Definition

There is a very rich scientific literature on the importance and functions of vegetated buffers, which have been studied worldwide. Extensive reviews of the vegetated buffer scientific literature have been provided by Sheldon et al. (2005), Hruby (2013), Mayer et al. (2006), Castelle et al. (1992, 1994), McElfish et al. 2008, Adamus (2007).

Sheldon et al. (2005) define buffers as "*vegetated areas adjacent to an aquatic resource that can, through various physical, chemical, and/or biological processes, reduce impacts from adjacent land uses. Buffers also provide the terrestrial habitats necessary for wildlife that use wetlands to meet their life-history needs*."

Castelle et al. (1994) write that "*there is rarely debate regarding the need for some buffering of valuable aquatic resources from potential anthropogenic degradation*."

Functions

Vegetated buffers provide multiple benefits to adjacent to wetland and aquatic resources (Sheldon et al. 2005; Sweeney and Newbold 2014):

- removal of sediments, excess nutrients (phosphorus and nitrogen), and toxics (bacteria, metals, pesticides)
- influencing the microclimate of the adjacent resource (e.g., soil and water temperature)
- maximizing channel width and reducing channel erosion and meandering
- export of large woody debris
- protection of finfish and stream macroinvertebrate communities
- maintaining adjacent habitat critical for the life needs of many species that use wetlands, as well as habitat connectivity
- screening wildlife from adjacent disturbances (noise, light, etc.)

Water Quality Protection

Buffers protect water quality in adjacent wetlands and aquatic resources by removing sediments and attached pollutants from runoff flowing across the buffer, plant uptake and chemical conversions of nutrients, binding dissolved pollutants onto humus and clay particles in the soil, and shading and blocking wind to prevent temperature elevation (Sheldon et al. 2005; Sweeney and Newbold 2014)). Importantly, a vegetated buffer (as opposed to a developed landscape), is a zone which, under most conditions, does not export pollutants to an adjacent wetland (Adamus 2007). Thus, in a developed landscape a vegetated buffer provides a physical separation between a wetland or aquatic resource and pollutants emanating from adjacent developed land.

Below is a discussion of characteristics that influence the capacity of a vegetated buffer to provide a water quality protection function (from Adamus 2007):

- Vegetation Type - There is no consensus in the scientific literature on the relative effectiveness of forested versus grass with regard to pollutant removal. Some studies have shown forested buffers to be superior, while others have found grass buffers to be more effective.
- Water Source - Pollutants in runoff are more susceptible to removal from subsurface flow compared with surface runoff, because under the former condition the runoff is more likely to pass through the biologically-active zones of plants in the buffer.
- Flow Pattern - Runoff traveling through a vegetated buffer as diffuse flow (surface sheet flow or subsurface lateral flow) is more susceptible to pollutant removal than flow that is concentrated in rills and gullies. Soil type and slope influence the flow pattern of runoff traveling through a buffer.
- Slope - All other things being equal, pollutant removal capacity declines as buffer slope increases, because there is less opportunity for runoff infiltration and pollutant treatment in the root zone.
- Soil Type and Infiltration Rate - Moderately coarse soils generally provide the best water quality protection. Fine textured soils may limit the infiltration of runoff to the root zone, and coarser-textured soils, particularly those with minimal organic content, tend to be less effective in retaining pollutants.

Vegetated buffers also can protect the ability of an adjacent wetland to provide a pollutant removal function, by slowing down the arrival of most runoff from a storm (Adamus 2007).

Sediment Removal

The rate of sediment removal by vegetated buffers varies widely across studies (Castelle et al. 1994), and is influenced by the slope of the study area, the velocity of runoff traveling across the buffer, the presence of sheet flow versus channelized flow, the type and density of buffer vegetation, the presence or absence of woody debris, and the size of sediment particles (Sheldon et al. 2005). As a result, it is very difficult to compare results across studies. Significant reductions in coarse sediments and the pollutants attached to them can take place in a relatively narrow buffer of 16-66 feet, although the removal of fine sediments requires much wider buffers (66-328 feet) (Sheldon et al. 2005). Sweeney and Newbold (2014) report that a 30-meter buffer can be expected to trap about 85% of sediments, likely including finer silts and clays.

