

WATER RESEARCH CENTER



# 2017 Annual Report

A YEAR IN REVIEW Keeping Water Fresh for Fifty Years



WikiWatershed Receives 2017 PA Governor's Award for Environmental Excellence

Wiki Watershed

### A | COVER CROPPING SERIES

Stroud<sup>™</sup> Water Research Center sponsored a series of articles about cover cropping by Steve Groff (center left), a cover crop farmer and consultant. The articles appeared in Lancaster Farming in 2016 and 2017. In March, Groff presented a lecture at the Stroud Center to educate the public about the latest farming techniques. Many of these techniques are being used by Jamie Hicks (center right), a local farmer working with the Watershed **Restoration Group.** 

### **B | WIKIWATERSHED**

WikiWatershed, an online toolkit featuring a watershedmodeling web app developed by the Stroud Center and partners, was awarded a 2017 Governor's Award for Environmental Excellence by the Pennsylvania Department of Environmental Protection. Awardees of 16 different projects that represent the very best in innovation, collaboration, and public service in environmental stewardship were recognized at an event hosted by DEP and the Pennsylvania Environmental Council. Photo courtesy of PEC.

### C | COSTA RICA

In July, (from left) Steve Kerlin, Diana Oviedo-Vargas, Tara Muenz, Lou Kaplan, and Rafa Morales visited Las Yegüitas, a stream north of the Maritza Biological Station in Costa Rica, as part of a research and education program planning expedition.

### D | THE WATER'S EDGE

His Serene Highness Prince Albert II of Monaco received the Stroud Award for Freshwater Excellence on September 17, 2017 at Winterthur as the Stroud Center celebrated its 50th anniversary. As an enlightened leader, Prince Albert has helped reduce water use and protected the quality of freshwater resources through his foundation. Photo: Christopher Brown (shootfromwithin.com)













A commissioned 2017 portrait of past Stroud Center directors Bern Sweeney and Robin Vannote, painted by Reenie Chase.

Last year, we celebrated a significant milestone: 2017 marked the 50th anniversary of Stroud<sup>™</sup> Water Research Center. It was also the year Bern Sweeney, who served as president and director for nearly three decades, decided to retire, focus more on his research, and spend some much-deserved time with family and friends. The reins were handed to me, and I became the Stroud Center's third executive director.

I am honored to fill this role and eager to lead as well as Bern did, and Robin Vannote and Ruth Patrick before him — with vision and humility, courage and compassion, integrity and cooperation.

As I look back on this past year, I also think of the future. We created new opportunities for children and adults to become leaders in their own communities, as they learned to understand, restore, and protect our waterways. I promise we will continue to share our knowledge.

We further integrated farm management insights into our scientific research and watershed restoration. I promise we will continue to practice what we preach.

We built new partnerships with other organizations, including Rodale Institute, which are equally committed to rigorous research and environmental stewardship. I promise we will continue to build bridges leading us to a brighter, safer, and healthier future.

While I can't predict the future, I can promise that in an uncertain world that often threatens the things we value most, for as long as we have your support, we will continue to be here — working to understand and protect one vital resource we can't live without: clean fresh water.

Making every drop count,

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"Helping at the [Stroud Preserve] helped us to earn our Bronze Service Award, which is the highest honor a Junior Girl Scout can achieve."

- JUNIOR GIRL SCOUT TROOP LEADER ROLANDA HYMAN OF TROOP 457



## Learning Leading to Action

YOUNG HEROES ARE NOT ONLY LEARNING HOW TO PROTECT OUR WATERWAYS; THEY ARE ALSO CONDUCTING THEIR OWN SCIENTIFIC RESEARCH OR RESTORING HEALTHY STREAMS — OR SOMETIMES BOTH.

By Matthew Gisondi, Diane Huskinson, Steven Kerlin, Tara Muenz, and Jennifer Totora

Stroud<sup>™</sup> Water Research Center's efforts to educate schoolchildren about freshwater science and stewardship have grown by leaps and bounds in recent years. The fruit of that labor is much more than just the number of students participating in our programs (though that too has grown). What we are most proud of is the students themselves, who are taking what they have learned and putting it into action. Here are a few examples of young heroes who are not only learning how to protect our waterways, but also doing it, whether through conducting their own scientific research or restoring healthy streams — or sometimes both.

### Students Monitor and Plant Streamside Forests

In the spring of 2017, more than 130 Girl Scouts and students from southeastern Pennsylvania schools helped the Stroud Center monitor streamside forests in the Middle Schuylkill and Brandywine-Christina watersheds. Some groups collected data on properties where trees already had been planted; others planted and monitored new trees.

The in-field, service-learning opportunities were funded by a grant from the William Penn Foundation.

Two of the groups, Junior Girl Scout Troop 457 and Westtown School, helped Distinguished Research Scientist Bern Sweeney, Ph.D., with a research project comparing the effectiveness of two different kinds of tree shelters. They gathered at Taylor Run to plant trees, install tree shelters, and collect data on 300 trees. Located within the Stroud Preserve, Taylor Run is a tributary of the east branch of the Brandywine River that is in great need of restoration, as it receives urban stormwater and lacks a healthy riparian corridor.



Assistant education director Tara Muenz (left) and volunteers from Brownie Troop 457 flex their tree planting muscles.



"Helping at the preserve helped us to earn our Bronze Service Award, which is the highest honor a Junior Girl Scout can achieve," said Junior Girl Scout Troop Leader Rolanda Hyman of Troop 457.

This area of the Stroud Preserve is in some way a legacy forest for the students involved in this project. Our intentions are to continue working with student groups to revisit the plantings, collect data, and maintain tree shelters.

Moving forward, results from this spring's experiences will help Stroud Center staff understand the role students can play in collecting meaningful reforestation data for scientists and land managers.

### **Creek Explorers Make a Scientific Discovery**

Last summer, the Stroud Center's education department ran its first summer camp in partnership with West Chester University. Called Creek Explorers Camp, this weeklong day camp brought children ages 6 to 11 to the Robert B. Gordon Natural Area for Environmental Studies, a nearly 100-acre woodland on the South Campus of the university.

Once there, the young nature explorers participated in Stream Fever, a program funded by the National Science Foundation, which involves collecting and assessing stream temperature data. Walking along Plum Run and an ephemeral stream, they collected their data from a variety of ecosystems, including riffles, runs, pools, sun, and shade at upstream and downstream locations.

They made an exciting discovery. Temperatures in the ephemeral branch were higher than in the main branch of Plum Run. They concluded this higher temperature was most likely caused by

Junior Girl Scout Troop Leader Rolanda Hyman of Troop 457 said that volunteering at the preserve helped her troop earn the Bronze Service Award, the highest honor a Junior Girl Scout can achieve.

a shallow, swampy area the ephemeral stream ran through, where the water had a chance to warm up. This conclusion was only possible because they had been hiking in every tributary of the stream through the natural area and had the chance to feel the water flowing around their feet.

