DELAWARE RIVERKEEPER NETWORK

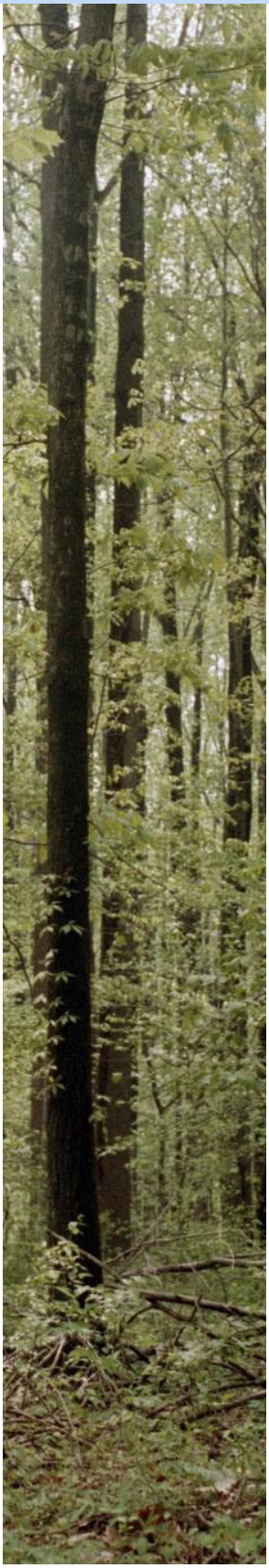
WHITE PAPER 2019

Vegetated Riparian Buffers

Water Quality Protectors

Vegetated Riparian Buffers

WHAT - Lands next to bodies of water that are planted with trees, shrubs, and other vegetation
WHERE - Can be planted along rivers, streams, ponds, estuaries, and wetlands
WHY - Because buffers at least 100 feet wide on each side of a waterway help protect water quality



Role and Context of Vegetated Buffers

A stream corridor is composed of several essential elements including the stream channel itself, associated wetlands and vernal ponds, floodplains, and forests. The body of scientific research has documented that stream buffers, particularly those dominated by woody vegetation, are instrumental in providing a variety of benefits. Vegetated riparian corridors protect and restore the functionality and integrity of streams and in doing so help protect us from pollution, flooding and erosion, while providing us clean drinking water, healthy fish, recreation and associated jobs.

In eastern North American, healthy streams were historically bordered by natural forests that acted as the interface between the land and aquatic environments.[1] The ramifications of the clearing of forested streamside lands over time have been significant – including water pollution, loss of habitat in the stream and on the land, increased erosion, increased flooding, damaged stream channels, altered stream flows, and development in locations that have increased flood damages.

Deforestation along waterways continues with hundreds of acres of heavy forest canopy lost to development (residential, commercial, and agricultural). For example, the Delaware Valley region of southeastern Pennsylvania and southern New Jersey lost 31,271 acres of forest canopy between 1985 and 2000.[2] As the impacts of deforestation on streams and rivers became known, reestablishment of forests (afforestation) along waterways, has become an important tool for protection of freshwater streams and rivers and is now considered a Best Management

1 West, E., & Rurak, G. (2004). A long, long time ago… Historical evidence of riparian forests in the Great Plains and how that knowledge can aid with restoration and management. Journal of soil and water conservation, 59(5), 104A-110A.; Sweeney, B. W., & Blaine, J. G. (2007). Resurrecting the In-Stream Side of Riparian Forests. Journal of Contemporary Water Research & Education, 136(1), 17-27.; Richardson et al. (2012). How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices?. Freshwater Science, 31(1), 232-238.

2 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.

Practice (BMP) in the United States.[3] Although formal government guidance for streamside buffer width varies among jurisdictions, research has continually shown zones of streamside vegetation are effective at protecting streams and enhancing water resources from land-use impacts in the watershed with an increasing body of research honing in on 100-foot widths as the minimum that should be required.[4] Buffers of 300 feet or more have been shown to be even more protective of stream ecosystems[5] and have been adopted to safeguard water quality and protect high quality streams.[6]

Stream buffers provide a variety of ecological and socioeconomic benefits.

The removal of vegetated riparian buffers contributes to increases in water temperatures as well as nutrient and sediment inputs, bank and channel erosion, and other degradation.[7] Nationally, 41% of river and stream miles are rated poor for nitrogen levels (i.e., high); 46% or river and stream miles are rated poor for phosphorous levels.[8] These and other pollutants can be found in runoff from the landscape, with widespread and severe impacts to stream ecosystems. Reducing levels of pollutants is necessary to ensure healthy streams. Scientific research has documented that vegetated riparian buffers can help improve the water quality of adjacent streams, and reduce pollutant concentrations in runoff through biological processes (plant uptake and soil bacterial transformations),

Healthy streams are bordered by natural forests that act as the interface between the land and water.

An increasing body of research supports a 100 foot riparian buffer as the minimum width required to protect streams.

3 Richardson et al. (2012). How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices?. Freshwater Science, 31(1), 232-238.; Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584.

4 Newbold et al. (1980). Effects of Logging on Macroinvertebrates in Streams with and without buffer strips. Canadian Journal of Fisheries and Aquatic Sciences 37(7): 1076-1085.; Welsch, D. (1991). Forest Resources Management, USDA Forest Service, "Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources", NA-PR-07-91.; 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., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584.

