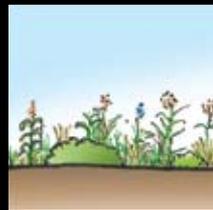
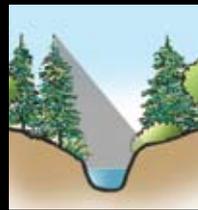
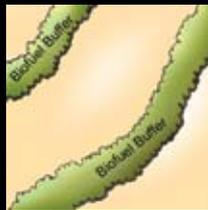
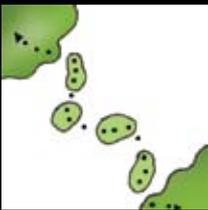
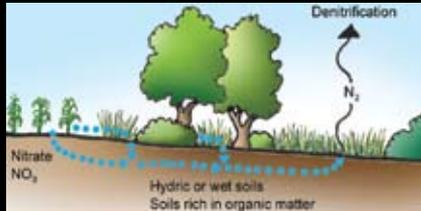
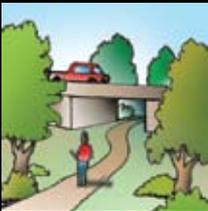
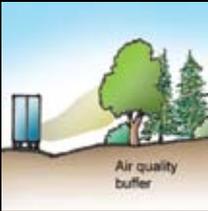




# Conservation Buffers



## Design Guidelines for Buffers, Corridors, and Greenways



## Abstract

**Bentrup, G.** 2008. Conservation buffers: design guidelines for buffers, corridors, and greenways. Gen. Tech. Rep. SRS-109. Asheville, NC: Department of Agriculture, Forest Service, Southern Research Station. 110 p.

Over 80 illustrated design guidelines for conservation buffers are synthesized and developed from a review of over 1,400 research publications. Each guideline describes a specific way that a vegetative buffer can be applied to protect soil, improve air and water quality, enhance fish and wildlife habitat, produce economic products, provide recreation opportunities, or beautify the landscape. These science-based guidelines are presented as easy-to-understand rules-of-thumb for facilitating the planning and designing of conservation buffers in rural and urban landscapes. The online version of the guide includes the reference publication list as well as other buffer design resources [www.bufferguidelines.net](http://www.bufferguidelines.net).

**Keywords:** Buffer, conservation planning, conservation practice, corridor, filter strip, greenway, riparian, streamside management zone, windbreak.

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**National  
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Center**



# Table of Contents

Acknowledgments .....	ii
<b>USING THE GUIDE</b>	
Purpose of this Guide .....	1
The Guide Online .....	2
Limitations of this Guide .....	2
Landscape Design Concepts .....	3
Planning Conservation Buffers .....	5
How to Use this Guide .....	11
<b>DESIGN GUIDELINES</b>	
1. <b>Water Quality</b> .....	15
2. <b>Biodiversity</b> .....	43
3. <b>Productive Soils</b> .....	61
4. <b>Economic Opportunities</b> .....	67
5. <b>Protection and Safety</b> .....	77
6. <b>Aesthetics and Visual Quality</b> .....	89
7. <b>Outdoor Recreation</b> .....	99
Glossary .....	107



Click Here

- Online version with over 1400 references
- Online slideshow with guidelines
- Additional buffer design resources

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## PURPOSE OF THIS GUIDE

Conservation buffers are strips of vegetation placed in the landscape to influence ecological processes and provide a variety of goods and services to us. They are called by many names, including wildlife corridors, greenways, windbreaks, and filter strips to name just a few (fig. 1).

Benefits that conservation buffers provide to us include protecting soil resources, improving air and water quality, enhancing fish and wildlife habitat, and beautifying the landscape. In addition, buffers offer landowners an array of economic opportunities including protection and enhancement of existing enterprises.

A large body of scientific knowledge exists to help guide the planning and designing of buffers. Unfortunately, this information is widely dispersed throughout the vast repositories of research literature and is not easily accessible or usable for most planners.

The purpose of this publication is to provide a synthesis of this diverse knowledge base into distilled, easy-to-understand design guidelines.



Figure 1—Conservation buffers in an agricultural landscape.

## The Guide Online

Over 80 design guidelines were developed from more than 1,400 research articles from disciplines as diverse as agricultural engineering, conservation biology, economics, hydrology, landscape ecology, social sciences, and urban ecology.

