CAWS White Paper On Vegetative Buffers

VEGETATIVE BUFFERS FOR WATER QUALITY PROTECTION:
AN INTRODUCTION AND GUIDANCE DOCUMENT

DRAFT VERSION 1.0

February 18, 2004
Rev. to February 21, 2004

KEYWORDS: RIPARIAN BUFFER AREA, VEGETATIVE BUFFER, VEGETATIVE BUFFER STRIP, BMP…

Need to be sure of the use of buffer, vegetated buffer, and are they equal and interchangeable?.

Also need to clarify the use of Riparian, by definition it refers to the zone next to a water-way (as in a river) but sometimes refers to lakeside or pond side and wetland habitats.

The term 'riparian corridor' is not necessarily used in the sense of 'connecting two things' but rather a use synonymous to 'riparian zone or ecosystem'. However, I do see the use of a riparian zone serving as a wildlife or dispersal corridor, as a function second to its nature. Maybe this is semantics.

Your thoughts to clarify would be appreciated.

1.0 Introduction

1.1 Purpose and Scope

A great deal of research has been conducted on the treatment and control of pollutants from non-point sources. Vegetative buffers have been used as one mode of treatment for the control of pollutants found in runoff. This first effort white paper is focused on defining vegetative buffers, reviewing buffer functions and introducing design criteria as they relate to protecting or enhancing water quality. The primary pollutants of interest are sediment, nitrogen and phosphorous. It is intended that future versions of this white paper will be expanded to address related issues of wildlife, habitat connectivity, and related functions.

Design criteria for determining the proper dimensions for buffers are variable and often based on economic, legal and political considerations. This paper represents an initial effort by the Connecticut Association of Wetland Scientist to objectively review the issues relative to determining effective vegetative buffer widths and offer design criteria to both consultants and regulators for effective vegetative buffer function and management.

"Deforestation of riparian areas is the major factor in the decline of water quality and habitat value of stream ecosystems" (Sweeney 1992, 1993). As watershed development increases, so does the impervious cover of the watershed. Schuler (19--) observes that when the impervious surface within a watershed exceeds 10% of the watershed area, water quality is degraded. This increase in impervious cover results in aquatic systems (lakes, ponds, streams and wetlands) receiving more runoff and non-point source pollution. Reestablishment of riparian forest buffers to their quasi-natural condition is considered a Best Management Practice (BMP) (EPA, 1995, Lowrance, et al. 1995, 1997). Vegetative buffers are one of the best BMPs to treat runoff before it enters these systems. (Little Androscoggin Watershed Website, 2003)

Regulatory agencies and designers have typically incorporated the use of vegetative buffers into the site development plans as mitigation or as part of riparian area restoration projects to protect water quality from sediment or other contaminants contained in stormwater runoff. In some cases the width of the vegetative buffers may be fixed or variable depending on existing site conditions, proposed land use or mitigation plan objectives. Arguments have been advanced to support both approaches. The fixed width approach being more easily applied and apparently based more on political and administrative considerations, i.e., review and enforcement. The variable width buffer has support in the literature, but is more difficult to apply requiring trained staff and designers to evaluate natural resource conditions, potential impacts to water quality and buffer effectiveness.

While upland vegetative buffers ("setbacks") are typically imposed to prevent intrusion into wetlands and watercourses, they are also successfully applied to agricultural activities and land development proposals to protect surface water quality and wetland functions by removing nutrients and other pollutants from storm water runoff. In specific instances, buffers may also be applied to provide corridors for wildlife movement.

For agriculture and most residential post-development applications, vegetative buffers are a "stand alone" (BMP). Effective and consistent regulation or management of vegetative buffers is a burden to regulatory agencies. The "bigger is better" mentality has been the justification for the application of wider vegetative buffers. Since the type of contaminant dictates the structure and width of the vegetative buffer strip, the 'wider is better' approach is not always effective (Schmitt, et al., 1999)

1.2 WHAT IS A VEGETATED BUFFER?

Definitions

A vegetated buffer is a transitional vegetated area located between upland and aquatic habitats. (Fischer et al. 2000) Typically they are long strips of natural or managed vegetation adjacent watercourses, ponds, lake and other aquatic systems, e.g. inland wetlands. Buffer strips have traditionally been used to separate human activity within an upland from a wetland or water resource or any other valuable and/or sensitive environment.

A number of terms have been used to describe these areas e.g. riparian buffers, corridors. Collectively, they are riparian zones and most commonly referred to as buffer strips or *riparian buffer strips* or as wildlife movement corridors or *riparian corridors*. For the purposes of this paper, *riparian* shall mean the area adjacent aquatic ecosystems including watercourses (perennial or intermittent), ponds, lakes and wetlands.

They are also referred to as vegetative buffer strips (VBS), setbacks, and stream belts. Closely related are filter strips or grass filters, which are often used to renovate barnyard wastewater or agricultural runoff. Quite often, the best way to protect valuable natural resources is to utilize existing natural landscape features. A good example of this approach is the use of forested vegetated buffers to protect wetlands, water quality, and wildlife habitat. The intended function or purpose of each is important to defining and managing each system.

Riparian Buffer Strips

These are lineal bands of permanent vegetation, natural or managed (enhanced or introduced) adjacent to an aquatic ecosystem and are intended to maintain or improve water quality by trapping or removing various non-point source pollutants from over land and shallow subsurface flow (Fischer and Fischenich, 2000). Buffer strips may be composed of grass, shrubs and trees or a combination of the three. Depending on its width and physical characteristics (soils, hydrology, slope and degree of disturbance) the buffer strip may support a variety of vegetation, provide movement corridors for wildlife or connections between large undisturbed blocks of vegetation.

In urban environments, vegetative riparian zones along rivers or streams are often referred to as "*Greenways or Greenbelts*" and are protected and managed under conservation easements or open space designations, e.g. linear parks. They provide for community recreational activities such as trail systems or bikeways or other recreational activities. In addition to recreational facilities, these systems can also provide treatment of non-point source pollutants and wildlife habitat.

Corridor

A corridor is a strip of vegetation that connects two or more large patches of habitat ("islands") and through which organisms are likely to move over time. Other synonymously used terms include: "*conservation corridors, wildlife corridors and dispersal corridors"* (Fischer and Fischenich, 2000)

Buffer Types

Buffers are also classified into types based on the degree of management they receive. (Little Androscoggin Watershed Website, 2003) These include: 1) "natural" or "undisturbed buffer" where existing vegetation has been allowed to remain or permitted to move through natural floral succession from grass to climax forest, 2) "Enhanced buffers" which increase the density of existing plants with like or missing species and composition (i.e., grass, shrubs, trees), reflecting what might occur under final succession, and 3) “Landscaped buffers” which introduce the variety and number of typically native plant species that the designer wants in the buffer to accomplish goals individually or collectively (e.g., aesthetic, runoff filtration, bank stabilization).

