Universities Council on Water Resources
Journal of Contemporary Water Research & Education
Issue 136, Pages 17-27, June 2007

Resurrecting the In-Stream Side of Riparian Forests

Bernard W. Sweeney and James G. Blaine

Stroud Water Research Center, Avondale, PA

"With all the trees you folks are planting around here," the old farmer said as he watched staff members from the Stroud Water Research Center place yet another row of flags along a meadow creek on a clear fall morning, "pretty soon this whole area will be woods. You know," he went on, "when our forefathers first set foot on this ground, there wasn't a tree anywhere around here." So began a conversation with a man who had no idea that the land his family had farmed for generations in "Penn's Woods" had once been completely forested. This is less surprising than it may at first appear because within a century after the first Europeans had settled, virtually every tree in southeastern Pennsylvania (PA) had been felled. Some of the first to go were those in riparian forests, which were cut for firewood and building material, for agricultural land and access to fresh water. The streams and rivers became the flowing commons of the New World, providing drinking water and waste disposal, hydropower and irrigation, food, transportation, and hygiene – all free of charge. As settlers marched westward across the continent, chopping down riparian forests, planting crops up to the river's edge, and letting their livestock contaminate creeks, they wrote a tragedy of those commons (Hardin 1968), for which the nation continues to pay.

Even as the world increasingly acknowledges the vital things trees do for people and their environment, the destruction continues. During the 15-year period from 1985 to 2000, for example, the Delaware Valley region of southeastern Pennsylvania and southern New Jersey lost 12,655 ha or 1.5 percent of its heavy forest canopy, representing an annual loss of at least 1.5 million m^3 of stormwater retention, 750,000 kg of air pollution abatement, and 643 million kg of stored carbon (American Forests 2003). Perhaps nowhere has the destruction of America's forests been more devastating than along its streams – and particularly its small streams – which are the source of most of the nation's fresh water. In fact, a recent study found 19 percent of the total length of small streams in the U.S. to be in poor condition due to "severely simplified riparian vegetation" (U.S. Environmental Protection Agency 2006).

Note our use of the phrase "riparian forests" rather than "riparian buffers." In the last two decades, many policy makers have come to recognize the need to create a physical space – or buffer – to protect their freshwater sources from the harmful effects of human activity. Such policies have been supported by a significant body of scientific research demonstrating that buffers act as barriers to keep sediment and other pollutants from running off the land and into the stream (see reviews by U.S. Environmental Protection Agency 1995, Lowrance et al. 1997, Bentrup et al. 2005, Mayer et al. 2005). As a result, riparian buffers have become best management practice in most U.S. landscapes. While the recognition of the importance of such buffers has been a valuable addition, both to the scientific literature and to public policy debates, it has also had a little-noted but marked negative effect. The emphasis on the role of the buffer as a barrier, shielding a stream from harmful human activities, caused people to overlook the substantial benefits that riparian forests provide to the health and integrity of the stream itself.

In this essay, we explore the important role riparian forests play in protecting our streams and rivers in a number of ways:

1. Why the focus on buffers as barriers pushed the in-stream benefits and services provided by

riparian forests from the scientific and political stage,

2. How the results of a comparative study of 17 forested and deforested stream reaches in eastern North America helped resurrect the recognition of the in-stream benefits provided by riparian forests,
3. What the implications of that study hold for understanding and managing pollutants from a variety of sources,
4. Why the newly described benefits of riparian forests should have far-reaching effects for the economic and physical health of human communities, and
5. How and why the Stroud Water Research Center and other organizations need to communicate that information in ways that will make the public understand the importance of riparian forests and provide the scientific foundation for more informed and effective public policies.

Buffers as Barriers

Although scientists had recognized for some time that healthy streams were typically bordered by natural riparian forests, both the early scientific research on buffers and the political drive to implement them focused almost exclusively on their ability to intercept sediment and nutrients before they enter a stream or river (see earlier reviews by Newbold et al. 1980, Lowrance et al. 1984, Peterjohn and Correll 1984). Such nonpoint-source pollutants were a growing national concern, agriculture was perceived as a major source of the problem, and buffers represented a simple and positive step that farmers could implement. Adding buffers to the existing set of farm BMPs, which included contour farming, grass waterways, and terracing, seemed a logical step, particularly because the infrastructure provided by USDA's Natural Resource Conservation Service and Forest Service was already in place to market and subsidize the program. Even so, adding buffers to the "Farm Bill" or Food Security Act (1985) required data proving they worked. Since the ability of buffers to intercept nutrient and sediment flux dominated the peer-reviewed literature at the time and shortly thereafter (Phillips 1989), their role as barriers emerged as the principal argument for including them in the legislation. The 1985 act established the conservation reserve program (CRP), which provided money to remove up to 45 million acres of highly erosive land from agricultural production. One of the program's priorities was to establish "stream borders" of grass or trees to reduce erosion. This represented the first major political recognition of the importance of riparian buffers.

