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January 2000

This book is dedicated to the Stroud family



While many people have played important parts in making the Stroud Center what it is today,

it was your vision for what the Center could become and your unwavering support throughout the journey that encouraged our efforts to create a unique and vibrant institution and continue to inspire our pursuit of excellence

The Staff at the Stroud Center



Understanding biodiversity and the ecosystems representing nature on this planet is a complex task. It is slow to develop and guided largely by unproven hypotheses and uncertain theories rather than by well-behaved physical laws. Progress occurs in steps - steps made or taken by scientists working singly or in teams, focused on a particular portion of the natural world. The scientists must be supported by an institution - formal or informal - that embraces that focus. For we are, after all, social animals.

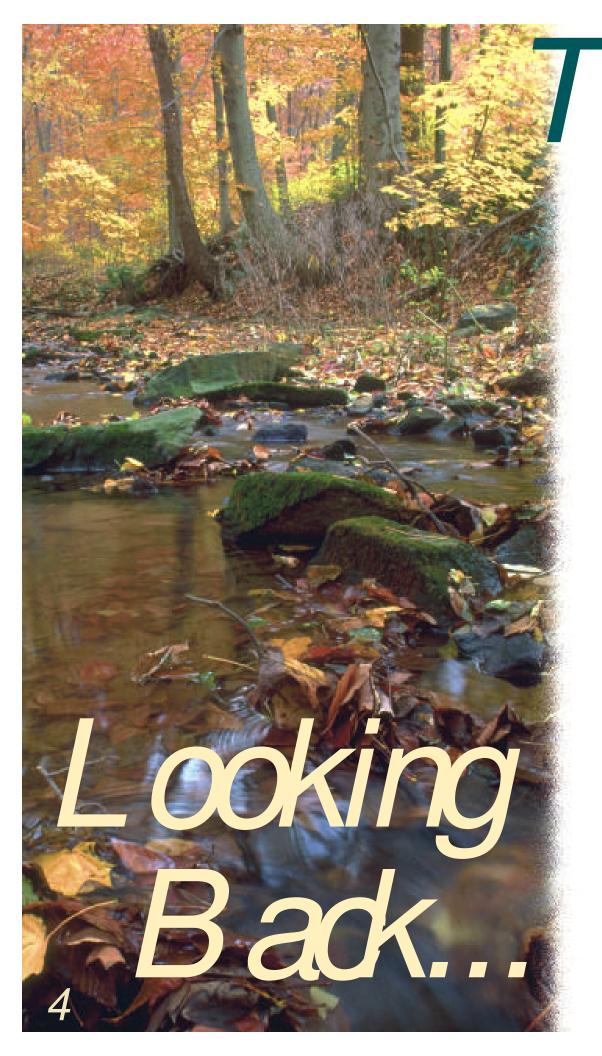
When the Stroud family and Dr. Ruth Patrick persuaded the Academy of Natural Sciences of Philadelphia to establish the Stroud Water Research Center 34 years ago, they germinated an institution devoted to understanding the ecology of streams and rivers and their watersheds. It was an institution whose scientists understood the critical importance of small steps. And yet growth and development of the Stroud Center has been remarkable.

The "field station" began by focusing on one small temperate watershed, White Clay Creek in Chester County, Pennsylvania. It soon metamorphosed into a large independent institution pursuing knowledge and understanding of temperate river systems far beyond the banks of the White Clay - to the Susquehanna, Potomac, Salmon, and Mississippi Rivers, to name a few. About 11 years ago, I urged the Stroud Center to expand its scientific horizons and program even further to include tropical streams and rivers. I particularly wanted the Stroud scientists to study the streams flowing through my backyard in the Area de Conservacion Guanacaste (ACG) in northwestern Costa Rica. Fortunately, they accepted my challenge.

I have enjoyed helping their tropical research program grow and develop during the past decade. It has been very supportive for the growing ACG to have this independent research program developing on site, something driven by its own motivation and not requiring substantial attention from us. I have learned so much from watching over their shoulders as they peer intently at the streams I have always ignored. I have seen them unravel the details of the ACG natural stream ecosystem in true academic fashion - molecule by molecule, species by species, bug by bug. And I have watched as they used the data they collect in the still relatively pristine streams of the ACG, to understand and interpret their findings on the disturbed and polluted tropical streams that have become far too common outside of the ACG in Costa Rica and elsewhere.

As you read through this history of the Stroud Center, you may find yourself wondering whether the Stroud Center is a kind of university, focused on basic research and education? Or is it a museum, focused on collecting and discovering new species and understanding their ecological and evolutionary relationships? Or is it an environmental consulting firm using its basic research findings to prescribe remedies for disturbed stream and river ecosystems? Well, it is none of these solely, but rather a unique, unusual and fortunate blend of them all.

Dan Janzen Professor of Biology University of Pennsylvania



he Stroud Water
Research Center has
changed forever the way
the world thinks about
water. From the moment Robin
Vannote, the first director,
diverted part of White Clay
Creek into a flume he had
designed to carry water through
the new laboratory and return it
downstream, Stroud scientists
have sought to break through
the constraints of conventional
thinking.

They began with a fundamental question: How do streams work? And they have been seeking to answer that question ever since. Their search has led them to an endless series of more focused questions, which they have tested both in their laboratories and in hundreds of bodies of water. They have conducted countless experiments and analyzed immense sets of data. Above all, they have waded into streams and rivers all over the world in their quest to understand everything they can about fresh water.

In pursuit of that aim, Stroud scientists have followed their experiments, hypotheses and imaginations wherever they have led. Over the past 33 years they have invented and customized a variety of Rube Goldberg-like devices that sit in, stand beside or hover above the creek that runs past their laboratory in Chester County, Pennsylvania. They have used these devices to scrutinize virtually every aspect of the rural stream, and they have applied the knowledge they have gained to river systems throughout the United States and around the world.

The Stroud Center staff brings an enormous range of talent to their work. Their approach is fully interdisciplinary, involving microbiologists, entomologists, stream ecologists and chemists, and all their projects are conducted as team efforts, composed of both senior scientists and experienced technicians. While each scientist is an acknowledged expert in his or her field, they see themselves as parts of a single whole. They understand that it is the mesh of their individual talents that enables them to weave an institutional cloth of such exceptional strength.

The team approach has enabled the Stroud staff to redefine stream research. Previously, scientists had applied to streams and rivers the same analytical framework and methods used to study lakes – the intensive investigation of a small section of water. But Stroud scientists realized that a stream cannot be isolated and defined at any particular point in time. For a



Robin Vannote, the Center's first director.

stream is never at rest – what is in any part of its water at one moment had not been there

moments before, and it will soon be far downstream.

The state of any stretch of stream depends on what is coming from above it, and that, in turn, determines what goes on below it. A river changes constantly as it makes its way from

its source to the sea.

The Stroud staff's perception that a river is a system corresponds with their belief that scientific research is an interconnected whole, greater than the sum of its parts. Just as the life of a stream is affected by what flows into it from above and what enters it from the land and air around it, so the scientists recognize that they must be fully engaged

with the world outside the laboratory. In the end, a river can only be understood as part of a watershed, its welfare dependent on a vast range of natural events and human activities beyond its banks. So too with a community of scientists.



Dave Leib and John O'Brien electrofish in White Clay Creek.

In 1987 the Stroud Center added a major new dimension to its mission by helping to establish the Maritza Station, a permanent laboratory in the dry forest of Costa Rica's Guanacaste National Park. The Center's research on that region's mountain streams has enabled Stroud scientists to collect and analyze long-term data from tropical watersheds and has provided an important counterpart

to their work in the temperate zone. It has also given them access to streams that have not yet been subjected to the ravages of pollution and whose water is still clean enough to drink.

The Maritza Station is part of a larger collaborative effort with scientific researchers, environmentalists and the government of Costa Rica. Despite its distance from Chester County, the program was a natural progression for Stroud scientists, whose drive to understand the fundamentals of aquatic ecology has led them to streams and rivers far from the familiar waters of White Clay Creek.

water flea

In addition to the need for a broad geographical scope and a wide variety of sites, the scientists need an environment that encourages creative thinking and the financial independence to cope with economic uncertainty and stay on the frontier of discovery. The Stroud Center has taken pains to ensure the existence of both.

Perhaps nowhere is the emphasis on creativity more immediately visible to the outsider than in the sphere of art. Many think of science and art as incompatible disciplines, practiced by people of vastly different temperaments and points of view. Yet the Stroud Center is filled with art, much of it original, and its public spaces have become small galleries for changing exhibitions.



Sherman Roberts and Heather Brooks sample the Center's indoor stream.

The role of the art is not merely decorative. It bears witness to the imaginative process that the staff believes is critical to scientific discovery. An intellectual breakthrough that emerges from years of research is not just the accumulated result of massive data analysis. It requires a flash of insight, and like great works of art it compels us to look at the world in new ways.

Conversely, the painstaking hours of research it takes to produce a flash of insight require a firm foundation of financial security. The Stroud Center has been responsible for its economic well-being from the outset, and over the years it has raised the money it needed in three ways:

- through research grants from public agencies and private foundations, ranging from a few thousand to millions of dollars;
- through contracts with corporations and government bodies for specific, often long-term, projects and
- through the generosity of its friends.

This process depends on both scientific accomplishment and effective public outreach, a combination that coexists uneasily in many research institutions. But those who founded the Stroud Center believed that its long-term health would always depend on the integrity of its research – which, in turn, would depend on the ability of its supporters and staff to secure the funds necessary to do that research without compromise.



Paintings by Leonid Berman are displayed throughout the Center.

The people at Stroud bring to their endeavors a clear sense of both the mission of the institution and the role they play in it. They do what they do because they are scientists whose particular passion is to understand every aspect of stream life. They do it because they are professionals who have built their careers on their research. They do it for the thrill of discovery, and perhaps most of all, they do it

because they believe it is important.



aquatic beetle

Theirs is not an easy faith. They look at things that are often too small for the rest of us to see in the hope of discovering something most of us won't understand. They spend hours examining infinitesimal organisms, trusting that what they find may shed light on some of the biggest issues we confront. In the face of persistent assaults on the integrity of our water, they believe that each small discovery is a potential building block for a cleaner future. For they are convinced that by unlocking the secrets of the stream, they will increase our understanding of the natural world – and they believe that, armed with such understanding, we can collectively make the world a better place for all its inhabitants.

This drive to seek answers to questions of global importance has drawn Stroud scientists out of the familiar surroundings of their laboratories and streams. They feel obligated to communicate their findings to a world in grave need of environmental understanding, and so they seek to apply their knowledge to real problems that require farsighted solutions.



Children learn about stream ecology at the Center's "Stream Day traveling exhibit.

Their mission - which mandates solving problems, promoting public understanding and communicating new ideas, as well as performing basic research - charges them to do so. The applied research projects they undertake on behalf of public agencies and private corporations are a two-way street. On the one hand, they allow Stroud scientists to disseminate their findings to people and organizations where they will make a difference. On the other, they provide a unique alternative laboratory in which the scientists can observe the impact of human activities on the natural world.