Buffer Strip Functions

A vegetated buffer can serve many useful purposes:

1. Buffers can protect adjacent wildlife habitat, wetlands, and water bodies from harmful human activities.
2. A vegetated buffer of the proper width can effectively intercept sediments and remove nutrients and other non-point source (NPS) pollutants from surface runoff (Lowrance et al. 1984, 1986; Peterjohn and Correll 1984; Pinay and Decamps 1988).
3. Vegetated buffers serve to prevent erosion of soil through soil stabilization.
4. Buffers attenuate/renovate runoff. "Maintenance of riparian vegetation or stream buffer strips and reduction of erosion lowers the potential for substance movement by surface runoff, thereby reducing the potential for water quality degradation" (Herricks and Osbourne, 1985).
5. Buffers can increase wildlife habitat by providing more forage sites, additional nesting and breeding areas, and by serving as migration corridors.
6. Buffers enhance the landscape diversity, providing visual appeal and also serve to conserve and/or supplement open space.

2.0 Potential Water Quality Impacts from Development

Sediment: Impacts and Loading

The most commonly identified sediment components are the mineral particles of clay, silt, sand, and gravel (Witkowski et al., 1987). The most obvious impact of suspended sediments on water quality is the increase in turbidity and the potential for rapid siltation of receiving waters. Construction related erosion and sedimentation was identified in 1988 as a known source of water quality problems in fourteen Connecticut reservoirs and a suspected source in twenty-one additional reservoirs (CT DEP, 1988). The accumulation of sediment within water bodies also creates shallow areas, which may give rise to the establishment of nuisance aquatic plants. The accumulation of sediment within watercourses can also obstruct channel flow and thus may lead to an increase in flood crests and flood damage.

The potential impact of suspended solids on biological systems includes the physical burial of plants and animals and changes in the nature of the substrate, which may cause alteration of fauna and flora (Sartor and Boyd, 1972). High suspended solids concentrations reduce light penetration through the water column and may inhibit photosynthesis. Suspended sediments may also clog respiratory, feeding and/or digestive organs of aquatic organisms (Wilber, 1969).

In addition to direct impacts, sediments also carry many adsorbed pollutants. While the sorptive capacity of mineral sediments for nonionic organic compounds in water is small relative to the sorptive capacity of organic matter, it is not negligible (Chiou et al., 1985). The mineral sediments are commonly coated with organic sheaths that provide a micro-scale medium for sorption of nonionic organic compounds. These sorptive interactions are important because they provide a mechanism through which persistent manmade contaminants (e.g., turf chemicals) are transported by sediment particles (Witkowski et al., 1987).

In addition, up to 85% of phosphorus and 70% of nitrogen in surface runoff is adsorbed to sediment (Karr and Schlosser, 1977). The potential impact from nitrogen and phosphorus in runoff is primarily the threat of accelerated eutrophication of receiving water bodies. Sediment is the principle source of phosphorus enrichment of surface waters (Boto and Patrick, 1979; Nowak, 1988). In most Connecticut lakes, elevated phosphorus loading is the key to eutrophication (CT DEP, 1982; CT DEP, 1988; Norvell and Frink, 1975; Frink and Norvell, 1984).

Metals are often associated with suspended particles (inorganic, organic, or biota); the dominant mechanism of such association is adsorption (Elder, 1988). Suspended sediments also may carry oxygen-demanding substances (i.e, …) (Alonso et al., 1975; Wilber, 1969; Hammer, 1976).

(The following paragraph is adopted from Dillaha et al., 1986). “The major pollutant mechanisms associated with buffers are thought to involve changes in flow hydraulics which enhance the opportunity for the infiltration of runoff and pollutants into the soil profile, deposition of solids, filtration of suspended sediment by vegetation, adsorption on soil and plant surfaces, and absorption of soluble pollutants by plants and microflora. Infiltration is one of the most significant removal mechanisms affecting buffer performance because many pollutants associated with surface runoff enter the soil profile as infiltration takes place. Once in the soil profile, a combination of physical, chemical, and biological processes remove most of the pollutants. Infiltration is also important because it decreases the amount of surface runoff, which reduces the ability of runoff to transport pollutants. Buffers also purify runoff through the process of deposition. Vegetation within buffers offers high resistance to shallow overland flow; this decreases the velocity of overland flow within the buffer causing decreases in sediment transport capacity. Presumably, sediment-bound pollutants will also be removed during this deposition process. The filtration of solid particles by vegetation during overland flow and the adsorption process are not as well understood as the infiltration and deposition processes. Filtration is probably more significant for the larger soil particles and aggregates while adsorption is probably more significant with respect to the removal of soluble pollutants”.

Generally the amount of sediment that erodes from a given area increases with development. While woodlands may export up to 100 tons/sq. mile/year, this figure increases to 10,000 tons/sq. mile/year for land under light development (Thurow et al., 1977; U.S. EPA, 1973). A Maryland study of construction impact on erosion levels found increases from 3 to 100 times the sediment yield from areas undergoing development as compared to dominantly rural areas (McKee, 1964). Suburban expansion has been identified as the principle source of sediment to water bodies (Faber, 1987; Wilber, 1969).

3.0 Pollutant Removal

The principal pollutants of concern from residential development are fertilizers (nitrogen and phosphorous), herbicides and pesticides associated with turf care. Excessive nutrients and other turf care products may be found in storm water runoff. The reason these pollutants are of concern is that they are generally applied on a “calendar” rather than a “need” basis. The type of fertilizer used (typically coated, slow release), the nutrient concentration and application rate, the timing of release, the soil conditions, and the slope and turf condition all affect the amount of migration.

For freshwater environments, phosphorus is the pollutant of concern due to it tendency to accelerate enrichment (cultural eutrophication) of surface waters. Sediment is the principal mechanism for the deposition of phosphorus (85%) and 70 % of the nitrogen delivered to surface water bodies (Karr and Schlosser, 1977) and the principal source of phosphorus enrichment of surface waters (Boto and Patrick, 1979; Nowak, 1988).

In estuarine (mix of fresh and salt water) and saline (sea water) environments, nitrogen is the limiting nutrient. Dissolved nitrogen (nitrate, NO_3) in runoff or groundwater is the form most frequently associated with eutrophication, because it is negatively charged, as are soil particles. Nitrate in solution can move freely through the soil matrix with the ground water.