There was also, however, a negative side: the scientific focus on the buffer's role as a barrier combined with existing political, social, and even aesthetic ideas to make grass the vegetation of choice for riparian buffers in many geographic areas and, in the process, to push out of sight the additional and perhaps more important benefits provided by riparian forests. If the sole purpose of a buffer is to provide a filtration barrier, then any vegetation that intercepts sediment and nutrients running off the land will do. As it turned out, grass often proved more attractive than trees in an environment in which many farmers, landowners, developers, public officials, and others strongly opposed taking riparian land out of production or excluding it from development, preferred the aesthetics of a meadow stream view to one obstructed by trees, and objected to government interference with private property rights (Dutcher et al. 2004). In contrast to a riparian forest, it was known at the time that grass buffers: (1) often permitted an annual harvestable crop (hay); (2) did not have the historical stigma of a forest as an impediment to agriculture (Williams 1989); (3) did not produce the "edge effect" of trees that shade crops; (4) provided habitat for game animals; (5) had banks that were more easily accessible for fishing and recreation; (6) did not clog streams, at a time when falling trees were believed to impede water flow and led to major clearance projects by the U.S. Army Corps of Engineers (see also Montgomery and Piegay 2002); (7) were in harmony with prevailing landscape concepts that favored open views; and (8) had solid scientific support regarding their ability to remove significant amounts of nutrients and sediments (Dillaha et al. 1988, 1989, Magette et al. 1989, Osborne and Kovacic 1993, Castelle et al. 1994). As a result, grassy riparian buffer strips became a well-established and government-sanctioned practice for protecting water quality, reducing bank erosion, and improving wildlife (Natural Resource Conservation Service 1997).

Moreover, despite a growing body of scientific research demonstrating the vital role that riparian forests play in protecting and restoring the overall habitat of streams and rivers (Welsch 1991, Wenger 1999), the arguments against trees as best management practice persisted (Trimble 1997, Lyons et al. 2000). Later studies would reveal that, while there may well have been good reasons to justify planting grass instead of trees in riparian zones, the health of the stream's ecosystem and its ability to deliver ecosystem services was not one of them (Sweeney et al. 2004).

Beyond Barriers

Largely overlooked in the enthusiasm over grass buffers during the 1980's and 1990's was the fact that, while buffers were a stream's first line of defense against non-point source pollutants, they were less than 100 percent effective. From the outset it was known that a buffer – whether grass or forest – could intercept anywhere from 10 to 85 percent of sediment and nutrients, depending on the site characteristics, which means that the remaining 15 to 90 percent of overland pollutants were penetrating the buffers and entering the streams and rivers (see Wenger 1999 and Mayer et al. 2005 for historical reviews). But intercepting some pollutants was a clear improvement over intercepting no pollutants, and so little attention was paid to what was happening to the sediment and nutrients that were getting through the buffers. Clearly they were being carried downstream – but what, if anything, was happening along the way? Streams and rivers, after all, are not just pipes that transport sediments, nutrients, and other debris to estuaries and eventually the oceans. At least in their natural state, they are efficient and effective processors of "stuff" coming from their watersheds. Otherwise, for example, Vicente Gonzalez, the Spanish explorer who sailed into Chesapeake Bay in 1561, would have found the bay and its shores choked by the old-growth timber, leaves, and dead animals that had fallen into its upstream tributaries and washed downstream. The ability of streams and rivers to process so much stuff became the foundation of the river continuum concept over 400 years later, when Vannote et al. (1980) hypothesized that aquatic species formed communities throughout a river system that effectively processed the organic matter moving through it. It seemed, then, worth asking whether the streams themselves might serve as a second line of defense against nonpoint-source pollutants – and, if so, what role riparian buffers might play in the process?

One clue that led a team of scientists from the Stroud Center to ask those questions in the 1980s and 1990s was the fact that grass-banked streams are unnatural to most landscapes in North America. For example, it is well known that a forested riparian zone represents the natural state along most U.S. streams east of the Mississippi River (Williams 1989), but it now appears that the riparian areas of even prairie (Matthews 1988, West and Ruark 2004) and desert streams were forested (Minkley and Rinne 1985 as cited by Montgomery and Piegay 2003). In the early 1990s, data suggested that most organisms native to streams with naturally forested riparian areas are adapted to physical, chemical, and trophic stream conditions that reflect the presence of riparian trees, and that the disappearance of those trees must have imposed significant stress at the individual, population, community, and ecosystem levels (Sweeney 1992, 1993). Given that trout have always been considered cold-water fisheries and riparian deforestation often leads to their demise in small streams (see Waters 2000 for discussion), Stroud Center scientists questioned whether there might also be cold-water algivories and insectories – and more generally, whether the lack of trout in deforested, warm-water streams pointed to broader deficiencies in stream ecosystem function. Riparian deforestation might make streams less healthy and therefore less able to deliver high levels of ecosystem services (sensu Daily and Ellison 2001).