The Stroud Center is also involved in more direct educational activities. The scientists are on the faculties of several universities, where they teach courses in various aquatic disciplines. And since its inception in 1990, the on-site education staff has turned the Center's research into programs and teaching tools for a broad range of students.

> As a result of all that has happened at the Stroud Center since its founding in the summer of 1966, the world knows a lot more



cleaning up our waterways stems, at least in part, from the dedicated research and critical insights of all those who have labored there over the years.

The mission of the Stroud Water Research Center is to advance knowledge of stream and river ecosystems through interdisciplinary research; to develop and communicate new ecological ideas; to provide solutions for water resource problems worldwide; and to promote public understanding of freshwater ecology through education programs, conservation leadership, and professional service.

The Beginning

he story of one of the world's foremost freshwater research institutions began in the salt waters of the Pacific Ocean. In 1956 W. B. Dixon Stroud joined a snail-collecting expedition from the Academy of Natural Sciences and spent two months off the coast of New Guinea diving for live shells.

This was not Dick Stroud's first immersion in Pacific waters. Eleven years earlier he had been officer of the deck when the *USS William D. Porter* was

hit by a kamikaze pilot during the Battle of Okinawa. The ship sank in 90 minutes.

None of the crew was killed in the attack,

but, as second in command, Lieutenant Stroud was the next-to-last man off. His subsequent Pacific voyage left a better memory. It also introduced Dick Stroud to the scientific research efforts of the Academy.

That introduction bore fruit nine years later when he and his wife, Joan, met Ruth Patrick, the head of the Academy's limnology department. The three quickly became friends, and

Strouds to build it.

Dr. Patrick urged the Strouds to build a small laboratory dedicated to freshwater research along White Clay Creek on their farm in southern Chester County.

They made a special team. Ruth was a relentless worker and one of the country's foremost scientists. Dick had a head for business, a fascination with science and a love of the outdoors.





W.B. Dixon Stroud and Joan Milliken Stroud.

Dr. Ruth Patrick conceived the

idea of the Center and urged the

Joan brought a deep commitment to education, a drive to get things done and an unquenchable curiosity. "I remember an early trip to a forestry conference at Oregon State," said Robin Vannote, the Center's first director. "Joan was studying every inch of the way." Perhaps above all, she had an unsurpassed ability to turn an empty building into an inviting and inspiring place.

In the summer of 1966 the Stroud Water Research Center began its existence as a field station of the Academy in a hastily cleared space above the Strouds' garage. Hot, dusty and dark, the attic made the cool streams, where the real scientific work was to be done, look inviting indeed.



Robin Vannote works in the Center's indoor stream, which he designed and built.

Dr. Patrick's first act was to hire Vannote, a young scientist working for the Tennessee Valley Authority. By early fall his experimental leaf packs had become a familiar sight in the local streams.



Dick Stroud and Ruth Patrick hold part of timber framing for the Center's new addition.

In a letter dated June 30, 1966,
Academy President John Bodine
outlined the first year's budget to
Dick Stroud. Because the \$46,100
total included \$15,000 for equipment,
Bodine estimated a figure of \$36,250
for subsequent years. It was up to the
Strouds and the Center staff to come
up with the money.

The forecast was on target. The Center's expenditures for its first fiscal year were \$46,126.29. It is one measure of how much has happened in the intervening years that the Center now has a multi-million dollar budget.

But while the Center has grown, its essence has not changed. "Ruth and Robin set the tone," said Bern Sweeney, the current director. "They were constantly challenging, asking hard questions, never satisfied, always demanding another experiment. It's the same now.

It's an intense and focused place."

The scientists continue to ask fundamental questions. They work as a team, and their sights are still set on the long term. In a world where clean water is no longer taken for granted, they remain determined to make a difference.



Timber-framed entrance to the Stroud Center.

Ruth Patrick



Time seems to stand still for Puth Patrick.
Seventy years after graduating from college, 65 years after receiving her PhD, and more than 50 years after creating the Academy's Limnology
Department and pioneering the use of biological communities in river assessment, she remains actively involved in scientific research.

In a series of experiments conducted in 1948 on Conestoga Creek in Lancaster County, Pennsylvania, Dr. Patrick and her Academy research team sought to understand how all forms of life — from bacteria to fish to humans — interact in a stream. The scientists believed that the best way to gauge a river's health was to analyze the diversity of its biological communities and their "ecosystem approach" represented a completely new way of looking at a river.

They found a direct correlation between species diversity and the health of a stream. In severely polluted waters, in fact, most species had ceased to exist. By devising a quantifiable way to measure water quality, the Patrick team laid the foundation on which almost all future aquatic and environmental studies were built.

Dr. Patrick, who holds the Francis Boyer Chair of Limnology and is honorary chairman of the Academy of Natural Sciences, was elected a Fellow of the National Academy of Science in 1970 and of the American Philosophical Society in 1974. She has received over 25 honorary degrees, as well as dozens of awards, including the John and Alice Tyler Ecology Award, the environmental equivalent of the Nobel Prize. In 1996 President Clinton presented her with the National Medal of Science, the nation's highest scientific honor.

The Watershed

hile Stroud scientists have long been engaged in studying rivers around the globe, the heart of their enterprise has always been the East Branch of White Clay Creek. A quiet stream that runs past the Center, the East Branch drains an 1,800-acre basin in southern Chester County,

about 45 miles from Philadelphia. The entire White Clay watershed covers 100 square miles in Pennsylvania and Delaware, with the creek itself flowing southeast to the Christina River in Newport and on into the Delaware River at Wilmington.

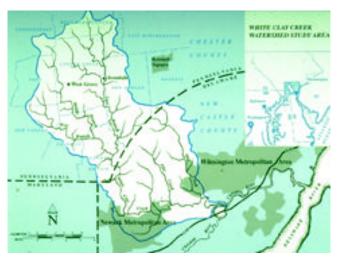
The Pennsylvania side of the watershed is still largely rural, although it is experiencing rapid development. The population of the White Clay's drainage basin doubled between 1960 and 1990, and it is expected to double again by 2020, making it the fastest growing part of Chester County. Because most of the new growth involves the conversion of farms and wood-



East Branch of White Clay Creek near the Center.

lands to large-lot residential and commercial sites, open land will disappear even faster than the population will grow. With its developed acreage slated to triple by 2020, the watershed faces the highest rate of loss in the county.

Still, the watershed remains a beautiful, if threatened and fragile, place. Large stretches of the East Branch continue to flow through green meadows, along corn rows and hayfields, and in and out of small hardwood forests. The National Science Foundation designated the watershed around the Stroud Center an Experimental Ecological Reserve in 1981. Three years



White Clay Creek Watershed, Pennsylvania and Delaware. Compiled by the University of Delaware Water Resources Agency for the National Park Service.

later Pennsylvania named the East Branch an Exceptional Value Stream, its highest water-quality designation. And in 1998, the National Science Foundation included the Center and its watershed among its 35 sites in the prestigious "Long-Term Research in Environmental Biology" program.

The creek contains about 20 species of fish, hundreds of species of algae and insects, and an unknown but immense number of species of bacteria and fungi. Although most are not visible to the naked eye, the various organisms all play critical parts in the life and health of a stream, and the functioning of the system depends on each of the species fulfilling its role.

After three decades of intensive study, the scientists at Stroud have come to know the East Branch with an unusual intimacy. Their access was simplified by the fact that the watershed's 1,800 acres belonged to only about a dozen property owners, almost all of them sympathetic to the Center's research aims and intent on keeping the land open. Thus, the scientists were able to plan long-term experiments with considerable confidence.

Under a five-year grant from the Rockefeller Foundation that began in 1969, they gathered extensive data on almost every aspect of stream life and many important characteristics of the watershed. Their experimental sites ranged in size from a single riffle and pool to the entire stream. They looked beyond the creek's banks to the impact of farming and industrial practices; and they studied the importance of streamside forests as natural buffers against pollution from poor land-use practices. Out of that work, which continues to this day, came an extraordinary set of baseline data from which the Stroud staff has been able to construct an unparalleled portrait of a stream and its watershed.

adult stonefly



Stroud research has shown that restoring impacted streams such as this requires the fencing and reforestation of its banks.

The Wetlab



Dave Rebuck takes samples from an indoor stream.

Most visitors to the Stroud Center are amazed to find part of White Clay Creek flowing through the building. Some of its water has been diverted into an experimental channel that reproduces the natural world so well that algae, insects and fish mature in the lab at the same rate they do outside. While scientists generally prefer a natural stream as their experimental setting, the study of many aspects of stream ecology requires controlled experiments performed under near-natural conditions. In response, Stroud ecologists have designed artificial systems for their laboratories. The smallest are tray-sized containers through which water flows for a few days. The largest is a stream ecosystem that fills a room in the Center's basement. Thousands of gallons of water have flowed through it daily for the past 30 years.



Roberta Weber checks the indoor nursery for aquatic insects and fish.

The Facility

he original building of the Stroud Water Research Center was completed in early 1968. It housed seven research laboratories, a library-seminar room, offices, technical staff areas and storage space. Within six years, the research programs had outgrown their original walls, and additional space was required for graduate and post-doctoral students who wanted to work at the Center. In addition, classrooms and a large lecture room were needed to teach courses the senior scientists offered through nearby universities, to host scientific meetings and to reach the general public through a proposed lecture series.



Dr. Ruth Patrick poses inside one of the Center's research greenhouses.



Stroud Center research greenhouse with indoor stream.

With pledges from the Stroud Foundation and family in hand, the Center approached the Kresge Foundation for a construction grant. Weathering a lightning strike on their plane as it approached the runway in Detroit, Dick Stroud and Ruth Patrick secured the funds to build four new laboratories, a large wet lab and an education center housing a large lecture room, teaching laboratory, student research areas, and office and storage space. When the additions were completed in late 1976, the Center had adequate space to offer courses to university students, provide opportunities for professional groups to come and learn about new research findings, and host a public

lecture series which featured distinguished scientists discussing significant environmental issues. Seventeen years later it became clear that the growing research and education programs had again outgrown their space. Laboratories for invertebrate biology and toxicology studies were added, storage areas for collections and office space for visiting scientists were enlarged, a new



teaching laboratory was designed for school groups, the meeting room was expanded to hold 175 people comfortably and a lunch room was added. When the new areas were opened in October 1996, the 24,820-square-foot facility was four times the size of the original building. The final project of this phase — a new streamhouse for both research and education — was dedicated in October 1999.

One of the most striking aspects of the Stroud Water Research Center is how well its design reflects the rural character and heritage of Chester County, a direction encouraged by the Stroud family. The building sits on the site of an 18th-century



The Stroud Center added much-needed research and education space in 1996.

barn, whose original stone wall was incorporated into the first conference room. The architecture of the education center was taken from that of two Quaker meeting houses



Stroud Water Research Center front entrance 1996.

nearby. And what appeared to be a run-down house across the courtyard from the laboratory turned out instead to be a 1710 cabin whose log walls had been preserved as well as camouflaged by clapboard siding. It has been restored to its original style and now houses visiting scientists.