Nutrient Removal: Phosphorus

The two nutrients that have the greatest potential to impact the chemistry of a wetland or aquatic resource are nitrogen and phosphorus. Much of the phosphorus in runoff is bound up with sediments, and can thus be removed by trapping the sediments (Karr and Schlosser 1977; Wenger 1999). Many researchers have found that phosphorus removal takes place in the outer portions of a buffer (closest to the pollutant source), due to sediment removal. However, removal of phosphorus attached to finer sediment particles requires wider buffers.

Nutrient Removal: Nitrogen

Nitrogen enters wetlands and aquatic ecosystems in a variety of forms, including nitrate nitrogen (e.g., fertilizers), particulate nitrogen (e.g., forest litter), ammonium (e.g., sewage disposal), and nitrous oxides (e.g., fossil fuel combustion, via atmospheric deposition) (Schlesinger 1997). Buffer effectiveness depends on the capacity to intercept the various forms of nitrogen traveling along surface and subsurface routes, and in general, subsurface nitrogen removal is more effective than nitrogen removal at the soil surface (Mayer et al. 2006).

The dissolved forms of nitrogen (e.g., nitrate-nitrogen) are not attached to sediments, and are best removed in a buffer by subsurface contact with fine roots (Muscutt et al. 1993**)**. Nitrate nitrogen is also removed through a process known as denitrification (Mayer et al. 2006) , which involves the anaerobic microbial conversion of nitrate nitrogen to inert nitrogen gas under anoxic or very low oxygen soil conditions, and which requires high levels of organic carbon in the soil (Sweeney and Newbold 2014). It should be noted that anoxic or very low oxygen soil conditions more typically occur in poorly and very poorly drained wetland soils, rather than in upland buffers.

Mayer et al. (2006) report that nitrogen removal varies considerably among studies (due to factors such as soil type, presence/absence of soil saturation, groundwater flow paths, organic carbon supply), but that overall, buffers removed large percentages of the nitrogen that they received. These researchers found that forested buffers were more effective at removing nitrogen than grass buffers. Mayer et al. (2006) suggest that 50%, 75%, and 90% nitrogen removal efficiencies occur in buffers of approximately 10 feet, 92 feet, and 367 feet wide, respectively (see Figure 1 in this Appendix). Wenger (1999) recommends a minimum 50 foot wide buffer for effective nitrogen removal. Sweeney and Newbold (2014) write that "*effective nitrogen removal at the watershed scale probably requires buffers that are at least 30 meters wide*."

Microclimate Modulation

Forested buffers moderate and influence the microclimate of adjacent wetland and aquatic resources through the processes of shading and wind reduction (Oke 1987). The benefits of shading and wind reduction extend a short distance from the buffer edge (Hruby 2013). Most of the research on buffers and microclimate modulation has been in riparian ecosystems (streams and rivers). Sweeney and Newbold (2014) write that "… *it appears that buffer widths of ≥ 20 meters will keep stream temperatures within 2° C of those that would occur in a fully forested watershed but that full protection from measurable temperature increases is assured only by a buffer width of ≥ 30 meters*".

Stream Channel Integrity

Many studies have shown that low-order rural streams have significantly wider channels when their banks are forested, which is important because stream ecosystem processes are mostly associated with the streambed (Sweeney and Newbold 2014). They report that stream channel width can be maximized by a 25 meter wide forested buffer. Riparian forests also reduce bank erosion and the rate of channel migration (Sweeney and Newbold 2014).

Large Woody Debris (LWD)

Streamside forests are an important source of LWD (stems, branches, rootwads), which provides a source of food and instream habitat for finfish and macroinvertebrates. LWD plays an important role in nutrient cycling, channel development, oxygenation and instream flow patterns (Sweeney and Newbold 2014). Sweeney and Newbold (2014) write that "*… a streamside forest can best provide a natural level of LWD to streams if its width is generally 30 meters or equal to the height at maturity of the dominant streamside trees*".

Finfish and Benthic Macroinvertebrates

Many studies have shown that the size and makeup of the finfish and benthic macroinvertebrate communities in a stream is strongly related to the presence or absence of a riparian forest (Sweeney and Newbold 2014). These authors write that a streamside forest of ≥30 meters is required to maintain these communities in a natural or near-natural state.