From Square Meter to Stream Reach to a Hypothesis

Although scientific research about stream health and stream ecosystem services can take place at a variety of scales, the stream reach has generally not been one of them. However, landowners and the general public think about and view streams on a reach by reach basis – a well known fact with the media. For example, on June 14, 2006, more than 1,000 dead fish suddenly appeared downstream of Upper Gwynedd Township's wastewater treatment plant on Wissahickon Creek, not far from Philadelphia, PA. The incident became frontpage news, triggered government advisories, and prompted investigations by city, state, and federal agencies. Images of dead fish floating 2.5 miles downstream from the plant sent a message to the public that the creek was sick and they should stay away from it. One thousand dead fish, 2.5 miles, and a big stream near a major city – such details captured the public's attention. It is unlikely that a *Philadelphia Inquirer* story about the death of 0.04 fish per square meter would have sold many extra copies of the newspaper.

That, however, is precisely how scientists might have expressed it – for scientists commonly approach fieldwork and report data on a per unit area basis, and for many the square meter or hectare is the Holy Grail of ecological and ecosystem level studies. Yet two stream reaches that deliver the same amount of ecosystem services on a per unit area basis can provide vastly different amounts of total services because of differences in their width and length. And it is the total amount of services a stream delivers that ultimately matters to the health of the river, estuary, and ocean into which it discharges its water. Consequently, stream ecologists who sought to understand in-stream responses to buffers needed to pay attention, not just to the square meter, but also to the reach itself. The need to focus on factors such as stream width, which affect the amount and quality of stream ecosystem per unit reach in a watershed, was highlighted in a series of studies of first- through fourth-order tributaries of White Clay Creek in southeastern PA. The results of these studies demonstrated that riparian areas in which trees had been removed and replaced with grass exhibited significant and permanent channel narrowing (Sweeney 1992, 1993).

While the narrowing of small streams in response to deforestation had been observed 25 years earlier (Zimmerman et al. 1967), its implications for stream ecosystem structure and function and for the delivery of stream ecosystem services had gone unnoted until the White Clay Creek studies demonstrated that stream narrowing resulted in as much as a 50 percent loss of total benthic habitat – and therefore of stream ecosystem – from the watershed. In light of the perceived connection between a stream's geomorphology, its ecosystem, and services provided by that ecosystem, Stroud Center scientists proposed the following hypothesis: deforestation of riparian zones in certain landscapes leads to stream narrowing and a corresponding loss of benthic habitat per unit stream reach that significantly reduces a stream's ecosystem, its health, and its ability to deliver ecosystem services for the benefit of humans and wildlife. This hypothesis led to a case study funded by the NSF-EPA Water and Watersheds program entitled: Streamside Reforestation: An Analysis of Ecological Benefits and Societal Perceptions.

A Case Study of Forested and Deforested Piedmont Streams

The Stroud Center launched its Water and Watersheds project in 1997 on adjacent pairs of forested and deforested reaches in 16 first- to fifth-order streams in rural Piedmont watersheds in eastern North America. The watersheds ranged in size from 11 to 12,329 hectares. The forested reaches, which were immediately upstream from the deforested reaches at 11 sites and immediately downstream at five, had been forested for at least 50 years. The absence of tributaries and similar topographic gradients and riparian soils characterized most pairs of study sites. In addition, all deforested reaches lacked the typical anthropogenic disturbances – from equine, bovine, or row crop agriculture or from urbanization – that were common in the region. The results of the study demonstrated unequivocally that riparian deforestation caused significant channel narrowing of small Piedmont streams, which reduced the total amount of stream habitat and ecosystem per unit channel length and compromised the in-stream processing of pollutants (Sweeney et al. 2004). The forested reaches were wider and had more macroinvertebrates, total ecosystem processing of organic matter, and nitrogen uptake per unit channel length than the contiguous deforested reaches. Moreover, stream narrowing nullified any potential advantage that deforestation might have had for fish abundance, the quality of dissolved organic matter, and pesticide degradation.The results show definitively that the wider and more natural configuration of forested stream channels significantly affects the total amount and activity of the stream's ecosystem, including its ability to process pollutants.

The project included a sociological component, which consisted of semi-structured interviews with riparian landowners in central PA. Its aims were to probe the respondents' perceptions about the role and importance of streamside forests and to gauge their willingness to participate in efforts to protect or establish such forests on their lands. This component was added because of the recognition that crafting good riparian policies and practices requires not just sound scientific research but also an understanding of people's values, beliefs, and perceptions. The study found that the landowners were driven by competing considerations (Dutcher et al. 2004). On the one hand, they expressed a community obligation to consider the downstream consequences of their land management and a responsibility not to degrade water quality. On the other hand, they often failed to recognize their own contributions to water pollution and were reluctant to abandon the mowed landscapes to which they were accustomed. This inconsistency between their expressed environmental concern and their actual conservation practices suggested that programs to establish and protect riparian forests on private land must incorporate the concurrent and often conflicting beliefs in individual rights and community responsibility. Drawing comparisons to the earlier recycling movement, the study recommended that planners and policy makers steer clear of abstract arguments and generalized goals and should focus instead on helping landowners develop personal riparian restoration plans that incorporate their individual interests while allowing them to live up to their aspirations to be good upstream neighbors. Given the substantial ecosystem services that forest buffers provide, it seems likely that planners will also be able to show that individual acts to protect or restore riparian forests will have long-term economic benefits for the entire watershed.