By the end of the week, the children knew the area well, and having had the opportunity to collect real data on their own while simultaneously having free rein to explore and investigate, they were excited by their scientific discovery. Not only were they learning; they were loving it!

### Fourth-Graders for Fresh Water

More than 900 fourth-grade students from 10 schools visited the Stroud Center last fall to learn about their impact on waterways, how to collect and interpret real scientific data, and why native trout need trees around their stream.

Their visit was the start of a new partnership between West Chester Area School District and the Stroud Center and was brought forth by Paul Joyce, the district's supervisor of science and technology education. Joyce saw the need for students and teachers from his district to experience more hands-on science.

The first to experience the Stroud Center's newly enhanced fourth-grade program, the students learned how insects have adapted to survive, how and why streamside forests protect freshwater ecosystems, and how to steward newly planted tree seedlings while collecting data about their growth. They also tracked stream pollution and raced rubber ducks to learn about stream habitats.

Each student received a field notebook to use during the field trip and back at school as they review concepts and reflect on their connection to water with their teachers.

### **Environmental Heroes-to-Be**

So that more students can share in experiences like the Creek Explorers Camp and Stream School, the Stroud Center recently entered into a cooperative agreement with the National Oceanic and Atmospheric Administration (NOAA) and Pennsylvania partners to improve and expand environmental literacy and watershed education and stewardship for Pennsylvania K-12 students and educators.

The Stroud Center–led project assembles a task force of representative leaders across the commonwealth to address



These fourth-graders from West Chester are learning about the importance of planting trees in the riparian zone and how to monitor their health to ensure they successfully grow into mature trees.

environmental literacy. It does so by increasing the use of Meaningful Watershed Educational Experience (MWEE) programming — that is, locally relevant, hands-on programs that promote experiential learning, critical thinking, and actions to improve freshwater resources.

The Pennsylvania Watershed Education Task Force brings together approximately 25 collaborators from a mix of state agencies, leading environmental education organizations, business and industry leaders in the environmental workforce, post-secondary institutions, and K-12 schools. On the leadership team, the Stroud Center is joined by the Pennsylvania Department of Environmental Protection, Pennsylvania Department of Education, Pennsylvania Association of Environmental Educators, Pennsylvania Bureau of State Parks, and Millersville University. With a three-year grant from NOAA, the task force is working to expand partnerships for advancing environmental literacy, increase the number of NOAA Bay Watershed Education and Training (B-WET) grant proposals, research and promote high-quality MWEEs, and provide training for approximately 400 watershed education professionals and traditional K-12 educators — all throughout the commonwealth.





Pennsylvania Association # Environmental Educators





Millersville University



## This summer, join us at Creek Explorers Camp

Young nature explorers are invited to join us this summer as we host the Creek Explorers Camp at the Stroud Center. For more information and to register, visit stroudcenter.org/education/camps.



"The health of our water is the principal measure of how we live on the land."

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LUNA LEOPOLD



Left: Paul Courter, Clinton County farmer. Right: Willis Miller, Clinton County farmer. Photos: Lisa Blazure

## The Restored Watershed: 50 Years of Solutions

By James G. Blaine

This is one of those good news stories.

Several years ago, Bern Sweeney met a farmer named Gabe Brown who had introduced multispecies cover cropping on his Midwestern farm in the hope of increasing his crop yield and improving his bottom line. Brown lives in a region of the country that averages only about 11 inches of rain a year, a fact that had historically required him and other farmers to spend a lot of money on irrigation, synthetic fertilizers, and pesticides. Then he began to look more closely at the native prairie beyond his fields, and he noticed that it regularly produced a variety of healthy plants without the benefit of irrigation, fertilizers, or pesticides; and he thought, "I wonder what would happen if I tried that?" So he began to grow his corn in a setting that mimicked the prairie, gradually weaning his land from its manmade dependence on irrigation, pesticides, and synthetic fertilizers. Not long thereafter, he was producing the same volume of crops at a vastly reduced cost and "making more money than I'd ever imagined."

"And I'm sitting there," remembered Sweeney, "thinking, 'wow!' What are the three biggest issues in stream ecology: sediment [from runoff], nutrients [from fertilizers], and pesticides. If we really want to make a difference throughout the system, from headwater streams to, say, the Chesapeake Bay dead zone, it would take something like multi-species cover cropping applied to all farm fields. This could be a game changer." Sweeney was open to Gabe Brown's message. For the last 50 years he and other scientists at Stroud<sup>™</sup> Water Research Center have demonstrated the connection between good land-use practices and clean fresh water, between healthy soil and healthy water. That connection was the foundation of the River Continuum Concept, the first unified hypothesis about how streams and their watersheds interact. As they analyzed the results of their long-term studies in the White Clay Creek watershed, Stroud Center scientists realized that pollutants often traveled a long way to the streams, and so they began to implement preventive measures farther away from the stream itself. In 1982, Sweeney and then director Robin Vannote planted one of the first forest buffers to impede the enormous volume of topsoil that was eroding from upland cornfields and making its way into White Clay Creek — and subsequent studies have made streamside forests a best management practice for protecting streams and rivers from soil-borne pollutants. Eighteen years later, Stroud Center researchers embarked on a six-year project, which concluded that the most efficient and effective way to protect New York City's drinking water was to preserve watersheds as much as 100 miles away. Not only runoff over ground imperils streamwater: Laurel Standley's studies at the Maritza Biological Station in Costa Rica found pesticides in the water, in the soil, and even in the bark of trees, which had originated in sugar fields on far-off Caribbean islands and had been carried hundreds of miles in the clouds.



## What is soil health?

By Lisa Blazure, Pennsylvania No-Till Alliance

The discussion of soil health has moved beyond agricultural circles and now involves mainstream media and those outside of the farming community. The universal quality about improving soil health is that it applies to any scale of food production – from the backyard garden to the ten-acre organic farm to the thousand-acre conventional farm. It is revolutionizing agriculture and changing conversations, education programs, and on-farm management.

Instead of viewing soil as an inert medium that only provides nutrients and water to a growing plant, soil health management recognizes that the soil is a diverse, dynamic ecosystem that, under proper management, will support healthy crops with fewer inputs. Healthy soils are a win for the farmers, and also a win for the environment.

Soil health management follows four basic natural principles: always have a living plant in the soil, minimize the amount of soil disturbance, keep the soil covered with the previous crop residue, and maximize diversity in the system.

A key management aspect is planting a cover crop in the fall after the main crop harvest. Living plant roots are critical for building soil carbon; the main component of organic matter. Roots exude simple sugars that feed the soil microbes (primarily bacteria and fungi) and pump carbon into the system. The soil biology also creates a porous, crumbly soil structure that allows rainwater to infiltrate and reduces the amount of stormwater runoff to local waterways.

