) determine whether water quality has changed significantly since Stroud Center scientists sampled it in 1998–1999, (3) assess the quality of water entering the preserve to see if it has been compromised by land use activities upstream of the preserve (e.g., farms, small urban centers, housing developments, etc.), and (4) to provide a baseline regarding water quality for future assessment.

Principal Investigators: Bernard W. Sweeney and **John K. Jackson**

Physical, Chemical, and Biological Assessment of Streams and Rivers in Bhutan

Funded by: Stroud Endowment for Environmental Research, W. B. Dixon Stroud Jr., and Peter Kjellerup

Scientists evaluated the water quality of streams and rivers flowing through the major districts of Paro, Thimphu, and Punakha in Bhutan. They studied the levels of *E. coli* bacteria, total coliform bacteria, and nutrient chemicals. They also studied the relative abundance and diversity of macroinvertebrates. In all three districts, the population centers had a substantial negative impact on water quality for both the mainstem and associated small tributaries.

Principal Investigator: Bernard W. Sweeney

Collaborators: Anthony Aufdenkampe; Beth Fisher (University of Minnesota)

Coatesville Youth Initiative students learn about fish inhabiting the Brandywine Creek. *Photo: Tara Muenz*

Stroud Center board member Dixon Stroud and organic geochemist Anthony Aufdenkampe, Ph.D., measure stream discharge in Bhutan. *Photo: Mandy Cabot*

Restoring Flood Attenuation and Ecological Resiliency in the Mid-Atlantic Piedmont

Funded by: National Fish and Wildlife Foundation

For this project, scientists and watershed restoration professionals restore one headwater basin to reduce flooding to downstream communities, improve water quality, and increase stream-ecosystem resilience so that it will once again support a breeding population of native brook trout and other coldwater fish species. The restoration work includes 14,000 feet of infiltration berm to intercept and infiltrate surface runoff from fields, 30 acre-feet of floodplain wetland flood storage, and extensive riparian buffer reforestation. Pre- and post-project measures of water quality, hydrologic regime, and biological communities will determine the project's effectiveness.

Principal Investigator: Melinda D. Daniels

Collaborators: Bernard W. Sweeney, **David B. Arscott**, **Matthew J. Ehrhart**, **William H. Eldridge**, **John K. Jackson**, and **Susan E. Gill**

Scientific Software Integration (SSI): The Community-Driven BiG CZ Software System for Integration and Analysis of Bio- and Geoscience Data in the Critical Zone

Funded by: National Science Foundation ACI 1332257

The goal of this project is to develop a Web-based integration and visualization environment for joint analysis of cross-scale bio- and geoscience processes in the Critical Zone (BiG CZ), spanning experimental and observational designs. Collaborators include members of the Critical Zone science and broader communities, including natural resource managers and stakeholders. The BiG CZ Portal and Toolbox are built on foundations developed by the Model My Watershed v2 and Observations Data Model v2 projects.

Principal Investigators: Anthony K. Aufdenkampe

Collaborators: Ilya Zaslavsky (University of California, San Diego); Kerstin Lehnert (Columbia University); Jeffrey Horsburgh (Utah State University); Emilio Mayorga (University of Washington)

Supporting Citizen Science Within the Delaware River Watershed Initiative Cluster Teams

Funded by: William Penn Foundation

The Stroud Center is working to expand and encourage higher-quality citizen-science monitoring and volunteer participation in the Delaware River Initiative cluster of streams. One- and two-day traveling workshops focus on general stream and watershed ecology, monitoring, and restoration. Remote sensors monitor water quality continuously and provide data for analysis. Efforts continue in the Circuit Rider program to facilitate cluster planning, coordination, project implementation, and monitoring, and to improve ongoing and future restoration project implementation.

Principal Investigators: Matthew J. Ehrhart, **John K. Jackson**, and **David B. Arscott**

Collaborators: Bernard W. Sweeney, **Jinjun Kan**, **Melinda D. Daniels**, and **Anthony K. Aufdenkampe**

Threats and Opportunities in the Conservation of Native Pelagic Spawning Fishes in Kansas

Funded by: Kingsbury Family Foundation

This project documents how small dams have fragmented stream networks in the Central Great Plains region. Many fishes native to this region lay buoyant eggs that float downstream while developing. Juveniles then migrate back upstream to breed as adults. Using geographic information science, we are documenting fragmentation points (dams) that capture downstream drifting eggs as well as block maturing fish from returning to upstream portions of the stream network.