Nutrient Removal Mechanisms

Nutrients are attenuated in the soil environment by chemical and physical adsorption to soil particles, microbial decomposition and plant up-take during the growing season. Soil organic content, drainage characteristics and microbial populations (denitrifiers) all affect nutrient movement and disposition.

Nitrogen

Water with dissolved nitrate nitrogen (NO_3) moving from well drained to poorly drained conditions undergo denitrification (conversion of nitrate, NO_3) by denitrifying bacteria producing nitrogen gas (N) and nitric oxide (NO_2). (Groffman, et al., 1992) Denitrification generally takes place rapidly within the first one to two meters of the somewhat poorly drained transitional soils and wetland soils. (Martin and Clausen, undated; Lowrance, et al., 2002) The characteristics of these soils (saturated soil conditions, high organic content, low oxygen tension, slow water movement) when combined with denitrifying bacterial populations are ideal for the conversion of nitrate nitrogen.

Plants remove nitrogen in the form of ammonia, bind it in organic tissue and then release it upon decomposition. The top meter (3.2 ft) of the soil environment is the most active. (Groffman, et al., 1991) Microbial populations, like plants, respond to increases in nutrients (nitrate), and likewise decrease in numbers as the amount of nutrient declines.

Well-drained soils are the primary soils for phosphorus removal, while the somewhat poorly drained and poorly drained soils (wetlands), with their denitrifying microbial populations, are the principal soils for nitrogen removal. Plants stabilize, aerate (maintain permeability) and enrich the organic content of the soil with roots and leaves and seasonally remove and release nutrients.

Subsurface migration of dissolved phosphorus as demonstrated by laboratory and field studies is generally limited to two feet by adsorption to soil particles and precipitation (binding with soil metals, i.e., iron, calcium), even in sandy soils. (Tofflemeyer and Chen, 19____).

Vegetative Buffer Strips

EPA has determined agricultural settings to be the primary source of non-point source pollutants. Studies of sediment and nutrient removal by vegetative buffer strips (VBS) in agricultural settings have shown effective removal of pollutants in stand alone VBS that are 5-9 meters (15-30 ft) wide. (Lee, et al., 2000; Schmitt, et al., 1999; Martin and Clausen, undated) Removal efficiencies range from 61-92% of the nitrate, 72-93% of the total phosphorous and 44-85% of the orthophosphates from grass and combined grass and woody buffers, respectively. (Lee, et al., 2000) This is achieved in environments with no management, exposed soils under cultivation, and application of crop nutrients, pesticides and herbicides in excess of what are typically applied to individually managed, residential turf grass.

Sediment removal within buffers is affected by filter width, sediment load, flow rate, slope, vegetation height and density, as well as the degree of submergence (Wilson, 1967). Neibling and Alberts (1979), observed that the majority of sediment deposition occurred just upslope and within the first meter of the buffer, until the upper portions of the buffer were buried in sediment. Subsequent flow of sediment into the buffer resulted in the advance of a wedge-shaped deposit of sediment down through the buffer. Doyle (et al., 1971) applied dairy manure to buffers planted with fescue on a silty loam soil; soluble phosphorus was reduced 62% in a 4 meter buffer. Thompson (et al., 1978) studied the effectiveness of orchardgrass filter strips on a sandy loam soil in reducing nutrient loss from the application of dairy manure to frozen or snow covered orchardgrass plots during natural storm events; total phosphorus was reduced an average of 55%.

Woodward (1988) studied the effectiveness of natural undisturbed vegetation (mixed deciduous hardwoods with a sparse understory) in controlling the migration of suspended solids from land undergoing residential development in Maine. All six experimental sites and the single control site were chosen because of their similarity and lack of surface rills that might channelize flows. Preliminary results indicate that natural buffers 75 to 189 feet in width reduced phosphorus concentrations in runoff from sites undergoing residential development by 96%, and suspended solids concentrations by 99%.

4.0 Buffers: Sizing and Design.

4.1 General Considerations

Sizing and design criteria of vegetated buffers to serve specific functions are not well established and design recommendations are highly variable. (Fischer & Fischenich, 2000) The "one-size-fits-all" approach to sizing a riparian buffer will not achieve all possible desired functional properties. A buffer must be designed with end goals of function in mind. Factors to be considered in the design of a buffer include: 1) identification of primary buffer objectives, 2) the buffers position in the watershed, 3) existing plant species composition and density and 4) soil~~s~~ and slope conditions. While focusing on agricultural applications, the Virginia Best Management Handbook: Agriculture (VSWCB, 1979) lists factors, which should be considered in determining buffer width for any application. They include: land use and management above the buffer, land slope above the buffer, soil erodibility above the buffer, slope across the buffer and type of buffer vegetation. (The Connecticut River Joint Commissions, 2000) All these factors will influence the ability of the buffer to meet identified objectives. The size, both width and length, should match the land use, physical features of the site and the intended use of the buffer.

4.1.1 Objectives

Buffers have been proven effective in protecting watercourses and wetlands from the negative influence of increased runoff, sedimentation, biochemical degradation, and thermal pollution associated with development. Other objectives for the introduction and implementation of buffers can include: runoff filtration and infiltration, streambank stabilization, downstream flood attenuation and wildlife habitat and corridors.

4.1.2 Watershed Placement

The location of the buffer within the watershed can have demonstrable impacts on protection water quality. Buffering low order streams (1st, 2nd and 3rd) has greater positive influence on water quality than wider buffers on portions of larger order streams already carrying polluted water. (Alliance for the Chesapeake Bay, 1996)

4.1.2 Soils and Slope

The interactions between upland and aquatic environments (wetlands, stream banks, watercourses) soil type and topography (slope) play an important role in evaluating soil erosion potentials and thus vegetative buffer placement. Placement of well developed vegetative buffers down gradient of highly erosive soils or soils exposed for extended periods of time play a critical role in reducing the velocity of runoff generated by steeper slopes and thus reduce sediment movement. The erosion potential of concentrated runoff is also diminished as flows are dispersed through the buffer vegetation.