No-till planting is another key management practice. By eliminating plowing and tilling, soils are less prone to erosion and can build organic matter more quickly. Undisturbed soil can better support a vast underground network of fungi that taps into the plant root system and scavenges water and nutrients to feed the crops.

Soil health includes bringing diversity back into farm systems. This can involve adding more crops in the rotation, planting multi-species cover crops, and adding grazing animals to the farm. Diverse natural systems are more resilient to weather extremes, pests, and disease outbreaks.

Soil health management is gaining momentum in the agricultural community. Farmers adopting these practices are seeing positive changes in their fields and their crops. Some have even begun reducing fertilizer and pesticide inputs. These positive changes in land management should have a lasting effect on the quality of local water resources.

Learn more about soil health from the National Resources and Conservation Service: https://tinyurl.com/yb3mk93j

### Soil health management follows 4 basic natural principles:



It seemed that the farther the researchers moved from the stream, the more they realized how much its health ultimately depends on taking care of often-distant landscapes. Moreover, the farther away they moved, the larger the area they had to consider, which systematically confirmed what they had intuitively known: that every square meter of land in a watershed affects the stream into which it drains and that the impacts multiply as streams merge into rivers and ultimately end in the ocean. Finally, as the Watershed Restoration Group's David Wise wrote last year, "the same biological principles nurturing the microbes and other organisms that do the real work — apply to achieving both healthy soils and healthy streams. Farmers sympathetic to soil health will understand the importance of forested buffers to streams. Stream health proponents will realize more profoundly that healthy soils in the entire watershed are a great ally for clean streams." Just as a stream is not simply a pipe for delivering water but an ecosystem filled with living organisms, so soil is not just dirt for growing food. It is "a vital, living ecosystem that sustains plants, animals, and humans,"1

Over the years, these and other studies have led to a better understanding of how to reduce the amount of sediment, nutrients, and pesticides that get into streams and rivers. Yet much remains to be done. As Sweeney tells farmers, a 100foot buffer of trees can keep about 26% of nitrogen, 50% of sediments, and 60% of pesticides out of a stream, and while that is a huge improvement, it also means that 40% of the pesticides, 50% of the sediments, and 74% of the nitrogen are still getting in. The result is that, despite all the improvements over the years, more than half the nation's streams remain in poor condition, the United States still loses soil 10 times faster than it can be replenished, and rising populations and increasing water use continue to put immense pressure on the world's finite and fragile sources of both food and fresh water.

Agriculture is by far the largest user of ground and surface water, accounting for about 80 percent of U.S. consumption, but as much as half the water used to irrigate the nation's farmland is lost to runoff and evaporation. It carries with it both the soil and the things that are in the soil, including fertilizers loaded with nutrients and pesticides heavy with poisons. Farmers see something else washing away with the topsoil — their hard-earned money.

1. Principles for High Functioning Soils (NRCS), https://www.blogs.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=stelprdb1049236.



A visibly brown farm field with no cover crop is separated from a green field with a cover crop by a grass waterway. Both are CIG study sites. The seed for the cover crop was planted among mature soybeans so that by fall harvest, the cover crop would be established. In this way, the soil is always green and covered with plants.



### 2017

Last year, Stroud Center scientists made important progress in their understanding of how healthy soil ecosystems can improve the land and protect the water, while the watershed restoration staff expanded its collaborative efforts with farmers to increase multi-species cover cropping and no-till agriculture for both environmental and economic reasons.

The Watershed Restoration Group received two grants in 2017 to work with the farmer-run Pennsylvania No-Till Alliance to provide workshops, individual consulting, and occasional financial assistance to the state's farmers. "While we have long recognized the importance of soil health," said Lamonte Garber, "we have really focused on integrating the concept into our restoration practices over the last two years."

It is not, he noted, a tough sell: in an effort to improve their soils and increase productivity, some farmers have been doing no-till and cover cropping for decades. In addition to erosion control, better nutrient management, the conservation and infiltration of water, and improved soil health, no-till and cover cropping can improve the farm's bottom line over the long term by lowering costs and maintaining or even improving yields.

"I started down the road of soil health 35 years ago," said Steve Groff of Lancaster County who works closely with the Water Restoration Group. "Severe erosion of my soil during rain events was the motivating factor — I hated closing up ditches in order to harvest cash crops, and I just didn't think the loss of good topsoil was right! I added a very intentional cover-crop program over the years, and my organic matter has more than doubled, which makes the soil more resilient to weather extremes and, as a bonus, effectively lowers my input costs."

Of no minor significance to the Stroud Center is that these practices have a great impact on fresh water, which led to a three-year Conservation Innovation Grant (CIG) from the U.S. Department of Agriculture in 2015.

"I proposed to USDA that we could demonstrate that there was more to multi-species cover cropping than improving the profit margins of farmers," said Sweeney. "There was also an environmental goal — namely, to reduce the amount of water being used overall and to improve the quality of the water that moved off the fields, both on and below the surface."

Now in its final year, the pilot project is testing whether converting farmland from conventional tillage practices to multi-species, year-round cover cropping can maintain cash crop yields while (1) increasing the infiltration of rainwater into soils, (2) reducing stormwater runoff and upland erosion, and (3) decreasing the flux of nutrients and toxic chemicals to nearby streams.

### **Looking Ahead**

With the CIG nearing completion, and with the Watershed Restoration Group's expanding work with the Pennsylvania No-Till Alliance and its deepened focus on soil health, the Stroud Center has embarked with Rodale Institute on a six-year project to evaluate the impact of different kinds of farm management practices on soil health, farm productivity and profitability, and water quality throughout the 8.7 million acre Delaware River Watershed. Funded by a nearly \$6 million grant from the William Penn Foundation, the project brings together two organizations with a combined 120 years of studying land and water issues.

"The devil is always in the details," said Sweeney. "We have good anecdotal evidence that improving soil health will improve water infiltration and thereby reduce the need for irrigation, synthetic fertilizers, and pesticides.

"What we need now is rigorous scientific research to identify the exact mechanisms that underlie these observations. That will give farmers the confidence to make changes in their practices and help policymakers incorporate those changes into new public initiatives."

Facing page from top to bottom, left to right: Jeffrey Frey and Jeremy Weaver, a TeamAg partner; Jim Hershey, President, Pennsylvania No-Till Alliance; cover crop seeding into mature beans. *Top and bottom left photos: Lisa Blazure* 



"At our farm, we try to mimic nature by having something growing at all times and using less insecticide, while increasing water infiltration. These are all great ways to improve soil health."

- JEFFREY FREY, WILLOW STREET, PENNSYLVANIA, BOARD MEMBER, PENNSYLVANIA NO-TILL ALLIANCE

Just as a stream is not simply a pipe for delivering water but an ecosystem filled with living organisms, so soil is not just dirt for growing food. It is "a vital, living ecosystem that sustains plants, animals, and humans."