Wetland Wildlife Habitat Protection

Buffer zones provide a habitat that is transitional between wetlands and uplands, and as a result support a diverse community of flora and fauna. The "edge effect theory" proposes that the diversity of flora and fauna increases at the boundary between wetlands and upland buffers (Castelle et al. 1994).

Buffers also improve the wildlife habitat of adjacent wetlands and watercourses by screening these resources from disturbances (noise, light) emanating from adjacent developed landscapes (Sheldon et al 2005; Castelle et al. 1994). Castelle et al. (1992) report that many wildlife species in wetlands are disturbed by unscreened human activity within 200 feet, while other researchers recommend a buffer with of approximately 50-100 feet for the purposes of screening disturbances.

Wetland Plant Community Protection

Craft et al. (2007) report that "*nutrient enrichment is an increasing threat to aquatic and wetland ecosystems*", and that a decline in plant species richness often occurs with progressive nutrient enrichment, as aggressive species such as *Typha* spp., *Phalaris arundinacea* and *Phragmites australis* colonize and dominate the resource.
Buffers protect wetland plant communities from nutrient enrichment by removing nutrients from inflowing runoff. According to Hruby (2013) buffers at least 231-330+/- feet wide are necessary for the protection of the wetland plant community.

Buffer Width Guidelines

It is difficult to compare scientific studies of buffer width vs. effectiveness because the many parameters that influence buffer function vary across studies (Sheldon et al. 2005). The determination of a buffer size that is necessary to protect the various functions of a specific wetland or aquatic resource from a proposed disturbance is a complex undertaking because studies reported in the scientific literature may vary in their applicability to a given project (Adamus 2007). Sheldon et al. (2005) write that "*The conclusions of a scientific study done at* *one time in one wetland with specific characteristics may not be directly transferable to circumstances that develop in the future or at sites that have different characteristics or situations*." Professional judgment is required to determine when it is appropriate to extrapolate from public scientific research to conditions present in a specific wetland and buffer (Adamus 2007).

Unfortunately, the state of the science in vegetated buffers has not developed to the point where regression equations exist that would allow a user to input specific site characteristics and proposed land use changes and derive a recommended vegetated buffer size. Instead, municipalities across the country have developed a variety of strategies to prescribe vegetated buffer sizes, based upon a review of the scientific literature.

Many municipalities across the country have established buffer ordinances in order to protect wetlands and aquatic resources (McElfish et al. 2008). Many ordinances prescribe a fixed buffer size for all wetlands, so that all wetlands receive the same level of protection. This "one-size-fits-all" approach may provide insufficient protection to high-quality resources, and excessive protection to lower quality resources. Other ordinances prescribe variable buffer widths, depending upon a number of factors identified as important in the scientific literature (Hruby 2013; Sheldon et al. 2005; Castelle et al. 1994; Adamus 2007):

- The functions and values of the adjacent wetland or aquatic resource. Larger buffers are recommended for protecting more valuable wetlands and aquatic resources.
- The characteristics of the buffer (e.g., slope, vegetation type and density, surface roughness, etc.). Buffer width should be increased if the buffer is steeply sloping, sparsely vegetated, and lacking surface roughness
- The intensity of the adjacent proposed land use. Generally, the more intense the adjacent land use, the wider the buffer required to protect the adjacent wetland or aquatic resource.

Hruby (2013) provides the following buffer width guidelines:

Wetland Functions and Values	Intensity of Adjacent Land Use	Recommended Buffer Width (ft.)
Minimal	Low	25-75
Moderate	Moderate or High	75-150
High	Low, Moderate or High	150-300+

Castelle et al. (1994) report that buffers smaller than 16.5-33+/- feet provide little protection to aquatic resources under most conditions, and recommend a minimum buffer with of 50-100 feet under most circumstances.

Figure 2 in this Appendix (from McElfish et al. 2008) is a diagram that illustrates effective buffer widths for water quality and wildlife protection functions, based upon a survey of the literature. This diagram illustrates the variability in buffer performance that has been reported in the literature. The thick bars in this graph represent the buffer widths that may be most effective at providing each function (30-100 feet for sediment and phosphorus removal; 100-160 feet for nitrogen removal, and 100-300+ feet for wildlife protection).