These articles are cited in the online version of this guide. These references can serve as a valuable resource for additional design information.



- Online version with over 1400 references
- Online slideshow with guidelines
- Additional buffer design resources

## Limitations Of This Guide

This guide is not a cookbook for design. Some of the guidelines reflect many years of research and are offered with a high level of confidence while other guidelines are based on limited research and reflect a greater degree of extrapolation to generalize them. There are still many gaps in our understanding of buffers and their ecological and socioeconomic functions and impacts. The planner must weave these guidelines together with first-hand knowledge of the site, the landscape, and landowner goals to create a design that optimizes benefits and minimizes potential problems.

Consequently, this guide should not serve as a sole source for design information but rather as a means to facilitate and communicate the design process. Additional resources, standards, and expert advice should be consulted as appropriate.

## Landscape Design Concepts

One method of describing landscapes divides a landscape into three basic elements: patches, corridors or buffers, and matrix (fig. 2).



Figure 2—The landscape described in basic landscape ecology terms.

**Patch:** A relatively small area that has distinctly different structure and function than the surrounding landscape.

**Corridor or Buffer:** A linear patch typically having certain enhanced functions due to its linear shape (see box on next page).

**Matrix:** The background within which patches and buffers exist.

In developed landscapes, patches are often remnant areas of woodland or prairie; corridors are linear elements such as windbreaks, fencerows, and riparian areas; and the matrix is often developed lands such as cropland or urban areas.

While this guide focuses on designing buffers, the patches and matrix areas must be considered in the design process to help achieve many desired objectives. Location, structure, and management of nearby patches and matrix influence the types of functions that buffers will perform and their effectiveness.

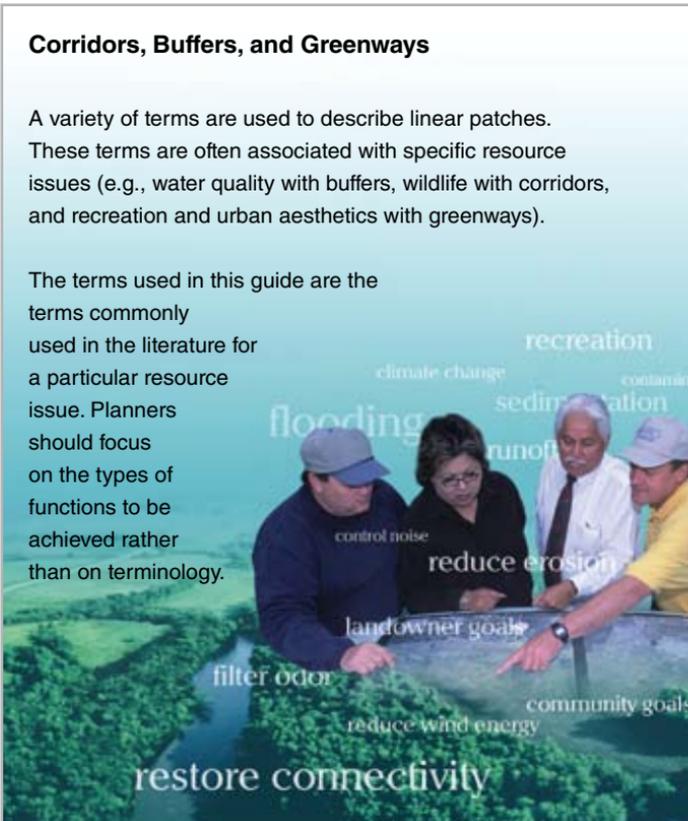
Buffer installations may be ineffective if they are designed without an understanding of landscape processes. For example, buffers installed for streambank stabilization may be ineffective in an urbanizing watershed unless they account for stream flows that are dramatically increasing due to impervious cover.

Buffers are only one tool in the planner's tool box. Planners need to be realistic in applying buffers, acknowledging both the strengths and limitations of buffers to solve and manage resource concerns.

### **Corridors, Buffers, and Greenways**

A variety of terms are used to describe linear patches. These terms are often associated with specific resource issues (e.g., water quality with buffers, wildlife with corridors, and recreation and urban aesthetics with greenways).

The terms used in this guide are the terms commonly used in the literature for a particular resource issue. Planners should focus on the types of functions to be achieved rather than on terminology.