4.2 Determining Buffer Size (Width & Length)

The width of the buffer has been the principal focus of most designers and regulators. For consistency, buffer width shall be measured from the top of the bank (bankfull condition, typically a 2-year storm event) or wetland edge. The applications of buffer widths by regulatory agencies have been either “fixed-width” or “variable-width.” Fixed–width buffers are generally based on one parameter or function. They are easier to enforce, but may fail to provide a variety of ecological functions. Variable width buffers typically take into account a variety of functions and site conditions, thus adjusting the width of the buffer along its length depending on adjacent land use, soils, vegetation, slope, hydrology and wildlife. (Castelle, Johnson and Conolly, 1994)

While the protection of or improvement of water quality is the principal application of vegetative buffers, providing wildlife habitat and movement corridors are also important considerations when establishing buffer widths. Species composition and type of aquatic environment are important (Spackman and Hughes, 1995). Buffer widths for ecological concerns are typically wider than those for water quality functions. (Fischer, et al. 1999; Fisher, 2000) Long continuous wide-buffer strips adjacent aquatic environments (rather than fragmented), are more effective at moderating stream temperatures, treating non-point sources of pollution and providing movement corridors and habitat for wildlife (Weller, Jordan and Correll, 1998)

4.2.1 Recommended Widths

The importance of riparian buffers and corridors has been recognized by a variety of Federal, state and local regulatory agencies. This recognition has led to the establishment of restoration and preservation programs. (Fischer and Fischenich, 2000) In an effort to protect aquatic resources, especially wetlands and water quality, vegetative buffer designers and regulators have relied on antidotal evidence as well as the results of investigations on buffer effectiveness to establish riparian buffer widths for land use permits.

The Virginia handbook suggests that buffer widths for effective sediment removal vary from only a few feet in relatively well drained flat areas to as much as several hundred feet in steeper areas with more impermeable soils; a minimum width of 12 feet was recommended for herbaceous buffers. Buffers should not contain gullies or topography that would cause concentrated or channelized flow; such drainage results in much less effective sediment and phosphorus removal (Dillaha et al., 1986b; Dillaha et al., 1986c).

The BMPs from Westchester County Environmental Management Council (1981) recommend a minimum buffer width of 25 feet. This width should be increased 3 feet for each degree of slope. Conversely, a reduction in width of one foot can be made for each three feet of width of adjacent brushy or woodland growth in good hydrological condition (organic ground cover). Additional controls such as sediment barriers, benches, mulches or traps are required when 1) slope angles exceed 15%, 2) when slope runs are greater than 200 feet, or 3) the filter is in heavy shade or subject to heavy traffic. Additional recommendations include the use of a level spreader before the filter.

The distinction between regulated setbacks and buffers must be restated. A regulatory setback is only a physical distance, which is not necessarily stipulated to be a planted zone, but a "buffer" is a BMPs that has a defined function, i.e., stormwater treatment. It may cause confusion to use buffer interchangeably with setback.

To protect streams, some municipalities have adopted fixed point boundaries for regulated areas; they range from 25 to 300 feet (Thurow et a1., 1977). Regulated areas are not functional entities, but do provide the benefit of physically separating activities from the immediate shoreline and from the edge of wetlands and watercourses. The towns of Brooklyn and Marlborough, Connecticut have established regulated areas of 150 feet outside of wetlands and watercourses (Thurow et a1. , 1977). The Connecticut Council of Soil and Water Conservation (1984) recommends a minimum vegetative filter width of l5 feet for light sediment loads. This width is increased proportionately for slopes longer than 150 feet in length. The Danbury, Connecticut watershed protection plan recommends a setback distance (a regulated area) of 100 feet for all watercourses within public water supply watersheds (HVCEO, 1989). A 100-foot setback in public water supply watersheds has also been recommended by the Connecticut Department of Agriculture (CT Dept of Agriculture, 1972).

In the publication *Native Vegetation for Lake Shores, Stream Sides and Wetland Buffers* (1994), the Vermont Department of Environmental Conservation suggests that for bank stability the vegetative buffer should be 50 feet wide, 100 feet wide for water quality protection and 200-600 feet wide for wildlife habitat protection. It is recognized that most property owners do not have this much land available to work width and that any vegetative buffer width will have positive impacts on water quality. The State of Maine mandates a 75-foot buffer from the high water mark of lakes, rivers, or streams for all new development.

A procedure for the design and evaluation of filter strips has been presented by Dillaha et a1. (1986c); it considers the effects of natural drainageways and concentrated flow. While meant for filter strips receiving barnyard wastewater or agricultural runoff, it offers an example of how the quantification of the renovation functions provided by vegetative buffers can lead to the development of models which can be used in site-specific designs and evaluations. The discussion of this methodology that follows was taken directly from Dillaha (et a1., 1986, pages 8-9). The series of regression equations below were developed to describe buffer performance with respect to sediment, nitrogen, and phosphorus removal.

$$RTSS = 71.41 - 29.23Q2 + 2.55w \qquad r2=0.87 \quad (1)$$
$$RTN = 70.38 + 88.26Q - 110.26Q2 \qquad r2=0.91 \quad (2)$$
$$RTP = 14.03 + 74.47Q — 91.96Q2 \qquad r2=0.90 \quad (3)$$

where RTSS, RTN, and RTP are the percent reductions in total suspended solids, total nitrogen, and total phosphorus, respectively; Q is the flow rate into the filter per unit length, L/s-m, (liters/sec/min); and W is the filter width, m. Buffer slope was not statistically significant in the regressed equations.

Equation (1) describing the percent reduction in sediment is appropriate for filter strips less than 11.2 meters in width and for flow rates less than 1.8L/s-m. At higher flow rates, RTSS was assumed negligible.

Equations (2) and (3), describing the percent reductions in total nitrogen and total phosphorus, are appropriate for flow rates between 0.4 and 1.3 L/s-m, RTN, and RTP were assumed to be 90%.

Using these regression equations, the following design/evaluation procedure was developed:

1. Obtain a topographic map of the area proposed for protection by the buffer;
2. From a topographic map delineate the sub-watershed, within the area which will drain through the buffer and determine the drainage area for each sub-watershed;
3. Estimate the total volume of runoff which will be discharged from each sub-watershed using the Soil Conservation Service total runoff volume method or other appropriate method for the desired design storm;
4. Estimate the buffer length through which flow will pass for each sub-watershed, buffer longitudinal length in area with shallow sheet flow or channel width through the buffer in sub-watersheds with developed drainageways;
5. Determine flow rate per unit length through the buffer for each sub-watershed;
6. Estimate percent reduction in desired pollutant for each sub-watershed using the regression equations; and
7. Weight percent reductions on an areal basis to determine if the buffer is appropriate for the area under investigation.

The authors recommend that the design equations be used cautiously because of the limited database from which they were derived.

Fisher and Fischenich (2000) have compiled a table of recommended widths of buffer zones and corridors for water quality protection. Table #1 is modified from their publication and expanded to include additional citations and separate pollutant types. Table 2 also provides guidance from Fisher and Fischenich (2000) on general Riparian Buffer Strip widths.