5 Pollock, M. M., & Kennard, P. M. (1998). A low-risk strategy for preserving riparian buffers needed to protect and restore salmonid habitat in forested watersheds of Washington State. 10,000 Years Institute, Bainbridge Island, Washington.; Belt et al. (1992). Design of forest riparian buffer strips for the protection of water quality: analysis of scientific literature. Id. For., Wildl. and Range Policy Anal. Group. Rep. No. 8. 35 pp.; Knutson, K. L., & Naef, V. L. (1997). Management recommendations for Washington's priority habitats: riparian. Washington Dept. Fish and Wildlife, Olympia. 181 pp.

6 N.J.A.C 7:8-5.5

7 Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics, 257-284.

8 USEPA (2013). National Rivers and Streams Assessment 2008-2009: A Collaborative Survey. EPA/841/D-13/001. 110 pp.

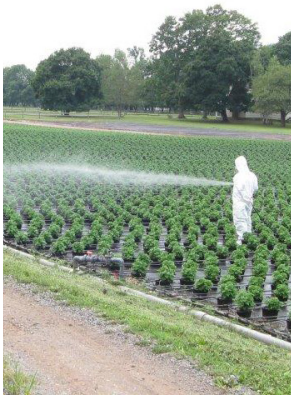
chemical processes (soil particle absorption), physical processes (sediment filtering), and in-stream processes.[9]

Water Pollutants

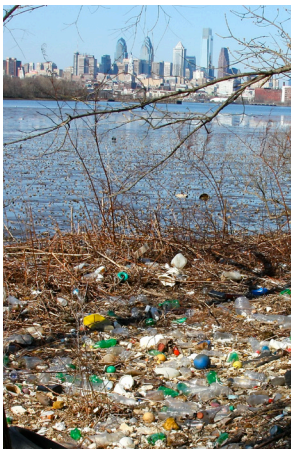
Some water pollutants are naturally occurring, some result only from human activities, but most come from both sources. Typical pollutants of concern to water quality include nutrients, pesticides, and sediment. The impacts of these distinct pollutants vary and depend on the characteristics of the specific pollutant and the concentration in runoff.

Nutrient pollution is a widespread environmental problem caused by too much nitrogen and/or phosphorus. Common human sources of nutrients include fertilizer runoff, wastewater discharges from leaking septic systems or sewage treatment plants, animal wastes, and atmospheric deposition.

Although both nitrogen and phosphorus are essential elements for all life, human alteration of the landscape has bloated our aquatic systems with nutrients far in excess of natural background levels. These excess nutrient levels lead to harmful effects on rivers, streams, estuaries, and lakes. In lakes and estuaries, excess nutrients frequently lead to over-stimulation of algal growth, including toxic algae, and mass die-offs of that algae that then strips the water of essential dissolved oxygen and the death of fish and other life needing that oxygen to breath.



In streams and rivers, excess nutrients can likewise stimulate excess algae, but this over-supply of nutrients will also produce "scums" on all rocks and hard surfaces and will disrupt all of the ecosystem services provided by the aquatic community, from the microscopic to the largest fish, insects, and mussels. So fundamental are the transformations that it is nearly impossible to have a healthy stream or river when nutrient pollution disrupts the ecosystem's normal functions and impacts native biodiversity.[10]



9 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.; Hefting et al. (2005). The role of vegetation and litter in the nitrogen dynamics of riparian buffer zones in Europe. Ecological Engineering 24: 465-482.; Backer et al. (2006). Water management practices, rain-fed cropland. In: Environmental Benefits of Conservation on Cropland: The status of Our knowledge, M. Schnepf and C. Cox (editors). Soil and Water Conservation Society. Ankeny, Iowa, pp. 89-130.; Dosskey et al. (2010). The role of riparian vegetation in protecting and improving chemical water quality in streams. JAWRA 46(2): 261-277.

10 Correll, D. L. (1998). The role of phosphorus in the eutrophication of receiving waters: A review. Journal of Environmental Quality, 27(2): 261-266.; Howarth, R.W., (2008). Coastal Nitrogen Pollution: A Review of Sources and Trends Globally and Regionally. Harmful Algae 8:14-20.

Additionally, excess nitrogen in drinking water can be harmful to people. Nitrates are converted to nitrites in the digestive system. Nitrites, when absorbed into the blood stream, can decrease the blood's ability to carry oxygen. Infants, pregnant women, those with reduced stomach acidity or who lack a necessary enzyme are most at risk for health effects. If infants under six months of age are given formula made with water high in nitrates, they may develop blue baby syndrome, a condition that can result in brain damage or even death.

Pesticides in runoff are ubiquitous and therefore, detected in most streams throughout the U.S.[11] Defined as chemicals and substances used for preventing and controlling insects, weeds, and other undesirable animals,[12] pesticides by their very nature create some risk of harm and reach waterways through leaching, runoff, spills, eroding soil, or direct application. Pesticide-contaminated runoff can be highly lethal to fish and other aquatic life. Additionally, bioaccumulation of pesticides can result in harm or death to wildlife that feed on aquatic organisms. Repeated exposure to sub-lethal concentrations can cause physiological and behavioral changes that reduce fish and invertebrate survival or reproduction.[13]

The flow path of water determines the pollution concentrations in stormwater that runs off the land into streams.

