A Scientific Foundation for Shaping Riparian Buffer Protection Regulations

PENNSYLVANIA LAND TRUST ASSOCIATION

BRANDYWINE CONSERVANCY

Extensive scientific research documents that vegetated strips of land along water bodies provide extensive water quality and other environmental benefits. The science shows that development should be kept away from the water's edge, wider protected strips provide greater benefits, forested buffers are more effective than grassy ones, and forested buffers in headwaters provide the greatest benefits of all.

Overview

Summary

Scientific research has strongly established the harm to water quality, the increased flooding and the damage to the ecosystem that results from failure to protect riparian buffers. This guide identifies the key scientifically grounded principles that municipalities should follow when developing riparian buffer protection regulations.

Pennsylvania's streams, rivers, wetlands, and other natural water bodies are a major part of our state's "life blood" and at one time, virtually all were in a naturally forested landscape that contributed to their high quality. Riparian buffers, particularly when forested, effectively prevent non-source pollutants from degrading these resources. Extensive scientific research documents that undisturbed, vegetated buffers provide extensive water quality and other environmental benefits. New research shows an even higher ecological value of riparian buffers in headwaters, or first-order streams that should be protected from disturbance or degradation. As explained in later sections, headwater streams are primary food/fuel production areas and have been found to be essential to the health of the entire aquatic system.

Conservation Impact

- Riparian buffers, particularly forested buffers, have been documented to provide the following conservation benefits: prevent stream bank erosion; protect natural stream morphology (i.e., broad meanders with maximum stream bottom habitat); remove excess nitrogen, phosphorus and sediment from surface water runoff; reduce downstream flooding; provide thermal protection to adjoining streams, wetlands, and water bodies; provide food and habitat for wildlife; provide food and habitat for fish and amphibians; form corridors for habitat conservation and greenways; and protect associated wetlands.
- Forested riparian buffers in headwaters (first-order streams) generate high levels of organic inputs directly from land to water, which in turn maximize in-stream processing functions that provide the "fuel" needed for downstream energy and nutrient processing.

Riparian Buffer Defined

Riparian buffers are vegetated lands, ideally forested, that border streams, rivers, reservoirs, ponds, lakes, and wetlands. Riparian buffers provide an array of valuable ecological functions (often termed "eco-services") and are critical natural resources worthy of both public and private landowner protection efforts. Riparian buffers effectively intercept non-point source pollutants carried by surface water runoff or groundwater from adjoining land uses, preventing these pollutants from reaching water bodies. Forested buffers, in particular, minimize erosion of stream- or river-banks, help to control stream temperature fluctuations and elevated temperatures harmful to aquatic life, provide food and habitat for wildlife, fish and amphibians, allow for wildlife movement within stream or river corridors, reduce downstream flooding, and help to protect associated wetlands.

Scientifically, the width of the buffer relates directly to buffer function and the level of environmental benefit or eco-service provided. Different environmental benefits tail off at different rates (i.e., filtering out sandy particulates happens much faster and in less distance than filtering out dissolved pollutants). In general, the wider the buffer the more functions, or eco-services, it performs. Because the effect of the riparian buffer protection ordinance is to restrict use of land within the buffer, deciding upon an appropriate buffer width when developing riparian buffer protection regulations may trigger controversy.

Content of Guide

This guide provides a scientific foundation for approaching any controversy and drafting effective riparian buffer protection regulations. Its companion guide, *Riparian Buffer Protection Via Local Regulation*, provides a model riparian buffer ordinance well grounded in Pennsylvania constitutional and statutory law that protects many of the functional benefits of buffers while including provisions to address unique circumstances.

The Science

In a nutshell, in a naturally vegetated pervious condition, a “no-build,” “no disturbance” buffer around streams, rivers, lakes, ponds, and reservoirs provides an array of aquatic and related benefits. For some time now, watershed scientists have warned against paving over or next to streams, arguing to keep streams naturally buffered. Furthermore, research findings urge keeping streams here in Pennsylvania buffered with native forest and other vegetation in order to maximize these watershed benefits.

More recent research demonstrates that these watershed benefits increase as one “moves up” the watershed stream system (i.e., moves from higher third order to second order to first order headwaters streams). In other words, maintaining and protecting forested riparian buffers is even more beneficial in first order streams than in higher order, larger streams farther “down” in the watershed (see explanation below). In sum, maintaining and protecting forested riparian buffers, though essential throughout a watershed system, is most critical at the very “top” of the watershed system along the smallest headwaters streams.