Fisher and Fischenich (2000) observe that a 10 m (30 ft) wide vegetative buffer is needed to promote an optimum range of objectives for water quality protection and treatment and 100 m+ for wildlife habitat and migration corridors. If only a narrow buffer is possible, then it should be wide enough to sustain a forest or shrub community and adequately stabilize the bank from erosion, usually the total width of floodplain on lower order streams.

Three Zone Watershed Approach

The three zone buffer approach was developed by Welsch (1991) to protect water quality in the Chesapeake Bay watershed. The width of the zones varies based on site conditions and objectives.

Zone 1 is from the top of bank and extends 5- 8m (15-25 ft) landward. Its purpose is to stabilize stream banks, moderate water temperature by providing shade, promote algal growth, allow for the input of coarse woody debris and promote the biogeochemical processing of nutrients and detritus

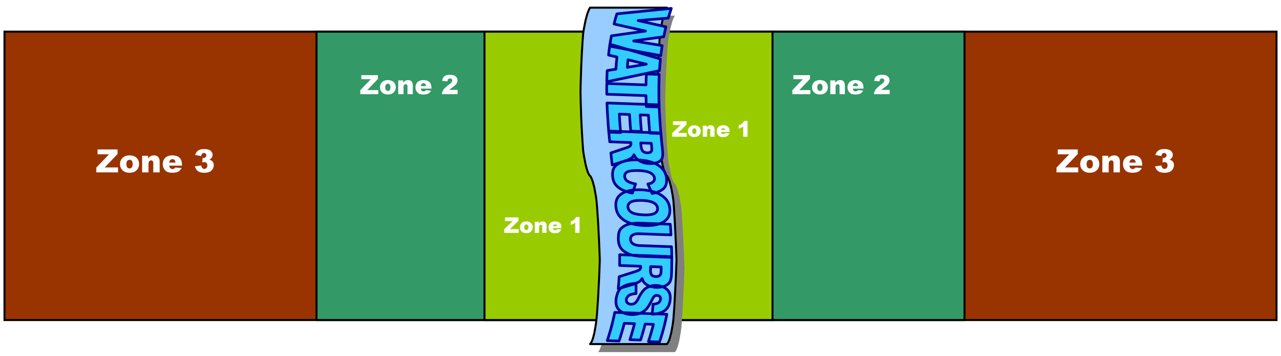

Table #1. Recommended Widths of Buffer Zones and Corridors for Water Quality

Authors	State	Width	Buffer Type	Benefit & Pollutant
Young et al. (1980)		≥25m/82 ft	Vegetated Buffer	**Sediment** 25m buffer reduced the suspended sediment in feedlot runoff was reduced by 92%
Horner and Mar (1982)		≥61m/200 ft	Grass filter strip Vegetated buffer strip	Removed 80% of suspended sediment in stormwater
Lynch, Corbett, and Mussalem (1985)		≥30m/98 ft		30m buffer between logging activity and wetlands and streams removed an average of 75 to 80% of suspended sediment in stormwater; and maintained water temperatures within 1^{o} C of their former mean temperature.
Ghaffarzadeh, Robinson, and Cruse (1992)		≥9m/29 ft	Grass filter strip	Removed 85% of sedimentation 7 and 12% slopes
Dillaha et al. (1989)		≥9m/29 ft	Vegetated filter strip	Removed an average of 84% of suspended solids, 79% of phosphorus, and 73% of nitrogen
Self-Davis, et al. 2003	Arkansas	6.1m/20 ft	Grass filter strip	Kentucky 31 Tall fescue (Festuca arundinacea Schreb.) more effective than other forage species in reducing runoff and increasing infiltration, thus loss of sediment and nutrients
Mickelson, et al., 2003	Iowa	4.6m/15 ft & 9.1m/ 30 ft	Grass filter strips	Sediment loads reduced by 87% in 9.1m long strip 71% reduction in 4.6m long strips.
Magette, et al.		4.6m/15 ft & 9/1/30 ft	Grass filter strip	Nutrient loss variable, but sediment reductions were consistent and effective
Gharabaghi, et al. 2000	-	2,5,10,15m/6.5, 16.5, 33, 49 ft	Grass filter strips	Average sediment removal ranged between 80 and 95% for variable width vegetative strips
Barfield, et al., 1998		--	Natural riparian grass filter strips	Sediment removal efficiency increased within and increase in filter strip length

Authors	State	Width	Buffer Type	Benefit & Pollutant
Lee, et al, 2000	Iowa	7.1m/23 ft & combined 7.1 and 9.2m/30 ft	Grass and combined grass & shrub	Grass alone removed 70% of sediment while combined grass and shrub removed 93%. Length of buffer and infiltration key
Woodward and Rock (1995)	Maine	$\geq$15m/49 ft	Hardwood Buffer	**Phosphorus** The effectiveness of natural buffer strips is highly variable, but in most cases, a 15m natural, undisturbed buffer was effective in reducing phosphorus concentrations adjacent to single family homes
Madison et al. (1989)		$\geq$5m/16 ft	Grass filter strip	Trapped approximately 90% of nitrates and phosphates
Lowrance et al. (1992)		$\geq$7m/23 ft		Nitrate concentration almost completely reduced to microbial denitrification and plant uptake
Doyle et al. (1977)		$\geq$4m/13 ft	Grass filter strips and forested buffers	Reduced nitrogen, phosphorus, potassium, and fecal bacteria from runoff
Shisler, Jordan, and Wargo (1987)	Maryland	$\geq$19m/62 ft	Forested riparian buffer	Removed as much as 80% of excess phosphorus and 89% of excess nitrogen
Lee, et al, 2000	Iowa	7.1m/23 ft & combined 7.1 and 9.2m/30 ft	Grass and combined grass & shrub	Grass alone removed 64% Total N, 61% NO_3; 72% Total & 44% of available P (PO_4); combined grass and shrub removed 80% Total N, 92% NO_3, 93% Total P and 85% PO_4
Nichols et al. (1998)	Arkansas	$\geq$18m/59 ft	Grass filter strip	**Hormones/Pesticides/Herbicides** Reduced estradiol (estrogen hormone responsible for development of the female reproductive tract) concentrations in runoff into surface water by 98%
Mickelson, et al., 2003	Iowa	4.6m/15 ft & 9.1m/ 30 ft	Grass filter strips	Atrazine reduced by 80% in 9.1m long strip 31% reduction in 4.6m long strips.
Rhode, et al. 1980	-	-	-	Trifluralin reduced 96% in runoff over dry vegetative filter strip and 86% reduction when moist. 50% reduction attributed to adsorption on vegetation, organic matter and soil.
Asmussen, et al. 1977		24.4m/80 ft	Grassed waterways	2,4-D in runoff reduced by 98% and 94% for dry and wet antecedent moisture conditions, respectively due to water loss via infiltration, reduction of sediment transport and adsorption to vegetation and organic matter.