In addition to chemical pollution, excess sediment in runoff impacts the biological condition of rivers and streams.[14] Hydrologic alteration of the landscape due to agriculture, construction, and urban development, can increase the amount of fine sediments delivered to waterways. Suspended sediments block the penetration of light in water affecting the growth and reproduction of aquatic plants, cover stream bottom habitats filling in spaces were aquatic organisms live or breed, and clog the gills of fish potentially resulting in death.[15]

Streamside vegetation helps prevent polluted runoff from entering streams.

The flow path of water will determine which biological, chemical, and physical processes occur and thus the pollution concentrations in the water that will ultimately be released into the river channel. As water flows across the landscape, plants and soil microbes utilize

11 Gilliom et al. (2007). The Quality of our nation's waters: Pesticides in the nation's streams and ground water, 1992–2001. US Geological Survey.

12 http://www.epa.gov/pesticides/about/index.htm#what_pesticide

13 Baldwin et al. (2009). A fish of many scales: extrapolating sublethal pesticide exposures to the productivity of wild salmon populations. Ecological Applications, 19(8), 2004-2015.; Schäfer et al. (2007). Effects of pesticides on community structure and ecosystem functions in agricultural streams of three biogeographical regions in Europe. Science of the Total Environment, 382(2), 272-285.

14 USEPA (2013). National Rivers and Streams Assessment 2008-2009: A Collaborative Survey. EPA/841/D-13/001. 110 pp.

15 Welsch, D. (1991). Forest Resources Management, USDA Forest Service, "Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources", NA-PR-07-91.

or degrade compounds in runoff through biological processing. Plants also modify the flow of runoff by encouraging soil infiltration and consequently allowing for additional processing and filtering in the subsurface.[16] Furthermore, the below ground biomass (e.g., roots) of plants retains sediments and reduces erosion resulting in less sedimentation.[17] Since vegetated buffers intercept the diffuse flow of runoff from adjacent land,[18] streamside buffers help prevent or reduce the water pollution in runoff before it enters the stream channel.[19]

Biological Removal of Pollutants

Riparian vegetation absorbs pollution removing it before it can get into the stream. Plants, via their root systems, take up pollutants, especially nitrogen and phosphorus that are essential for plant growth.[20] Vegetated buffers can also reduce the concentrations of pesticides delivered to adjacent waterways through plant uptake.[21] Nonnutrient chemicals can also be absorbed from the soil by plant roots including heavy metals (e.g., cadmium, chromium,

16 Gageler et al. (2014). Early response of soil properties and function to riparian rainforest restoration. PloS one, 9(8), e104198.

17 Gurnell, A. (2014). Plants as river system engineers. Earth Surface Processes and Landforms, 39(1), 4-25.

18 McGlynn et al. (2002): A review of the evolving perceptual model of hillslope flowpaths at the Maimai catchments, New Zealand. Journal of Hydrology 257, 1–26.; Burt, T. P., & Pinay, G. (2005). Linking hydrology and biogeochemistry in complex landscapes. Progress in Physical geography, 29(3): 297-316.

19 Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584.

20 Peterjohn, W. T., & Correll, D. L. (1984). Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology, 65(5), 1466-1475.; DNREC and Brandywine Conservancy. (1997). Conservation Design for Stormwater Management: A Design Approach to Reduce Stormwater Impacts from Land Development and Achieve Multiple Objectives Related to Land Use, September, 1997, p. 1-25.; Hefting et al. (2005). The role of vegetation and litter in the nitrogen dynamics of riparian buffer zones in Europe. Ecological Engineering 24: 465-482.; Kiedrzyńska et al. (2008). Quantification of phosphorus retention efficiency by floodplain vegetation and a management strategy for a eutrophic reservoir restoration. Ecological Engineering, 33(1), 15-25.; Roberts et al. (2012). Phosphorus retention and remobilization in vegetated buffer strips: a review. Journal of environmental quality, 41(2), 389-399.

21 Maas et al. (1984). Best Management Practices for Agricultural Nonpoint Source Control: IV. Pesticides. North Carolina State University, National Water Quality Evaluation Project, Raleigh, NC.; Paterson, K.G. and J.L. Schnoor, (1992). Fate of Alachlor and Atrazine in a Riparian Zone Field Site. Water Environment Research 64(3):274-283.; Yamamoto et al. (2003). Effects of Physical-Chemical Characteristics on the Sorption of Selected Endocrine Disruptors by Dissolved Organic Matter Surrogates. Environmental Science and Technology 37:2646-2657.; Juraske et al. (2008). Estimating Half-Lives of Pesticides in/on Vegetation for Use in Multimedia Fate and Exposure Models. Chemosphere 70:1748-1755.

mercury, nickel, lead), metalloids (e.g., arsenic, selenium), and other elements (e.g., boron, cesium, strontium).[22]

Riparian vegetation, via their root systems, can take up excess nitrogen and phosphorus.

In addition to plant uptake, bacteria and fungi in the soil can both take up nutrients and facilitate chemical transformations resulting in lower concentrations and compounds that are less harmful.[23] Riparian forests in particular support a diverse community of soil microorganisms that perform these various chemical degradation processes.[24] Uptake of nutrients by soil microbes only temporarily stores these compounds as organic nitrogen or phosphorus, returning them to the soil during decomposition. However, soil microbes can switch from using oxygen to alternative electron acceptors such as nitrate and sulfate. Since these microbes do not require oxygen they can thrive where there is a limited supply of oxygen in wet and saturated soils. As soil microorganisms use alternative compounds during respiration, they convert nutrients and other chemicals into different compounds, and in the process change the solubility and mobility of those chemicals. These transformations can result in permanent removal of compounds from runoff water. For example, denitrying bacteria convert nitrate into nitrogen gas. This biological process can be a major pathway of nitrogen removal from groundwater and subsurface water in riparian zones.[25] Furthermore, some synthetic organic chemicals, pesticides, and endocrine disruptors have been shown to decrease up to 85% due to microbial breakdown processes.[26]

Denitrifying bacteria present in riparian forest soils can remove excess nitrogen from groundwater and subsurface water.