The major line of technical argument for application of this conservation tool follows several points:

1. Maintain generous riparian buffers that do not allow development to encroach into and around water resource features (streams, rivers, lakes, wetlands, etc.).
2. Maximize minimum buffer widths.
3. Keep these riparian buffers in natural forested cover.
4. Protect forested riparian buffers especially in headwaters streams (i.e., maintaining forested riparian buffers in first order streams is more valuable than second order streams, and so forth).

Point 1. Do Not Allow Development to Encroach into Riparian Buffers

Most scientific studies now have demonstrated that riparian buffers, when maintained and protected from land disturbance and pavement/placement of impervious cover, intercept and physically remove sediment and nutrients from stormwater in the form of sheet flow (non-channelized) runoff from upslope areas (Newbold et al. 1980, Lowrance et al. 1984, Peterjohn and Correll 1984). Some years ago, the role of riparian buffers as barriers which serve to filter nonpoint source pollutants from runoff was embraced especially by government programs with an agricultural focus, such as the Conservation Reserve Program (CRP); in this context, riparian buffers took the form of grassed buffers with their proven ability to remove sediment and nutrients (Dillaha et al. 1988, 1989, Magette et al. 1989, Osborne and Kovacic 1993, Castelle et al. 1994). Research results vary depending upon the specific experimental design and have demonstrated that these buffers or filters can remove 10 to 85 percent of nonpoint source sediment and nutrient pollutant loads. Depending upon a variety of factors, substantial quantities of pollutants may still move through the buffer and reach the receiving water body. In sum, these grassed buffers provide benefit, but can be substantially less than ideal in their water quality performance.

Historically, early buffer literature has focused on removal of sediment and nutrients, phosphorus and nitrogen. To quickly summarize, in one applied experiment, orchard grass filter strips (300 feet wide) removed 84 percent of the sediment and soluble solids from surface runoff, while at another site, filter strips only 15 feet wide removed 70 percent sediment (Dillaha et al. 1989). In another applied experiment, 84 to 90 percent of sediment from adjacent cultivated fields was removed by hardwood forests with sand deposited at the edge of the forest and silt and clay removed further into the forest (Cooper et al. 1987); Lowrance et al 1986 found that 311,600 to 471,900 pounds per year per acre of sediment had been deposited in riparian forests along the Little River in Georgia; grass and grass-forest filter strips reduced sediment loads by 60 to 90 percent in Piedmont areas of North Carolina (Daniels and Gilliam 1996). Still other studies have suggested that grassed filters might lose some of their filtering power over time; and with the finer and smaller particles in the sediment load (i.e., as the sediment becomes siltier and more clay-like), a greater width is needed in the riparian buffer. Maintaining non-concentrated sheet flow into the riparian buffer is also essential if physical filtering is to be successful.

The nutrients phosphorus and nitrogen—critical "resources out of place" in so many Pennsylvania waters—are also reduced by riparian buffers of all types. Particulate-form phosphorus tends to bind to sediment particles so that as sediment is deposited, phosphorus is deposited as well (Brinson et al. 1984; Walbridge and Struthers 1993). Dissolved phosphorus may attach itself to clay and is less easily removed by the riparian buffer. Nitrogen removal is more complex and often more challenging than phosphorus, given its various nitrogen and nitrate forms. Lowrance et al 1984b have demonstrated removal of an impressive 68 percent of total nitrogen from agricultural runoff by forested riparian buffers. Peterjohn and Correll (1984) demonstrated removal of 89 percent of nitrogen from field runoff; Jordan et al 1993 found 95 percent removal of nitrates from agricultural runoff by riparian buffers. Very important for nitrogen removal is the process of denitrification (whereby dissolved nitrogen is converted into gaseous release), which is facilitated by wet soils, a high water table, certain denitrifying bacteria, available organic carbon, and alternating periods of aerobic and anaerobic processing. Riparian buffers may also reduce pollutant loads of various pathogens (bacteria, viruses, protozoa) and toxins (pesticides, metals) although the pathways for this removal tend to be much more complex and are less studied and not as well documented.