- DAVID WISE, (PRINCIPLES FOR HIGH FUNCTIONING SOILS, NRCS)



"I never thought when I started no-tilling 30 years ago that I would be so entrenched and interested in what is happening underneath the soil surface. Cover crops and soil biology have brought so much more meaning to me. I've learned by using covers for more than 15 years — and now multi-species covers for more than five years — how much healthier my corn and beans look, and I'm feeding all the microbes by managing my covers."

– JIM HERSHEY, PRESIDENT, PENNSYLVANIA NO-TILL ALLIANCE

"Here on our farm, we have been no-tilling for over 40 years. What started as a way to conserve soil has evolved into a 'jump-start' to better soil health, and we are now using cover crops to help take us to the next level. To us, soil health means faster water infiltration, higher yields on our poorer soils, and better utilization of soil resources."

— DEAN JAMES, DANVILLE, PENNSYLVANIA



## Research Projects

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

### Assessment of Environmental Conditions in Bennetts Run at Kendal-Crosslands Based on Physical, Chemical, Macroinvertebrate, and Fish Monitoring

Funded by: Phoebe A. Driscoll and the Phoebe Internship Fund

Bennetts Run is a small tributary to Brandywine Creek in southern Chester County, Pennsylvania, including portions of Kendal-Crosslands Communities and Longwood Gardens. This study focuses on more upstream segments, using water chemistry, temperature, aquatic macroinvertebrates, and fish to quantify the condition of Bennetts Run as it exits Longwood Gardens and enters Kendal-Crosslands, and then again when it exits the Kendal-Crosslands property.

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

### Assessment of Environmental Conditions in Streams of the Runnymede Sanctuary Based on Physical, Chemical, and Macroinvertebrate Monitoring

Funded by: Runnymede Sanctuary

The 1,670-acre Runnymede Sanctuary was created to preserve the extensive natural, historic, and scenic resources harbored by the property and to facilitate appropriate study and use of those resources. Its forests, shrublands, meadows, and hayfields offer important habitat for local and migratory wildlife and ensure replenishment of groundwater that supports the many water sources feeding Doe Run. This study quantifies the condition of Doe Run and its tributaries as they enter and exit the sanctuary based on water chemistry and aquatic macroinvertebrates at the sanctuary and at other streams in the region.

Principal Investigators: John K. Jackson and Bernard W. Sweeney Collaborators: Melinda D. Daniels and Valérie Ouellet

## 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



Research technician Kelly McIntyre processes a macroinvertebrate sample from Six Penny Creek in French Creek State Park.

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, and David B. Arscott; The Nature Conservancy – Delaware Chapter

### Characterizing Stream Connections and Physical, Chemical, and 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. Department of Justice in the matter of Foster et al. v. EPA et al., No. 2:12cv-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

### 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 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)

### Collaborative Research: Sediment Stabilization by Animals in Stream Ecosystems: Consequences for Erosion, Ecosystem Processes, and Biodiversity

Funded by: National Science Foundation

Caddisflies and other net-spinning macroinvertebrates attach gravels to one another within the streambed. These attachments result in more force required for flowing water to move the gravels, limiting erosion and creating a more stable habitat for biofilm and other macroinvertebrates. Researchers are running laboratory experiments in experimental streams, conducting field experiments and surveys, and modeling the landscape-scale effects of these tiny ecosystem engineers on stream-ecosystem processes.

Principal Investigator: Melinda D. Daniels Collaborators: Lindsey Albertson and Wyatt Cross (Montana State University); Leonard Sklar (San Francisco State University)



A curious cow looks on as research technicians Katie McFadden and Sally Peirson investigate Manor Creek in Berks County.

### 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 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, Marie J. Kurz, 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, and Bernard W. Sweeney

**Collaborators:** Berks Nature; Brandywine Conservancy; Brandywine Red Clay Alliance; Natural Lands; 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

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:** Green Valleys Watershed Association; Natural Lands; French and Pickering Creeks Conservation Trust; Partnership for the Delaware Estuary; Audubon Pennsylvania

### Ecotoxicity Study for Mayflies Exposed to Elevated Concentrations of Chloride at Different Temperatures

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. At times, it appears that ambient chloride concentrations now reach levels that may have a negative effect on aquatic organisms. This project measures responses of four mayfly species exposed to elevated chloride concentrations at temperatures that range from 5-25 degrees Celsius.

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

## 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 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

## Experimental Streamside Forest Restoration to Improve Water Quality – Irwin Property

**Funded by:** TreeVitalize Watersheds, a partnership between the Pennsylvania Department of Environmental Protection and the Pennsylvania Horticultural Society

This project involved an experimental planting of 1,150 trees and shelters on 3.8 acres of riparian land along Red Clay Creek in East Marlborough Township, Pennsylvania. The project was designed to test the long-term effectiveness of herbicide application around seedlings on their growth and survivorship.

### Principal Investigator: Bernard W. Sweeney

**Collaborators:** Exelon Generation; Dansko Co.; BB&T; Cheshire Hunt Conservancy; Colonial Pipeline; Hugh Lofting Timber Framing

## Experimental Streamside Forest Restoration to Improve Water Quality – Elkins Property

**Funded by:** TreeVitalize Watersheds, a partnership between the Pennsylvania Department of Environmental Protection and the Pennsylvania Horticultural Society

This project involved an experimental planting of 1,050 trees and shelters on 2.5 acres of riparian land along Buck Run in East Fallowfield Township, Pennsylvania. The project was designed to test the long-term effectiveness of Tubex and Combitube shelters on seedling growth and survivorship.



Laura Zgleszewski collects water samples for microbial monitoring.

Principal Investigator: Bernard W. Sweeney

**Collaborators:** Brandywine Conservancy; Wilmington Trust; Dansko Co.; Meridian Bank; Colonial Pipeline

## Experimental Streamside Forest Restoration to Improve Water Quality – Fortunato Property

**Funded by:** TreeVitalize Watersheds, a partnership between the Pennsylvania Department of Environmental Protection and the Pennsylvania Horticultural Society

This project involved an experimental planting of 350 trees and shelters on one acre of riparian land along Brandywine Creek in Pennsbury Township, Pennsylvania. The project was designed to test the long-term effectiveness of various shrub protection methods on seedling growth and survivorship.

Principal Investigator: Bernard W. Sweeney

Collaborator: Tower Hill School

### Experimental Streamside Forest Restoration to Improve Water Quality – Dixon Property

**Funded by:** TreeVitalize Watersheds, a partnership between the Pennsylvania Department of Environmental Protection and the Pennsylvania Horticultural Society

This project involved an experimental planting of 600 trees and shelters on 1.8 acres of riparian land along Buck Run in East Fallowfield Township, Pennsylvania. The project was designed to test the long-term effectiveness of Tubex and Combitube shelters on seedling growth and survivorship.