# Planning Conservation Buffers

## Functions

Conservation buffers improve resource conditions by enhancing certain landscape functions. Major issues that buffers can be designed to address and their associated functions are listed in table 1.

Most buffers will perform more than one function, even if designed with only one function in mind. Buffer design should take into account intended functions as well as unintended ones that may or may not be desirable.

## Location

Location determines a buffer's juxtaposition to problem conditions in the surrounding landscape. It also determines important site characteristics, such as soil type and slope, that can influence how effective a buffer can be. One location may be better for one function, while a different location would be better for another function (fig. 3).

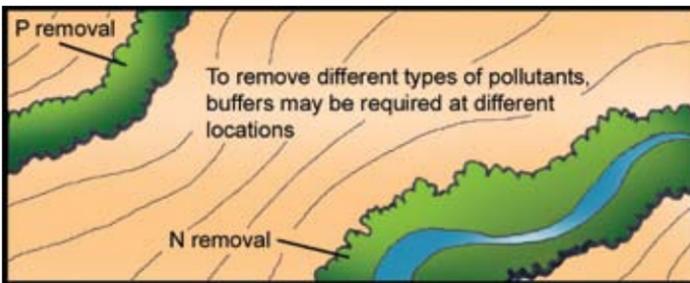


Figure 3—Buffer location will determine actual functions.

Geographic Information Systems (GIS) can be used for identifying suitable locations for buffers. By querying the landscape for site factors required for a desired function, better locations can be identified where an objective can be addressed with a buffer. GIS is particularly useful for identifying locations where a buffer can serve multiple functions.

For more information on GIS and buffer planning and design, go to [www.bufferguidelines.net](http://www.bufferguidelines.net).

**Table 1—Buffer functions related to issues and objectives**

<b>Issue and Objectives</b>	<b>Buffer Functions</b>
<b>Water Quality</b>	
Reduce erosion and runoff of sediment, nutrients, and other potential pollutants	Slow water runoff and enhance infiltration Trap pollutants in surface runoff Trap pollutants in subsurface flow
Remove pollutants from water runoff and wind	Stabilize soil Reduce bank erosion
<b>Biodiversity</b>	
Enhance terrestrial habitat	Increase habitat area Protect sensitive habitats
Enhance aquatic habitat	Restore connectivity Increase access to resources Shade stream to maintain temperature
<b>Productive Soils</b>	
Reduce soil erosion	Reduce water runoff energy Reduce wind energy
Increase soil productivity	Stabilize soil Improve soil quality Remove soil pollutants
<b>Economic Opportunities</b>	
Provide income sources	Produce marketable products Reduce energy consumption
Increase economic diversity	Increase property values
Increase economic value	Provide alternative energy sources Provide ecosystem services
<b>Protection and Safety</b>	
Protect from wind or snow	Reduce wind energy
Increase biological control of pests	Modify microclimate
Protect from flood waters	Enhance habitat for predators of pests Reduce flood water levels and erosion
Create a safe environment	Reduce hazards
<b>Aesthetics and Visual Quality</b>	
Enhance visual quality	Enhance visual interest Screen undesirable views
Control noise levels	Screen undesirable noise
Control air pollutants and odor	Filter air pollutants and odors Separate human activities
<b>Outdoor Recreation</b>	
Promote nature-based recreation	Increase natural area Protect natural areas Protect soil and plant resources
Use buffers as recreational trails	Provide a corridor for movement Enhance recreational experience

## Structure

Structural characteristics of a buffer such as size and shape and the structure of the vegetation largely determine how well a buffer is capable of functioning at a given location. Planners can manipulate these variables to achieve desired objectives. The guidelines in this publication address many of these design and management considerations.

## Systems

Buffers are typically designed to achieve multiple objectives—objectives of individual landowners, the community, and general public. Often multiple objectives must be addressed by multiple buffers with different designs in different locations, creating a system of buffers.

