Wetland and Stream Buffer Size Requirements—A Review

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ABSTRACT

Upland vegetated buffers are widely regarded as being necessary to protect wetlands, streams, and other aquatic resources. Buffer size requirements, however, have typically been established by political acceptability, not scientific merit. This often leads to insufficiently buffered aquatic resources. In order to assist public agencies in formulating appropriate buffer standards, we conducted a literature search of the scientific functions of buffers. The literature search reconfirmed the need for buffers and emphasized the importance of considering specific buffer functions. A range of buffer widths from 3 m to 200 m was found to be effective, depending on site-specific conditions; a buffer of at least 15 m was found to be necessary to protect wetlands and streams under most conditions.

AQUATIC RESOURCES such as wetlands and streams are subject to disturbances that originate in adjacent upland areas. These disturbances can result in changes in the biological, chemical, and physical properties of wetlands and streams. As a result of external influences, aquatic resources may be exposed to higher levels of noise, light, temperature, pollutant loading, stormwater runoff, invasive species establishment, and human activity. These disruptions often lead to a reduction in wetland and stream functional value.

A common method for reducing or eliminating impacts to aquatic resources from adjacent land uses is to maintain buffers around the resources. *Buffers* are vegetated zones located between natural resources and adjacent areas subject to human alteration. In some locations, a buffer may be referred to as a *vegetated filter strip*. The emphasis on the filtering functions of buffers is derived from their widespread use to remove sediments and other waterborne pollutants from surface runoff.

There is rarely debate regarding the need for some buffering of valuable aquatic resources from potential anthropogenic degradation. However, there is often little agreement regarding the degree of buffering necessary or how best to achieve that measure of protection. One of the important factors which determines the effectiveness of a buffer is its size. Buffers that are undersized may place aquatic resources at risk; however, buffers that are larger than needed may unnecessarily deny landowners the use of a portion of their land. Therefore, it is important to be able to determine the minimum buffer width necessary for aquatic resource protection.

Resource agencies are most often responsible for setting buffer requirements. Many agencies seek to attain *no net loss* of wetlands. However, wetland buffer policies have often been established with significant regard for political acceptability but with little consideration of scientific data. As a result, many people are unable to recognize that the resources may be at serious risk because of the false perception that the resources are being properly buffered from potential impacts.

In order to balance development with effective natural resource protection, a rational strategy for protecting aquatic resources must be developed. It appears that the use of buffers will continue to be an important element of this strategy. To accomplish this, scientifically based criteria for establishing buffer requirements must be utilized by resource agencies.

In this paper, we address the status of wetland and stream buffers to provide a basis for establishing wetland buffer requirements that are scientifically sound. Much of the information presented here was obtained during the completion of recent studies sponsored by the Washington State Department of Ecology and King County (Washington) Surface Water Management Division. The former study focused on wetland buffers (Castelle et al., 1992a,b); the latter study concentrated on stream buffers (Johnson and Ryba, 1992).

For purposes of this paper, buffers consist of either native vegetation, which is left undisturbed, or may be areas that were wholly or partially cleared and then subsequently revegetated. Further, we focused on buffers intended to reduce or eliminate potential damage to wetlands and streams from anthropogenic sources. We realize, however, that other natural resources are also threatened by human activities and are similarly in need of protection. Additionally, we have not specifically addressed potential adverse impacts to aquatic resources due to natural processes (for example, slope failures and floods); however, we recognize that in many instances aquatic resources are protected from such occurrences by surrounding uplands.

DISCUSSION

Four criteria have been identified for determining adequate buffer sizes for aquatic resources: (i) resource functional value, (ii) intensity of adjacent land use, (iii) buffer characteristics, and (iv) specific buffer functions required (Castelle et al., 1992a). Generally, smaller buffers are adequate when the buffer is in good condition (e.g., dense native vegetation, undisturbed soils), the wetland or stream is of relatively low functional value (e.g., high disturbance regime, dominated by nonnative plants), and the adjacent land use has low impact potential (e.g., park land, low density residences). Larger buffers are necessary for high value wetlands and streams that are buffered from intense adjacent land uses by buffers in poor condition.