### Principal Investigator: Bernard W. Sweeney

Collaborators: Exelon Generation; Dansko Co.; Whole Foods

### 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 Pennsylvania Department of Environmental Protection 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 farm fields over a three-year period after shifting from conventional tillage practices to cover cropping. They are also measuring 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, Melinda D. Daniels, Jinjun Kan, and David B. Arscott

### 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 reproduction by shunting energy away from egg production 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

Stream restoration in the United States is a multibillion-dollar industry. Yet long-term monitoring of its effectiveness is virtually nonexistent. Stroud Center scientists are studying 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 characterize the changes in the aquatic biological communities and their associated activity. Teachers are 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, John K. Jackson, Jinjun Kan, Melinda D. Daniels, and Diana Oviedo-Vargas Collaborators: J. Denis Newbold, David B. Arscott, Charles L. Dow, Steven C. Kerlin, Tara K. Muenz, and Louis A. Kaplan

### 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 compared to historical conditions

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

## 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 demonstrated 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<sup>®</sup> 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.

### Principal Investigators: Steven C. Kerlin and David B. Arscott

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

### North American Macroinvertebrate Taxonomic Certification Program

Funded by: Society for Freshwater Science

This program coordinates and executes the taxonomic certification program for the Society for Freshwater Science, conducting family- and genus-level tests throughout the year.

Principal Investigator: John K. Jackson

Collaborator: Michael C. Broomall

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

### Funded by: Stroud Water Research Center

Scientists are studying a number of mayfly species in White Clay Creek as well as in streams throughout eastern North America to better understand virgin reproduction and hybridization in mayflies, confirm the biological integrity of species that are genetically distinct but have the same name, explore life history variation within a species, and develop 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 applied best management practices at several dairy farms in the White Clay Creek and Red Clay Creek watersheds to reduce the amount of pathogens upstream of its Stanton plant. Scientists are monitoring water quality near and below these farms to measure the effectiveness of these best management practices.

### 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 Assessment of Streams and Rivers in Bhutan and Bangladesh

**Funded by:** Stroud Endowment for Environmental Research and The Walker Fund of the University of Pennsylvania

Scientists continue to evaluate the water quality of streams and rivers flowing through the major districts of Paro, Thimphu, and Punakha in Bhutan, as well as the Sreemangal and Dholubari Tripura Para areas of Bangladesh. Three monitoring stations equipped with real-time sensors were established in 2015 on the Thimphu River in Bhutan and were operated continuously during 2017.

### Principal Investigator: Bernard W. Sweeney

Collaborators: Bryan Currinder and Naimul Islam (University of Pennsylvania)

## 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 downstream, 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. 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, John K. Jackson, Tara K. Muenz, and Steven C. Kerlin



Michael Broomall, Katie McFadden, and David Funk collect aquatic insects from the Susquehanna River in August 2017.



Part-time environmental educator Vince O'Donnell joins fellow retired Unionville High School science teacher Fred Stauffer for a jaunt at a timber rattlesnake gestation area in Pennsylvania's Northern Tier last summer.

### 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<sup>®</sup> v2 and Observations Data Model v2 projects.

Principal Investigator: Anthony K. Aufdenkampe (adjunct)

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

## Significance of Streambank Legacy Sediments as Nutrient Sources and Their Implications for Aquatic Nutrient Cycling

Funded by: U.S. Department of Agriculture

The potential for streambank legacy sediments as nutrient sources for aquatic ecosystems has been understudied and is a critical gap in our knowledge. We hypothesize that erosion of streambank legacy sediments, especially from mid-Atlantic and northeastern watersheds, will result in substantial inputs of nitrogen and phosphorus to receiving waters. Contribution of legacy sediments/nutrients to sediment loads suspended by storm events will be determined using mixing models based on elemental, isotopic, biomarker, and microbial fingerprints and next-generation sequencing techniques.

Principal Investigator: Jinjun Kan

Collaborator: Shreeram Inamdar

## Source Tracking and Spatial/Temporal Dynamics of Bacterial Contaminants in Red Clay Creek

Funded by: Starrett Foundation

Scientists monitored fecal indicator bacteria on a monthly basis in the east and west branches of the Red Clay Creek watershed. Principal Investigator: Jinjun Kan

### Spatio-Temporal Dynamics of Thermal Refugia in Streams: Consequences for Brook and Brown Trout Interactions

Funded by: Susquehanna University Freshwater Research Initiative

All species of trout are highly sensitive to stream temperature. Native brook trout are the most sensitive, needing colder temperatures than brown and other non-native species, making them most vulnerable to stream warming caused by land-use changes, such as deforestation and climate change. This project tracked trout habitat use and stream water temperature in three

headwater streams of the Loyalsock River, Pennsylvania, to evaluate how brook and brown trout compete for thermal refugia habitats. Principal Investigators: Valérie Ouellet and Melinda D. Daniels

## Supporting Citizen Science Within the Delaware River Watershed Initiative Cluster Team

### 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 Steven C. Kerlin; Anthony Aufdenkampe (LimnoTech)

## 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, and David B. Arscott

### Using Microbial Source Tracking (MST) to Identify Potential Bacterial Sources in White Clay Creek to Target Best Management Practices (BMPs) and implementation strategies Funded by: White Clay Creek National Wild & Scenic River

Scientists monitored fecal indicator bacteria in White Clay Creek during summer and identified potential bacterial contamination by molecular microbial source tracking.

Principal Investigator: Jinjun Kan

### Water-Quality Monitoring at Fair Hill Training Center

Funded by: Fair Hill Training Center, MD

Scientists are monitoring fecal indicator bacteria, sediment, and water chemistry from the barns at the Fair Hill Training Center. Based on the data collected, the scientists and restoration team will apply effective best management practices to reduce the potential contaminants to the adjacent streams and rivers.

Principal Investigators: Jinjun Kan and Bernard W. Sweeney



Executive Director Dave Arscott congratulates Eagle Scout Payton Shonk for his outstanding project in which he designed an education kiosk for the Stroud Center's outdoor classroom. The kiosk uses environmentally friendly materials, includes a rotating two-sided display with a magnetic dry-erase board on one side and space for a permanent outdoor educational sign on the other side.

## **Education Projects**

### 2017 Brandywine River Trek

### 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 and canoeing 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: Steven C. Kerlin

Collaborators: Tara K. Muenz and Jennifer M.R. Totora; Jarvis Berry (Coatesville Youth Initiative)

### 2017 Schuylkill Acts & Impacts River Trek

Funded by: Schuylkill Headwaters Association, Fairmount Water Works, William Penn Foundation, Education Programs

Schuylkill Acts & Impacts is a weeklong river trek for 12 high school students from across all counties that touch the Schuylkill. Students travel from the headwaters to downtown Philadelphia learning about the history of human impacts on the river and collect stream quality data to compare different sections of the river.