Vegetated riparian buffers enhance soil infiltration which allows pollutants in runoff to bind to soil particles.

22 Adriano, D. C. 1986. Trace elements in the terrestrial environment. Spring-Verlag, New York.; Roca, M. C., & Vallejo, V. R. (1995). Effect of soil potassium and calcium on caesium and strontium uptake by plant roots. Journal of Environmental Radioactivity, 28(2), 141-159.; Dix et al. (1997). Potential use of Populus for phytoremediation of environmental pollution in riparian zones. UNITED STATES DEPARTMENT OF AGRICULTURE FOREST SERVICE GENERAL TECHNICAL REPORT RM, 206-211.; Adriano, D. C. (2001). Trace elements in terrestrial environments: biogeochemistry, bioavailability, and risks of metals.

23 Lowrance et al. (1984). Riparian forests as nutrient filters in agricultural watersheds. BioScience, 34(6), 374-377.; Hill, A.R., (2000). Stream Chemistry and Riparian Zones. In: Streams and Ground Waters, J.B. Jones and P.J. Mulholland (Editors). Academic Press, New York, pp. 83-110.

24 Palone, R. S., & Todd, A. H. (Eds.). (1998). Chesapeake Bay riparian handbook: a guide for establishing and maintaining riparian forest buffers. US Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry.

25 Hill, A.R., (1979). Denitrification in the Nitrogen Budget of a River Ecosystem. Nature 281:291-292.; McClain et al. (2003). Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. Ecosystems, 6(4), 301-312.; Collins et al. (2010). Opportunities and challenges for managing nitrogen in urban stormwater: A review and synthesis. Ecological Engineering, 36(11), 1507-1519.;

26 Lin et al. (2008). Bioremediation of Atrazine-Contaminated Soil by Forage Grasses: Transformation, Uptake, and Detoxification. Journal of Environmental Quality 37:196-206.

Infiltration in vegetated buffers can reduce pesticide concentrations in runoff because of the strong bonds pesticides form with soil particles.

Chemical Removal of Pollutants

Soils in riparian buffers also play an important role in pollution reduction because soil is not an inert material but instead interacts chemically with water as it passes through on its way to the stream channel and underground aquifers. Minerals and organic matter in soils are key components affecting the mobility and release of environmental contaminants through sorption.[27] Sorption is a process in which dissolved compounds bind to the surface of a solid material. Due to the flow alterations of runoff by vegetation in riparian buffers, soil infiltration is enhanced allowing for sorption within the subsurface to occur.

Nutrients and pesticides can bind strongly to soil organic matter or other charged soil particles immobilizing them and preventing them from being transported to nearby waterways.[28] For example, dissolved phosphorus is sorbed to clay particles within the soil, particularly where there are high levels of aluminum and iron.[29] Furthermore, sorption in the soil is probably the most important control on the concentration of pesticides in runoff because pesticides form strong bonds with soil particles leading to a decrease in the interaction with biota, a reduction in toxicity, and immobilization.[30]

Riparian buffers can help filter sediment-laden runoff that, upon entering a stream, would increase the cloudiness of the water and impact the biological condition of the stream bottom.

The capacity of soils to reduce pollutant concentrations in runoff will depend on both the properties of the soil (pH, mineralogy, organic carbon content, surface charge, surface area) and the characteristics of the pollutant compound (solubility, charge distribution, concentration). Variations in the abundance, surface area, and charge of particles influence the sorption characteristics of a given soil.[31] Despite the heterogeneity in composition of soil particles, pollutant concentrations also have a significant influence on sorption capacity because of the principles of chemical equilibrium that govern

Buffers act as a physical barrier decreasing the velocity of stormwater runoff.

27 Thompson, A. & Goyne, K. W. (2012) Introduction to the Sorption of Chemical Constituents in Soils. Nature Education Knowledge 4(4):7.

28 Brady, N.C. and R. Weil, (2008). The Nature and Properties of Soils (Fourteenth Edition). Prentice Hall Publishing Co., Upper Saddle River, New Jersey.; Benoit et al. (1999). Isoproturon Sorption and Degradation in a Soil from Grassed Buffer Strip. Journal of Environmental Quality 28(1):121-129.;

29 Nair, V. D. (2014). Soil phosphorus saturation ratio for risk assessment in land use systems. Agroecology and Land Use Systems, 2, 6.; Kerr et al. (2011). Phosphorus sorption in soils and sediments: implications for phosphate supply to a subtropical river in southeast Queensland, Australia. Biogeochemistry, 102(1-3), 73-85.; Hoffmann et al. (2009). Phosphorus retention in riparian buffers: Review of their efficiency. Journal of Environmental Quality, 38(5), 1942-1955.

30 Navarro et al. (2013). Review. An overview on the environmental behaviour of pesticide residues in soils. Spanish journal of agricultural research, 5(3), 357-375.