Principal Investigator: Melinda D. Daniels

Transforming Water Quality in the Sharitz Run Headwaters of Brandywine Creek

Funded by: Pennsylvania Department of Environmental Protection

This Watershed Renaissance Initiative grant will enable Stroud Water Research Center to implement extensive watershed restoration projects designed to capture and control excess water and sediment production from agricultural hillslopes. The grant also provides funding to support extensive and highly rigorous monitoring efforts targeted at measuring the effectiveness of restoration projects. Results will help provide guidance to maximize the effectiveness of future restoration designs and investments at the regional and national levels.

Principal Investigators: Melinda D. Daniels and **Matthew J. Ehrhart**

Collaborators: Bernard W. Sweeney, **Louis A. Kaplan**, **Jinjun Kan**, **David B. Arscott**, and **Anthony Aufdenkampe**

Education Projects

2015 Brandywine Trek at Point Lookout

Funded by: Point Lookout Foundation

The Brandywine Trek is a youth leadership and environmental awareness program that combines outdoor learning and physical activities over five days of hiking, canoeing, and camping along the Brandywine River. Trek activities are designed to build leadership skills, promote cultural and historical competence, and develop an understanding of watershed management and water resource linkages among our communities.

Project Lead: David B. Arscott

Collaborators: Tara Muenz; Jarvis Berry (Coatesville Youth Initiative); Sky Prestowitz (UrbanPromise, Wilmington)

Collaborative Research: Introducing Critical Zone Observatory (CZO) Science to Students and Teachers

Funded by: National Science Foundation

The Critical Zone encompasses the external or near-surface Earth extending from the top of the vegetation canopy down to and including the zone of

freely circulating groundwater. This project engages college students and teachers in a summer research internship studying two observatories: the Christina River Basin and the Susquehanna Shale Hills site. Participants engage in real-world, hands-on experiences examining and presenting on their particular research focus within the Critical Zone.

Principal Investigators: Anthony K. Aufdenkampe and **Susan Gill**; Timothy S. White (The Pennsylvania State University)

Collaborators: Tara Muenz, **David B. Arscott**, **Jinjun Kan**, **Melinda D. Daniels**, and **Heather Brooks**; Holly Michael and Jim Pizzuto (University of Delaware)

Consortium for Scientific Assistance to Watersheds (C-SAW)

Funded by: Pennsylvania Department of Environmental Protection's Growing Greener Program

Stroud Center educators and scientists provided technical assistance to county conservation districts, municipal environmental advisory committees, watershed associations, and citizen action groups as part of a partnership of nine organizations across Pennsylvania whose goal is to teach conservation groups how to conduct effective watershed assessments and restoration efforts.

Project Leads: David B. Arscott and **Tara Muenz**

Collaborators: Alliance for Aquatic Resource Monitoring at Dickinson College; Conemaugh Valley Conservancy; Delaware Riverkeeper Network; Pennsylvania Lake Management Society; United States Geological Survey; Pocono Northeast Resource Conservation and Development Council

SFS Leaf Pack Workshop

Funded by: Society for Freshwater Science

Stroud Center staff and members of the SFS Education and Diversity Committee held a Leaf Pack workshop at the University of Wisconsin-Milwaukee's School of Freshwater Sciences prior to the society's annual meeting. The workshop introduced educators and citizens to the Leaf Pack Experiment and its utility as a stream assessment and teaching tool for middle school and high school students and interested members of the public.

Project Lead: Tara Muenz

Collaborator: Bernard W. Sweeney

Stream School for New Jersey Department of Environmental Protection (NJ DEP)

Funded by: NJ DEP

Stroud Center continues to provide expertise in two sets of two-day stream ecology trainings for AmeriCorps New Jersey Watershed Ambassadors and citizen water-quality-monitoring volunteers. NJ DEP utilizes volunteer data, at the state level, for assessing the health of its water bodies.

Project Lead: Tara Muenz

Stroud Stream Programs for Public Schools

Funded by: The Education Improvement Tax Credit Program (EITC)

Stroud Center educators conduct a four-hour, boots-in-the-water stream program for students in fourth through 12th grade. During their visit at the Stroud Center, students learn about freshwater research, aquatic insect collection and identification, and the importance of trees for stream health. The program helps students better understand their impact on waterways and how they can protect and improve this vital resource for all life.