The result of all the building and renovation is a modern, well-equipped laboratory overlooking a gentle stream and situated on a country lane. It seems a place of contrasts — rustic in appearance yet sophisticated in operation, filled with art and devoted to science. Perhaps above all, it evokes a sense of warmth and comfort that is an ideal



The historic log cabin houses visiting scientists and graduate students at the Center.

climate in which research

can flourish.

Square Footage

	1968- 1975	1976- 1995	Today
Use	O riginal building	Phase Two	Phase Three
Research laboratories	3,005	6,005	10,204
O ffices	680	680	935
Library/ Conference room	480	480	480
Technician/ Student areas	695	1,375	1,495
Education		1,160	1,335
O utreach			748
Administration			1,531
Meeting Room		1,289	2,395
Lunch Room	1		796
Other	1,980	3,511	4,901
Total	6,840	14,500	24,820



The research and education "streamhouse" was completed in the fall of 1999.

Rockefeller Grant

n the Stroud Center's early years most people still thought of rivers as conduits that transported things — from ships to sewage — to the sea. With Lake Erie slowly suffocating in its own pollution, the plight of lakes seemed, in those days, a far more urgent issue.

Rachel Carson was an early, and often lonely, voice decrying the assault on rural waterways in Silent Spring, her 1962 environmental classic. In a chapter on "Rivers of Death" she described the decimation of fish populations from DDT pesticide programs meant to protect commercial forests. In a remarkably short time, the DDT wiped out a river's food chain, and the stream died.



Sally Peirson (foreground) and Roberta Weber sample aquatic insects in White Clay Creek.

Carson evoked, as few others had, the unseen life of a stream: "Before the spraying there had been a rich assortment of water life that forms the food of salmon and trout — caddis fly larvae, living in loosely fitting protective cases of leaves, stems or gravel cemented together with saliva, stonefly nymphs clinging to rocks in the swirling currents, and the wormlike larvae of blackflies edging the stones under riffles or where the stream spills over steeply slanting rocks."

She popularized what Ruth Patrick's team had demonstrated on the Conestoga — that a river is an interrelated biological system in which the health of each part depends on the vitality of all the others.

By the 1960s, it was clear that our rivers were in trouble. Massive weeds clogged once-navigable waterways. The water in many streams had become too polluted to swim in, let alone drink. And on June 22, 1969, Cleveland's Cuyahoga River caught fire, the flames leaping five stories into the air.



Larval mayfly eats algae from the surface of a rock.

That so year year year year and year year and ye

Clockwise from top left: (1) Leaves and (2) sunlight leading to algal (green algae, diatoms) production are major sources of energy; (3) microorganisms (bacteria, protozoa and fungi) decompose dead particulate material, use dissolved organics and recycled nutrients, (4) invertebrates harvest algae, ingest detritus, and serve as food for (5) fish.

That same year the Stroud Center received a fiveyear grant from the Rockefeller Foundation

to study the White Clay watershed. Faced with a new sense of urgency symbolized by the black smoke over the Cuyahoga, Stroud scientists set out to learn all they could about how a stream works.

Following the trail Patrick had blazed on the Conestoga, an interdisciplinary team set out to scrutinize the watershed. Some biologists studied the production of algae which compose one base of the food web, while others analyzed how bacteria and fungi break down leaf litter. Entomologists examined insect groups,

discovering that species replacement enables a stream to maintain its energy balance throughout the year. A chemist investigated the influence of geology, land use and rain storms on the chemical composition of the water.

The research did not stop at the banks. Looking beyond to the entire watershed, the scientists began to measure the impact of activities outside the stream itself — both natural factors, such as falling leaves and changing sunlight, and human actions, ranging from farming practices and deforestation to industrial discharge and suburban lawns.

As a result of their massive sets of data, Stroud scientists expanded the knowledge of how biological communities interact in a stream and how they react to stress from both natural disturbances and human activities. At the close of the grant period they had painted an unprecedented portrait of a watershed.



The Salmon River Valley in Idaho where Stroud scientists tested the "River Continuum Concept" that evolved from the research under the Rockefeller grant.

Portrait of a River

A river system can be roughly divided into three categories.

Small headwater streams make up over 90 percent of all stream channels. Their flow is dominated by ground water, and their chemistry and temperature tend to be uniform throughout the year. Heavy shading limits the supply of algae, and most food is provided by the surrounding watershed — directly as leaves, twigs and fruit, and indirectly as dissolved organic compounds entering with the ground water. The biological community is primarily composed of microorganisms which feed on dissolved and particulate food and invertebrates which shred and eat leaves and other forest products, and small fish.

Intermediate streams are wide enough to cause the overhead tree canopy to part and shallow enough to allow sunlight to reach the streambed. As a result, they are subject to pronounced annual, and even daily, temperature changes. Food is produced by the stream itself (algae), supplied directly by the watershed (leaves) and transported from upstream (bacteria/algae/leaf fragments). The biological community is correspondingly diverse, with species specializing in grazing algae, shredding leaves and collecting drifting particles of food. As many as 200 species of algae, 500 species of insects and 25 species of fish can coexist in one stream.

Large rivers are primarily unshaded, their waters are deep and often turbid, and their physical, chemical and biological characteristics are primarily determined by upstream conditions. In contrast to smaller streams, where almost all ecosystem activity occurs on the bottom, the food supply in large rivers consists mostly of fine particles traveling downstream.

Consequently, their biological communities are marked by species that collect food in transport, as well as those which feed on the bottom. Both, in turn, provide food for a wide variety of fish.



The River Continuum

t the end of the Rockefeller study, the Stroud Center invited water researchers from across the country to a two-day conference. It was here that Robin Vannote first presented his hypothesis that was to have a deep impact on aquatic studies.

"In those days," he recalled years later, "most people studied a square meter of water to death."

But, he told the assembled scientists, it is time to move beyond the notion that you can understand how a river works by studying a tiny piece of it. A stream is fundamentally different from a lake, and you

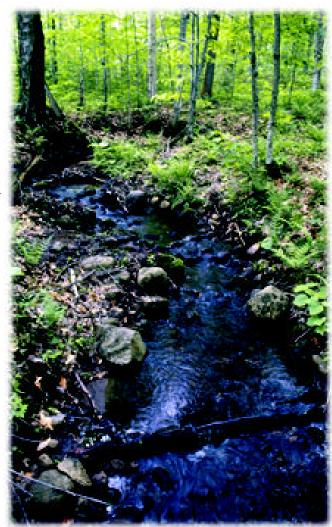
must consider how the entire system is functionally linked. Because a river changes constantly as it

moves downstream, it can only truly be understood as a continuum. As a young graduate student named Bern Sweeney remembered it, when Vannote outlined his seemingly simple notion, "the scientists gathered in that room were just in awe. It was a major, major event."

From those early insights, Vannote, other Stroud staff and a few university colleagues developed the River Continuum Concept, which would revolutionize stream research.

The concept did not materialize out of thin air. Vannote had a voracious intellectual appetite, and his ideas were built on earlier work, both within and outside his field.

There was a direct line to the 1948 Conestoga studies, in which Ruth Patrick had broken new ground with her insistence that the diverse biological communities inhabiting a stretch of stream make up a single mosaic. In their Rockefeller work two decades later, Stroud scientists established the importance of studying the entire watershed.



Food energy in small, forested headwater streams comes mainly from surrounding terrestrial sources such as leaves and dissolved organics.

A young brook trout native to White Clay Creek. During the same period, noted geologist Luna Leopold was developing a formula for understanding a stream's physical behavior. He saw that a river's width, depth, velocity and temperature change constantly as the water flows downstream.

More importantly, he



In mid-sized streams the forest canopy opens up to allow in-stream plants (algae) to become an important energy source.

recognized that those changes are interrelated — and because a change in one factor affects all the others, a river's pattern is predictable.

Draw

In large rivers the biological communities depend on the transport of organic materials from upstream as well as in-stream plant production.

Drawing on these earlier biological, chemical and physical studies, Vannote and his colleagues added a critical

element to the puzzle of how streams work. They argued that a river's biological and chemical processes correspond to its physical attributes, and that the nature of biological communities changes in a downstream direction just as the river itself does. This means that the structure of the biological communities is also predictable and that the communities adapt, as we saw in the last chapter, to the particular conditions of a stretch of stream.

A river is more than the sum of its parts, Vannote asserted. It is not a static body of water. It is a single continuum that flows ceaselessly from its source to the sea. To understand what is happening at any point along the way, you must understand both what is happening upstream and what is entering from the watershed.

The River Continuum

Concept was the first unified
hypothesis about how streams
and their watersheds work. It
dominated river studies for the
next decade, and it established
the Stroud Center as a pioneer
in innovative research.



River Continuum project culminated in a study of the large, relatively pristine Salmon River basin in Idaho.

Robin Vannote



"We were thinking streams, streams, streams, day and night," recalled Pobin Vannote of the early days at Stroud. It was by all accounts a heady time and the Stroud Center was an exciting place, filled with intensity, dedication and focus. No idea went unchallenged and every hypothesis demanded another experiment. The tone was set by the director.

"The clock didn't mean anything to Robin," remembered Bern Sweeney, who in 1972 arrived at Stroud as a first-year graduate student at the University of Pennsylvania. The demands of working at the Center were enormous, in terms of both the time and the intellectual rigor required. No one worked longer hours or asked tougher questions than Robin Vannote.

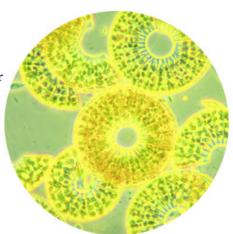
A young scientist who had come from Chattanooga and the Tennessee Valley Authority to be the Center's first director, Vannote quickly gained a reputation not just for the quality of his research but for the breadth of his interests. He had a voracious appetite for all kinds of knowledge and he refused to be confined by the traditional limits of his discipline. His insatiable, sometimes chaotic, curiosity became a defining characteristic of the Stroud Center.

It paid enormous dividends in the early 1970s when Vannote drew widely on analogies from other fields to produce the River Continuum Concept, which fundamentally changed the way the scientific community perceived the life of a stream. Those who witnessed his presentation were astonished by his ability to synthesize, from the vast sweep of his ideas, a concept whose brilliance was its combination of intellectual grandeur and stunning simplicity.

Microbes & Molecules

M ost of us experience streams through our five senses. We hear the sounds the water makes as it runs over rocks, we feel its coolness when we dip our hand, and while it is no longer a recommended activity, we once tasted it when we slaked our thirst. Many modern rivers are identifiable by their odors. Perhaps most of all, we experience a stream with our eyes, watching the play of sunlight on its surface or a fish taking a fly.