31 Johnston, C. T. & Tombácz, E. (2002) "Surface chemistry of soil minerals," in Soil Mineralogy With Environmental Applications, eds. J. B. Dixon & D. G. Schulze, 37-67, Madison, WI: Soil Science Society of America.

sorption reactions. Because sorption occurs concurrently with biotic and abiotic transformations, this chemical process is an important retention mechanism for nutrients, pollutants, and other chemicals in the soil.

Physical Removal of Pollutants

In addition to chemical removal of pollutants, riparian buffers can help filter sediment-laden runoff that would otherwise enter a stream. An increase in sediment loads to rivers has resulted from human activity that accelerates erosion.[32] Buffers change turbulence conditions, affect deposition processes, and reduce erosion.[33] These physical mechanisms both prevent and reduce the amount of sediment that reaches the stream channel.

Buffers act as a physical barrier decreasing the velocity of runoff water. Vegetation, dead foliage, and litter increase the surface roughness slowing down the flow of water across the land surface.[34] As water slows, soil particles settle out of suspension and are left behind in the buffer before the water enters the stream or other waterway.[35] Particulates are also physically trapped by the structure of the forest floor especially when the flow is shallow and uniform.[36] Although large particles fall out of suspension quickly, removal of small sized sediments can only occur through water infiltration.[37] The retardation of flow that occurs in buffer zones allows more time for infiltration and encourages percolation of water into the soil so filtration can occur.[38]

In addition to preventing sediments in runoff from reaching waterways, buffers also reduce the sediment load by reducing erosion resulting from increased stormwater

32 Walling, D.E. (2006) Human impact on land-ocean sediment transfer by the world's rivers. Geomorphology 79, 192-216.

33 Gumiere et al. (2011). Vegetated filter effects on sedimentological connectivity of agricultural catchments in erosion modelling: a review. Earth Surface Processes and Landforms, 36(1), 3-19.

34 Järvelä, J. (2002). Flow resistance of flexible and stiff vegetation: a flume study with natural plants. Journal of Hydrology, 269(1), 44-54.

35 Liu et al. (2008). Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. Journal of Environmental Quality, 37(5), 1667-1674.; Gharabaghi et al. (2006). Effectiveness of vegetative filter strips in removal of sediments from overland flow. Water Quality Research Journal of Canada, 41(3), 275-282.

36 Lambrechts et al. (2014). Impact of plant growth and morphology and of sediment concentration on sediment retention efficiency of vegetative filter strips: Flume experiments and VFSMOD modeling. Journal of Hydrology, 511, 800-810.; Camporeale et al. (2013). Modeling the interactions between river morphodynamics and riparian vegetation. Reviews of Geophysics, 51(3), 379-414.

37 Gharabaghi et al. (2006). Effectiveness of vegetative filter strips in removal of sediments from overland flow. Water Quality Research Journal of Canada, 41(3), 275-282.

38 Bharati et al. (2002). Soil-water infiltration under crops, pasture, and established riparian buffer in Midwestern USA. Agroforestry systems, 56(3), 249-257.

Forested streams have healthier biological communities which can further reduce pollution concentrations of stream water.

runoff levels. Erosion along the banks introduces additional sediment into the water column.[39] Vegetation root systems hold on to soil, thereby preventing erosion of sediment and lowering the potential for particulates to move into the channel.[40] Estimates suggest that establishment of streamside forests could reduce bank soil loss and additional sediment releases by 77% to 97%.[41]

In-stream Removal of Pollutants

The benefits of riparian buffers extend into the stream ecosystem such that healthier streams have a greater ability to remove pollutants through in-stream processing. Forested streams have healthier biological communities and wider channels with greater surface area.[42] These healthier streams are more capable of processing the pollutants found in the stream channel – they literally reduce pollution.

Streams require food sources, habitat diversity, and consistent temperatures to support healthy biological communities. Streamside forests supply stream communities with decaying leaves and woody debris which make up as much as 75% of the organic food base.[43] Macroinvertebrates feed on this material and form the bottom of the aquatic food chain. Healthy macroinvertebrate communities support ecologically important fish species. In addition to providing a food base, vegetated buffers enhance habitat quality and regulate

In addition to providing a food base for aquatic life, buffers enhance habitat quality and regulate water temperatures.

Research shows that buffer width is important for pollutant removal efficiency.

39 Hassan et al. (2005). Sediment Transport And Channel Morphology Of Small, Forested Streams. JAWA 41: 853-876.

40 Allmendinger et al. (2005). The influence of riparian vegetation on stream width, eastern Pennsylvania, USA. Geological Society of America Bulletin, 117(1-2), 229-243.; Zaimes et al. (2004). Stream bank erosion adjacent to riparian forest buffers, row-crop fields, and continuously-grazed pastures along Bear Creek in central Iowa. Journal of Soil and Water Conservation, 59(1), 19-27.

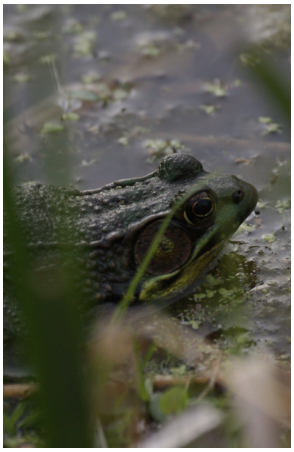
41 Zaimes et al. (2006). Riparian land uses and precipitation influences on stream bank erosion in central Iowa. JAWRA. 42: 83-97.