Project Lead: Tara Muenz

Stroud Water Research Center Streamside Classroom Project

Funded by: E. Kneale Dockstader Foundation

This project enhances our streamside classroom along White Clay Creek at Stroud Water Research Center with the construction of three educational kiosks and various interpretive signs and seating areas. Interpretive signage promotes a more innovative, intimate, and open learning environment while also effectively addressing the important connection between streamside forests and the ecology of rivers and streams. Components of this infrastructure were built by a student seeking Eagle Scout rank with the Boy Scouts of America.

Project Lead: David B. Arscott

Collaborators: Tara Muenz, **Rebecca Duczkowski**, and **William Milliken**; Yeda L. Arscott (Arscott Architectural and Graphic Design)

Teaching Environmental Sustainability — Model My Watershed

Funded by: National Science Foundation, Discovery Research K–12

Stroud Center educators and scientists are enhancing the Model My Watershed application by integrating water-quality and terrain-analysis models. This work is being completed in partnership with the Concord Consortium, which will lead the curriculum development, and Millersville University of Pennsylvania, which will conduct research on learning. The geographic extent of this expansion will be the contiguous 48 states. Professional development for teachers will take place in California, Iowa, Kansas, Pennsylvania, and Virginia.

Principal Investigators: Melinda D. Daniels; Nanette Marcum-Dietrich (Millersville University of Pennsylvania); Carolyn Staudt (Concord Consortium)

Collaborators: Anthony K. Aufdenkampe and **Susan E. Gill**; Emilio Mayorga (University of Washington); Robert Cheetham (Azavea, Inc.)

Trout Grow on Trees

Funded by: DuPont Clear Into the Future and Royal Bank of Canada

This project connects citizens to the idea that healthy forests make healthy streams and, thus, healthy trout populations. Funding supports hands-on experiences for students and families to learn about the importance of streamside forests and their connection to trout populations. It also supports our involvement with Pennsylvania's Trout in the Classroom program.

Project Lead: Tara Muenz

Collaborator: Bernard W. Sweeney

Water SCIENCE

Funded by: National Science Foundation, Innovative Technology Experience for Students and Teachers

The Stroud Center's education department is collaborating with the Concord Consortium on a project to introduce middle school students to engineering practices for water resources. This project targets schools in Boston; Kennett Square, Pennsylvania; and Phoenix/Tempe, Arizona. Millersville University of Pennsylvania is also involved.

Principal Investigators: Carolyn Staudt (Concord Consortium); **Melinda D. Daniels**; Nanette Marcum-Dietrich (Millersville University of Pennsylvania)

Collaborator: Susan E. Gill

Art is used as a teaching tool during a Trout Grow on Trees event. *Photo: Tara Muenz*

Watershed Restoration Projects

Ag BMP Planning and Implementation for Berks County (DEP); Leveraging Ag BMPs and Forested Buffers for Middle Schuylkill Cluster (NFWF)

Funded by: Pennsylvania Department of Environmental Protection and National Fish and Wildlife Foundation

This project operates the Farm Stewardship Program in Berks County, assisting farmers to implement whole-farm conservation while leveraging USDA funding for work including forested buffers. To date, the project has enrolled six farms implementing 96 best management practices, including 18 acres of forested stream buffer averaging 81 feet on each side.

Project Lead: Matthew J. Ehrhart

Collaborators: Red Barn Consulting, Inc.; TeamAg, Inc.; Berks County Conservation District; Berks Nature; Partnership for the Delaware Estuary; USDA; others

Ag BMP Planning and Implementation for Chester County

Funded by: Pennsylvania Department of Environmental Protection

This project operates the Farm Stewardship Program in Chester County, assisting farmers to implement whole-farm conservation while leveraging USDA funding for work, including forested buffers. To date, the project has enrolled six farms implementing 52 best management practices, including about 3 miles of forested buffer averaging 50.5 feet on each side.