Getting to the Point (Source)

Based on the magnitude of the in-stream benefits provided by streamside trees, Sweeney et al. (2004) recommended that riparian forests be preserved and restored "along as many reaches as possible in the Piedmont and other landscapes, especially those that were historically forested." The ability of forested streams to process a portion of the nonpoint-source nutrients that pass through the buffer seemed sufficient reason to make forest buffers best management practice for riparian areas. The case study's nitrogen data, however, suggested another contribution of riparian forests that had hitherto been underestimated. Because the ability of buffers to mitigate nitrogen pollution had previously been tied to the amount of ground water nitrogen they intercepted in the riparian zone, the debate over the merits of grass and trees had turned on the relative ability of each to mitigate nonpoint-source pollution; and available data showed about the same rate of subsurface removal by soil in grass and forest buffer zones (Addy et al. 1999, Mayer et al. 2005). The 1997 study results helped resolve the debate by showing that a forested stream ecosystem delivered 2 to10 times more uptake of nitrogen than its grass counterpart. While uptake does not necessarily translate into removal, it does interrupt the downstream transport of nitrogen and thus allows more time and opportunity for its removal via in-stream denitrification or terrestrial export. Moreover, the study suggested that it made no difference to the stream how the nitrogen got into it because the ammonia used in the field tests could as easily have come directly from sewage treatment plants as from farm fields or other nonpoint sources. As a result, the authors proposed a novel idea – that riparian forests be designated as best management practice for point- as well as nonpoint-source pollution.

A large-scale field experiment recently completed in western North Carolina supported that idea. Clinton and Vose (2006) attributed "significant reductions in chemicals such as nitrates, ammonium, and phosphorus" to in-stream processing by a forested reach of the Chattooga River below a small town. Not only did the reach receive run-off from houses, roads, and storm water, it also got the effluent from a wastewater treatment plant immediately upstream. In other words, the stream appeared to be processing both nonpoint and point-source pollutants. While a careful and detailed valuation of all the benefits of in-stream services has yet to be published, we believe that they will ultimately prove to be the most important contribution of riparian forests, and that restoring the forest along stream ecosystems will enable them once again to play a significant role in the filtration and treatment of water and materials moving out of their watersheds.

Neglected Waters: The Importance of Small Streams

The resurrection of the importance of in-stream benefits of riparian forests, especially the recognition that properly forested small streams can play a major role in mitigating both point- and nonpoint source pollutants, builds on Meyer et al.'s (2003) scientific imperative for defending small streams, and reinforces their importance to the overall health of our rivers, estuaries, and oceans. A good deal of the public – and its elected officials – seems to view first-to-fourth-order streams as of little consequence. To them what matters are the large rivers where they fish and boat and beside which they camp and picnic. Yet, small streams generally represent greater than 90 percent of any stream network, are interspersed throughout most watersheds (Leopold et al. 1964), and thus are likely to be major points of entry for pollutants (Meyer et al. 2003). They also make more effective use of streamside forests than their larger counterparts because their size allows riparian trees to have a relatively greater impact on the stream's ecosystem (e.g., providing better shade and temperature control, more stable and diverse habitat, and greater diversity and abundance of food). Finally, small streams are functioning ecosystems that have proved vulnerable to human impact, a fact that was recently made manifest by a report that 42 percent of small stream length in the U.S. is in poor condition (U.S. Environmental Protection Agency 2006), despite protection for over 35 years by the Federal Water Pollution Control Act (1972), more familiarly known as the Clean Water Act. For all these reasons, Sweeney et al. (2004) maintained that the "restoration and preservation of small stream ecosystems should be a central focus of management strategies to ensure maximum nitrogen processing in watersheds."

Economic Impact

Clearly, the in-stream benefits and point-source applications of forest buffers should enhance the recognition of, and appreciation for, the value they provide. What remains is the need for a precise accounting of that valuation. Given that total ecosystem services are estimated between $18 and $61 trillion (average ~ $38 trillion) worldwide (Costanza et al. 1997) or more than the combined gross domestic products of all the nations in the world, and that investing in the preservation of intact ecosystems yields a conservative return of 100 to 1 (Balmford et al. 2002), it is imperative that efforts to quantify those services continue and that effective ways be found to inform the public about the economic benefits nature confers on human beings free of charge. For example, a survey of 27 water suppliers conducted in 2002 by the Trust for Public Land and the American Water Works Association showed that "the more forest cover there is in a watershed the lower the treatment costs for suppliers drawing from surface water sources." Specifically, "[f]or every 10 percent increase in forest cover in the source area, treatment and chemical costs *decreased* approximately 20 percent, up to 60 percent forest cover" (Ernst et al. 2004). Based on the benefits of riparian forests noted above, the return per tree in reduced treatment costs may be higher depending on its location in the watershed, with riparian trees able to deliver more in-stream services.