What we can't see, at least without the help of a good microscope, is the teeming world of tiny organisms that sustain the stream's life and health. It is as if we were to go to New York and marvel at the huge buildings, while the millions of people who are the lifeblood of the city remain invisible. Yet as many as a billion bacteria, plus millions of protozoa and hundreds of thousands of diatoms, occupy a square centimeter of a streambed, and the collective efforts of such microorganisms provide or process most of the energy that supports the visible life of the stream.



Diatoms, common algae in White Clay Creek.

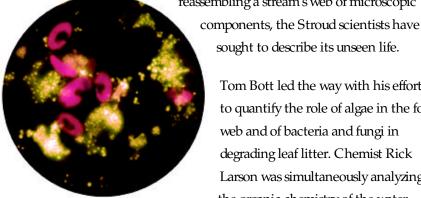
Almost all the biologically useful energy on Earth comes from plant life. Some of it is consumed directly, but most dies and decays. Fungi and bacteria decompose the decaying matter, and in the process they cycle essential nutrients back to a mineral form to be consumed again by algae. The decomposers are, in turn, eaten by larger organisms in an ongoing process that returns much of the original energy back to the food chain.

Since the period of the Rockefeller grant, studies at the Center have pioneered the investigation of energy flow in streams. By teasing apart and

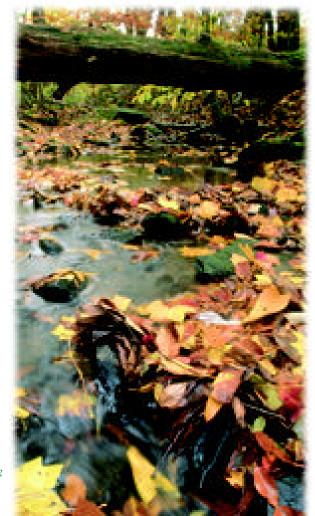
reassembling a stream's web of microscopic

sought to describe its unseen life.

Tom Bott led the way with his efforts to quantify the role of algae in the food web and of bacteria and fungi in degrading leaf litter. Chemist Rick Larson was simultaneously analyzing the organic chemistry of the water.



Fluorescing bacteria (yellow) and diatoms (red) on surface of a leaf in White Clay Creek.



When Lou Kaplan came to the Center, he joined the other two scientists in exploring the linkages among watershed processes, dissolved organic matter and bacterial production. In the course of that work, they applied to freshwater systems a concept known as the "microbial loop," which had been developed in marine studies. It suggested that bacteria play a vital role in the food web by using organic matter excreted by algae and becoming a direct food resource for more complex organisms.

These early investigations have advanced in two directions:



Tom Bott measures conditions in chambers used for determining algal growth rates.

- What happens to the bacteria and how important is the transfer of energy through microscopic animals to higher organisms such as insects and fish?
- **What is the chemical structure of dissolved organic matter and how does it influence the availability of food to groups of decomposers?

Today, Laurel Standley contributes to both efforts, following the transfer of toxins through the food web and using organic molecules to trace the movement of dissolved organic matter from the watershed to the stream.

Both strands build on the insights gained from the Rockefeller studies and the

River Continuum Concept. Their goal is to understand the critical relationship between land and water in stream ecology and to describe the interconnectedness of microorganisms with the visible members of aquatic communities in our streams and rivers.



Organic chemicals that dissolve out of leaves into stream water provide the food for bacteria which form the basis of the organic food web.

Watershed Tea

In studying the hidden life of streams, Stroud scientists discovered that rain water picks up an enormous variety of molecules as it passes through a watershed. When the water enters a stream, it carries with it a special blend of dissolved organic matter, which is then dispersed in the water much like tea from a tea bag. So specific is each watershed's "tea," that migrating salmon use it to find their way home at spawning time.

The tea provides food for bacteria, and recent studies at the Stroud Center indicate that each watershed produces a community of bacterial species which are uniquely fitted to the local food supply. Because of that degree of specificity, the activity of microscopic organisms in our streams and rivers may yield important insights into a wide range of issues.

For example, water utilities are turning increasingly to biological filtration to remove impurities from drinking water. The more we know about how bacteria consume organic matter, the better we can design and evaluate these purification systems. If they prove effective, water utilities will be able to reduce their dependence on chemical disinfectants, which will be more cost-effective for them and less harmful to consumers and the environment.

Despite the efforts of watershed bacteria, however, much of the organic matter ultimately ends up in the ocean, where over time it can be degraded to carbon dioxide, a greenhouse gas. By studying the interactions of bacteria and watershed tea, Stroud scientists hope not only to help provide clean drinking water in a world where it is in dangerously short supply, but also to understand how the organic matter that is delivered to oceans impacts global warming.



Lou Kaplan obtains water samples from White Clay Creek for analysis of dissolved organic carbon (watershed tea).

Thermal Equilibrium

eginning in the 1950s, both scientists and the general public had begun to grow increasingly concerned about the effects of thermal pollution in streams and rivers. Researchers documented critical changes — and in many cases the extinction of entire species — in plant and animal communities in streams that experienced significant shifts in temperature patterns. Such stress occurred in a wide variety of areas: in streams below power plants, industrial operations and top-release dams that discharged warm water; in streams below bottom-release dams and refrigeration facilities that discharged cold

water; in streams whose channels had been dredged and in those whose watersheds had been deforested.

Initial laboratory experiments focused on the tolerances of individual species. By progressively increasing or decreasing temperatures, researchers discovered upper and lower thermal limits. When these were exceeded, over half the test organisms died. In the field, however, scientists found that the correlation between survivorship and water temperature was more complicated than the limits established in the laboratory.



A large nuclear power plant on the Savannah River, site of long-time Stroud research.



Thermal stunting of the growth of mayfly laroae results in lower egg production at maturity and gradual extinction of the population.

In 1972 Bern Sweeney and Robin Vannote took a different tack. Abandoning the idea of thermal limits, they hypothesized that temperature changes altered the normal characteristics and growth cycle of a species, which in turn reduced its adult size and reproductive activity. Instead of occurring catastrophically when a lethal limit had been exceeded, extinction happened gradually over several generations — in response to factors that were not in themselves lethal. Sweeney and Vannote further proposed that the sensitivity of a species to temperature change also had a geographic component.

For example, because a species near the southern limit of its range would already be stressed by the heat, it would be more vulnerable to rising water temperatures than if it were further north. After four years of experiments,



Bernie Anderson boats up the Potomac River to sample the water near the discharge point of a power plant.

Sweeney and Vannote published their results in *Science* (1978) and *The American Naturalist* (1980). Their Thermal Equilibrium Concept proposed two hypotheses:

- that for many cold-blooded aquatic animals, especially insects, a direct correlation exists between water temperature and reproductive potential;
- that changing temperature cycles affect the geographic distribution of a species by gradually lowering its reproductive vitality.

Between 1980 and 1985 these ideas were put to a rigorous test on 25 river systems that stretched across the eastern Piedmont region of North America from Florida to Quebec. This remains the largest project ever undertaken at the Stroud Center, and its results

confirmed the essential tenets of both hypotheses. While many species evolve elaborate genetic mechanisms to cope with severe seasonal changes in temperature, such adaptations offer little protection against human activities. In a world increasingly intent on protecting its water, the Thermal Equilibrium Model provided a quantifiable way to measure the impact of pollution on stream life.

Location of ricers used by Stroud scientists to test their model of how natural and artificial temperature gradients affect stream life.

Bernard Sweeney



Part ivory tower refuge and part business enterprise, a non-profit organization demands of its leader a host of contradictory attributes — the academic achievements of a scholar, the mediating skills of a diplomat, the attention to detail of an accountant, the fund-raising prowess of a politician. In Bern Sweeney the Stroud Center believes it has such a leader.

Sweeney spent much of his childhood looking under rocks and collecting crayfish in Neshaminy Creek in rural Bucks County, Pennsylvania. That led, years later, to graduate work under Pobin Vannote and then, in 1988, to succeeding him as director of the Stroud Center.

His academic credentials are impeccable: He was the main author on the Stroud Center's article in Science; and he, Laurel Standley and Dave Funk produced the first patent ever granted the Academy of Natural Sciences for their use of a mayfly to test for water pollution. But his responsibilities are no longer primarily to himself or his work. They are to the institution as a whole. And while his accomplishments can be measured in the Center's financial strength and professional standing, the greatest testament to his leadership has been the vision and courage he displayed in charting the Stroud Center's path to becoming an independent research institution.

"You start out loving the research," he said. "Then you fall in love with the place where you do the research. The challenge now is to ensure the long-term vitality of this place — to make it the Woods Hole of the freshwater world."

Applied Research

ecause the Academy's mission includes "the advancement of useful learning," the Stroud Center has sought to address practical issues from its inception.

In the Center's early years, however, the scientists focused most of their attention on basic research. Many of their projects involved gathering and analyzing raw data from a variety of geographical areas and over a long time, and this purely descriptive work established a baseline of information which scientists, at Stroud and elsewhere, continue to use and refine more than 30 years later.

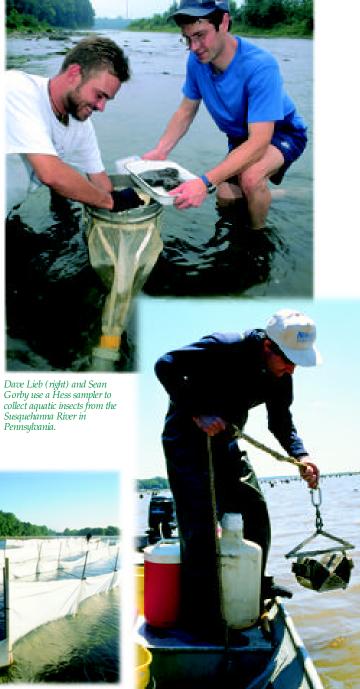
By the early 1980s, however, it had become clear that federal funding for basic scientific and environmental research was about to decrease significantly. Since the availability of public money would shrink and the competition for it would become even more intense, contracts for applied research assumed greater importance and the need to set clear parameters for such work became imperative.

In a memo, dated April 6, 1981, Robin Vannote wrote that acceptance of any proposal should be

based on the "perception of the project as an opportunity to do reasonably imaginative research in an area with broader application or to conduct long-term or large-scale analysis of ecosystem response to perturbation."



John Jackson (foreground) and Dave Montgomery tend experimental chambers constructed on the Susquehanna River to test the effects of Bti.



Bernie Anderson prepares to take a Ponar drudge sample from the Flint River in Georgia to evaluate the discharge from a paper plant.

By that time the Stroud Center had built a reputation for its insights into the diagnosis, prevention and restoration of polluted waters, and its services were being sought by private companies, public agencies and all levels of government. In responding to requests for such work, Vannote cautioned the scientists to avoid performing routine services "that are nothing more than 'number mills' or 'overhead money generators."