Many agencies throughout the USA rely primarily on a combination of political acceptability and assumed aquatic resource functional value to establish buffer stan-

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Abbreviations: VFSs, vegetated filter strips; HSI, habitat suitability index; DHD, direct human disturbance.

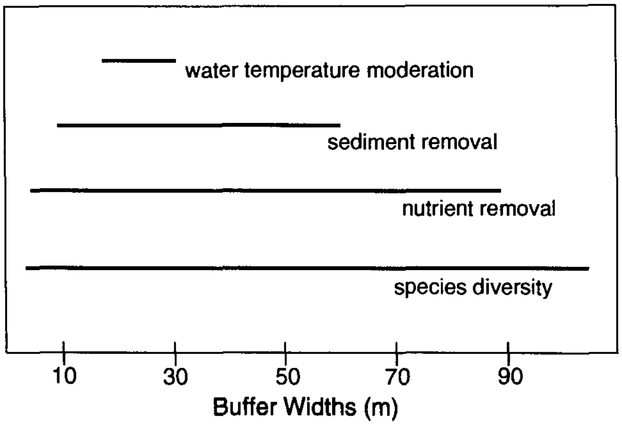

Fig. 1. Range of buffer widths for providing specific buffer functions.

dards (Castelle et al., 1992a). A search of the literature suggests, however, that a scientific approach would depend on the specific functions that a buffer needs to provide under site-specific conditions. Accordingly, this discussion presents the findings of the literature, focusing on specific buffer functions.

Buffer Size Requirements

Buffer widths necessary for adequate performance of several specific buffer functions – based upon their biological, chemical, and physical characteristics – are given in Fig. 1. The results illustrate that buffer sizes may vary widely, depending on the specific functions required for a particular buffer. The following presents an overview of some important buffer functions and the buffer widths necessary to achieve those functions. Note that in addition to SI units given for buffer sizes, English units are included in parentheses. The alternative units are included because these are the units typically used by regulatory and resource agencies in the USA.

Sediment Removal and Erosion Control. Vegetated buffers control erosion by blocking the flow of sediment and debris, by stabilizing streambanks and wetland edges, and by promoting infiltration (Shisler et al., 1987). Buffer vegetation forms a physical barrier that slows surface flow rates and mechanically traps sediment and debris. Roots maintain soil structure and physically restrain otherwise erodible soil. Flow rates are generally lower for sheetflow than for channelized flow. Therefore, where vegetation helps resist the formation of channels, water will flow more slowly, allowing more time for settling of sediments and infiltration.

Wong and McCuen (1982) derived an equation to determine effective buffer widths, based upon sediment particle size, slope, surface roughness, and runoff characteristics. While small buffers were found to remove small amounts of sediments, the relationship between buffer width and percent sediment removal was nonlinear. Disproportionately large buffer widths were required for incrementally greater sediment removal. For example, if the sediment removal design criteria were increased from 90 to 95% on a 2% slope, then the buffer widths would have to be doubled from 30.5 to 61 m (100–200 ft).

Young et al. (1980) found that a 24.4 m (80 ft) vegetated buffer reduced the suspended sediment in the feedlot runoff by 92%, but Schellinger and Clausen (1992) determined that a 22.9-m (75-ft) *filter strip* removed just 33% of the suspended solids from dairy farm runoff. Horner and Mar (1982) reported that a 61-m (200-ft) grassy swale removed 80% of the suspended solids and total recoverable Pb; Broderson (1973) also found buffers that are 61 m wide to effectively control sedimentation, even on steep slopes. According to Lynch et al. (1985), a 30-m (98-ft) buffer between logging activity and wetlands and streams removed an average of approximately 75 to 80% of the suspended sediment in stormwater. Greater sedimentation resulted from forested areas that had been commercially clear-cut and then denuded with an herbicide because of channelization, which developed following these activities. Ghaffarzadeh et al. (1992) examined sediment removal by grass vegetated filter strips (VFSs) ranging from 0 to 18.3 m (60 ft) on 7 and 12% slopes. They found no difference in VFS performance on either slope beyond 9.1 m, where 85% of the sediment was removed. Further, there was no difference in sediment removal between the two slope angles beyond 3.1 m.