Although assigning an economic valuation translates ecosystem services into terms that decision-makers and the general public can understand, most ecosystem services remain unvalued and unmarketed (Carpenter et al. 2006). For example, we do not have a good estimate of the total economic impact of a given tree in a riparian forest or a group of trees clustered as a buffer, although much has been written about the role of individual trees in combating global climate change, absorbing carbon, reducing energy costs, and even increasing property values. We note, however, that one study of urban trees found that over a 40-year period each large tree produced a net savings to the community of between $2,600 and $3,400 (McPherson et al. 2001), while another by the University of Pennsylvania's Wharton School estimated that planting trees in a Philadelphia neighborhood increased home values by about 9 percent or $3,400 (Wachter and Gillen 2005).

In its comprehensive study of "The State of Chesapeake Forests," The Conservation Fund (Sprague et al. 2006) reported that a conservative estimate of the ecological services provided annually by forests in the Chesapeake Bay watershed is approximately $23 billion – services, the study noted, that "are rarely accounted for in private and public decision-making..." That figure does not include water quality, even though the report also states that "forests do more to protect the Bay's water quality than any other type of land cover, since they act as natural filters and reduce the prevalence of the Bay's two primary pollutants, nitrogen and phosphorus." Once water quality is factored in, we expect that the forest products industry, which already provides 140,000 jobs, $6 billion in income, and a total industry output of $22 billion each year to the Chesapeake Bay watershed's economy, may be redefined as the "forest products and services" industry with significantly greater valuation. Consequently, protecting riparian forests where they are and restoring them where they once existed should be viewed as long-term investments in infrastructure that reduce the direct costs of water treatment and the indirect costs associated with water-quality degradation.

Spreading the Word

The scientific data from the Water and Watersheds project, including the sociological results indicating the need to address the issues faced by landowners and policy makers, pushed scientists and educators at the Stroud Center to rethink and redirect their education programs. Even before submitting a final project report in 2002 and publishing the summary results in 2004, the in-stream benefits of riparian forests and the need for them as best management practices had become a major theme of Stroud Center technical papers, public lectures, and educational workshops.

It soon became clear that, if the project findings were to make a difference in the public arena, all aspects of riparian buffers – including the scientific justification for them, their design and implementation, and the legislation and funding needed to ensure their widespread and enduring application – had to be addressed. The foundation of the discussion had to be credible data, and in 1998 the Stroud Center began a conscious effort to communicate the results of its research at a variety of levels and to a diversity of audiences. That effort involved activities ranging from addressing local community and environmental organizations to delivering technical papers to national professional organizations such as the North American Benthological Society.

The outreach efforts quickly gained momentum. Bern Sweeney's 1998 keynote speech to the Delaware Nature Society, for example, became the script for "Protecting Your Water: Who's Got the Power," a video co-produced by the Stroud Center and Delaware Nature Society on the importance of riparian forests to small streams. In 1999 the "other side of buffers" became the theme of a series of workshops targeted at federal, state, and municipal employees, as well as non-governmental organizations (NGOs) involved in the design and implementation of riparian buffers. These workshops have to date been presented to employees of USDA's Natural Resource Conservation Service and Forest Service, the Pennsylvania Department of Environmental Protection (PA DEP) and the Pennsylvania Department of Conservation and Natural Resources (PA DCNR), to elected officials of a number of municipalities in PA, and to such NGOs as Trout Unlimited, the Chesapeake Bay Foundation, and others.

Although the Stroud Center had been preaching the gospel of riparian forests in professional publications for a long time (Newbold et al. 1980, Sweeney 1992, 1993), the new Water and Watersheds project findings inspired its staff to focus their lectures and workshops on the most effective way of communicating the concept to landowners, policy makers, and others interested in protecting small streams and their fresh water. This new approach transformed the workshops. "Before a recent trip to the Stroud Water Research Center in Chester County (PA), I thought I had the lowdown on the importance of streamside forests," wrote Roy Brubaker of the PA Bureau of Forestry in the opening sentence of "Gleanings from the Stream," (2001). In the wake of the workshop, however, he felt compelled to write about what he had learned. "By sharing the knowledge I gleaned from the field trip, I hope that others will also come to a deep appreciation for the need to restore and enhance forests along our streams and rivers."