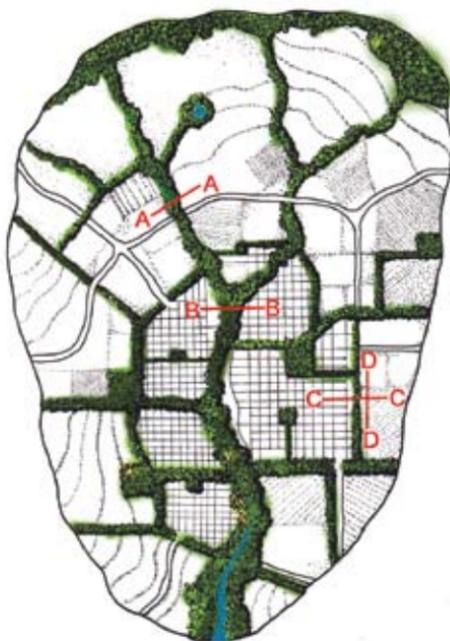
Each objective has its own scale, and each buffer function operates at its own scale. It's a complex task to address multiple objectives and functions. A planning process is a structured method to organize and conduct this task and ensure that all objectives are addressed. The result is called a landscape plan.

A typical planning process includes the following steps:

- Identifying problems and opportunities
- Determining objectives
- Inventorying resources
- Analyzing resources
- Developing alternatives
- Evaluating alternatives and making decisions
- Implementing the plan
- Evaluating the plan

For more information on planning processes, go to [www.bufferguidelines.net](http://www.bufferguidelines.net). Figure 4 illustrates a conceptual buffer landscape plan developed through a planning process. The following page provides a brief description of the plan.

Figure 4—Conceptual plan and sections illustrating several types of conservation buffers in a watershed. Each buffer accomplishes different sets of functions and objectives.



**Section A-A**



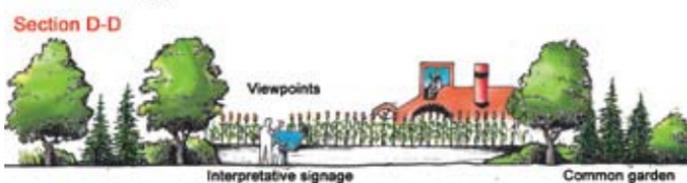
**Section B-B**



**Section C-C**



**Section D-D**



The buffer plan (fig. 4) demonstrates how the buffer location in the watershed plays a key role in determining the functions and objectives for a particular segment of the buffer system.

**Section A-A:** a buffer designed to filter agricultural runoff to reduce a community's drinking water treatment costs. This buffer provides habitat and a conduit for wildlife while offering a public recreational trail.

**Section B-B:** a buffer in a more urbanized area. A constructed wetland in the buffer treats runoff before it flows into the stream. An active recreation area in the buffer provides a firebreak to protect homes. Wildlife still benefits from this buffer, but this objective plays a less significant role than in Section A-A due to the buffer location.

**Section C-C:** a buffer between an agricultural field and a residential area. This buffer serves as a common garden for both rural and urban residents. Noise control and protection from agricultural spray is also provided by the buffer. Products such as fruits, nuts, and Christmas trees can be harvested from the buffer.

**Section D-D:** a buffer illustrating how the buffer in Section C-C provides aesthetic views at selected locations. Other aesthetic considerations are incorporated in the design to encourage human use. Signage informs residents about conservation measures being used to protect natural resources.

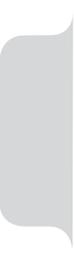
In summary:

- Consider the landscape context when designing buffers
- Design each buffer for multiple objectives
- Be aware of potential unintended effects of buffers
- Recognize the benefits and limitations of buffers
- Use a planning process

To begin using this guide, refer to the **How to Use This Guide** section.







## HOW TO USE THIS GUIDE

This guide provides science-based guidelines for designing buffers. The guidelines are organized into seven resource sections:

1. Water Quality
2. Biodiversity
3. Productive Soils
4. Economic Opportunities
5. Protection and Safety
6. Aesthetics and Visual Quality
7. Outdoor Recreation

A simple step-by-step process is suggested for using the guide effectively.

### Using the Buffer Design Guidelines

1. Identify resource issues of concern
  2. Select desired buffer functions for each issue from table 1
  3. Refer to the resource section for guidelines that address each desired buffer function
  4. Prepare a preliminary buffer plan or design
  5. Refine the plan using other resources as necessary
1. Issues of concern and related objectives should be identified with assistance of the landowner or stakeholder group using a planning process. Record the objectives (see table 2 for an example).