Project Lead: Matthew J. Ehrhart

Collaborators: Red Barn Consulting, Inc.; TeamAg, Inc.; Chester County Conservation District; Brandywine Conservancy; Brandywine Valley Association; USDA; others

Comprehensive Agricultural Stewardship in Lancaster County (DEP); Ag BMP Implementation and Nutrient Trading Assessments (NFWF)

Funded by: Pennsylvania Department of Environmental Protection and National Fish and Wildlife Foundation

Stroud Center's Farm Stewardship Program provides technical and financial assistance to farmers and landowners to implement best management practices (BMPs) to protect water quality and improve stream health. In total, it has assisted 22 farmers to install more than 235 ag BMPs (including 85 acres of forested buffers on 11.3 miles of streambanks). This work leveraged roughly $1.5 million in USDA funds. In addition, the potential for farmers to engage in nutrient trading was also assessed on 231 farms. The intent was to see if income from nutrient trading could motivate and reward installation of ag BMPs. In most cases, work simply brought farmers up to baseline levels of conservation. In a few cases, tradable credits were generated.

Project Lead: Matthew J. Ehrhart

Collaborators: Red Barn Consulting, Inc.; TeamAg, Inc. Berks County Conservation District; Chester County Conservation District; multiple land trusts, conservancies, and others

Delaware River Watershed Initiative Circuit Rider for Technical Assistance to Grantees

Funded by: William Penn Foundation and National Fish and Wildlife Foundation

This project provides technical assistance to grantees of the William Penn Foundation and the National Fish and Wildlife Foundation to develop and implement watershed restoration efforts and grants to monitor the impact of projects implemented in the Delaware River Watershed Initiative (DRWI) clusters. Stroud Center's efforts with DRWI partners will lead to better proposals and projects as well as improved assessment of the project outcomes.

Project Leads: Matthew J. Ehrhart, **John K. Jackson**, and **David B. Arscott**

Collaborators: Bernard W. Sweeney, **Jinjun Kan**, **Melinda D. Daniels**, and **Anthony K. Aufdenkampe**

Delivering the NFWF RCPP in Lancaster County, Pa.

Funded by: National Fish and Wildlife Foundation

This project provides outreach and technical assistance to farmers to ensure full implementation of funds provided by USDA's Regional Conservation Partnership Program for constructing ag best management practices (BMPs). The Stroud Center is NFWF's lead partner in this effort.

Project Lead: Matthew J. Ehrhart

Collaborators: USDA Natural Resources Conservation Service; National Fish and Wildlife Foundation; Red Barn Consulting, Inc.; TeamAg, Inc.; others

Demonstrating Low-Cost Methods for Reforestation

Funded by: National Fish and Wildlife Foundation

Four sites in New York, Pennsylvania, and Maryland demonstrated options for improving the cost-effectiveness of reforestation methods, including direct seeding, innovative fencing in lieu of tree shelters, live stakes, improved methods for managing herbivore competition, and more. Preliminary findings from the second year's data suggest that direct seeding is a viable option and might not require some specialized equipment (e.g., no-till seed drills). This would make the method more practical and affordable.

Principal Investigator: Bernard W. Sweeney

Collaborators: David S. Wise; Paul Salon (U.S. Dept. of Agriculture); Art Gover (private contractor); Andy Duncan (Pennsylvania Department of Conservation and Natural Resources); Natural Lands Trust

Leveraging Farm Bill Funds for Water Quality in the Brandywine-Christina and Middle Schuylkill Clusters

Funded by: National Fish and Wildlife Foundation

This project provides outreach and technical assistance to farmers in Chester and Berks counties to ensure full implementation of funds provided by USDA's Regional Conservation Partnership Program for constructing ag best management practices (BMPs). While USDA National Resources Conservation Service administers the program, the Stroud Center secured the funding and is ensuring full delivery of BMPs, including forest buffers on all enrolling farms.

Project Lead: Matthew J. Ehrhart

Collaborators: USDA Natural Resources Conservation Service; Chester County Conservation District; Berks County Conservation District; Berks Nature; Partnership for the Delaware Estuary; Mowery Environmental, LLC; Brandywine Conservancy; Red Barn Consulting, Inc.; TeamAg, Inc.; others

Whole-Farm Conservation Including Forested Buffers

Funded by: National Fish and Wildlife Foundation

This project expands the Farm Stewardship Program in Lancaster and Franklin Counties — the top two dairy counties in Pennsylvania. To address water-quality issues, whole-farm conservation with forested buffers is implemented, leveraging USDA funding. Advanced conservation methods are promoted, including precision agriculture that reduces environmental impacts from farming. Farmers who install forested buffers receive incentives that can only be used to pay for other needed ag best management practices on the farm. The approach shows that whole-farm conservation is achievable, leverages CREP and other USDA funds, and raises the bar on the returns on investment of conservation funds.