The response to this outreach effort has been exciting, especially in the Stroud Center's home state of PA where the diffusion of the study results and the message about the in-stream benefits of buffers have had the most immediate impact. For example, since 1998 the USDA's Conservation Reserve Enhancement Program in PA has witnessed over 8.5 times more acreage planted in forest buffers (15,012) than in grass buffers (1,754). On Feb. 1, 2005, PA became the first state to officially recognize the in-stream benefits of riparian forest buffers and to make riparian trees mandatory for a landowner to be eligible to receive the PA subsidy associated with the enhanced CRP federal program. While the decision by PA DEP Secretary Kathleen McGinty was controversial, it was based on sound science – including the case study highlighted in this paper. Around the same time as the PA DEP decision, the William Penn Foundation awarded a two-year grant to the Stroud Center's education department to work with local land trusts, community organizations, a non-profit law firm, and others in a concerted effort to persuade municipal governments in the Schuylkill River watershed to adopt ordinances and other strategies to restore and protect riparian forests – another example of the importance of bringing credible science to bear on the preservation and restoration of streams and their ecosystem services.

Putting the recommended changes into practice, either through public acts or private decisions, depends in the end on educating people about the environmental importance and economic benefits of riparian forests. To reach people most effectively, wrote Judy Meyer (1997), requires a concept of stream health that "explicitly incorporates both ecological integrity (maintaining structure and function) and human values (what society values in the ecosystem)." The first step in that process is to translate the technical findings of science into language that is accessible to non-scientists. The results of the case study presented here have to date been summarized in three articles aimed at non-technical audiences: (1) "Buggy Water is Cleaner" (Margolis 2004); (2) "Riparian Forests: Improving Water Quality within the Stream" (Sweeney 2005); and (3) "Stroud Center Study Shows Value of Streamside Trees" (Sweeney 2006). Recently, the Chesapeake Bay Foundation (CBF) (2006) published "Forested Buffers: the Key to Clean Streams," a lay summary of the case study results that is being widely circulated in the Chesapeake Bay watershed to help CBF build on its recent accomplishments in implementing buffers (viz. reforesting 1500 miles of streams since 1997).

The critical need to base environmental policies on good science makes it incumbent on scientists to make their findings accessible to as broad an audience as possible. Yet the journey from scientific research to public policy is not an easy one because the two disciplines operate in very different ways. Science requires its practitioners to follow the data wherever it leads. Public policy, on the other hand, seeks to make the world conform to the needs of the community and the wishes of the electorate. The role of science in the debate over how best to protect freshwater ecosystems is to provide credible, independent data. It is then up to public officials to use those data to create good policies. The Water and Watersheds case study described above has shown that riparian forests help streams and rivers deliver ecosystem services of enormous value such as nutrient and organic matter processing, flood mitigation, wildlife habitat and corridors, and places for human recreation and contemplation. Riparian forests also present a first line of defense against nonpoint-source pollutants and create conditions that improve stream integrity and health.

Because the image of a buffer intercepting nonpoint-source pollutants tends to obscure the role trees play in increasing the capacity of a stream to process "watershed waste," we believe it is time to shift the focus (and the terminology) from riparian buffers to riparian forests. While grass and trees may work equally well as barriers to certain nutrients (Mayer et al. 2005), it is now well documented that riparian forests more effectively sustain stream-bank stability, moderate light and temperature levels, increase benthic habitat, and supply a more diverse food base for aquatic life (Allan 1995). In sum, they promote a more natural, stable, and effective stream ecosystem than do their grass counterparts. A riparian forest is not simply a semi-porous wall between human activities and a stream. It is an integral part of the stream's ecosystem. Changing the composition of the riparian area does not just expose the stream to higher levels of infiltration from external sources. It fundamentally alters the stream ecosystem itself. Therefore, we believe that it is time for policy makers at all levels of government to follow PA's lead by providing incentives to landowners to restore and conserve riparian forests in areas where the riparian zone was historically forested.

Acknowledgements

We are grateful to John K. Jackson and J. Denis Newbold of the Stroud Water Research Center for a careful reading of, and insightful suggestions for,

a draft of this paper.

Author Bios and Contact Information

Bernard W. Sweeney is Director, President, and Senior Research Scientist at the Stroud Water Research Center, an independent research institution focused on stream and river ecology. He is an adjunct Professor at the University of Pennsylvania. His research interests include the ecology of stream invertebrates, the importance of riparian forests to stream ecosystems, the genetic structure of aquatic insects, stream pollution assessment, and stream restoration. He received the 2003 National Award of Excellence in Conservation from the USDA Natural Resource Conservation Service for research and education on the restoration of streams. He has a Ph. D. from the University of Pennsylvania.

Bernard W. Sweeney, Stroud Water Research Center, 970 Spencer Road, Avondale, PA 19311. sweeney@stroudcenter.org.