Excess Nutrient and Metal Removal. Buffers can remove metals and excess nutrients from runoff by both filtering water and via plant uptake. Madison et al. (1992) examined the ability of grass VFSs to reduce NH_4-N, NO_3-N, and PO_4-P from two simulated storm events (the equivalents of the 1-yr and 10-yr events). Reporting the results as *trapping efficiencies*, they found that a 4.6 m (15 ft) VFS trapped approximately 90% of each of these nutrients. Grassy VFSs which were 9.1 m (30 ft) wide had trapping efficiencies of between 96 and 99.9%. Vegetated filter strips wider than 9.1 m did not result in further improved trapping efficiencies. Earlier, Dillaha et al. (1989) reported that 9.1 and 4.6 m VFSs removed an average of 84 and 70% of suspended solids, 79 and 61% of P, and 73 and 54% of N, respectively. Xu et al. (1992) found that NO_3 concentrations were reduced from 764 mg NO_3-N kg^{-1} soil to approximately 0.5 mg NO_3-N kg^{-1} soil in a 10-m mixed herbaceous and forested buffer strip in the North Carolina Piedmont.

Murdock and Capobianco (1979) found that mannagrass (*Glyceria grandis*) took up 80% of the available P, and also took up significant quantities of Pb, Zn, and Cr. Gallagher and Kibbey (1980) found that other species accumulated Cu, Cr, Fe, Mn, Sr, Pb, and Zn. Hubbard and Lowrance (1992) noted the NO_3 had "very little impact" on riparian systems after passing through a 7-m (23.2-ft) forested buffer. They attributed the loss of NO_3 in the buffer to a combination of microbial denitrification and plant uptake.

Vanderholm and Dickey (1978) monitored feedlots and found buffer widths ranging from 91.5 m (300 ft) at 0.5% slope to 262.2 m (860 ft) at 4.0% slope to be effective in removing 80% of the nutrients, of the solids, and of the biological oxygen demand from surface runoff through sediment removal and nutrient uptake. Doyle et al. (1977) found that 3.8 m (12.5 ft) forested buffers and 4.0 m (13.1 ft) grass buffers reduced N, P, K, and fecal bacteria levels. Lynch et al. (1985) evaluated the ability of vegetated buffers in reducing soluble nutrient levels in runoff from logging operations. They found that a 30-m (98 ft) buffer reduced nutrient levels in the water to "far below drinking water standards."

A slightly different approach was used by Bingham et al. (1980), who studied pollutant runoff from caged poultry manure. Rather than recommending specific buffer widths, the authors reported that a 1:1 ratio of buffer area to waste area (the cumulative surface area of the poultry cages) was successful in reducing nutrient runoff to background levels for animal waste practices. Overcash et al. (1981) analyzed grass buffer strips as vegetative filters for nonpoint-source pollution from animal waste with a one dimensional model, and also concluded that a 1:1 ratio was sufficient to reduce animal waste concentrations by 90 to 100%. Wooded riparian buffers in the Maryland coastal region were found to remove as much as 80% of excess P and 89% of excess N, most of it in the first 19 m (62.3 ft) (Shisler et al., 1987).

Moderation of Stormwater Runoff. Wetland and stream buffers affect the quantity as well as the quality of stormwater runoff. A vegetated buffer zone that resists channelization is effective in decreasing the rate of water flow, and in turn, increasing the rate of infiltration (Broderson, 1973). Bertulli (1981) concluded that adjacent forest vegetation and litter lowered stream water elevations from 9.9 m (32.3 ft) to 5.3 m (17.3 ft) for a 100-yr flood.