Project Lead: Matthew J. Ehrhart

Collaborators: Red Barn Consulting, Inc.; TeamAg, Inc.; others

Published Titles

Caldas M. M., M. R. Sanderson, M. Mather, M. **D. Daniels**, J. S. Bergtold, J. Aistrup, J. L. Heier Stamm, D. Haukos, K. Douglas-Mankin, A. Y. Sheshukov, and D. Lopez-Carr. 2015. Opinion: Endogenizing culture in sustainability science research and policy. *Proceedings of the National Academy of Science of the United States of America* 112(27): 8157–8159.

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Hatched at the Stroud Center last November, this brook trout, along with dozens more, will be released in the spring. *Photo: Tara Muenz*

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We gratefully acknowledge the following 363 donors who generously contributed $568,522 to our annual fund. This is a new record in dollars and donors! Our annual fund covers operational expenses, not supported by grants, and it allows us to continue our work in freshwater research, education, and restoration. Thank you!

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Bern Sweeney, Ph.D., (center) stands with Dansko co-founders Mandy Cabot and Peter Kjellerup, at the dedication of the Cabot-Kjellerup Public Outreach Wing in the Moorhead Environmental Complex. *Photo: Beverly Payton*

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If you have already made a bequest intention, please let us know. We would like the opportunity to thank you.

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Guests at Sustainable Splurges enjoyed a relaxing evening of delicious food and delightful conversation at The Farm at Doe Run. *Photo: Beverly Payton*

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Three generations of Phoebes work toward conservation and preservation of their community. From left: Phoebe Fisher (Phoebe Driscoll's daughter), Phoebe Fisher (granddaughter), and Phoebe Driscoll. Not pictured: granddaughter Lydia Fisher, another third-generation conservationist. *Photo: Tom Volk*

From Generation to Generation, Advancing Watershed Stewardship

Phoebe Driscoll's commitment to land conservation started when she was a farm girl living on her parent's working farm in Maryland. After marrying Lee Driscoll, she moved to North Wales, Pennsylvania, and they raised four children as well as plenty of horses, pigs, chickens, and assorted fowl. Sharing a deep appreciation of nature, the couple decided to give 50 acres of their land to the Natural Lands Trust.

Phoebe's love of the land led her to pursue watershed monitoring of Bennett's Run, which flows near her home in Kennett Square, Pennsylvania. Phoebe and her granddaughter, Lydia, explored Bennett's Run together. "We walked every bit we could and took pictures," she says. "We spent a good deal of time writing an amateur report." Wanting to do more, they reached out to Stroud Center Director Bern Sweeney, and the Stroud Center responded by offering guidance and setting up temperature monitors.

Then last spring, some Stroud Center researchers took samples of the aquatic insects living in the stream. Later, Phoebe watched Stroud Center entomology interns sort and identify the different species. "They spent hours looking through microscopes," she recalls.

Last year, Phoebe had the opportunity to make a once-in-a-lifetime gift. Her daughter, also named Phoebe, told her, "If you wish to make a difference to the world, give it to the Stroud Center." So she did, and the Phoebe Internship Fund was created to forever benefit science interns.

By exposing future scientists to collaborative freshwater research and training them how to advance knowledge and stewardship of fresh water, the Stroud Center's internship program — like the three generations of Phoebes pictured above — can ensure a brighter future for both land and water. "Who knows," said Phoebe, "tomorrow's intern could end up being the next Bern Sweeney!"

Entomology interns enjoy a day of insect identification. *Photo: Tara Muenz*

Volunteers help protect the headwaters of White Clay Creek. *Photo: David B. Arscott*

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Yard's Brewery
Yo'r So Sweet

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Wegman's Market
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Yeda Arscott
Amy Borun
Kay Dixon
Evie Dutton
Laurie de Grazia
Anne Stroud Hannum
Kristine Lisi
Jessica Provinski
Trish Scott
Donnan Sharp
Boo Stroud

Please join us for more fabulous events throughout the year. Go to www.stroudcenter.org/events to learn more. *Photos (all except noted): Beverly Payton*

Photo: Stacey Gentile

Financials

Operating Statement
for the year ended December 31, 2015

Revenues & Support

Research Programs (Grants & Contracts)	$ 3,255,008
Endowment	2,233,675
Watershed Restoration Group Programs	1,251,900
Education/Public Programs	940,013
Annual Fund	568,522
Other Contributions & Income	269,659
Reserves	0
Total Revenues & Support	**8,518,777**