Figure 3 in this appendix, from Sheldon et al. (2005) is a compilation table of recommended buffer dimensions from the scientific literature. Recommendations that consider wildlife habitat protection are generally in the 100-300+ feet range.

Castelle et al. (1994) recommend 50-100 feet "*minimum buffers necessary to protect wetlands and streams under most circumstances*".

Sweeney and Newbold (2014) write that "*… streamside forest buffers ≥30 meters wide are needed to protect water quality, habitat and biotic features of streams … about fifth order or smaller in size*."

Figure 4 in this appendix, from McElfish et al. (2008), is a matrix that recommends buffer widths based upon functions to be protected (wildlife habitat or water quality), land use intensity, wetland category, and whether or not the wetland has an outlet. This matrix recommends the largest buffers for the most valuable wetlands lacking an outlet, and adjacent to a high land use intensity.

Mr. Brian Murphy of the Connecticut DEP Department of Fisheries conducted a review of literature and published guidelines that recommend the preservation of a 100 foot wide buffer adjacent to streams and rivers.

Recommended buffer widths for the protection of wildlife that utilize wetland and riparian resources varies considerably depending upon the target species. Most of these recommended widths range from 100 feet to several hundred feet (Sheldon et al. 2005).

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Figure 1. From Mayer et al. (2005)

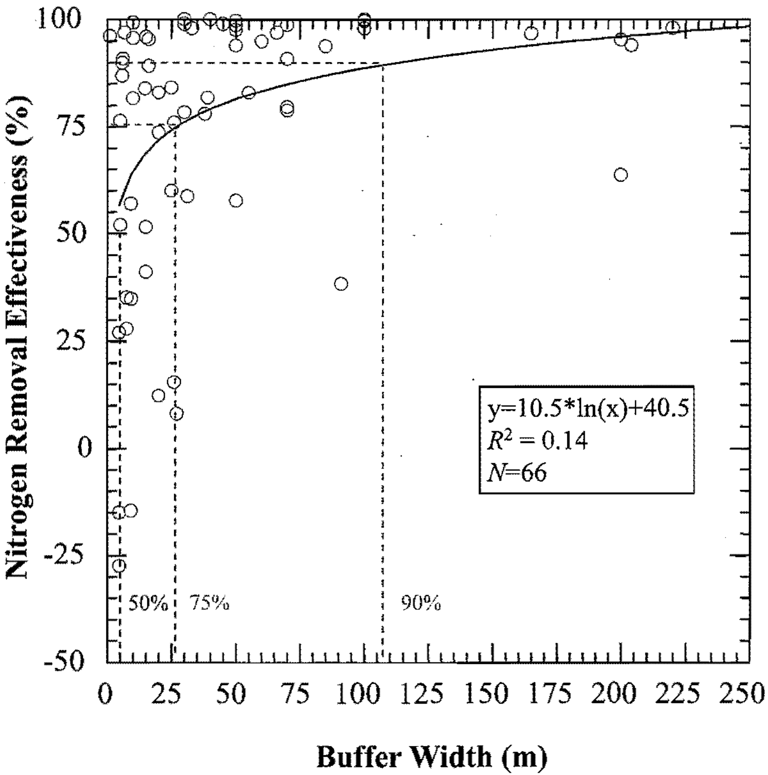
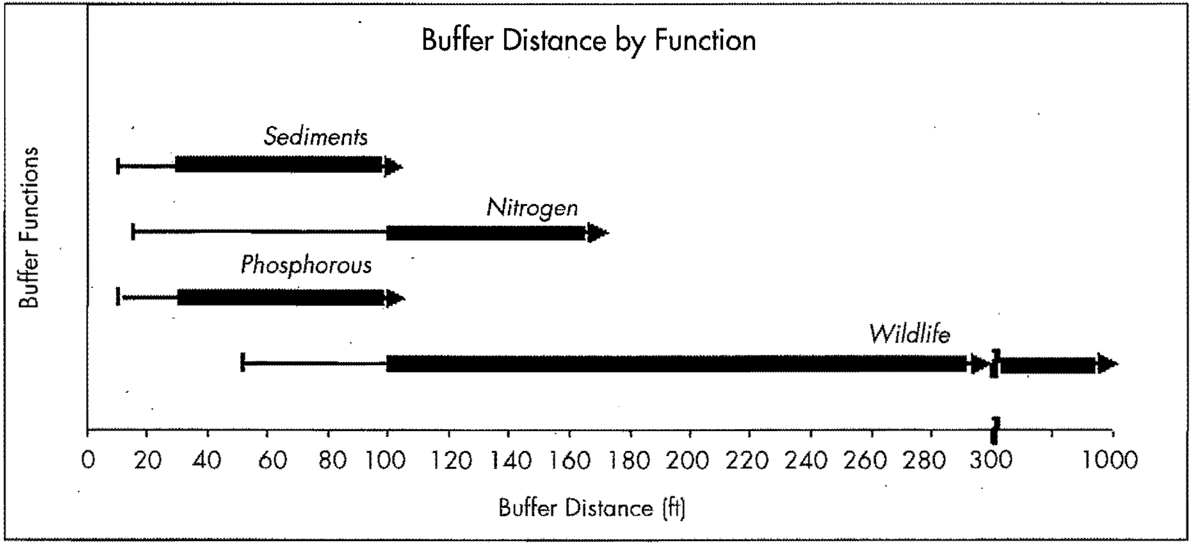