Project Lead: Alexa Kramer (Schuylkill Headwaters Association)

**Collaborators: Steven C. Kerlin** and **Jennifer M.R. Totora**; Ellen Schultz (Fairmount Water Works)

## Advancing Education Programs and Community Outreach With Oxford Area Audiences

### Funded by: Oxford Area Foundation

This new project enables the Stroud Center to expand education and outreach to the local Oxford community and Oxford Area School District. It includes increased opportunities for programs for schools and youth groups, professional development, public programs, and education resources.

### Project Lead: Steven C. Kerlin

Collaborators: Tara K. Muenz and Jennifer M.R. Totora

### Captain John Smith Chesapeake National Historical Trail Contact Point, Program, and Training Initiative

Funded by: United States Department of the Interior, National Park Service, and American Gift Fund

As a partner in this cooperative agreement with the National Park Service and Sultana Education Foundation, Stroud Center educators will expand programming to teachers and schools in Pennsylvania's lower section of the Susquehanna River Basin. Education programs focus on the history and human impact on the river and feature school, streamside, and canoe programs.

Project Lead: Drew McMullen (Sultana Education Foundation) Collaborators: Steven C. Kerlin, Tara K. Muenz, and Jennifer M.R. Totora

### 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 K. 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

### Greening STEM Technologies: A Model for Advancing Do-It-Yourself (DIY) Environmental Sensing Networks to Support Citizen Science and Primary and Secondary Education

Funded by: U.S. Environmental Protection Agency

Stroud Center education and technical staff created STEM technologies to enhance public capabilities in citizen science. Partnerships with schools will lead to curricula and tools in 2017 and the installation of streammonitoring stations.

Project Leads: David B. Arscott and Tara K. Muenz Collaborators: Shannon Hicks, Steven C. Kerlin, and Heather Brooks

## Published Titles

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Ouellet, V., E.E. Gibson, M.D. Daniels, and N.A. Watson. 2017. Riparian and geomorphic controls on thermal habitat dynamics of pools in a temperate headwater stream. *Ecohydrology* 10(8): e1891.

Joshi, I.D., E.J. D'Sa, C.L. Osburn, T.S. Bianchi, D.S. Ko, D. Oviedo-Vargas, A.R. Arellano, and N.D. Ward. 2017. Assessing chromophoric dissolved organic matter (CDOM) distribution, stocks, and fluxes in Apalachicola Bay using combined field, VIIRS ocean color, and model observations. *Remote Sensing of Environment* 191: 359–372.

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Petrakis, S., A. Seyfferth, J. Kan, S. Inamdar, and R. Vargas. 2017. Influence of experimental extreme water pulses on greenhouse gas emissions from soils. *Biogeochemistry* 133: 147–164.

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Spencer, D., D. Haukos, C. Hage, M. Daniels, and D. Goodin. 2017. Conservation Reserve Program mitigates grassland loss in the lesser prairie-chicken range of Kansas. *Global Ecology and Conservation* 9:21–38.

Sweeney, B. W., D.H. Funk, R. W. Flowers, T. Gonzales, and A. Huamantinco. 2017. Cusco and Puerto Maldonado, Perú: Macroinvertebrates of rivers and creeks along the interoceanic Highway. *The Field Museum Guide* no. 843.

Wang, J., J. Kan, X. Zhang, Z. Xia, X. Zhang, G. Qian, Y. Miao, X. Leng, and J. Sun. 2017. Archaea dominate the ammonia-oxidizing community in deep-sea sediments of the Eastern Indian Ocean from the Equator to the Bay of Bengal. *Frontiers in Microbiology* 8: 415.

### Learning to See, Seeing to Learning

Funded by: National Science Foundation

Stroud Center educators in collaboration with Carnegie Mellon University created and implemented a national survey of macroinvertebrate trainers and training programs. Education and entomology staff helped decide which 150 macroinvertebrates will be shown as gigapan images on Macroinvertebrates.org. Education staff continue to contribute to the development of the site.

Project Lead: Marti Louw (Carnegie Mellon University)

Collaborators: Steven C. Kerlin, John K. Jackson, Matthew J. Wilson, Michael C. Broomall, Kelly C. McIntyre, and Tara K. Muenz; John Morse (Clemson University); Lauren Allen (Carnegie Mellon University); John Wenzel (Carnegie Museum of Natural History)

### Pennsylvania Environmental Literacy and MWEE Programming Capacity Building

Funded by: National Oceanic and Atmospheric Administration

The goal of this statewide project is to improve environmental literacy and stewardship of K-12 students by building capacity of environmental education programs across Pennsylvania for increased implementation of high-quality, meaningful watershed educational experience programming. Highlights of the project include research about successful watershed education programs, training programs, and the creation of a statewide providers network.

### Project Lead: Steven C. Kerlin

**Collaborators:** Bert Myers (Pennsylvania Department of Environmental Protection); Judd Pittman (Pennsylvania Department of Education); Scott Cope (Pennsylvania Association of Environmental Educators); Carissa Longo (Pennsylvania Bureau of State Parks); Nanette Marcum-Dietrich (Millersville University)

### 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 Sacramento Waldorf School in California 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 teachers and interested conservationists.

Project Lead: Tara K. Muenz

Collaborators: Bernard W. Sweeney and Matthew J. Wilson

## 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 K. 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 Leads: Steven C. Kerlin, Kristine C. Lisi, and Tara K. Muenz Collaborators: Jessica M. Provinski, Jennifer M.R. Totora, and David B. Reinfeld

## 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<sup>®</sup> 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.

**Project Leads: Steven C. Kerlin** and **Melinda D. Daniels**; Nanette Marcum-Dietrich (Millersville University of Pennsylvania); Carolyn Staudt (Concord Consortium)

**Collaborators:** Anthony Aufdenkampe (LimnoTech); Emilio Mayorga (University of Washington); Robert Cheetham (Azavea, Inc.)

### Water Quality Mobile App for Android Devices

**Funded by:** Stroud Center Education Product Development The Android version of the Water Quality app for tablets and smartphones was created to mirror the Apple version. The Stroud Center now manages both versions and distributes the app as part of WikiWatershed.org.

Project Leads: Steven C. Kerlin and David B. Arscott Collaborator: Chris Rider (Northern Kentucky University)

### 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.

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



New educator Chris Leonard begins a lesson about macroinvertebrates with fourth-graders.