In fact, only by maintaining its reputation as "a laboratory known for conducting first-rate basic ecological studies and for understanding the structure and function of river ecosystems" could the Stroud Center effectively address practical problems over the long term.

There are inevitably conflicts with applied research, as there must be whenever someone else is paying the bills. At Stroud such conflicts are limited by the scientists' determination to provide honest answers to scientific questions and to advance the Center's mission "to provide solutions to water resource problems worldwide." They accept such work not just as an important source of revenue but also as a way to pursue fundamental research on disturbed and polluted waters and as an opportunity to produce information that will help people make educated decisions. They insist the projects involve long-term data analysis, address significant scientific questions, and not compromise the integrity of the institution.



An underwater chamber for measuring the impact of a paper plant's discharge on the oxygen supply of the Flint River.

Working with public agencies and private corporations has turned out to be an integral and critical component of the Center's mission. From the beginning, the scientists have sought to make a difference by bringing their knowledge to bear on real problems in the real world. Applied research has provided them with a ticket out of the ivory tower.

Susquehanna Black Flies

In 1989 the Commonwealth of
Pennsylvania hired the Stroud Center to
answer a question: Does use of the
pesticide Bti to control black flies on the
Susquehanna pose a threat to other life
in the river?

With so many basic issues about stream and river ecology waiting to be addressed, the Stroud staff faced a difficult question: How could they justify spending time on an issue that seemed to matter primarily to the state tourism industry?

In the end, they undertook the project for several clearly defined reasons. First, they believed their combination of team problem-solving and research technology could best answer the state's question. Second, they had the opportunity to gather new information on one of the region's largest and most important rivers. Third, because the entire staff was involved, the experience and knowledge they stood to gain would deepen their basic understanding of river systems.

And there was something more. The ramifications of the issue resonated far beyond the banks of the Susquehanna.

Not only do black flies have a significant impact on Pennsylvania's economy, according to staff scientist and the project's director, John Jackson, but they also spread "river blindness," a devastating parasitic disease endemic to large parts of Africa and South America. The Stroud scientists took on this project, at least in part, because it spoke to their mission "to provide solutions to water resource problems worldwide."

They found that a single application of Bti appears to affect black flies only. They are now poised to test the impact of multiple applications.



Education

n October 1990 Bud Rockey's ninth-grade science class at nearby Upland Country Day School placed leaf packs — small mesh bags filled with tree leaves — in White Clay Creek.

"The reason we were interested in doing this experiment," wrote Jessica Small, a student, in her final report, "is because before man settled on this continent, streams flowed mostly through the forest and leaves were an important food source for the animals living there. Large quantities of these leaves fell in the streams. Over the years man has removed most of the trees from along the streams. If man keeps on removing the trees, the animals that specialize in eating the stream-borne leaves will die



Students measure stream flow in White Clay Creek.

because there will not be a sufficient food source. Man is now also introducing foreign trees into our environment. We do not know if the stream animals are eating the foreign tree leaves or whether they can digest them." The students sought to find the answers to such questions by monitoring the packets they put in the stream.



Ann Faulds teaches students at the Center how trout eggs can be used to assess the quality of water in small streams.

Thus was born the education program at the Stroud Center, and since then thousands of students and their teachers have put on rubber boots and waded into White Clay Creek to explore a hidden world of insects, snails, crayfish and worms beneath the water's surface. The leaf packs they study are the descendants of the ones Robin

Vannote developed in the first days of the Center and that Stroud scientists continue to use in their experiments. The students, in other words, do real science.



The program evolved from Bern Sweeney's belief that the declining interest he encountered while teaching college science and ecology courses stemmed from a lack of stimulating science in high school. "We need to get to students in a new way," he told Ensley Fairman of the Longwood Foundation, which provided seed money for the program. "We want to open our doors to the public and broaden the way we convey our knowledge of stream and river ecosystems." To that end, he proposed to make Stroud research the basis for educating a broad spectrum of students and to expand the Center's role in education beyond the courses the scientists taught at local universities.

The programs are for anyone who wants to learn about streams, rivers and their watersheds.

- To reach schools that are unable to get to a stream, Stroud educators bring traveling, hands-on programs directly into the classroom.
- To serve as a resource for teachers, the education staff launched a summer institute in 1995. Funded by the National Science Foundation, the institute enables middle-school teachers to design field projects based on stream research and curricular needs.
- Hundreds of adults have attended the Stroud Stream School, and its graduates now watch over rivers and streams throughout the region.
- The Center sponsors public lectures throughout the year and conducts outreach programs and workshops for community groups.

The staff does these things because they believe that exposure to the work of Stroud scientists will excite students of all ages, help improve science education, disseminate knowledge about freshwater ecosystems and enhance the stewardship of watersheds.



Students plant trees along the bank.

Leaf Pack

The Leaf Pack Experiment is a good example of the interconnectedness of research and education at the Stroud Center. Leaves from deciduous trees accumulate in streams in the fall and provide food for aquatic animals throughout the year. For decades researchers have used leaf packs to explore the dynamics of organic matter in stream ecosystems and to understand the nutritional ecology of streams.

Placing bags of leaves in streams and retrieving them over the course of several weeks also enables students to learn about the biodiversity of streams, their food chains and issues related to streamside forests. In the early 1990s Stroud educators developed a leaf pack kit with materials a teacher can use to engage students in a variety of scientific experiments. In 1992 the Center began a pilot project with the new leaf pack in local schools, and over the next several years the staff was able to get the kits into the hands of science teachers throughout Pennsylvania.

After incorporating reviews and comments from dozens of teachers, the staff refined the Leaf Pack Experiment and turned it over to the LaMotte Company, a national firm that specializes in hands-on products for science education. Because of the scope and reach of its operations, LaMotte is able to provide access to a larger and more diverse audience than the Stroud Center could reach on its own. In the past few years the company has placed the Leaf Pack Experiment in hundreds of schools across the country.

Stroud Preserve

ransversed by the East Branch of Brandywine Creek, characterized by upland meadows, woodlands, agricultural fields, and several small ponds and streams, and situated just 15 miles from the Stroud Center, the 332-acre Stroud Preserve is a place of scenic beauty, historic interest and economic value. To a visitor it offers a variety of extraordinary vistas. To the Center staff it offers the rare opportunity to do long-term research on a site that has been preserved forever.

Formerly known as Georgia Farm, the Stroud Preserve was created by Dr. Morris W. Stroud shortly before his death in 1990. It is a unique collaboration among three of the region's most important research and environmental organizations. Dr. Stroud, who was Dick Stroud's elder brother and a pioneer in the study of geriatrics, bequeathed the ownership of his farm to the Natural Lands Trust, with instructions that the land and water be managed for the benefit of science, education and the environment. He simultaneously donated conservation easements to the Brandywine Conservancy to assure the permanent integrity of the landscape. And he granted the Stroud Center perpetual use of the entire property to conduct scientific research and education programs. He charged the Center to develop a long-term research plan that would advance the knowledge, appreciation and understanding of streams and rivers and the conservation of their watersheds.

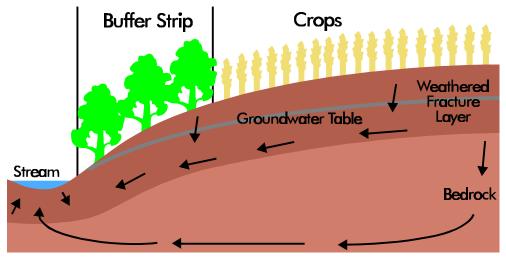


The Stroud Preserve is the site of a long-term research effort to study the ability of streamside forests to mitigate pollution from agricultural run-off.

Dr. Stroud then took the necessary steps to assure the success of this collaborative effort by providing endowment funds to all three organizations — to manage the land for research, inspect and defend the easements, and carry out the scientific and education programs. His novel gift to future generations came as no surprise to his family, friends and colleagues, who remember his resolute belief in scientific research as the ultimate source of knowledge for the benefit of humanity. Today, his vision is reality.

The Stroud Preserve is part of the Environmental Protection Agency's National Monitoring Program, a network of sites which have been set up across the nation to evaluate how land use and human practices affect water quality. It is the only such site in Pennsylvania. The Preserve is also used for a host of public education programs and as a graduate research site for local universities.

The long-term research project that led to the EPA designation is focused on the role riparian tree buffers play in mitigating stream pollution in an agricultural watershed. In conjunction with the U. S. Forest Service, Stroud scientists have set up experiments in three small watersheds on the Preserve in an effort to understand how buffers filter agricultural nutrients — such as nitrogen, phosphorus and other chemicals — which pose a major threat to downstream waters and the Chesapeake Bay. The study, which began in 1992 and will stretch over the entire span of a forest's maturation, is part of a broader effort by Stroud scientists to analyze the impact of streamside forests on the quality of water in our streams and rivers.



This profile of a landscape shows the underground pathways water takes to a small stream and the role a buffer of deciduous trees can play in filtering contaminants.

Dr. Stroud's Legacy



Why did Morris Stroud leave his farm as a research site and set up the Pennswood Endowment Fund to support scientific research and education at the Stroud Center?

Not a man who acted on impulse. Dr. Stroud thought long and hard about his decision. In the end, he told Bern Sweeney, he wanted to make a permanent contribution of the resources he had acquired during his life to a cause that would make a difference to the world he would leave behind. In pursuit of that goal, he transformed a piece of his property into a laboratory dedicated to understanding how humans can use the land without imperiling its water. To support that effort, he sold stock he had received as a wedding gift 50 years earlier, and he used the proceeds to create an endowment. It was time, he said, to stop growing more money for its own sake and to invest it instead in ideas and programs that will benefit future generations.

Dr. Stroud's gift established his farm as a premier site for studying water resources in agricultural settings. It created an environmental education department that has helped thousands of students, teachers and others understand, appreciate and develop a sense of stewardship for streams and their watersheds. It has provided critical seed money which has helped Stroud scientists turn interesting ideas into fundable projects. And it has ensured that the Stroud Center can pursue in perpetuity its mission of science and education about stream and river ecology.

Riparian Buffers

or the past few years in southern Chester County, young trees have been appearing beside streams that had flowed for years across open land. Near the Stroud Center, many meadow reaches are now surrounded by dozens or even hundreds of plastic tubes, each containing the sapling of a species once common to the stream bank. The idea that a forest is the proper habitat for a stream has recently begun to catch on, but its origins go back almost two decades, and Stroud scientists have been centrally involved in its development from the outset.



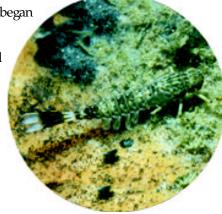
A team of Stroud technicians electroshocks fish as part of a project to evaluate the effect of streamside forests in fish production.