Figure 1. *Relationship of nitrogen removal effectiveness to riparian buffer width. All studies combined. Lines indicate probable 50%, 75%, and 90% nitrogen removal efficiencies based on the fitted non-linear model.*



Effective buffer distance for water quality and wildlife protection functions. The thin arrow represents the range of potentially effective buffer distances for each function as suggested in the science literature. The thick bar represents the buffer distances that may ***most*** *effectively accomplish each function (30 - > 100 feet for sediment and phosphorous removal; 100 - > 160 feet for nitrogen removal; and 100 - >300 feet for wildife protection. Depending on the species and the habitat characteristics, effective buffer distances for wildlife protection may be either small or large.*

Figure 2. From McElfish et al. 2008

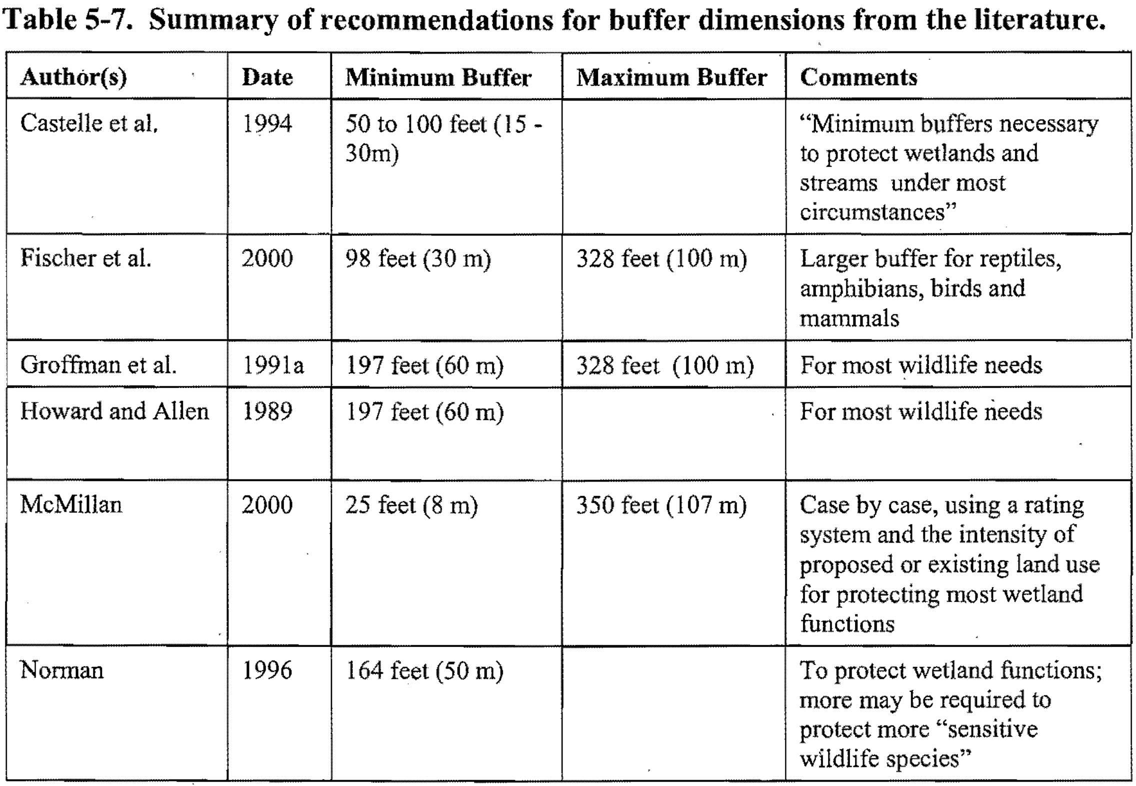


Table 5-7. Summary of recommendations for buffer dimensions from the literature.

Author(s)	Date	Minimum Buffer	Maximum Buffer	Comments
Castelle et al.	1994	50 to 100 feet (15 - 30m)		"Minimum buffers necessary to protect wetlands and streams under most circumstances"
Fischer et al.	2000	98 feet (30 m)	328 feet (100 m)	Larger buffer for reptiles, amphibians, birds and mammals
Groffman et al.	1991a	197 feet (60 m)	328 feet (100 m)	For most wildlife needs
Howard and Allen	1989	197 feet (60 m)		For most wildlife needs
McMillan	2000	25 feet (8 m)	350 feet (107 m)	Case by case, using a rating system and the intensity of proposed or existing land use for protecting most wetland functions
Norman	1996	164 feet (50 m)		To protect wetland functions; more may be required to protect more "sensitive wildlife species"

Figure 3. From Sheldon et al. 2005

Appendix II. Matrix Approach to Buffer Distance

Island County, Washington:
This excerpt is based on Island County's *draft ordinance* from November 2007, which reflects a sophisticated use of the matrix approach to buffer distance. The ordinance first prescribes buffers for a few types of particularly sensitive wetlands (especially bogs, coastal lagoons and estuarine wetlands), with wider buffers for more intensive land uses. Then it establishes matrices to calculate buffers for *other* wetlands based on land use intensity, habitat condition, and wetland sensitivity (as predicted by slope and presence or absence of a surface water outlet). Wetlands that lack outlets and are adjoined by steep slopes are presumed to be more sensitive to accumulation of sediment and contaminants, so receive larger buffers. For most wetlands both habitat and water quality buffers are calculated separately and the *larger* buffer (usually habitat) is applied. (The numbers below should be taken as illustrative). The habitat calculation is:

Habitat Buffers					
Land use Intensity	Habitat Functions Score				
	50 or higher	42-48	39-41	32-38	Less than 32
Low	150 ft	125 ft	100 ft	75 ft	Use Water Quality & Slope Tables
Moderate	225 ft	175 ft	150 ft	110 ft	
High	300 ft	200 ft	175 ft	150 ft	

The water quality calculation includes differing buffers based on wetland type (A-E) and whether there is a surface water outlet from the wetland.

Water Quality Buffers						
Land Use Intensity	Wetland Category					
	Wetland Outlet	A	B	C	D	E
Low	Yes	40 ft	35 ft	30 ft	25 ft	20 ft
	No	75 ft	50 ft	40 ft	35 ft	25 ft
Moderate	Yes	90 ft	65 ft	55 ft	45 ft	30 ft
	No	105 ft	90 ft	75 ft	60 ft	40 ft
High	Yes	125 ft	110 ft	90 ft	65 ft	40 ft
	No	175 ft	150 ft	125 ft	90 ft	50 ft

The water quality value is then adjusted for slope:

Slope Adjustment	
Slope Gradient	Additional Buffer Multiplier
5-14%	1.3
15-40%	1.4
>40%	1.5

This matrix approach is more complex than a single number, but can better reflect scientific understanding, particularly with diverse wetland types and land use conditions in a locality. With appropriate public outreach and technical support, a matrix-driven buffer can gain public support and achieve good results.

Figure 4. From McElfish et al. 2008