Moderation of Water Temperature. Forested buffers adjacent to wetlands provide cover, thereby helping to maintain lower water temperatures in summer and lessen temperature decreases in winter. Broderson (1973) found that 15.2-m (50-ft) buffers provided adequate shade for small streams; further, buffer widths along slopes could decrease with increasing tree height with no significant loss of shading.

Lynch et al. (1985) determined that a 30-m (98-ft) buffer from logging operations maintained water temperatures within 1°C of their former average temperature. Barton et al. (1985) found a strong correlation between maximum water temperatures and buffer length and width for trout streams in southern Ontario, Canada. They derived a regression equation in which buffer dimensions accounted for 90% of the observed temperature variation.

In their study, Brazier and Brown (1973) sought to define the characteristics of buffer strips that were important in shading small streams adjacent to logging. They found that 24 m (73 ft) forested buffer was often sufficient to shade these streams, maintaining prelogging temperature ranges. Buffers that are at least 30 m wide have generally been found to provide the same level of shading as that of an old-growth forest (Beschta et al., 1987).

Maintenance of Habitat Diversity. Some wetland-dependent birds and animals have specific needs that can only be met in the adjacent upland buffer (Naiman et al., 1988). Species such as wood ducks, great blue herons, pileated woodpeckers, and ospreys require large trees for nesting. Amphibians such as the pacific tree frog spend only a short portion of their life span in a wetland, although they cannot complete their life cycle without one. This is often true of small wetland-dependent mammals as well (Castelle et al., 1992a), because these animals must burrow above the water table to avoid inundation of their burrows.

Isolated wetlands, riparian corridors, and their buffers often afford most of the green space in urban environments. These green spaces allow animals and birds to travel through the urban landscape with some protection from humans and domestic animals in *wildlife corridors.*

Buffers may also form a transition zone between upland and aquatic environments. The ecotone, or area where one ecotype touches another, is recognized as a boundary having a set of characteristics uniquely defined by space and time scales, and by the strength of the interaction between the adjacent ecological systems (Naiman et al., 1988). *Edge effect* theory proposes that species numbers of both plants and animals increase at edges, due to overlap from adjacent habitats and to creation of unique edge-habitat niches.

Wildlife Species Distribution and Diversity. Milligan (1985) studied bird species distribution in 23 urban wetlands in King County, Washington. Bird species diversity, richness, relative abundance, and breeding numbers were positively correlated with wetland buffer size. Hickman and Raleigh (1982) studied cutthroat trout, and recommended that 30.5 m (100 ft) buffers be employed, although no data were presented to support this recommendation. Moring (1982) assessed the effect of sedimentation following logging with and without buffer strips of 30 m (98 ft) and found that increased sedimentation from logged, unbuffered stream banks clogged gravel streambeds and interfered with salmonid egg development. With buffer strips of 30 m or greater, salmonid eggs and alevins developed normally. Erman et al. (1977) also found that a 30-m buffer zone was successful in maintaining background levels of benthic invertebrates in streams adjacent to logging activity in a study of California streams.

Finally, a series of habitat suitability index (HSI) models has been published by the U.S. Fish and Wildlife Service for a variety of wildlife species, including birds, mammals, reptiles, and amphibians (e.g., Raleigh, 1982; McMahon, 1983; Sousa and Farmer, 1983; Raleigh et al., 1984; Schroeder, 1984). Space limitations do not permit a proper review of studies based on HSI models in this paper. In summary, however, these studies have demonstrated a need for buffer widths of between 3.0 and 106.7 m (10 and 350 ft), depending on the particular resource needs of individual species.