James G. Blaine is Director of Education at the Stroud Water Research Center, an organization based in Avondale, PA. whose mission is to advance knowledge and stewardship of stream and river ecosystems through research and education. He also consults with non-profit organizations on strategic planning and publications. Previously he founded and published a group of weekly newspapers, taught at a variety of levels ranging from elementary school to university, worked with inner city development groups for the Ford Foundation, and ran an environmental organization. He received his BA from Harvard College and an MA and Ph.D. from the University of Michigan. James G. Blaine, Stroud Water Research Center, 970 Spencer Road, Avondale, PA 19311. jblaine@kennett.net.

References

Addy, K. I., A. J. Gold, P. M. Groffman, P. A. Jacinthe, and P. A. Jacinthe. 1999. Ground water nitrate removal in subsoil of forested and mowed riparian buffer zones. *Journal of Environmental Quality* 28: 962-970.

Allan, J. D. 1995. *Stream Ecology*. Chapman and Hall: London.

American Forests. 2003. *Urban ecosystem analysis: Delaware valley region.* Special publication of American Forests and the U. S. Department of Agriculture Forest Service. Washington, DC.

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and R. K. Turner. 2002. Economic reasons for conserving nature. *Science* 297: 950-953.

Bentrup, G. M., M. Schoeneberger, M. Dosskey, and G. Wells. 2005. *Conservation buffers: Planning and design principals*. USDA National Agroforestry Center: Lincoln, NB.

Brubaker, R. 2001. Gleanings from the stream. *Forest Leaves* 11 (1): 1-4.

Carpenter, S. R., R. DeFries, T. Dietz, H. A. Mooney, S. Polasky, W. V. Reid, and R. J. Scholes. 2006. Millennium ecosystem assessment: Research needs. *Science* 314: 257-258.

Castelle, A. J., A. W. Johnson, and C. Conolly. 1994. Wetland and stream buffer requirements – A review. *Journal of Environmental Quality* 23: 878-882.

Chesapeake Bay Foundation, 2006. *Forested buffers: The key to clean streams*. Special publication of the Chesapeake Bay Foundation: Annapolis, MD.

Clinton, B. D. and J. M. Vose. 2006. Variation in stream water quality in an urban headwater stream in the southern Appalachians. *Water, Air, and Soil Pollution* 169: 331-353.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, S. Naeem, K. Limburg, J. Paruelo, R.V. O'Neill, R. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.

Daily, G. and K. Ellison, 2001. *The New Economy of Nature*. Island Press: Washington, DC.

Dillaha, T. A., J. H. Sherrard, D. Lee, S. Mostaghimi, and V. O. Shanholtz. 1988. Evaluation of vegetative buffer strips as best management practice for feed lots. *Journal of the Water Pollution Control Federation* 60 (7): 1231-1238.

Dillaha, T. A., R. B. Reneau, S. Mostaghimi, and D. Lee, 1989. Vegetative filter strips for agricultural nonpoint source pollution control. *Transactions of the American Society of Agriculture Engineers* 32 (2): 513-519.

Dutcher, D. D., J. C. Finley, A. E. Luloff, and J. Johnson, 2004. Landowner perceptions of protecting and establishing riparian forests: a qualitative analysis.

Society and Natural Resources 17: 319-332.

Ernst, C., R. Gullick, and K. Nixon, 2004. Protecting the source: conserving forests to protect water. *Opflow* 30 (5): 1-7.

Federal Water Pollution Control Act (Clean Water Act)., 1971. 33 U.S.C. §§ 1251-1387, October 18, 1972 (http://www.epa.gov/r5water/cwa.htm).

Food Security Act. 1985. (Farm Bill). U.S. Public Law No. 99-198, 99 Stat. 1354.

Hardin, G. 1968. The tragedy of the commons. *Science* 162: 1243-1248.

Leopold, L. B., M. G. Wolman, and J. P. Miller, 1964. *Fluvial processes in geomorphology.* W. H. Freeman and Company: San Francisco.

Lowrance, R., R. Todd, J. Fail, Jr., O. Hendrickson, R. Leonard, and L. Asmussen, 1984. Riparian forests as nutrient filters in agricultural watersheds. *Bioscience* 34(6): 374-377.

Lowrance, R., L. S. Altier, J. D. Newbold, R. R. Schnabel, P. M. Groffman, J. M. Denver, D. L. Correll, J. W. Gilliam, J. L. Robinson, R. S. Brinsfield, K. W. Staver, W. Lucas, and A. H. Todd. 1997. Water quality functions of riparian forest buffer systems in Chesapeake Bay watersheds. *Environmental Management* 21: 687-712.

Lyons, J., S. W. Trimble, and L. K. Paine, 2000. Grass versus trees: managing riparian areas to benefit streams of central North America. *Journal of the American Water Resources Association* 36 (4): 919-930.

Magette, W. L., R. B. Brinsfield, R. E. Palmer, and J. D. Wood, 1989. Nutrient and sediment removal by vegetated filter strips. *Transactions of the American Society of Agriculture Engineers* 32 (2): 663-667.

Margolis, A., 2004. Buggy water is cleaner. *Northern Woodlands* 11 (4): 43.