It had become well known by the mid-1980s that a streamside forest — also called a riparian forest because the area near a stream is the "riparian zone" — can filter out various pollutants which would otherwise enter the stream in ground water or overland runoff. As a result, Dave Welsch of the U.S. Forest Service began to compile a document to advocate for riparian forests. Many of the experts he consulted stressed the forest's role in pollution control. But at the Stroud Center, he got a unique perspective on the issue. From their experiments along White Clay Creek, Robin Vannote and Bern Sweeney had determined that forest buffers are much more than filters for pollution — they are an integral and essential part of the stream ecosystem.

In a series of experiments that began as part of the river continuum, geothermal, and microbial and molecular studies, Stroud scientists brought their interdisciplinary approach to the issue of riparian buffers.



Stroud research has shown that grasses growing on stream banks represent an unnatural condition and should be replaced by a streamside forest.



Mayfly larvae require the cool summer temperatures provided by small shaded streams for optimal survival and reproduction rates.

Their reforestation projects demonstrated that trees were critical to maintaining the natural width, depth and sediments of a stream. Feeding experiments showed that aquatic insects,



Small forested streams tend to be wide and shallow, a condition that leads to more effective nutrient spiraling within the stream ecosystem.

such as mayflies, thrive on leaf material from native trees but fare poorly on exotic invasives. Natural temperatures, which are maintained by forest shading, were found to be key factors in aquatic insects' life histories and successful reproduction. Finally, the scientists documented the importance of woody debris in creating stream habitat and of forest shading in providing a balanced food base.

Armed with these ideas, Welsch reoriented his document. In "Riparian Forest Buffers," a work that has gained wide recognition throughout the country, he proposed streamside buffers, not only as a means of cleaning the water but also as an essential component of a natural stream habitat.

The Stroud Center continues to do wide-ranging research on riparian forests. The project at the Stroud Preserve, which is probing the capacity of tree buffers to filter agricultural

run-off. In addition, a study sponsored jointly by the Environmental Protection Agency and the National Science Foundation seeks to assess the influence of the forest on the entire range of a stream life — the structure of its channel, its temperature and water quality, the cycling of nutrients, the production of algae, the activity of bacteria, and the diversity and production of aquatic insects and fish. The project involves every senior scientist at the Center and covers 15 streams in the White Clay, Brandywine and Elk watersheds.

A strip of forest along both banks helps protect the Chemung River near the Pennsylvania-New York border from polluted run-off.

Spiraling

Spiraling, a concept that describes how a stream uses nutrients, came on the heels of Robin Vannote's River Continuum Concept in the 1970s. Jackson Webster formulated the concept, and Denis Newbold, who was shortly to come to the Stroud Center, came up with the mathematical approach that is still widely

Elements such as nitrogen, phosphorus and carbon cycle through all ecosystems. By following the pathways along which food is produced, consumed and decomposed, these elements are used again and again. Ecologists study nutrient cycles to understand how the components of an ecosystem — plants, consumers, predators, decomposers, etc. — fit together. Disturbances, such as a sudden increase of nutrients from pollution or the loss of important species, can disrupt the entire system.

Nutrients cycle in streams and rivers much as they do in other ecosystems. But since they are simultaneously moving downstream, their pathway is better understood as a spiral, rather than as a cycle. Ecologists use spiraling length — the distance required to complete a cycle — as a measure of a stream's efficiency. The tighter the spiral, the more efficient the process because a nutrient makes more cycles in its downstream journey, is consumed more often as food and so produces more energy.

Stroud scientists are now studying both woodland and meadow streams to understand the effect of riparian forests on stream life. Their experiments have shown that spiraling length is always shorter in a forested stream. The reason turns out to be relatively simple: Because forested streams are wider, their streambeds provide more habitat for microbial activity. As a result, the spirals are tighter, and the average nutrient atom is used more intensively in its path to the sea.



Nutrients cycle between the riverbed and the water column as they move downstream in a motion that resembles a spiral.

Costa Rica

or the 40 years following Ruth Patrick's pioneering study of the Conestoga River, almost all research on stream and river ecosystems was conducted in temperate regions. But in 1987 Dan Janzen, a well-known tropical ecologist at the University of Pennsylvania, invited the Stroud Center to help create a research park in the Guanacaste Conservation Area of northern Costa Rica. By early 1988 the Stroud Center had begun to transform a small farm near the base of the Orosi Volcano on the continental divide into a biological field station devoted to understanding tropical streams and their watersheds.



tropical caddisfly

During the next two years, Stroud staff set up research projects and worked with local officials to design the Maritza Biological Station. Under an innovative "debt-for-nature" swap orchestrated by The Nature Conservancy and the Costa Rican government, the Stroud Foundation, the Stroud family and Ivan Maldonado, a family friend from Venezuela, provided the funds to

construct and equip five buildings

on the site. When President Rafael Calderon dedicated the Maritza Station as a permanent research facility on March 22, 1991, the Stroud staff already had intensive long-term investigations under way on the six streams that drain the volcano's virgin forest. The ongoing research includes detailed studies of hydrology, biogeochemistry, organic chemistry, organic food inputs, population and community ecology, pesticide analyses and genetics.



John Jackson prepares samples of tropical stream insects for shipment from the Maritza Station to the Stroud Center.

Because so much of it is, quite literally, in uncharted waters, the work at Maritza recalls the early years at Stroud. Thousands of miles from Pennsylvania's White Clay Creek, scientists are once again asking fundamental questions about the structure and function of streams. And they are trying to determine how tropical streams compare to the temperate ones on which they have spent their professional lives.



The Stroud Center's tropical stream ecology laboratory at the Maritza Biological Station in northern Costa Rica.



Tropical watersheds containing virgin forests and pristine streams surround the Maritza Station in Costa Rica.

Already the studies have yielded some of the most extensive data sets and important insights ever produced on tropical stream ecosystems. Much of what the Stroud staff is

learning is descriptive in nature, laying the foundation on which to build future knowledge. The constant heat and the seasonal weather patterns, in which dry spells follow periods of intense rainfall, make the tropics a vastly different habitat from anything the scientists have encountered before. In addition, researchers in northern waters almost never encounter streams as pristine as those around the Maritza Station.



Rafa Morales, Christian Collada and John Jackson (left to right) measure the flow in a tropical stream.

The excitement of working in such an extraordinary environment keeps the scientists ever mindful of the urgency of their work. The pressures of exploding population growth and unbridled development in Costa Rica are taking an enormous toll on the country's natural resources and environment. As a result, much of the basic research done by Stroud

scientists finds immediate application in the face of pressing human needs
— and data gathered at the Maritza
Station are already enabling the scientists to provide important insights into stream and river pollution, not just in Costa Rica, but in tropical and developing regions around the world.



Reflections

The buildings sit at the base of the Orosi, an extinct volcano which dwarfs everything around it. You can sit for hours, as clouds pass by its peak, contemplating the wildness of the volcano's virgin forest and the jaguars, tapirs, anteaters, monkeys, boa constrictors and butterflies that live there.

Each morning from the porch of any building, you can watch the sun rise over the volcano and slowly fill the valley with light, often producing expansive rainbows that frame the Pacific O cean or Lake Nicaragua in the distance. In the evening, in an amazing array of colors, the sun sets quickly over the Pacific. At night the absence of human inhabitants in the several-hundred-square-mile area makes for a spectacular display of the Milky Way and the southern constellations.

During the rainy season the station is extraordinarily calm, with only thunderstorms or the sounds of birds, monkeys and other wildlife breaking the silence. In the dry season, however, the wind howls almost constantly until you think it will blow the roofs off the buildings. A short hike into the volcano's forest, where only the sound of the overhead winds can penetrate its canopy, quickly restores your sense of tranquillity.

It is especially refreshing to venture into the forest in the dry season and encounter, within a 20-minute walk, at least six radiant streams, each flowing with water pure enough to drink by hand. Nowhere else in my 30-year career have I experienced the excitement of knowing that this is how it used to be everywhere.

Bern Sweeney

Art & Science

hen you enter the Quaker meetinghouse that constitutes the Stroud Center's conference room, you encounter Leonid's world — a world of soft oil paintings characterized by great canvases of gray, blue and green waters blending imperceptibly into similarly colored skies. Subtle colors portray reflected sunlight, an approaching storm, phosphorous on a wave. The humans in the



Leonid Berman's aquatic scenes are on permanent display at the Center.



paintings are sketchily drawn, at once dwarfed by and in harmony with the world of sky and water that envelops them.

Known simply as Leonid, the artist Leonid Berman spent much of his life painting pictures of people who make their living on the water. Born into a well-connected Jewish family in St. Petersburg near the end of the last century, Leonid escaped from Russia just after the Bolshevik Revolution and survived World War II as a prisoner on a labor gang in France. He emigrated to the United States after the war and became a close friend of the Stroud family. At his death in 1976, he left half his estate, which consisted almost entirely of his paintings, to the Stroud Foundation.

Throughout his wandering, ever-curious life, Leonid traveled all over the world, painting Norman mussel gatherers, Asian boat handlers, Mediterranean sailors and Maine lobstermen. The vast expanses of water and sky give a sense of calm to his oils that stands in stark contrast to the lives of the seafarers he paints — as if the artist who had seen such oppression from the hands of humans sought transcendence in the serenity of the natural world.

The paintings provide an apt backdrop for the Stroud meetinghouse. It isn't just the centrality of water to both the artist and the scientists. It is that, beneath the calm surface of both painting and laboratory, lies a barely concealed intensity born of a commitment to their work.

Art has played an essential role at Stroud from the beginning, and Leonid is not the only painter whose work is on view here. The Stroud family are both lovers and collectors of art, and they have provided their own works and quietly nourished a belief in the importance of



Art provides a background for science. Here Mike Gentile isolates humic compounds in the Center's dissolved organic chemistry laboratory.

art to the scientific process. Over the years, the hall onto which the staff offices open has become a gallery where changing shows of painting, sculpture and photography are regularly put on display.

The commitment to art has helped build an environment that encourages contemplation and innovation. "Science and art are both creative," said chemist Laurel Standley. "And both are habitat sensitive — you need the right environment or it just doesn't come. The art here stimulates our thinking."

The staff knows that they might not like, nor at times even understand, what they find hanging across from their offices, but they are eager to encounter it. They have learned that their initial inability to grasp an abstract painting is not so different from other people's inability to grasp the arcane language of their own field. And they have come to



believe that the two worlds are not as far removed as many think — that the creative process is as much a part of the science at the Stroud Center as it is of the art.

Jeffrey Funk's bronze-and-slate "Stream Language" sculpture greets visitors in the Stroud Center's courtyard.

Dick & Joan Stroud



The marriage of science and art that has done so much to define the spirit of the Stroud Center had its origin in another marriage that has meant at least as much. Dick Stroud and his late wife Joan are the kind of benefactors of whom most non-profits can only dream. They provided the financial support that launched the Center and the land on which it sits.