## Watershed Restoration Projects

### Ag BMP Planning and Implementation for Berks County (DEP); Leveraging Ag BMPs and Forested Buffers for Middle Schuylkill Cluster (NFWF); Delivering the Berks-Chester RCPP (DEP)

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 U.S. Department of Agriculture funding for work including forested buffers. Work on roughly 20 farms will leverage nearly \$1 million in USDA funds. Incentives to install forested buffers are working well, with buffers averaging roughly 80 feet per 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



Fourth-generation farmer Randy Balthazer and Watershed Restoration Coordinator Lamonte Garber discuss the planting of trees along a nearby stream.

### 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 U.S. Department of Agriculture 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

## 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, and Melinda D. Daniels

### Delivering the National Fish and Wildlife Foundation Regional Conservation Partnership Program 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 the U.S. Department of Agriculture's Regional Conservation Partnership Program for constructing ag best management practices (BMPs). The Stroud Center is NFWF's lead partner in this effort.



Stroud Preserve, a long-term research and restoration site for Stroud Water Research Center. Photo: Jayme Gittings

### Project Lead: Matthew J. Ehrhart

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

## Healthy Soils, Healthy Streams Training and Technical Assistance

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

This project will conduct trainings on soil health and stream health for nearly 6,000 farmers, conservation professionals, and others. The Pennsylvania No-Till Alliance will offer technical assistance on cover crops and no-till farming to 24+ farmers. The potential for synergy between the Alliance and the Stroud Center is promising. The same biological principles – nurturing the microbes and other organisms that do the real work – apply to achieving both healthy soils and healthy streams.

### Project Lead: Matthew J. Ehrhart

Collaborators: Pennsylvania No-Till Alliance; Cover Crop Coaching, LLC

### Leveraging Farm Bill Funds for Water Quality in the Brandywine-Christina and Middle Schuylkill Clusters (NFWF); Delivering the Berks-Chester RCPP (DEP)

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

The Stroud Center secured more than \$1 million in funding from the U.S. Department of Agriculture's Regional Conservation Partnership Program and is ensuring full delivery of best management practices on all enrolling farms, including forested buffers. Supporting funding is provided by the Pennsylvania Department of Environmental Protection in Chester and Berks counties.

### 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

### Outreach and Installation of Agricultural Best Management Practices in Brandywine-Christina

### Funded by: National Fish and Wildlife Foundation

This project will install conservation practices on farms to improve watershed health. It will provide outreach, technical assistance, and financial assistance to farmers to (1) plan and implement whole-farm conservation, including forested buffers; (2) leverage state and federal funds for the majority of costs; and (3) help fill the remaining financial gap as an incentive for farmers to agree to install forested buffers.

Project Lead: Matthew J. Ehrhart

**Collaborators:** Brandywine Conservancy; Brandywine Red Clay Alliance; Chester County Conservation District; Mowery Environmental, Inc.; Red Barn Consulting, Inc.; TeamAg, Inc.

### **South-Central PA Conservation Partnerships**

Funded by: National Fish and Wildlife Foundation

This project will assist roughly 24 farms in Lancaster and Chester County to install nearly 200 agricultural best management practices, including nine miles of forested buffers and nearly 21,000 acres of cover crops. It will also reach more than 11,000 farmers and conservation professionals to bolster training and outreach efforts.

### Project Lead: Matthew J. Ehrhart

**Collaborators:** Alliance for the Chesapeake Bay; Chesapeake Bay Foundation; Chester County Conservation District; Crow and Berry Land Management; Lancaster County Conservation District; Mowery Environmental, Inc.; Penn State Agriculture and Environment Center; Red Barn Consulting, Inc.; TeamAg, Inc.

### Stroud/DCNR Buffer Collaborative

**Funded by:** Pennsylvania Department of Conservation and Natural Resources This project includes two separate awards of funds from DCNR. The combined efforts will install nearly 80 acres of forested buffers, including efforts to demonstrate "multifunctional buffers" where income potential from buffers for fruits, nuts, and salable horticultural materials are a motivator. These nonfederal funds help fill niches for landowners who are either ineligible for or prefer non-federal options, such as some Plain Sect farmers.

### Project Lead: Matthew J. Ehrhart

**Collaborators:** Brandywine Conservancy; Berks County Conservation District; Chester County Conservation District; Crow and Berry Land Management; Mowery Environmental, Inc.; Red Barn Consulting, Inc.; TeamAg, Inc.

### SWRC Watershed Restoration Partnerships Project

### Funded by: Arbor Day Foundation

This project provides funding for nearly 4,000 trees to aid watershed restoration efforts with partners in Berks, Chester, and Lancaster counties. The resources are especially helpful for landowners who are either ineligible or prefer not to use USDA CREP for tree planting, including some Plain sect farmers.

### Project Lead: Matthew J. Ehrhart

**Collaborators:** Alliance for the Chesapeake Bay; Crow and Berry Land Management

## Financials

### OPERATING STATEMENT

for the year ended December 31, 2017

REVENUES & SUPPORT		EXPENDITURES	
Research Programs (Grants & Contracts)	\$ 4,434,251	Research	\$ 4,467,024
Watershed Restoration Group Programs	1,992,627	Watershed Restoration Group	1,763,108
Endowment	1,528,720	Facilities	1,109,246
Annual Fund	514,039	Administrative	671,239
Education/Public Programs	508,313	Education	505,934
Other Contributions & Income	451,916	Development/Outreach	396,159
Total Revenues & Support	\$9,429,866	Information Services	339,857
		Communications	89,060
		Other	88,239

**Total Expenditures** 

\$9,429,866

### **Financial Information**

Stroud<sup>™</sup> 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 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.



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 David B. Reinfeld, Director of Campaign Programs and Major Gifts, dreinfeld@stroudcenter.org, 610-268-2153, ext. 314 Kay D. Dixon, Associate Director of Donor Relations, kdixon@stroudcenter.org, 610-268-2153, ext. 303 Jessica M. Provinski, Associate Director of Special Events and Corporate Relations, jprovinski@stroudcenter.org, 610-268-2153, ext. 288

## Gifts and Contributions

We gratefully acknowledge the following 366 donors who generously contributed \$514,040 to our annual fund. These funds cover our operational expenses not supported by grants, and it allows us to continue and strengthen our work in freshwater research, environmental education, and watershed restoration. Thank you!