Table #2. General Recommended Widths of Buffer Zones

Function	Description	Recommended Width[1]
Water Quality Protection	Buffers, especially dense grassy or herbaceous buffers on gradual slopes, intercept overland runoff, trap sediments, remove pollutants, and promote ground water recharge. For low to moderate slopes, most filtering occurs within the first 10 m, but greater widths are necessary for steeper slopes, buffers comprised of mainly shrubs and trees, where soils have low permeability, or where NPS loads are particularly high.	5 to 30 m
Stream Stabilization	Buffers, particularly diverse stands of shrubs and trees, provide food and shelter for a wide variety of riparian and aquatic wildlife	10 to 20 m
Riparian Habitat	Riparian vegetation moderates soil moisture conditions in stream banks, and roots provide tensile strength to the soil matrix, enhancing bank stability. Good erosion control may only require that the width of the bank be protected, unless there is active bank erosion, which will require a wider buffer. Excessive bank erosion may require additional bioengineering techniques (see Allen and Leach 1997).	30 to 500 m +
Flood Attenuation	Riparian buffers promote floodplain storage due to backwater effects, they intercept overland flow and increase travel time, resulting in reduced flood peaks.	20 to 150 m
Detrital Input	Leaves, twigs and branches that fall from riparian forest canopies into the stream are an important source of nutrients and habitat.	3 to 10 m

Modified after Fisher and Fischenich, 2000

Zone 2 begins at the upland edge of zone 1 and extends 3 to >100m (10 to >200 ft) landward. It provides long-term sequestering of nutrients, sediments and other pollutants by trees and runoff infiltration via overland and shallow groundwater flow.

Zone 3 starts at the landward edge of zone 2 and extends 3m (15 ft) when used in conjunction with zones 1 & 2 or 10.6 m (35 ft) when used alone. It is composed of a grassed or herbaceous strip to slow runoff, promote infiltration and sediment filtering, nutrient uptake and sheet flow. Sweeney (1992) in his work restoring riparian forest buffers has rounded these zone widths to 4.6 m (15 ft.) for zone 1, 18.3 m (60 ft.) for zone 2 and 6.1 m (20 ft.) for zone 3.

Sediment trapping efficiency of vegetative buffer strips was observed to improve with a doubling of length from 4.6m (15 ft) to 9.1m (30 ft). (Magette, et al.1989, Barfield, et al., Dillaha et al., 1998) Dillaha, et al. (1989) and Magette et al., (1989) reported that while reduction in nutrient levels by vegetative filters was variable, their ability to remove sediment was most effective and consistent. Gharabaghi et al., (2000) reported average sediment removal from surface runoff of 80-95% for 2-15 meter (6.5-49 ft) long filter strips.

Mickelson, et al., (2003) observed significant sediment deposition within the first 1m (3.3 ft) of the vegetative filter. Soil erosion is a selective process with eroded soil containing more fines (silts, clays) and higher concentrations of phosphorus (Lee, et al. 2000). Cooper, et al. (1987) studies of a forested coastal plains watershed showed that sand deposition was highest at the forest edge, while silt and clay deposits were highest in the floodplain swamp.

Physical Environment

Soil Type

The hydrologic soil group both within the contributing drainage area and the vegetative buffer area need to be considered when establishing the functional goals of the buffer and plant selection. Soil moisture gradients transition from well drained and moderately well drained soils to the some-what poorly drained soils of the transition slope areas into the poorly and very poorly drained soil environments of the wetlands and riparian areas. This variation in soil moisture will affect the movement of pollutants, chemical reactions and soil bacterial species.

The top one meter (3.3 ft) of the soil profile is the most reactive and movement of shallow ground water though this biologically active zone will afford the greatest opportunity for bacterial nutrient transformations. Selection of plantings appropriate to the moisture conditions will insure greater survival and maintain the infiltrative capacity of the soils, which is a key factor in non-point source pollutant removal. Chemical retention within the buffer is strongly influenced by the amount of infiltration of runoff. (Mickelson, et al., 2003)

Soil type within the contributing watershed and its erosion index are also important when considering the potential effectiveness of the vegetative buffer and the amount of sediment that might be eroded during site development. By consulting the engineering tables in the Generalized Soil Mapping for the various counties an erosion factor can be determined for the various soil horizons. Using the Connecticut Erosion and Sediment Control Guidelines 2002 the potential amount of sediment generated during soil disturbing activities can be estimated. Temporary Erosion and Sediment control measures can be selected to reduce the potential for soil displacement and migration and thus influence the selection of an appropriate vegetative buffer width both during construction and following stabilization.

Topography

The surface topography of the buffer should be irregular not smooth, allowing for the ponding of surface runoff in irregular depressions within the buffer. This is often referred to as “hummocky” or microtopgraphy. (Little Androscoggin Watershed Website, 2003) This condition reduces the potential for flow-through, i.e., the development of channelized flow through the buffer, thus short-circuiting its effectiveness. Observations with “natural” agricultural buffers composed of trees adjacent row crops showed that after twenty-five (25) feet, runoff had channelized (Univ. of Wisconsin, 2003). The irregular surface topography reduces the flow rate and promotes infiltration of the runoff into the groundwater table where it receives renovation by physical filtration and microbial action, while recharging base stream flows.

Section 5.0 of the Connecticut Guidelines for Erosion and Sediment Control 2002 provides a table for selecting the proper width of a vegetative filter to remove sediment. The width of the filter increases with an increase in slope angle. This sediment control measure is meant to be a stand-along measure and results in a vegetative filter width (length), which may be significantly wider than a typical buffer area needs to be. For agricultural practices, Finley (1987) recommends that vegetative buffer widths start at 15m and increase 6m for each 5 degrees of slope to a maximum width of 150 at 25% slope.

The Natural Resources Conservation Service (NRCS, 2000) from New Hampshire recommends that the watershed area above the filter strip be >1%, but less than 10% slope when the principal object of the filter strip is sediment removal and adsorbed contaminants and reduction of soluble contaminants.