But it is the family's intangible gifts that have meant the most to the people here. They cared. They cared enough about the landscape in which they lived to welcome a laboratory dedicated to the environment. They cared enough to painstakingly oversee construction of the building to ensure that its esthetic quality reflected the spirit of the Stroud Center. They cared enough to fill the place with art which has proved a source of unique inspiration to those who work here. They cared enough to host Christmas parties and other events that give the Stroud Center the spirit of a family. They cared enough to learn about the things that go on here — to share a scientist's excitement over a discovery or a child's wonder at first looking though a microscope. And they cared enough not to interfere.

They had no agenda and they never sought to impose their point of view. But they have attended almost every forum and listened to the scientists discuss their work. They have asked questions, given encouragement and demonstrated by their presence a deep loyalty to the people here. They take pride, not in what they have built, but in what they have enabled others to do.

The Road to Independence

he intellectual roots of the Stroud Center trace back to 1947 when the Academy of Natural Sciences of Philadelphia created the Department of Limnology, dedicated to understanding aquatic ecosystems. Ruth Patrick, the driving force behind the new department, immediately launched her pathfinding study of the Conestoga Creek in Lancaster County. That study set the standard for future aquatic research. It also laid the foundation for the Stroud Center 19 years later.

The Conestoga study foreshadowed both the mission and the philosophy of the Stroud Center. And when, at her urging, the Academy chartered its new laboratory in rural Chester County, Dr. Patrick brought to it her reputation, her access to funding

and her extraordinary work ethic. It was largely through her influence, for example, that the Center secured the five-year Rockefeller grant that brought the financial stability and scientific repute that ensured its future prosperity.

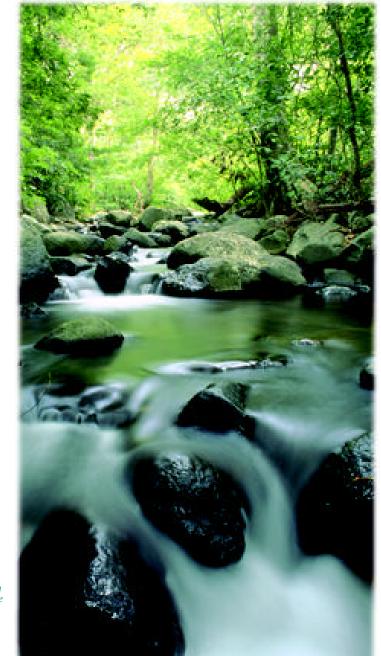
Over the next 33 years, the Stroud Center evolved from a small outpost on the banks of a small stream into a major research and

education facility with 23 full-time employees and a multi-million dollar annual budget. It grew from a makeshift laboratory over a garage into a multi-building research and education facility. Its research progressed from a focus on one tributary of White Clay Creek to

adult damselfly programs that span the globe, and its scientists

brought the institution a worldwide reputation for excellence.Finally, the Stroud Center helped spawn a rural outpost of its own— the Maritza Station in Costa Rica's Guanacaste National Park.

None of this could have happened without the support of the Academy, which incubated the Stroud Center and nurtured its growth. Above all, the affiliation with one of the oldest and most respected scientific institutions in the Western Hemisphere provided the Center with a mantle of credibility that proved invaluable to the fledgling organization.



This pristine stream in Costa Rica is a tropical research site for Stroud scientists.

By the 1990s, however, the Stroud Center had reached a critical stage in its evolution. Its growth, fiscal independence and physical distance from the Academy had given it unusual autonomy. The Academy had made clear from the outset that the Center must take full responsibility for its economic survival, and over the years the Stroud Foundation and family, with the help of Dr. Patrick and others, established several funds dedicated to its well-being. In addition, the quality of the staff's scientific work attracted significant funding

from research grants and from long-term contracts with

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Ruth Patrick and an assistant gather samples on one of her pioneering stream studies.

public agencies and private corporations. In the 1990s the Center set up its own education department and a development office that quickly embarked on a capital campaign for construction and endowment.

The logical next step came on April 22, 1999, when the Academy's trustees authorized the Stroud Center to become a separate non-profit corporation. On October 1, 1999, the Stroud Water Research Center became a fully independent organization.



The Academy of Natural Sciences of Philadelphia.

The Academy

Founded in 1812 "for the advancement and diffusion of useful, liberal, human knowledge," the Academy of Natural Sciences of Philadelphia is the oldest continuously operating natural sciences institution in the Western Hemisphere. Its history is dotted with the names of prominent scientists and explorers, and it has sponsored expeditions to every point on the globe.

New species of plants and animals collected on early journeys to the American West became the foundation of the Academy's scientific collection, which now numbers over 25 million specimens — including Thomas Jefferson's fossils, plants gathered by Lewis and Clark on their trek across North America and the birds John J. Audubon used as models for his paintings. Later voyages of discovery, from Africa to the Arctic, produced plants and animals that can still be seen in the Academy's renowned dioramas.

In 1948 the Department of Limnology, forerunner of today's Environmental Research Division, was established under the leadership of Ruth Patrick. Its scientists began studying the impact of human activity on rivers and their watersheds decades before water pollution and other environmental issues had even registered on political radar screens.

Today, the Academy is made up of four parts: the Museum; the Environmental Research Laboratories focused on watershed research and education; the Biodiversity Group, which targets its worldwide field research to areas where habitats are endangered and species threatened with extinction; and the Ewell Sale Stewart Library, which has been designated a major research library by the U.S. Department of Education.





n Feb. 2, 1999, Sherman Roberts, a lab technician with a thoughtful manner, a sandy beard and an easy smile, asked to say a few words at the Center's monthly staff meeting.

"Last Friday marked 27 years since I first came to work here," he began, "and over the weekend I got to thinking about why I had stayed so long." Then, with a mix of reticence and resolve, he talked about the sense of community which has meant so much to him over the years and which transcends the boundaries that so often divide people in the work place.

To Roberts the Stroud Center is not simply the place he goes to work. It is a community of people who are connected by a passion for what they do. "You are not just my co-workers," he told his colleagues. "You are my friends."

The shared sense of purpose stretches from Bern Sweeney, the executive director who came fresh out of college in 1972 and never left, to Catherine Ferranto, a laboratory aide who retired after 28 years only to stay on in a part-time role, to Sally Peirson, who followed both parents to the Center 27 years ago. It crosses all lines and it is obvious even to outsiders.

"The place just had a feel about it," remembered Laurel Standley of her first visit. "The people were genuine."

One result is remarkable continuity, an asset that is hard to overstate for an institution devoted to long-term research. In a place that is barely 30 years old, the average length of service is over 11 years. For senior staff it is almost 19 years — and that doesn't even count the fact that both Sweeney and Lou Kaplan came as graduate students and have been there ever since.

The benefits cannot be measured solely in longevity. "We seem to attract people who believe in the team approach," said John Jackson. "All our successes have been the result of collaboration."





Stroud researchers tend experimental chambers in the Susquehanna River.

"The low barriers between disciplines give us a power we couldn't find elsewhere," said Standley. "They allow us to be open and adventurous, to investigate and explore, and yet to feel safe. We can really share because we really trust each other."

From the beginning, said Tom Bott, that trust has produced "a group of people who like to work together on significant questions."

"The essence of Stroud?" mused Denis Newbold. "It's one institution with one mission."

"We bring a number of disciplines to bear on a question," said Kaplan. "We want to describe the ecology of streams and rivers. We want to understand how they work."

Our major accomplishment, said Sweeney, has been "maintaining an extremely focused mission for 30 years and pursuing it with a sense of camaraderie and an interdisciplinary approach that exists nowhere else."

"Together," said Standley, rhetorically underlining the word, "we have contributed to the basic understanding of stream and river ecology. That sometimes seems a small thing. But we have pushed science forward."

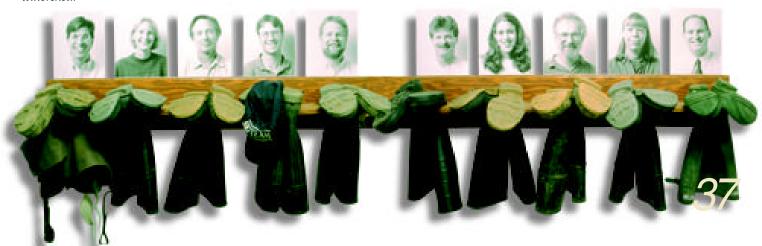
And expanded it outward. "That same sense of teamwork drives our education and public outreach efforts," said Jim McGonigle. "We want to make sure that the research done here reaches beyond the scientific community. Its applications touch everyone. We are all citizens of a watershed."

Continuity

At the Stroud Center's core is a group of scientists from a wide range of disciplines — chemistry, ecology, entomology, hydrology, mathematical modeling and microbiology. This mix is not accidental, nor are the fields chosen at random. The Center's mission rests on a foundation that encourages collaboration across conventional scientific lines, and its variety of disciplines allows Stroud scientists to explore issues and ideas as an integrated team.

The structure also provides the scientists with an unusual ability to build on the research that has gone before them. Perhaps the main reason for that is due to the composition and continuity of the staff itself. As we have seen, there is remarkably little turnover, particularly at the senior level. When new people are hired, they are selected for their ability to add to the overall value of the team. This has resulted over the past three decades in a host of projects that combine the efforts of two to four senior scientists, each of whom brings his or her individual discipline to the mix, and who together can build on the Center's formidable historical data base and tap into the collective memory of the institution.

The uncommon nature of such an operation becomes clear when it is compared with universities, where professors and resident scholars generally assemble their own individual teams, and departmental lines can make integrated research difficult. The result is that a specific line of research is often difficult to maintain beyond the retirement of the scientist who started it.



Building Blocks

he history of science at the Stroud Center is the story of scientists who have built on prior work, one experiment at a time. The study of dissolved organic matter (DOM), which began with the Rockefeller grant and most recently flowered in the concept of watershed tea, provides a case in point.

The timeline begins in the late 1960s, when Robin Vannote was putting leaf packs in White Clay Creek, Tom Bott was studying the microbial decomposition of those leaves and measuring the



impact of algae on stream life, and Rick Larson was providing one of the first in-depth looks at the organic chemistry of stream water. These varied activities were all part of an effort to understand the role terrestrial and in-stream sources of food play in stream ecosystems. And they led, in the early 1970s, to one of the River Continuum Concept's main hypotheses — that the diversity of DOM compounds was at its maximum in a small headwater stream and diminished rapidly as the stream grew into a large river.

The Center, however, did not have the instrumentation necessary to test the hypothesis. In the mid-1970s, Lou Kaplan secured a National Science Foundation grant to buy a DOM analyzer, which enabled him to investigate the sources and uses of DOM in the White Clay watershed.

By the end of the decade, Kaplan and Tom Bott had focused their joint studies on how DOM is used and degraded in a stream and how bacteria can actually acclimate themselves to the specific nature of a watershed's food supply. A few years later the scientists moved on to study how the DOM-fed bacteria interact with algae and protozoa to help form the basis of the stream's food web.