Point 2. The Wider the Buffer, the Greater the Benefit

Also important in crafting effective riparian buffer protection ordinances is the question of buffer width. Recommended minimum width depends to some extent on what benefits or eco-services are deemed important to protect, although virtually all sources acknowledge that the wider the buffer, the better the eco-services performance. In Riparian Buffer Zones: Functions and Recommended Widths (Ellen Hawes and Markelle Smith, Yale School of Forestry, April 2005), studies on recommended buffer widths have been summarized:

Erosion/sediment control:	30 feet to 98 feet
Water quality:	
Nutrients	49 feet to 164 feet
Pesticides	49 feet to 328 feet
Biocontaminants (fecal, etc.)	30 feet or more
Aquatic habitat:	
Wildlife	33 feet to 164 feet
Litter/debris	50 feet to 100 feet
Temperature	30 feet to 230 feet
Terrestrial habitat:	150 feet to 330 feet

Buffer widths depend not only on resources to be protected; the distances (widths) above reflect the fact that sediment and larger, heavier particles fall out and are physically filtered much faster than nitrogen in its dissolved forms. Different physical, chemical and biological dynamics are also occurring and require different distances for removal. Buffer width also varies with a variety of site factors, including site slope (more slope means greater width), soil type/permeability ("tighter" soil means greater width), and vegetation mix (certain vegetation types provide certain eco-services better than others). Some researchers (Brown et al. 1987 and Cook College of Environmental Resources) recommend a variable width buffer, although, from a regulatory perspective, fixed width buffers tend to be easier to administer. USDA (Welsch 1991) defined a seminal 3-zone system that totaled 75 feet with 15 feet of grass (outer edge) and 60 feet of variously maintained forest.

Point 3. Riparian Buffers Need to Be Forested

More recent analysis focusing on riparian buffers (Sweeney and Blaine 2007) emphasizes the function of *forested* riparian buffers to promote water quality and other environmental functions. For example, it is well known that stream temperature impacts the aquatic community in important ways (i.e., change/increase in temperature alters stream macro invertebrate taxa which in turn results in change in the fish community). Stream temperature increases impact other factors such as egg spawning and fish egg hatching. Stream temperature is typically dominated by temperature of groundwater flow. Warmer stream temperatures, in short, tend to impact seriously the nature and extent of the fish community. In Pennsylvania where cooler water species such as trout are so important and where natural trout reproduction is so valuable, this issue of elevated water temperatures is especially important. Sweeney (1993) has argued that removal of forested riparian buffers results in significant changes (increases) to stream temperature ("In the headwaters of WCC (White Clay Creek), a forested second order stream is on the average cooler from April through October and warmer from November to March than a meadow stream…." Sweeney 1993). Removal of forests from riparian zones combined with potential climate change warming trends suggests a dramatic change to our stream biotic community and overall ecology.

Additionally, forested riparian zones offer a variety of eco-services or positive "uptake" functions which are valuable to water quality. For example, shallow groundwater is intercepted by tree roots and nutrients are taken up before entering the stream. Tree root systems modify the soil structure (even relatively impermeable hydrologic soil groups become more permeable) which promotes infiltration and more contact time for increased biogeochemical processing. Shading modifies the extent and rate of photo-oxidation reactions which, in turn, affect aerobic processing of dissolved organic and inorganic compounds. In short, trees next to streams are valuable. Trees next to streams improve water quality in multiple ways.

When riparian buffers are forested, the adjacent water body's aquatic community processes and consumes watershed "stuff" – detritus that includes nutrients, sediment, organic matter, and other material that washes in from the watershed (as argued in the Vannote et al. 1980 river continuum concept that connects land and water in myriad ways). Without detailing the complex physical, chemical, and biological ways in which this in-stream processing occurs, stream processing efficiency and effectiveness has evolved over time in Pennsylvania streams to relate to adjacent riparian vegetation. The best processing and optimal level of stream ecosystem services occur when streams are bordered with naturally forested conditions (the natural condition in Pennsylvania). Pennsylvania streams need Pennsylvania trees!

There are multiple intermediate steps in understanding and studying this instream processing, which the Stroud Water Research Center and other research centers have now documented. For example, Stroud scientists, have documented that deforested streams result in narrowed streams with a corresponding reduction in benthic habitat. These scientists have been able to demonstrate in their NSF-EPA funded Water and Watersheds program that this deforestation also translates into reduced stream health, adverse impacts on the stream ecosystem, and overall loss in stream ecosystem services and processing of pollutants (Sweeney et al. 2004).