42 Bernhardt et al. (2005). Can't see the forest for the stream? In-stream processing and terrestrial nitrogen exports. Bioscience, 55(3), 219-230.; Sweeney et al. (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 101(39), 14132-14137.

43 Bott et al. (2006). Ecosystem metabolism in Piedmont streams: reach geomorphology modulates the influence of riparian vegetation. Ecosystems, 9(3), 398-421.; Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics, 257-284.; Welsch, D. J. (1991). Riparian Forest Buffers - Function for Protection and Enhancement of Water Resources. NA-PR-07-91. [Broomall, PA:] U.S. Dept. of Agriculture, Forest Service, Northern Area State & Private Forestry.

water temperatures.[44] Compared to open channels, the canopy of a forested stream reduces solar radiation and regulates stream temperatures.[45] Water temperatures directly affect the metabolic rates, growth, and even survival of aquatic organisms. For example, an increase in stream temperatures from 2.9°F to 4.2°F resulted in an 81% to 88% reduction in young trout populations.[46] Food availability, habitat quality, and temperature are all important factors regulating aquatic life that can uptake and convert water pollutants that enter the channel.

Furthermore, wider channels of forested streams have greater streambed surface area. Stream channels are substantially wider when the banks are forested because dense tree roots create banks that are difficult to erode.[47] The greater streambed surface area increases the area providing ecosystems services and enhances the potential for in-stream removal of pollutants. For example, dissolved nutrients are removed by sorption onto bottom sediments or through uptake by microbial communities attached to the bottom substrata. Even if the amount of uptake per unit area weren't higher in forested compared to unforested channels (indeed, uptake can be substantially higher), greater bottom surface area alone in forested reaches results in greater chemical removal per unit of channel length.[48]



Riparian buffers support healthy stream ecosystems and aquatic biological communities. Since some pollution still remains when runoff reaches stream channels, in-stream

44 Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584.; Richardson et al. (2010). Do riparian zones qualify as critical habitat for endangered freshwater fishes?. Canadian journal of fisheries and aquatic sciences, 67(7), 1197-1204.; Sweeney et al. (2007). Resurrecting the In-Stream Side of Riparian Forests. Journal of Contemporary Water Research & Education, 136(1), 17-27.; Sweeney et al. (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 101(39), 14132-14137.

45 Moore et al. (2005). RIPARIAN MICROCLIMATE AND STREAM TEMPERATURE RESPONSE TO FOREST HARVESTING: A REVIEW1.; Pusey, B. J., & Arthington, A. H. (2003). Importance of the riparian zone to the conservation and management of freshwater fish: a review. Marine and Freshwater Research, 54(1), 1-16.

46 Jones et al. (2006). Quantifying expected ecological response to natural resource legislation: a case study of riparian buffers, aquatic habitat, and trout populations. Ecology and Society, 11(2), 15.

47 McBride et al. (2008). Riparian reforestation and channel change: A case study of two small tributaries to Sleepers River, northeastern Vermont, USA. Geomorphology, 102(3), 445-459.; Allmendinger et al. (2005). The influence of riparian vegetation on stream width, eastern Pennsylvania, USA. Geological Society of America Bulletin, 117(1-2), 229-243.; Sweeney et al. (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 101(39), 14132-14137.

48 Sweeney et al. (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 101(39), 14132-14137.

processing is important for regulating the downstream export of contaminates to large rivers and estuaries.[49]

Pollution Removal Efficiency

Numerous studies have quantified the removal efficiencies of streamside buffers, and research shows that it is not just the mere presence of a buffer, but also the buffer width that is important (See Table 1, 2, and 3).[50] Although site specific conditions can influence buffer effectiveness, many researchers have concluded that buffers of 100 feet or more, on each side of a stream, can remove between 55% and 99% of nutrients, sediment, and other contaminants (See Table 1, 2, and 3).[51] Additionally, buffers of 100 feet or more on both streambanks, enhance stream health enabling it to better provide the ecosystem services needed to process the remainder of pollutants and protect downstream water quality.

Effective nitrogen removal requires buffers that are at least 100 feet wide on each side of the stream.

Wider vegetated buffers provide greater capacity for biological uptake to remove contaminants from runoff and groundwater. Greater buffer area equates to more biological organisms including plants, trees, and soil microbes. More plants and more microbes have a greater potential for uptaking more nutrients and processing higher concentrations of water pollutants. Removal efficiency per unit width of buffer varies inversely with water flux, but consistently increases with increasing buffer width.[52] For example, buffers greater than 100 feet have been shown to remove up to 99% of nitrogen (Table 1). Similarly, a buffer of 100 feet could effectively remove close to 100% of phosphorus (Table 2) and up to 93% of pesticides.[53]

Buffers of 100 feet or more enable streams to better provide the ecosystem services that protect downstream water quality.

49 Sweeney et al. (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 101(39), 14132-14137.

50 Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584.; Mayer, P.M., S.K. Reynolds, Jr., M.D. McCutchen, and T.J. Canfield, (2007). Meta-Analysis of Nitrogen Removal in Riparian Buffers. Journal of Environmental Quality 36:1172-1180.

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52 Vidon, P. G., & Hill, A. R. (2006). A LANDSCAPE-BASED APPROACH TO ESTIMATE RIPARIAN HYDROLOGICAL AND NITRATE REMOVAL FUNCTIONS1. JAWRA Journal of the American Water Resources Association, 42(4), 1099-1112.

53 Zhang et al. (2010). A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. Journal of environmental quality, 39(1), 76-84.