Area Ratio

Arora et al (1996) investigated the relationship between the area of the drainage area discharging to a vegetative filter strip and the size of the vegetative filter strip. The term “area ratio” represents this relationship. Ratios of 15:1 and 30:1 were evaluated for their impact on the reduction of three moderately adsorbed herbicides from agricultural activities. Lower area ratios buffers (meaning those with less area draining to filter strips than those of equal size) resulted in higher sediment trapping efficiencies and thus increased reductions of herbicides. Infiltration was a key factor in herbicide retention. Area ratios of 5:1 resulted in more significant filtering efficiency (Mickelson, et al., 2003)

4.3 Buffer Plant Composition

Invasive plant species typically become well established in disturbed riparian areas. Control of invasives and the re-establishment of native plant species common to these areas is the stated goal and policy of natural resource agencies and designers in ‘natural buffers’. Landscaped buffers, which may include non-native or ornamental species, are also acceptable as landscape focal points, but should avoid the use of invasive or aggressive non-native plants. …

Reestablishing native species is difficult due to reduced local seed species due to soil disturbance, foreign invasives, mammalian herbivores and perturbed site conditions, which results in high seedling mortality (Marquis 1977; Marquis & Brenneman, 1981; Davies, 1987; Opperman & Merenlender 2000; Ryder, et al. 2003, Sesto, 2003)

The goal of a riparian restoration/forest buffer plan is to preserve and or improve water quality and stream ecosystem function by maximizing plant survival and growth resulting in natural diversity of canopy-with stable plant survivorship four (4) years after introduction and canopy closure in 10-15 years (Sweeney, et al., 2002). Fisher and

Fischenich (2000), recommend a goal of shrub planting canopy closure within 3years for cluster plantings. These time frames for plant stabilization compare well with the Army Corps of Engineers Guidelines (2003) for wetlands mitigation, which uses a five (5) year growth period to establish a stable plant community.

Lee at al., (2000) evaluated various plant species within riparian buffers to remove sediment contained in runoff. They observed that a 7.1 meter (23 ft) switchgrass (*Panicum virgatum L*.) filter strip reduced sediment loads by 70%, a combined 7.1 meter switchgrass and 9.2 meter (30 ft) shrub buffer reduced sediment loads by 93%. The coarse grasses were effective in removing coarse sands and absorbed nutrients. The length of the filter strip and increased infiltration capacity was a result of the deep-rooted shrubs which were effective in trapping suspended clay and soluble nutrients. Self-Davis, et al. (2003) evaluated the effectiveness of forage grass species including Alamo Switchgrass (*Panicum virgatum L*.) and Kentucky 31- tall fescue (*Festuca arundinacea Schreb*.) to reduce runoff volumes from the edge of agricultural fields. Tall fescue was significantly more effective in reducing runoff volumes and increasing infiltration. Runoff volumes were less for full canopy cover with little difference between cut and full canopy cover of any one species. Other investigations of sediment removal by tall fescue (*F. arundinacea*) show that grass and combined grass and native riparian vegetation buffer strips can reduce sediment loads by 50-80% (Daniels and Gilliam, 1996).

Vegetation should be a mix of trees, shrubs and herbaceous plants native to the region and appropriate to the environment in which they are to be planted. Use adjacent reference riparian buffers as basis for selecting floral composition. Plan ahead for availability of planting material if possible. Select a minimum number of plants species and a minimum percentage of any one species. Other design factors to consider: 1) ultimate composition of the plant community, 2) plant function, 3) plant dominance, 4) growth characteristics and competition between species, e.g., fast growing Vs. slow growing species, and 5) maturity of the physical environments to support successional species, i.e., low light species such as ferns (Fisher and Fischenich, 2000). These same authors also provide a rating of the Effectiveness of Different Vegetation types Versus Benefits. The following table offers observations on the effectiveness of various plant types in removing pollutants.

Table # 3 Plant Type Vs Removal Efficiency

Function	Grass	Shrubs	Trees
Sediment trapping	High	Medium	Low
Filtration of Sediment born Nutrients, Microbe and Pesticides	High	Low	Low
Soluble forms of Nutrients and Pesticides	Medium	Low	Medium

Flood Conveyance	High	Low	Low
Reduce Stream Bank Erosion	Medium	High	High

Modified after Fisher and Fischenich, 2000

Native Plant Species

The use of native plant species is recommended to re-establish altered riparian floral communities and resist the establishment of non-native and in some instances invasive plant species.

Trees and Shrubs

Sweeney (1992) has identified the tree and shrub species for use within the riparian area, Zones 1 & 2 (see Welsch, 1991), hydrologic soils group D & C (SCS, Generalized Soils Mapping). These native streamside species include: red maple (*Acer rubrum*), Sugar Maple (*A. saccharrum*), Sweet Birch (*Betula lenta*), River Birch* (*B. nigra*), Black Gum (*Nyssa sylvatica*) Black Willow* (*Salix nigra*), Pin Oak (*Quercus palustrus*), American Sycamore* (*Platanus occidentalis*), Big Tooth Aspen (*Populus grandidentata*), Tulip Poplar, Red oak**, Black Walnut** (*Juglans nigra*), Ironwood (*Caprinus caroliniana*), American Basswood (*Tilia americana*), Silver Maple (*A. saccharinum*), Swamp White Oak (*Q. bicolor*), and Black Cherry* (*Prunus serotina*). * = fast growing, ** = slow growing

Native streamside shrub species for the riparian area, Zones 1 & 2 and hydrologic soils groups D & C, include: Red-Osier Dogwood (*Cornus stolonifera*), Spicebush (*Lindera benzoin*), Arrowwood (*Viburnum dentatum*), Swamp Azalea (*Rhododendron viscosum*), Elderberry (*Sambucus canadensis*). Because of the nitrogen fixing capabilities of Alder and Black locust, they should be avoided within streamside or coastal areas if nitrogen reduction is part of the long-term management plan.

Container Vs Bare Root planting studies have been conducted by Sweeney (et al., 2002) with Pin, Red and White oak (wettest to driest tolerance), Red maple and River birch. They found container grown plants less prone to desiccation, poor handling during planting and allowed for planting from early spring to late fall as opposed to bare root seedlings. Larger tree stock, 3-5 feet tall, in containers verses bare rootstock also fared well in wetlands restoration applications (personal observations Jontos et al., 2003).

Diversity and Survivorship

Diversification of plant species within the buffer insures better success in response to variable environmental conditions (i.e., temperature, herbivory, water levels). Vegetation should be a mix of trees, shrubs and herbaceous plants native to the region and appropriate to the environment in which they are to be planted. Use adjacent reference riparian buffers as basis for selecting floral composition. (Fisher and Fischenich, 2000) This follows the USACE concept of reference wetlands for mitigation practices, and wetland banking.

Survivability of plantings can be improved significantly by the use of tree protection via "Tree Shelters" to protect against overtopping/shading by herbaceous growth or browsing by herbivores (rabbits, deer, mice) for first two to five years (Sweeney, 1992). Other protective measures include the use of deer fencing to restrict browsing (Ryder, 2004; Sesto, 2000).