Researchers have attempted to estimate the economic value of forested riparian buffers. The Conservation Fund's "The State of Chesapeake Forests" (Sprague et al. 2006) conservatively estimated the eco-service value of all forests within the Chesapeake Bay watershed at $23 billion – excluding water quality (which is likely to be the source of greatest value, given the role of forests in reducing the Bay's great pollutant threats of nitrogen and phosphorus). On a unit basis, valuation of riparian forests is expected to be even greater. Urban tree studies (McPherson et al. 2001) have determined that each urban tree generated a 40-year net community value of between $2,600 and $3,400. Perhaps more of an aesthetic benefit, the Wharton School (Wachter and Gillen 2005) concluded that planting trees in Philadelphia increased home values by $3,400. The Trust for Public Land (Ernst et al. 2004) concluded that "…for every 10 percent increase in forest cover in the source area, treatment and chemical costs decreased by approximately 20 percent, up to 60 percent forest cover." Sweeney and Blaine conclude that "…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." (Sweeney and Blaine 2007).

Point 4. Protect Forested Riparian Buffers into Headwaters

If this instream processing described above is to have maximum watershed value, processing must start at the "top" of the watershed system – literally in first-order streams. Furthermore, because of the very nature of stream system division and patterning, virtually all watersheds have most of their stream footage/mileage in first-order streams, followed by second-order, then third-order, and so forth (Leopold et al. 1964). This means that first-order streams offer the greatest opportunity for good things to happen, and for bad things to happen (i.e., pollutant entry; Meyer et al. 2003). First-order streams, due to their small size, allow 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; Sweeney and Blaine 2007 p. 22). Additionally, forested buffers along first-order streams not only provide more benefits, but also protect the more fragile ecosystems which exist as part of first-order streams. All else being equal, first-order streams need protection even more than second-order streams and so forth. Sweeney et al. 2004 maintain that "…restoration and preservation of small stream systems ecosystems should be a central focus of management strategies…."

Note that this discussion excludes both intermittent streams and ephemeral streams. Across Pennsylvania, many municipalities have not mapped intermittent and ephemeral streams and rely basically on USGS perennial stream designations. The discussion of eco-services and stream processing, nonetheless, applies to these intermittent and ephemeral streams, such that some level of forested riparian buffer protection should be provided. Clinnick et al. 1985 recommend a reduced buffer width of approximately 60 feet. In the companion guide *Riparian Buffer Protection Via Local Regulation*, the model riparian buffer ordinance treats intermittent streams the same as perennial streams with regard to required buffer width.

Also of importance is the fact that headwaters streams (defined here as perennial first order streams) are critical repositories of biodiversity, especially aquatic insects (macro invertebrates), which play such a vital role in aquatic ecosystems and in the in-stream processing discussed above. Paraphrasing Kaplan et al. 2008, Stroud research has demonstrated that the aquatic insect community is remarkably abundant in headwaters zones, which contributes greatly to downstream stream energy and nutrient processing. In-stream processing needs fuel! It turns out that maximum "fuel" is provided in a variety of ways in these headwater streams, from algae, aquatic mosses, rooted aquatic plants, trees, understory shrubs, and other herbaceous vegetation. Furthermore…

> Measurements of the production of organic energy (algal photosynthesis) and its consumption (algal and bacterial respiration) in first-order streams complement our findings that headwaters have high levels of organic inputs (Bott et al. 1976 Appendix, Table 1) and further substantiate the importance of small 0- to first-order streams to the flow of energy within a drainage network. Respiration of the streambed community is driven by a combination of energy derived from primary production by algae as well as a subsidy of organic matter entering from the terrestrial environment, such as leaf litter (Bott et al. 1985). In fact estimates of litter inputs to the first-order stream are approximately eightfold greater than rates of algal productivity. The processing of organic matter in the first-order stream is 33 percent greater than in the next larger-sized downstream reaches. (Bott et al. 1985)

In summary, these complex and critical interactions are, of course, happening throughout a watershed system, but are especially important to manage and protect in headwaters streams. To maintain stream water quality, stream energy flow must be protected. To maintain stream energy flow, adjacent stream energy flow must be protected – through protection of the natural forest cover. *Maintenance of forested riparian buffers in first order headwaters streams and beyond is critical.*

We are still learning more about the real values provided by forested riparian buffers in Pennsylvania streams and about the real losses incurred when we lose these forested riparian values. From increased flood damages to increased water treatment costs to lost recreational values and so much more, municipalities need to consider enacting rigorous forested riparian buffer protections—benefits vastly outweigh the costs.

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Experts

Wesley R. Horner, Senior Advisor for Water Resources, Brandywine Conservancy

Bernard W. Sweeney, Ph.D., President, Director, Senior Research Scientist, Stroud Water Research Center

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Submit Comments and Suggestions

The Pennsylvania Land Trust Association would like to know your thoughts about this guide: Do any subjects need clarification or expansion? Other concerns? Please contact Andy Loza at 717-230-8560 or aloza@conserveland.org with your thoughts. Thank you.

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