Expenditures

Research	$ 3,508,026
Watershed Restoration Group	1,135,919
Facilities	1,080,086
Education	881,034
Administrative	624,781
Reserves	430,527
Information Services	344,915
Development/Outreach	320,848
Communications	134,352
Other	58,289
Total Expenditures	**8,518,777**

Financial Information

Stroud™ Water Research Center is a 501(c)(3) nonprofit organization registered with the Pennsylvania Bureau of Charitable Organizations.
Gifts to Stroud Water Research Center are tax deductible on a U.S. return as allowed by law.
The Stroud Water Research Center Employer Identification Number (EIN) is 52-2081073.
The fiscal year is January 1 to December 31.
The annual audit is performed by Gunnip & Company.
Investment assets are managed by New Providence Asset Management and Passive Capital Management. The Stroud Center is also the beneficiary of the Morris W. Stroud 3rd Pennswood No. 2 Trust managed by the Glenmede Trust Company.

Privacy Statement

Stroud Water Research Center donor records are not sold, bartered, leased, exchanged, or otherwise provided to any outside organizations.

SECURING THE FUTURE

Your continued generosity through annual, endowed, and planned gifts is vital to our research, education, and restoration programs. Below is a brief list of ways you can make a tax-deductible gift:

ONLINE
Visit www.stroudcenter.org/donate

CASH OR CHECK
Please mail donations to:
Stroud Water Research Center, 970 Spencer Road, Avondale, PA 19311

CREDIT CARD
Stroud Water Research Center accepts VISA, Mastercard, and American Express. Credit card gifts can be made as a one-time gift or as a monthly or quarterly contribution.

STOCK
Gifts of appreciated securities are an outstanding way to avoid 15 percent capital gains tax. Prior to transferring assets, please contact Stroud Water Research Center Development staff, since no name will be attached to the deposit of funds. Your broker can use this information:
Charles Schwab & Co.; DTC Clearing Number: 0164 – Code 40
Account name: Stroud Water Research Center; Account number: 1749-3778

WIRE TRANSFER
Funds may be wired directly to the Stroud Water Research Center's financial institution. Please contact the development department for instructions.

PLANNED GIVING
A planned gift can meet your short-term or long-term charitable and financial goals. Planned gifts include, but are not limited to, bequest intentions, charitable gift annuities, IRA payments, retirement plan assets, insurance policies, and other various trusts to fit your needs.

CORPORATE MATCHING GIFT
Several companies match an employee's personal charitable contribution. Double your gift by simply asking your HR person if your company participates in a gift-matching program.

MEMORIAL AND HONOR GIFTS
Remember a friend, neighbor, or loved one with a gift in his/her name. All tributes will be listed in the annual report, and, when an address is provided, a letter will be sent on your behalf.

Stroud Water Research Center Development Staff

Kristine C. Lisi, Director of Development, klisi@stroudcenter.org, 610-268-2153, ext. 304
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Jessica M. Provinski, Associate Director of Special Events and Corporate Relations, jprovinski@stroudcenter.org, 610-268-2153, ext. 288

Staff
2015

Photo: Beverly Payton

Administration
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President, Director, and Senior Research Scientist

David B. Arscott, Ph.D.
Vice President, Assistant Director, and Research Scientist

John D. Pepe
Controller and Treasurer

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Rebecca Duczkowski
Administrative Assistant

Jane Sowden
Grant and Contract Administrator

Biogeochemistry
Louis A. Kaplan, Ph.D.
Senior Research Scientist

STAFF

Michael D. Gentile
Research Tech III

Sherman L. Roberts
Research Tech III

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Director of Communications

Diane Huskinson
Consultant, Huskinson Communications

Kristine Parkes
Consultant, Kultivate

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Kristine C. Lisi
Director of Development and Outreach and Secretary to the Board of Directors