Table 1: Percent removal of nitrogen in riparian buffers of different widths.[54]

Study	< 100 ft (30 m)	~100 ft (30 m)	>100 ft (>30.5 m)
Young et al. 1980		87%	
Barker & Young 1984			99%
Magette et al. 1987	17-51%		
Schwer & Clausen 1989		76%	
Lowrance et al. 1995	4-23%	80%	
Lowrance et al. 2001	5-50%	80%	95%
Mayer et al. 2007	58-71%	85%	
Zhang et al. 2010	73-88%		92%
Sweeney & Newbold 2014	0-95%	55-99%	6-99%

Table 2: Percent removal of phosphorous in riparian buffers of different widths.[55]

Study	<100 ft (30 m)	~100 ft (30 m)	>100 ft (>30.5 m)
Young et al. 1980		88%	
Magette et al. 1987	41-53%		
Schwer & Clausen 1989		78%	
Lowrance et al. 1995	24-29%	77%	
Lowrance et al. 2001	62-65%	80%	90%
Blattel et al. 2005	14-28%		
Newbold et al. 2010	22%		

54 Young et al. (1980). Effectiveness of vegetated buffer strips in controlling pollution from feed lot runoff. Journal of Environmental Quality 9: 483-487.; Magette, W.L. et al. (1987). Vegetated filter strips for runoff treatment. CBP/TRS 2/87. U.S. Environmental Protection Agency. Region III, Chesapeake Bay Liaison Office, Annapolis, MD.; Schwer, C. B., & Clausen, J. C. (1989). Vegetative filter treatment of dairy milkhouse wastewater. Journal of Environmental Quality, 18(4), 446-451.; Lowrance et al. (1995). Water quality functions of riparian forest buffer systems in the Chesapeake Bay watershed. U.S. Environmental Protection Agency Rep. EPA903-R-95-004. Washington, D.C.:U.S. EPA; Lowrance et al. (2001). EVALUATION OF COASTAL PLAIN CONSERVATION BUFFERS USING THE RIPARIAN ECOSYSTEM MANAGEMENT MODEL. JAWRA 37(6): 1445-1455.; Zhang et al. (2010). A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. Journal of environmental quality, 39(1), 76-84; Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA 50(3), 560-584.

55 Young et al. (1980). Effectiveness of vegetated buffer strips in controlling pollution from feed lot runoff. Journal of Environmental Quality 9: 483-487.; Magette, W.L. et al. 1987. Vegetated filter strips for runoff treatment. CBP/TRS 2/87. U.S. Environmental Protection Agency. Region III, Chesapeake Bay Liaison Office, Annapolis, MD.; Schwer, C. B., & Clausen, J. C. (1989). Vegetative filter treatment of dairy milkhouse wastewater. Journal of Environmental Quality, 18(4), 446-451.; Lowrance et al. (1995). Water quality functions of riparian forest buffer systems in the Chesapeake Bay watershed. U.S. Environmental Protection Agency Rep. EPA903-R-95-004. Washington, D.C.:U.S. EPA; Lowrance et al. (2001). EVALUATION OF COASTAL PLAIN CONSERVATION BUFFERS USING THE RIPARIAN ECOSYSTEM MANAGEMENT MODEL. JAWRA 37(6): 1445-1455.; Blattel et al. (2005), ABATEMENT OF GROUND WATER PHOSPHATE IN GIANT CANE AND FOREST RIPARIAN BUFFERS. JAWRA Journal of the American Water Resources Association, 41: 301–307.; Newbold et al. (2010). Water Quality Functions of a 15-Year-Old Riparian Forest Buffer System1. JAWRA Journal of the American Water Resources Association, 46(2), 299-310.

Riparian buffers 100 feet in width can trap up to 85% of sediment.

Wider buffers enhance retention of herbicides.

In addition to greater biological ability to process contaminates, wider buffers have more capacity for chemical sorption. More soil means more soil surface area, and a greater potential for available sorption sites. Conversely, soil sorption sites in narrow buffers can become saturated reducing the effectiveness to retain certain pollutants.[56] Wider buffers also promote sorption by increasing the contact time between dissolved chemicals and soil particles. For example, enhanced retention of herbicides was shown in buffers with slower flow rates and longer buffer widths because of the greater opportunity for infiltration and sorption.[57]

In order for riparian buffers to physically retain water pollutants, there must be sufficient space to intercept runoff and slow the velocity of flow. Because deposition of sediments is a size-selective process, most of the larger particles settle out within the first few meters of a buffer. However, the effective removal of smaller silt and clay particles require wider buffers.[58] Numerous studies have shown that sediment removal consistently increases with buffer width (Table 3).[59] Buffers only 35 feet wide can be expected to remove as much as 65% of sediment, but 100-foot buffers can trap up to 85% of sediment.[60] The increased removal attained by wider buffers represents the fraction of sediments which are small in size but damaging to water quality and aquatic organisms.

56 Roberts et al. (2012). Phosphorus retention and remobilization in vegetated buffer strips: a review. Journal of environmental quality, 41(2), 389-399.

57 Krutz et al. (2005). Reducing herbicide runoff from agricultural fields with vegetative filter strips: a review. Weed Science, 53(3), 353-367.

58 Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584.; Gharabaghi et al. (2006). Effectiveness of vegetative filter strips in removal of sediments from overland flow. Water Quality Research Journal of Canada, 41(3), 275-282.