Seedling survival rates of 89% have been attributable to use of 1.2 m tall plastic tree shelter combined with application of herbicides (Round-up© in uplands and Rodeo© in wetlands) applied within 1.0 m of the tree base during period of mid June & mid August to control invasives and weed competition. Alternative management techniques using tree shelters with 1.0 m weed mats resulted in 57% sapling survival rates (Sweeney, et. al., 2002).

Habitat Diversity

Accomplish habitat diversity by selecting different amounts and types of plants including herbaceous, shrubs, saplings, tree species, and emergents, as appropriate; create a range of elevational changes within the buffer area (microtopgraphy). Suggested species diversity guidelines for trees within a buffer have been provided by Fisher and Fischenich (2000), which suggests that if 10-19 trees are planted then the-maximum percentage of any one species should be 50%; for 20-39 trees, 33%; and if 40 or more trees are planted, the maximum number of any one species should be 25%.

Plant Numbers and Sizing

The initial number of plants introduced affects survivorship of plantings. Ideal minimum planting density for seedlings is ~~of~~ 400 seedlings per ac, with a size range of 10 inches to 48 inches in height and an expected 50% minimum survival rate after 4 growing seasons. 200 seedlings/acre with 15 foot height has been offered as an "acceptable minimum" by ~~(~~Pannill et al. 2001~~)~~. Sweeney, et al. (2002) recommends spacing the trees 4.5 meters (14.8 ft.) on center.

The use of intermediate size tree seedlings (1.0 -1.5 m) may reduce the negative impacts from browse and transplant shock and thus improve the survival rate. Increased survival in planting stock appears to justify the higher initial cost of planting of intermediate sized stock. (Fischer and Fischenich, 2000)

Initial tree and shrub planting should be based on plant closure within 3 years. Pioneer species may need to be removed to allow natural succession.

Management

Managed restoration of vegetative (forested) buffer strips vs. natural regeneration is desirable and or necessary at many locations because of previous site disturbance, invasive plant competition, poor seed source of desirable native species, the presence of browsing herbivores (deer, rabbits and mice) and protection of water quality (Sweeney, et. al., 2002)

For grassed filter strips NRCS (2000) suggests that following management actions be applied for the filtering of contaminants. These include:

1. Plants be harvested to encourage dense growth, maintain upright growth and remove nutrients and associated contaminants contained in the plant tissue;
2. Control of noxious weeds **-**Provide mechanical weed control via mowing, hand weeding and mulching, the area should be mowed or cut spring and fall (May and August) for first three to five years, thus preventing overtopping by herb growth and competition from invasives.
3. Use prescribed burning, when an approved burn plan has been developed;
4. Inspect filter after storm event, repair gullies, remove deposited sediment that will disrupt sheet flow, re-seed disturbed areas and other measures to maintain sheet flow;
5. Fertilize as necessary based on fertility analysis of soils, and;
6. Remove accumulated sediment and recreate microtopography, as needed.

5.0 Observations and Recommendations

The following observation and recommendation are offered to designers and regulators when considering the application of vegetative buffers for the protection or improvement of water quality. These include:

1. Vegetative buffers are an effective best management practice to reduce non-point source pollution. One size does not fit all and bigger is not necessarily better.
2. Vegetation within the buffers (filter strips) provides a measure of erosion and sediment control and the removal of nutrients and other pollutants adsorbed to the surface of sediments or in solution in runoff from agricultural and urbanizing watersheds.
3. The effectiveness of a vegetative buffer is dependent on: 1) the species and density of vegetation, existing or introduced, 2) soil type within and above the buffer area, 3) slope of the buffer area and its contributing watershed, 4) the length (width of flow path) of the buffer and area ratio and 5) the proposed land use above the buffer area.
4. While vegetative buffers (filters strips) can be used as stand-alone BMPS for sediment attenuation and associated pollutant reduction, they are more effective when used in combination with other short and long-term BMPs.
5. Long continuous buffers are more effective in treating surface runoff than segment buffers. Buffer width (length of flow path) may be variable depending on site conditions and design functions.
6. A combined filter strip composed of an initial grass filter strip followed by a shrub filter strip is more effective in removing sediment loads, adsorbed nutrients and other non-point source pollutants or pollutants in solution and maintaining the infiltrative capacity of the soil within the filter strip.

7. Native species of vegetation should be used to enhance the species composition of a vegetative buffer in combination with long-term management goals. Reforestation (s*uccessful and stable community)* of riparian areas can be accomplished in 10 years or less (Sweeney, 1992). ...

8. Infiltration of runoff is a key factor in reducing sediment and adsorbed pollutants (e.g., herbicide, pesticides).

9. The “area ratio”, area of contributing runoff area (watershed) to the area of vegetative buffer (filter strip) is important in sustaining the efficiency of the vegetative buffer’s filtering capacity for sediment and associated pollutants. The smaller ratios (5:1) are more effective in reducing pollutant loads.

10. The length (width) of the vegetative buffer also affects its performance. Generally, the filtering capacity increases with an increase in buffer width (flow length). As the Massachusetts Department of Environmental Protection states “Any buffer is better than no buffer at all.” Minimum buffer widths of 5m (16 ft) to 15m (49 ft) have been shown to be effective in reducing sediment loads and protecting water quality.

    On gently sloping land (<10%), in an urbanized environment near a watercourse or wetland and residential use and limited available area, a 5m wide vegetative buffer composed of grass is capable of removing significant amounts of sediment and non-point source pollutants.

    In a watershed being considered for development with slope conditions of 10% or less and a typical transition of soils groups, a minimum buffer width of 10m (33 ft) will accomplish the intended goals of sediment and non-point source attenuation. When a slope condition exceeds 10%, or the regulated area (wetland or watercourse) contains moderate to high functional values or is deemed a critical habitat (i.e., bog, fen, tidal or wetland complex) or water quality is a critical issue (e.g., public water supply watershed or impaired watercourse), then a minimum buffer width of 10m (50 ft) or greater should be considered.

11. The functional goals of the vegetative buffer must be clearly defined and a management plan prepared to establish and maintain those functional goals both during and following development activies.

This concludes version 1.0 of the Connecticut Association of Wetland Scientist (CAWS) Vegetative Buffer white paper. It is fervently hoped that application of these practices and continued field observations and research will improve our knowledge of buffer function and management resulting in future expansion of topics and updates to this document. Practitioners, regulators and researchers are encouraged to comment on the content of this document and contribute to its content.

Robert Jontos, PWS on behalf of the White Paper Review Committee and CAWS