STAFF

Kay D. Dixon
Associate Director of Donor Relations

Jessica M. Provinski
Associate Director of Special Events & Corporate Relations

Education
Susan E. Gill, Ph.D.
Director of Education

STAFF

Elizabeth S. Gregg
Education Programs Assistant

Tara K. Muenz
Assistant Director of Education and Programs Manager

NSF RESEARCH EXPERIENCE FOR TEACHERS

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Ridley High School

Entomology
John K. Jackson, Ph.D.
Senior Research Scientist

STAFF

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Research Tech IV

Michael C. Broomall
Research Tech III

David H. Funk
Research Tech V

William L. Milliken Jr.
Field Assistant

Sally Peirson
Research Tech III

Kelly C. McIntyre
Research Tech II

Sherman L. Roberts
Research Tech III

Matthew J. Wilson
Research Tech III

INTERNS

Catherine R. McFadden
West Chester University

Kara M. Grubb
University of Delaware

Franklin D. Herr
Millersville University

Paige R. Minka
West Chester University

Christine M. Stephens
The Pennsylvania State University

Alexander V. Giannaris
West Chester University

Mark T. Gervasi
University of the Sciences

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Lauren McGrath
University of Pennsylvania

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David H. Funk
Director of Facilities

STAFF

William L. Milliken Jr.
Facilities Manager

Tonya Prigg
Housekeeping

Salomon Romero
Woodlot Tech

Javier Tinoco
Woodlot Tech

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Research Tech III

Fluvial Geomorphology
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STAFF

Lindsey Albertson
Post-Doctoral Associate

Sarmistha Chatterjee
Ph.D. Candidate, University of Delaware

Jennifer R. Matkov
Research Tech II

David S. Montgomery
Research Tech III

Valérie Ouellet
Post-Doctoral Research Associate

INTERNS

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Emily L. Scott

NSF RESEARCH EXPERIENCE FOR UNDERGRADUATES INTERNS

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Connecticut College

Kelly Shen
Duke University

VOLUNTEERS

Ali Corkran
Cornell University

Erica Fenza
College of Charleston

Frank Klein, Ph.D.
Research Tech and DuPont Chemist Retiree

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Charles L. Dow, Ph.D.
Director of Information Services and Research Scientist

STAFF

Melanie L. Arnold
Data Analyst

Heather P. Brooks
Web Developer

Elizabeth S. Gregg
Systems Administrator

Maritza Station* Costa Rica
Rafael A. Morales
Station Manager and Research Tech

STAFF

Cristian A. Collado
Research Tech

Microbiology
Jinjun Kan, Ph.D.
Assistant Research Scientist

STAFF

Laura K. Borecki
Research Tech III

NSF RESEARCH EXPERIENCE FOR UNDERGRADUATES INTERN

Pinky Liau
Rutgers University

NSF RESEARCH EXPERIENCE FOR TEACHERS INTERN

Adria M. Bondanza
Sun Valley High School

Organic Geochemistry
Anthony K. Aufdenkampe, Ph.D.
Associate Research Scientist

STAFF

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Research Tech III

Sara G. Damiano
Research Tech III

Steven D. Hicks
Research Engineer

David S. Montgomery
Research Tech III

Jennifer R. Matkov
Research Tech II

VOLUNTEER

Frank Klein, Ph.D.
Research Tech and DuPont Chemist Retiree

Watershed Installations
David S. Montgomery
Manager

Watershed Restoration
Matthew Ehrhart
Director of Watershed Restoration

STAFF

Stephanie M. Eisenbise
Watershed Restoration Coordinator

Lamonte Garber
Watershed Restoration Coordinator

David Wise
Watershed Restoration Manager

Research Scientists Emeriti
Thomas L. Bott, Ph.D.
Senior Research Scientist Emeritus

J. Denis Newbold, Ph.D.
Research Scientist Emeritus

Adjuncts
Rolf Aalto, Ph.D.
Adjunct Research Scientist, University of Exeter

William C. Anderson
Adjunct Researcher, Unionville High School Teacher Retiree

Barry M. Evans, Ph.D.
Adjunct Research Scientist, Penn State University

Nanette Marcum-Dietrich, Ph.D.
Adjunct Education Faculty, Millersville University

Stroud Center – University of Delaware Interns
NSF RESEARCH EXPERIENCE FOR UNDERGRADUATES INTERNS

Julianne E. Scamardo
The University of Texas

Katie Li
Pomona College

* *The Maritza Biological Station staff is employed by the Asociación Centro de Investigación Stroud, a non-governmental organization in Costa Rica that serves as the umbrella organization for all of tthe Stroud Center's research and education activities in Central and South America.*

Board of Directors

2015

**Stroud Center gratefully acknowledges the service of Chip Cruice, Peter Davenport, Stan Laskowski, and Stephanie Speakman, who retired from the board in 2015 after many years of service.*