Reduction of Human Impact. Buffers protect wetlands from direct human impact through limiting easy access to the wetland and by blocking or attenuating the conveyance of noise, light, odors, and debris. Shisler et al. (1987) analyzed 100 sites in coastal New Jersey to evaluate the relationship between buffer width and direct human disturbance (DHD) to wetlands. These authors found that the adjacent land use type accounted for much of the variation found in the level of human disturbance. In all cases, human disturbance was higher in wetlands adjacent to dense residential, commercial, or industrial uses. They also found that there was an inverse relationship between buffer width and DHD.

Harris (1985) studied noise attenuation (expressed as *insertion loss*) through vegetated borders along busy streets. This report concluded that the insertion loss through an evergreen vegetated buffer was between 0.7 and 1.0 db (A) per m. Therefore, a mature evergreen buffer 6.1 m (20 ft) wide would provide an insertion loss of approximately 4 to 6 db (A) per m. Without such a buffer, tripling the distance between the noise source and the receptor would be necessary to achieve an insertion loss of this magnitude. Groffman et al. (1990) recommended a heavily forested buffer of 32 m (100 ft) to reduce the noise of commercial areas to background levels.

Agency Applicability

Many regulatory agencies rely predominantly on wetland and stream rating systems (a measure of functional value) to establish buffer sizes (Castelle et al., 1992a). For example, in Washington State, the Washington Department of Ecology has developed a four-tiered wetlands rating system (Washington Dep. of Ecol., 1991) and King County has established a three-tiered rating system for both wetlands and streams (King County Sensitive Areas Ord., 1990). In each case, larger buffers are required around higher rated aquatic resources than around resources of lower relative value. While the Washington Department of Ecology system also considers the intensity of adjacent land use in establishing wetland buffers (Washington Dep. of Ecol., 1991), most other agencies apply a single buffer size requirement regardless of site-specific conditions (Castelle et al., 1992a).

Even in the Washington State example given, however, several important criteria identified in the literature have been omitted from consideration during buffer size establishment. First, despite the number of studies that have identified effective buffer widths for specific buffer functions, no buffer size regulations were identified that considered individual buffer functions (Castelle et al., 1992a). Secondly, buffer characteristics or conditions have seldom been addressed in current regulations. By considering only aquatic resource functional value in developing buffer requirements, agencies are utilizing only one of four of the criteria identified for establishing buffer sizes. Additionally, by not considering individual buffer functions, most of the scientific information available regarding buffers is ignored.

Given that agencies typically do not consider all of the criteria, and that buffer widths are most often based on functional value alone (and perhaps, more commonly, on political acceptability), it may be helpful to identify general guidelines for buffer sizes. Buffer size requirements may fall under one of two categories: fixed-width and variable-width. Each of these types of buffer requirements has advantages and disadvantages. Fixed-width buffers are most often based on a single parameter, such as functional value. Fixed-width buffers are more easily enforced, do not require regulatory personnel with specialized knowledge of ecological principles, allow for greater regulatory predictability, and require smaller expenditures of both time and money to administer. However, fixed-width buffer systems most often do not consider site-specific conditions, and therefore may not adequately buffer aquatic resources. Variable-width buffers are generally based on a combination of buffer sizing criteria, such as functional value and adjacent land use intensity. Variable-width buffer requirements consider site-specific conditions and may be adjusted accordingly to adequately protect valuable resources. Unfortunately, variable-width buffers also require a greater expenditure of resources and a higher level of training for agency staff, while offering less predictability for land use planning.

From the literature, it appears that buffers less than 5 to 10 m provide little protection of aquatic resources under most conditions. Based on existing literature, buffers necessary to protect wetlands and streams should be a minimum of 15 to 30 m in width under most circumstances. Generally, minimum buffer widths toward the lower end of this range may provide for the maintenance of the natural physical and chemical characteristics of aquatic resources. Buffer widths toward the upper end of this range appear to be the minimum necessary for maintenance of the biological components of many wetlands and streams. Note, however, that site-specific conditions may indicate the need for substantially larger buffers or for somewhat smaller buffers.

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