Matthews, W. J. , 1988. North American prairie streams as systems for ecological study. *Journal of the North American Benthological Society* 7 (4): 387-409.

Mayer, P. M., S. K. Reynolds, M. D. McCutchen, and T. J. Canfield. 2005. *Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: A review of current science and regulations.* U. S. Environmental Protection Agency publication EPA/600/R-05/118. Cincinnati, OH.

McPherson, E. G., J. R. Simpson, P. J. Peper, Q. Xiao, D. R. Pettinger and D. R. Hodel. 2001. *Tree guidelines for Inland Empire Communities.* Special publication of the Local Government Commission, Sacramento, CA.

Meyer, J. L., 1997. Stream health: incorporating the human dimension to advance stream ecology. *Journal of the North American Benthological Society* 16 (2): 439-447.

Meyer, J. L., L. A. Kaplan, J. D. Newbold, D. L. Strayer, C. J. Woltemade, J. D. Zelder, R. Beilfuss, Q. Carpenter, R. Semlitsch, M. C. Watzin, and P. H. Zedler. 2003. *Where rivers are born: The scientific imperative for defending small streams and wetlands.* Special publication of American Rivers (1101 14th Street NW, Suite 1400, Washington, D.C. 20005 USA) and the Sierra Club (85 Second Street, San Francisco, CA 94105 USA).

Minkley, W. L. and J. N. Rinne. 1985. Large Woody debris in hot-desert streams: an historical review. *Desert Plants* 7: 142-153.

Montgomery, D. R. and H. Piegay. 2003. Wood in rivers: Interactions with channel morphology and processes. *Geomorphology* 51: 1-5.

Natural Resource Conservation Service. 1997. Riparian vegetative buffers. Conservation practice standard code 393, U.S. Department of Agriculture, Washington, DC.

Newbold, J. D., D. C.Erman, and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 1076-1085.

Osborne, L. L. and D. A. Kovacic, 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biology* 29: 243-258.

Peterjohn, W. T., and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of riparian forest. *Ecology* 65: 1466-1475.

Phillips, J. D. 1989. Non-point source pollution control effectiveness of riparian forests along a coastal plain river. *Journal of Hydrology* 110: 221-237.

Sprague, E., D. Burke, S. Claggett, and A. Todd (eds.) 2006. *The state of Chesapeake forests*. The Conservation Fund: Arlington, VA. 115pp.

Sweeney, B. W. 1992. Streamside forests and the physical, chemical, and trophic characteristics of piedmont streams in eastern North America. *Water Science and Technology* 26: 2653-2673.

Sweeney, B. W. 1993. Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in eastern North America. *Proceedings of the Academy of Natural Sciences of Philadelphia* 144: 291-340.

Sweeney, B. W., T. L. Bott, J. K. Jackson, L. A. Kaplan, J. D Newbold, L. J. Standley, W. C. Hession, and R. J. Horwitz. 2004. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. *Proceedings of the National Academy of Sciences* 101 (39): 14132-14137.

Sweeney, B.W. 2005. Riparian forests: improving water quality within the stream. *Inside Agroforestry.* Summer issue: 4-6.

Sweeney, B. W. 2006. Stroud Center study shows value of streamside trees. *Pennsylvania Forests* 97: 21.

Trimble, S. W. 1997. Stream channel erosion and change resulting from riparian forests. *Geology* 25 (5): 467-469.

U.S. Environmental Protection Agency. 1995. *Ecological restoration: A tool to manage stream quality*. U. S. Environmental Protection Agency publication EPA 841-F-95-007, Washington, DC.

U.S. Environmental Protection Agency. 2006. *Wadeable streams assessment: A collaborative survey of the nation's streams.* U. S. Environmental Protection Agency publication EPA 841-B-06-002, Washington, DC.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, C. E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130-7.

Wachter, S. M. and K. C. Gillen, 2005. *Public investment strategies: How they matter for neighborhoods in Philadelphia*. Unpublished report of the Wharton School of the University of Pennsylvania.

Waters, T. F. 2000. *Wildstream: A natural history of a free-flowing river*. Riparian Press: St. Paul, MN.

Welsch, D. 1991. Riparian forest buffers: Function and design for protection and enhancement of water resources. United States Department of Agriculture Forest Service Report No. NA-PR-07-91.

Wenger, S. 1999. A review of the scientific literature on riparian buffer width, extent, and vegetation. Publication of the Office of Public Service and Outreach, Institute of Ecology, University of Georgia.

West, E. and G. Ruark., 2004. A long, long time ago. *Journal of Soil and Water Conservation* 59 (5): 104A-110A.

Williams, M., 1989. *Americans and their forest: A historical geography*. Cambridge University Press: Cambridge, UK.

Zimmerman, R. C., J. C. Goodlett, and G. H. Comer. 1967. The influence of vegetation on channel form of small streams. Pages 255-275 in *Symposium on river morphology.* International Association of Scientific Hydrology. Publication no. 75.