***It is with great sadness that we lost John Taylor last year, who passed away on April 4.*

STROUD™ WATER RESEARCH CENTER

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Avondale, PA 19311-9514
USA

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610-268-0490 Fax
www.stroudcenter.org

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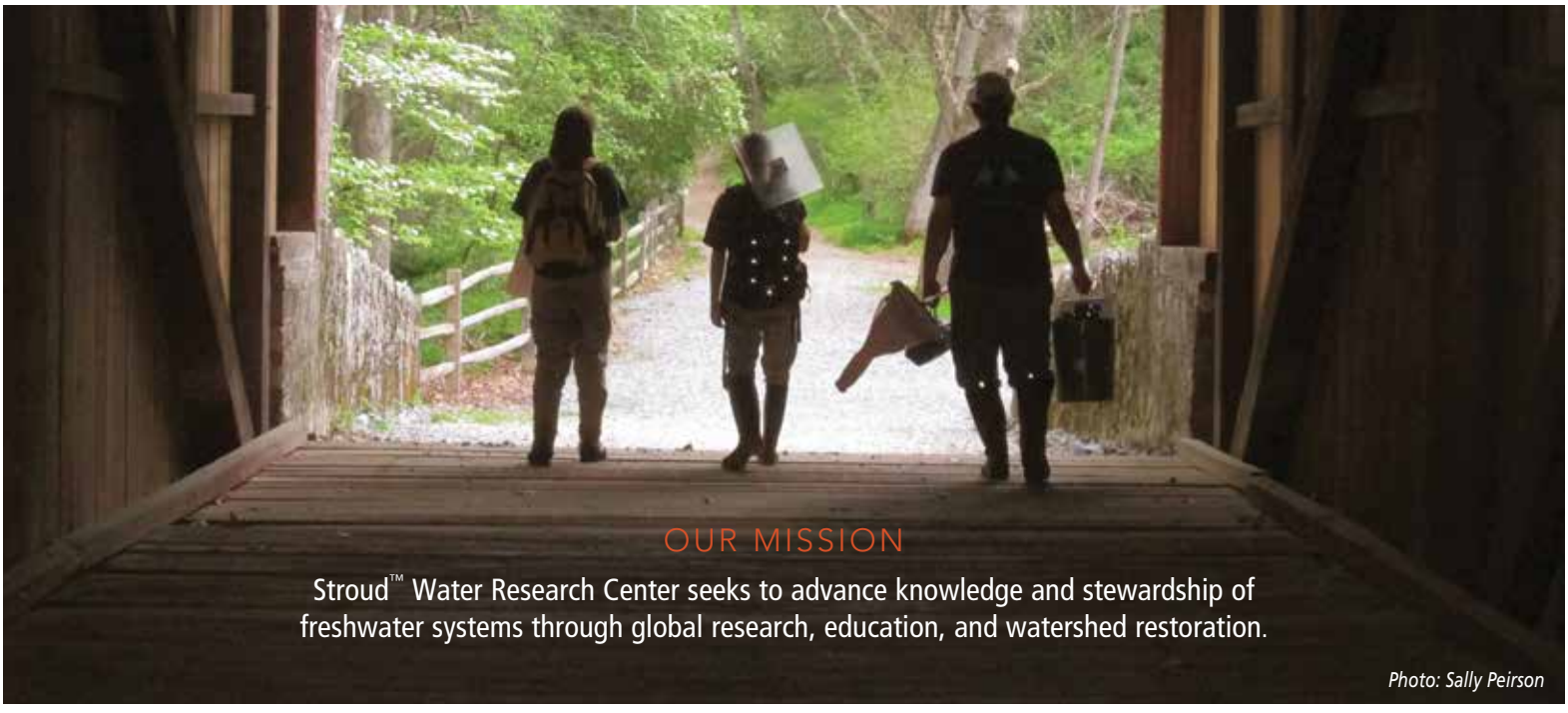
- **567** lbs. solid waste not created
- **1,562** lbs. CO2 of net greenhouse gases prevented
- **9,000,000** BTUs energy not consumed[1]
- **460** lbs. of GHG emissions not generated
- **0.15** barrels of natural oil unused
- **151** miles not driven
- **2** trees planted

1. Estimate of GHGs and equivalencies for clean wind energy RECs & Carbon Offsets



OUR MISSION

Stroud™ Water Research Center seeks to advance knowledge and stewardship of freshwater systems through global research, education, and watershed restoration.

Photo: Sally Peirson