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memory of Bill Anderson

On Saturday, September 30, 2017, Axalta Coating Systems partnered with the Stroud Center to host students from Young Men and Women in Charge (YMWIC) for a day of learning focused on freshwater conservation. The program, which took place at the world-renowned Longwood Gardens in Kennett Square, Pennsylvania, is an example of Axalta's commitment to nurture the next generation of science, technology, engineering, and math leaders. *Photo: John Nolan* 

Care has been taken to ensure the accuracy and completeness of this listing. We regret any omission and ask that you bring any corrections to our attention. Mr. and Mrs. Richard Doolan Gerard and Jean Dorrian Charles and Karen Dow\* Mr. Courtland E. Dunn Jr. Janet Ebert Janet and Michael Elling Dr. and Mrs. Leighton Everhart Exelon Generation Company LLC Exelon – Dollars for Doers Joan Fenza **Rick and Ingrid Fischer** Mr. Lamonte Garber and Mrs. Marcella Hostetler\* Mr. George Gaydos Mr. W. Thomas Gehrt Mr. John Gerbron in memory of Nicholas Stroud **Douglas Godfrey** Pete and Judy Goodman Mr. and Mrs. H. Barry Green Mr. and Mrs. Charles F. Gummey in memory of Dick Stroud Mr. and Mrs. John S. Halsted Shannon Hicks\* Mr. and Mrs. Loukianos Hionis Dr. and Mrs. William A. Hohman Mr. and Mrs. J. David Hucker Dr. John K. Jackson in memory of Dick Stroud\* Dr. and Mrs. Jinjun Kan\* Dr. Louis Kaplan and Mrs. Leslee A. Schad\* Mr. Julian Kattendahl Kennett Library Maurie Kerrigan in memory of Dick and Nick Stroud Mr. and Mrs. Wilson King Susan and Bob Kissell Mr. David B. Knapp

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If you have already made a bequest intention, please let us know. We want the opportunity to thank you. (There's nothing worse than finding out after the fact!)

We'd like to thank these Friends of the Stroud Center who have informed us of their intentions. They will remain an important part of the Stroud Center's future:

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As a result of a generous gift from brothers Greg, Keith, Barry, and Ray Bentley, the Chester County Council Boy Scouts of America and Stroud Water Research Center are expanding their partnership to offer additional outdoor and environmental education programs in 2018. Greg Bentley announced the \$55,000 gift establishing the Thomas P. Bentley Muddy Boots Program during the Scout's November 15, 2017 Distinguished Citizen Award Dinner, which recognized Greg for his significant and enduring contributions to Chester County.



Mr. and Mrs. Geoffrey Selling Seneca Valley Trout Unlimited #369 Mr. and Mrs. James A. Shissias Barbara Simonds in memory of Dick Stroud Ms. Susan Snyder **Charles Walter Stewart** Herbert Thal Charlene Thomas in honor of Michael and Anne Moran Anne Verplanck Mr. and Mrs. Christopher H. Washburn Matthew and Janet Weir Wynne and Sam Wharry Dr. and Mrs. Robert Whitlock Laura and David Zgleszewski\*



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The education department gratefully acknowledges these businesses for their support through Pennsylvania's EITC program. These dollars are used specifically to subsidize costs associated with field trips from Pennsylvania public schools. BB&T DNB First M&T Bank Meridian Bank Unban Outfitters/ Free People of PA, LLC

### **Gifts in Kind**

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### **Unrestricted Fund**

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Photo: (far right) Christopher Brown (shootfromwithin.com)

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\* The development department gratefully acknowledges the help it receives from staff members who volunteer on top of their other duties at Stroud Water Research Center.

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Catherine R. McFadden Research Technician I

Kelly C. McIntvre Research Tech III

Sally Peirson Research Tech III



Left: State Senator Andy Dinniman (center) met with Bern Sweeney (right) and Dave Arscott (left) last year to present them with a special Senate citation in honor of Stroud Water Research Center's 50th anniversary. "Stroud Water Research Center continues to be a treasure for Chester County as the international leader in the study of streams, aquatic ecology, and river science," said Dinniman, who serves on the Senate Environmental Resources and Energy Committee. Right: The theme for the 2017 holiday party was "50" in celebration of the Stroud Center's 50th anniversary, so Web Developer Heather Brooks (left) sported a giant "50" pin made out of photos of her colleagues, and System Administrator Libby Gregg adorned her sweater with 50 Christmas tree balls.

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Sherman L. Roberts Research Tech III Matthew J. Wilson Research Tech III Laura K. Zgleszewski

Research Tech III

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### Maritza Station<sup>\*</sup> Costa Rica

Rafael A. Morales Station Manager and Research Tech

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Cristian A. Collado Research Tech

### Microbiology

Jinjun Kan, Ph.D. Associate Research Scientist

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Jing Wang Visiting Scholar, China

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Lauren Kennedy West Chester University

### Watershed Installations

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Shannon D. Hicks Research Engineer III

### Watershed Restoration

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Lamonte Garber Watershed Restoration Coordinator

Matthew A. Gisondi Watershed Restoration Program Assistant

Rachel Johnson Research Engineer Technician David Wise

Watershed Restoration Manager Calen D. Wylie Watershed Restoration Program Assistant

### PART-TIME STAFF

Christa Reeves

CITIZEN SCIENCE INTERN Carol Armstrong

### **Research Scientists**

Emeriti

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INTERN

Benjamin Wood

#### Adjuncts

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

Anthony K. Aufdenkampe, Ph.D. Adjunct Research Scientist, LimnoTech

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

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



## REMEMBERING BILL ANDERSON

" My greatest success has been in leading students to understand the process of reasoning, experimental design, critical thinking, data analysis, collaboration, and discovery through the medium of science."

— WILLIAM C. ANDERSON

It is with great sadness that we said goodbye to our friend and colleague William (Bill) Anderson, who died on September 22, 2017. Bill was a retired high school advanced-biology teacher, a Stroud Water Research Center adjunct research associate, and an environmental educator in our Stream School. He is survived by his wife, Chris (Christina), and his son, Andrew, who is a software engineer for Apple Computer.

Anderson remained a dedicated scientist and educator until his death. In an interview last year, he spoke to Communications Manager and Editor Diane Huskinson about his passion for teaching freshwater science and stewardship to the students who visit the Stroud Center:

"It's such a marvelous place for the kids to get handson experience in the stream with experts in watershed science. ... Sometimes a parent or student will say, 'Thanks, mister. This is the best time we've ever had in school,' or something like that, and boy, you get a couple of those a month, and that's all you need!"

To read the entire interview, see pages 6–9 of our 2016 annual report at stroudcenter.org/annual-reports.

You can also watch a short video of Anderson talking last year about his career in water science on our YouTube channel at tinyurl.com/yahh6yem.

Above: Bill Anderson (left) discusses Stroud Center education programs with Education Director Steve Kerlin.

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



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The Stroud Center gratefully acknowledges the service of Bland Dickey who retired from the board in 2017.

\*Recognizing their decades of service to the board, Barbie Riegel and Bern Sweeney were unanimously awarded emeritus status.



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4₽	20 trees preserved for the future
Ċ	1 lbs. water pollutants not created
쮋	9,480 gallons water saved
Μ	635 lbs. solid waste not created

- 1,748 lbs. CO2 of net greenhouse ç gases prevented
- 5 10,000,000 BTUs energy not consumed 515 lbs. of GHG emissions not generated
- oto 169 miles not driven

0.16 barrels of natural oil unused

2 trees planted

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## **OUR MISSION**

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