59 Zhang et al. (2010). A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. Journal of environmental quality, 39(1), 76-84; Liu et al. (2008). Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. Journal of Environmental Quality, 37(5), 1667-1674.

60 Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584.

Table 3: Percent removal of sediment in riparian buffers of different widths.[61]

Study	<100 ft (30 m)	~100 ft (30 m)	>100 ft (>30.5 m)
Magette et al. 1987	72-86%		
Schwer & Clausen 1989		89%	
Lowrance et al. 1995	61-75%	97%	
Lowrance et al. 2001	60-80%	90%	90%
Lui et al. 2008	78-97%		
Yuan et al. 2009	84%		
Zhang et al. 2010	90%		
Newbold et al. 2010	43%		
Sweeney & Newbold 2014	64%	84%	

The width of a stream's riparian buffers also impacts its ability to process or handle pollutant loading from the landscape. Channel width, bank stability, temperature, inputs of debris, and biologic communities all respond to changes in the width of the streamside forest.[62]

A streamside forest of just under 100 feet maximizes the width of the stream channel, providing the greatest amount of stream bottom habitat per until length of stream, thus maximizing the potential for effective ecosystem services including the processing of pollutants by stream organisms.[63] In order to produce the stream temperatures that would occur in a fully forested watershed, a buffer

Streamside forests of 100 feet or more will provide the greatest potential for effective ecosystem services.

61 Magette, W.L. et al. 1987. Vegetated filter strips for runoff treatment. CBP/TRS 2/87. U.S. Environmental Protection Agency. Region III, Chesapeake Bay Liaison Office, Annapolis, MD.; Schwer, C. B., & Clausen, J. C. (1989).Vegetative filter treatment of dairy milkhouse wastewater. Journal of Environmental Quality, 18(4), 446-451.; Lowrance et al. (1995). Water quality functions of riparian forest buffer systems in the Chesapeake Bay watershed. U.S. Environmental Protection Agency Rep. EPA903-R-95-004. Washington, .C.:U.S. EPA; Lowrance et al. (2001). EVALUATION OF COASTAL PLAIN CONSERVATION BUFFERS USING THE RIPARIAN ECOSYSTEM MANAGEMENT MODEL. JAWRA 37(6): 1445-1455.; Liu, X., Zhang, X., & Zhang, M. (2008). Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. Journal of Environmental Quality, 37(5), 1667-1674.; Yuan, Y., R.L. Bingner, and M.A. Locke, 2009. A Review of Effectiveness of Vegetative Buffers on Sediment Trapping in Agricultural reas. Ecohydrology 2:321-336.; Zhang, X., Liu, X., Zhang, M., Dahlgren, R. A., & Eitzel, M. (2010). A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. Journal of environmental quality, 39(1), 76-84; Newbold, J. D., Herbert, S., Sweeney, B. W., Kiry, P., & Alberts, S. J. (2010). Water Quality Functions of a 15-Year-Old Riparian Forest Buffer System1. JAWRA Journal of the American Water Resources Association, 46(2), 299-310.; Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584.

62 Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association, 50(3), 560-584

63 Sweeney et al. (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 101(39), 14132-14137.

width of more than 100 feet is needed.[64] These factors among others impact a stream's ability to sustain healthy macroinvertebrate populations and fish communities.

Riparian areas have a microclimate that is more moist and moderate than upland areas.[65] Streamside vegetation influences riparian microclimate.[66] Removal of streamside forest and alteration of the landscape can bring about changes to the riparian microclimate which can subsequently impact the function of a stream ecosystem.[67] Vegetated buffers of 300 feet are recommended to maintain riparian microclimate.[68] A 300-foot buffer – the recommended width to protect water quality, wildlife, and riparian microclimate – was adopted in New Jersey to protect that state's highest quality streams

Considering these myriad benefits from forested riparian buffers along streams and rivers, there may be no more important requirement that protecting and restoring these vegetated strips in order to preserve these many benefits. From preventing water pollution to enhancing biodiversity to actually removing pollutants from our ecosystems, forested riparian buffers and the healthy streams they establish are vital to achieving high water quality. The scientific literature supports the conclusion that a minimum of 100-foot riparian buffer on both sides of a waterway must be maintained to provide both the upland and in-stream services necessary to protect the water quality of adjacent streams and rivers.

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64 Sweeney et al. (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 101(39), 14132-14137.

65 Thomas, J. W, (1979). Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. First d. U.S. For. Serv., Portland, Oreg. 512pp.

66 Naiman et al. (1993). The role of riparian corridors in maintaining regional biodiversity. Ecological applications, 3(2), 209-212.

67 Brosofske et al. (1997). Harvesting effects on microclimatic gradients from small streams to uplands in western Washington. Ecological applications, 7(4), 1188-1200.

68 Knutson, K. L., & Naef, V. L. (1997). Management recommendations for Washington's priority habitats: riparian. Washington Dept. Fish and Wildlife, Olympia. 181 pp.

A condensed version of this white paper is available from the Delaware Riverkeeper Network. Contact the Delaware Riverkeeper Network to request *Quick Facts: Vegetated Riparian Buffers - Water Quality Protectors*. When you contact us, be sure to ask about our other resources on riparian buffers.

DELAWARE RIVERKEEPER NETWORK
925 CANAL STREET, SUITE 3701 | BRISTOL, PA 19007
215-369-1188 | drn@delawareriverkeeper.org | www.delawareriverkeeper.org