After reading Kaplan and Bott's published results, scientists at the Environmental Protection Agency funded them to look at the growth of bacteria in drinking water and at the impact of organisms which had been genetically engineered to degrade DOM compounds. Bott's research expanded to more thorough investigations of the microbial food web, and he and Laurel Standley are working to determine what happens to toxic substances that enter the food web. Meanwhile, Kaplan developed a bioreactor that measures how efficiently bacteria consume DOM. Using his instrument, a water utility can determine the most effective treatment process, measure the results and monitor the quality of the treated drinking water. On Feb. 23, 1999, Kaplan was awarded a patent for his reactor and for the method he developed to measure contaminants in drinking water.

The next step in the research will be to measure the influence of DOM chemistry on the composition of bacterial communities. As part of that effort, new tools in molecular microbial ecology, such as DNA analysis, will provide a first look at the numbers and kinds of bacterial species in streams, and new tools in analytical organic chemistry will supply the data to test the River Continuum hypothesis on the diversity of DOM in stream ecosystems.

Thus does ongoing research at the Center build on the scientific foundation of the past, provide answers to questions posed decades earlier and become the stage from which future projects will be launched.

U.S. Patent 5,665,555

U.S. Patent 5,873,997



Of Patent & Parthenogens

When Bern Sweeney announced that Stroud scientists had discovered a parthenogenetic mayfly, almost no one at the Stroud Foundation's 1982 annual meeting had a clue what the word meant

— it seemed just another incomprehensible term scientists like to throw around. Then Sweeney mentioned that parthenogenesis was the ability to reproduce without the need for a male. That got people's attention. Sam Means, the rumpled South Carolina lawyer and trustee who was known to nod off when the science got obscure, snapped to attention. Morris Stroud jumped to his feet and stated emphatically that he and his brother Dick were opposed to the idea.

Beyond its unusual sexual proclivities, said Sweeney, *Centroptilum triangulifer* held



significant possibilities for scientific research. Most stream insects have relatively long life cycles, are difficult to grow under laboratory conditions and will only mate in the wild. But *C. triangulifer* consists entirely of females who produce viable eggs without mating, has a one-month life cycle and is easily cultured in the lab. Like all mayflies, it is extremely susceptible to pollution, making it the perfect candidate to become both the sensitive "canary" and the accommodating "white rat" of the aquatic testing world.

After Sweeney and Dave Funk had confirmed that the species reproduced as clones, they worked with Laurel Standley to test its use in evaluating toxic substances in streams. In 1997 the three scientists received the first patent ever granted to the Academy of Natural Sciences.



The specific programs and research projects the staff will undertake in the years ahead are impossible to forecast. It is safe to say, however, that they will cover a broad spectrum, ranging from the investigation of such minute phenomena as the molecular structure of dissolved organic matter or the genetic composition of a single bacterium to broad comparative studies of the physical, chemical and biological characteristics of streams, rivers and watersheds in different parts of the world and at different points in time.

The kinds of questions the scientists ask and the methods they employ have been shaped over the course of the Stroud Center's life; and regardless of the specific paths they may take, the projects will always seek to advance the basic understanding of the world's freshwater environment. Because of its continuity in staffing and the cooperation among disciplines as disparate as chemistry, entomology and microbial wecology, because of its uninterrupted access to experimental watersheds and the consequent evolution of extraordinary sets of long-term data, future Stroud research will bear the fingerprints of its past. It is, indeed, its combination of scientific collaboration, experimental longevity and institutional memory that makes the Stroud Center unique.

Over the years Stroud scientists have built a solid foundation on basic research. As a result, they have been able to expand their work from gathering, cataloguing and digesting massive amounts of information to suggesting ways to repair ecosystems that have been disturbed by natural and human forces. That pattern will continue. Through studies trying to predict the consequences of global warming, for example, they hope to understand the actual impact of climatic changes and to discover ways to mitigate them. By investigating the sources and effects of river pollution, they hope to identify both remedial activities and preventive practices. By understanding more and more about the dynamics of stream life, they seek to solve today's problems and to forestall tomorrow's disasters.



Qur Mission

The mission of the Stroud Water
Research Center is to advance
knowledge of stream and river
ecosystems through interdisciplinary
research; to develop and communicate
new ecological ideas; to provide
solutions for water resource problems
worldwide; and to promote public
understanding of freshwater
ecology through education
programs, conservation leadership,
and professional service.



nce the information has been compiled, the issues defined and potential remedies suggested, the next challenge is to disseminate that knowledge to others. This has led to the development of an educational process that is critical to the long-term success of the Stroud Center. The process is not simply a matter of having the scientists publish their research findings in professional journals, although that is part of it. It is, rather, a wide-ranging and ongoing conversation among Stroud scientists, educators and the public. Because the audiences vary – from scientific colleagues across the globe to middle-school students down the road – it is a conversation that must take place in many languages and at vastly different levels of sophistication. In particular, Stroud educators seek to talk with those who educate others, for they believe that the best way to reach the most students is through passionate teachers.

Whatever its language and its level of sophistication, the audience is not made up of passive recipients of information. At Stroud all learning is seen as part of a continuing dialogue in which the Center's intellectual resources grow as a direct result of its interaction with the natural and human world beyond its walls. Professional colleagues provide critical insights into complex problems. Non-scientists ask unexpected questions that compel scientists to look at aquatic and environmental matters in a new light. Individuals and communities seek to cope with water resource issues that demand fresh thinking and creative solutions. Young students and those who teach them reinstill in everyone the excitement of learning.

The fate of our streams and rivers lies in the hands of all of us. The great challenge the Stroud Center faces in the years ahead is to keep alive its passion to understand freshwater ecosystems, to ensure that people everywhere have safe, clean sources of water and to communicate its insights as clearly, as convincingly and as widely as possible. The Center's new status as an independent organization provides the framework for meeting that challenge. Its dedication to the guiding principles that have sustained from the beginning provides the substance.



To see a World in a grain of sand, And a Heaven in a wild flower Hold I nfinity in the palm of your hand, And Eternity in an hour

William B lake

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n its preceding chapters, this book has tried to tell the still-unfolding story of the Stroud Water Research Center. Born from an inspiration of Ruth Patrick, nurtured by the Stroud family and an ever-widening circle of friends, led by the strong wills of its two directors, the Stroud Center has remained first and foremost the creation of its staff. They have carried their dream to learn all they can about streams and rivers through three decades of change; and they have held steadfast to their belief that their work can make a difference in a world where fresh water is increasingly imperiled.

Now, after 33 years as a department of the Academy of Natural Sciences, the Stroud Center has set a new course into uncharted waters. The ship is in good shape. Its crew is well-tested. Its mission, recently written in new words, remains what it has always been: "to advance knowledge of stream and river ecosystems through interdisciplinary research; to develop and communicate new ecological ideas; to provide solutions for water resource problems worldwide; and to promote public understanding of freshwater ecology through education programs, conservation leadership and professional service." Stroud scientists seek, like the poet William

Blake, "to see a World in a grain of sand" – to study something as small as the bacteria under Tom Bott's microscope in the hope of unlocking the secrets of the river itself.

We all know far more about stream and river ecosystems than we did in 1966. But as each discovery opens up new questions and new avenues for research, Stroud scientists are discovering how much more there is to learn than anyone could have guessed 33 years ago, how many more ways there are to learn it and how many more reasons there are to want – and to need – to learn it. With almost one billion people now living without it, clean water is perhaps the most endangered commodity on Earth.



To that end the staff and board of the Stroud Water Research Center pledge always:

- To remember and respect the Center's past, but never to let it dictate its future.
- To persevere in their determination to be world leaders in science and education.
- To encourage long-term opportunities for all Stroud associates.
- To hold firm to the belief that solutions to environmental problems are rooted in basic research.
- To forge individual creativity and interdisciplinary teamwork into a firm foundation for scientific inquiry.
- To recognize the importance of research on polluted or disturbed streams, rivers and watersheds.
- To acknowledge that the value of their findings rests largely with sharing them with colleagues and the public.
- To be guided by a longterm vision, rather than short-term needs or passing fads.
- To never lose sight of the sheer joy of discovery.

Afterword

In 1997, ninety stakeholders including New York Governor George Pataki, New York City Mayor Rudolph Giuliani, the federal Environmental Protection Agency (EPA) Regional Administrator Jeanne Fox, five New York State and New York City agency commissioners, the executives of six upstate counties and supervisors of seventy five upstate towns joined leaders of New York State's environmental community to sign the historic 1,800 page New York City Watershed Agreement.

That agreement obligated the city to spend \$1.5 billion purchasing buffer lands and rebuilding environmental infrastructure in its upstate watersheds. In turn, EPA agreed to wave a catastrophically expensive order requiring the city to filter its water and the watershed communities agreed to allow the city to regulate pollution and development in its 2,000 square mile reservoir watersheds. The agreement had taken two years of blistering negotiations among stakeholders. I was chief negotiator for the environmental parties and water consumers.

For environmentalists there was no provision of the Watershed Agreement more important than the state's agreement to seek funding to create a state-of-the-art "enhanced monitoring program" that would identify the sources of pollution in the watershed and determine whether the agreement was actually protecting the reservoirs and tributaries from deterioration. The parties intended the program to serve as an "early warning system" allowing us to spot weaknesses in the city's regulatory and enforcement structure long before irreparable injury effected to the system.

Congress provided the funding for our program -- up to \$15 million per year -- in a special amendment to the Safe Drinking Water Act. Soon after signing the agreement, we began a national search to find a scientific consultant who could design and execute a stream sampling program that would meet our ambitious objectives.

All roads lead to Stroud. I had known about Stroud Water Research Center for about thirty years. As a young man, I had an intense interest in streams and fishes and had visited the center in 1969 when I was still in my teens and curious to see the famous laboratory where the stream flowed indoors.

Today, Stroud Water Research Center is known to stream specialists around the globe as the world leader in stream research and waterway restoration. During the 1980's and 1990's, Stroud revolutionized the study of stream ecosystems. Stroud gave the world its first definitive description of the complex interactions of stream ecology from bacteria to fish to humans. It was Stroud researchers who helped establish the correlation between species diversity and stream health, the critical importance of small headwaters to riverine ecosystems, the role of leaf litter in fostering and preserving health, biological diversity and basic function of stream chemistry and the dynamic spiral of oxygen, carbon and nutrient cycling. Among its many extraordinary accomplishments, Stroud was the first to document the critical importance of forested buffers to water quality and ecosystem health. These lessons are now regarded as the fundamental gospels of modern stream research. It is rare that a single institution plays such a central role in changing the paradigm for an entire scientific discipline. But Stroud has been at the forefront of the most groundbreaking and critical stream research over the past three decades and many of these discoveries now provide the basic assumption of stream research. Its long list of accomplishments has made Stroud the Woods Hole of the freshwater ecosystems. Stroud is currently designing an enhanced monitoring program for the New York City watershed. I feel confident that the city's water supply couldn't be in better hands.

Robert F. Kennedy, Jr. President, Water Keeper Alliance



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