Table 2—Example table used to organize a project’s objectives, the desired buffer functions, and the applicable design guidelines

Objectives	Buffer Functions	Guidelines To Consider
Reduce 50 percent of nitrogen from runoff and shallow groundwater flow	Slow water runoff and enhance infiltration Trap pollutants in surface runoff Trap pollutants in subsurface flow	1.1, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 1.12, 1.15, 1.19, 1.20, 1.21, 1.26, 2.7, 2.9, 3.1
Enhance habitat for salamanders to increase local population by 10 percent	Increase habitat area Protect sensitive habitats Restore connectivity	2.1, 2.2, 2.3, 2.4, 2.5, 2.8, 2.9, 2.10, 2.11, 2.12, 1.4, 1.14, 5.3
Reduce soil erosion by 50 percent	Reduce water runoff energy Reduce wind energy Stabilize soil	3.1, 3.2, 3.3, 1.1, 1.4, 1.6, 4.3, 4.4, 5.9
Produce five woody products for the decorative floral industry	Produce marketable products	4.1, 4.2, 4.4, 3.2
Increase biological pest control of aphids and thrips	Enhance habitat for predators of pests Modify microclimate	5.1, 5.2, 5.3, 2.1, 2.2, 2.9, 3.2, 3.3, 4.4
Enhance the views from the landowner’s residence	Enhance visual interest Screen undesirable views	6.1, 6.5, 6.6, 6.7, 2.1, 2.9, 2.1, 3.2

2. Based on the identified issues and objectives, select the appropriate buffer functions from table 1 and record these functions (see table 2 for an example).
3. Refer to each resource section and select guidelines that address the desired buffer functions using the guideline-function matrix (fig. 5). Use the additional design guideline-function matrix (fig. 6) to identify guidelines in the other resource sections that may be useful. Record the guideline numbers (see table 2 for an example).
4. Use the selected guidelines to prepare a preliminary buffer plan. Compromises and trade-offs may be necessary to address all of the objectives and buffer functions.
5. Optional step: Refer to the referenced publications used to develop the guidelines. The online version of this guide provides over 1,400 references ([www.bufferguidelines.net](http://www.bufferguidelines.net)). These publications may provide additional design information, including more detailed design criteria for specific geographic regions. Use other printed and Web resources, experts, and personal experience to refine the buffer plan.

Implement the plan and monitor the results over time. Make adjustments to the buffer design and future buffer plans based on the monitoring.

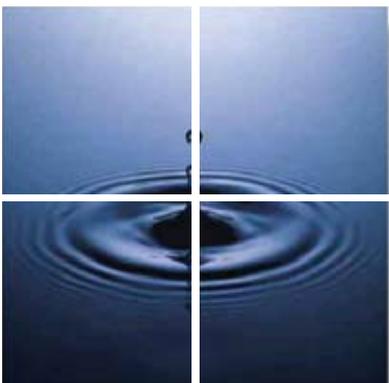


<b>Design Guidelines for Water Quality</b>	<b>Buffer Functions</b>				
	Slow water runoff and enhance infiltration	Trap pollutants in surface runoff	Trap pollutants in subsurface flow	Stabilize soil	Reduce bank erosion
<b>Location and Arrangement</b>					
1.1 Buffers and land management	✓	✓	✓	✓	✓
1.2 Karst landscapes	✓	✓	✓		
1.3 Frozen soils	✓	✓	✓		
1.4 Target buffers in watersheds	✓	✓	✓	✓	✓
1.5 Arrangement near sources	✓	✓	✓		
1.6 Buffer site design	✓	✓	✓	✓	✓
<b>Size and Pollutant Type</b>					
1.7 Variable buffer width	✓	✓	✓		

Figure 5— An example of a guideline-function matrix.

<b>Additional Design Guidelines that may Benefit Water Quality</b>	<b>Buffer Functions</b>				
	Slow water runoff and enhance infiltration	Trap pollutants in surface runoff	Trap pollutants in subsurface flow	Stabilize soil	Reduce bank erosion
2.1 Matrix primer	✓	✓	✓	✓	
2.2 Patch primer	✓	✓	✓	✓	
2.9 Corridor width	✓	✓	✓	✓	✓
2.11 Aquatic habitat and buffers	✓	✓	✓	✓	✓
2.12 Stream temperature and buffers		✓			
3.1 Buffers and cropland management	✓	✓		✓	
3.2 Windbreaks for wind erosion				✓	

Figure 6— An example of an additional design guideline-function matrix.







# 1. Water Quality

## Objectives

- Reduce erosion and runoff of sediment, nutrients, and other potential pollutants
- Remove pollutants from water runoff and wind

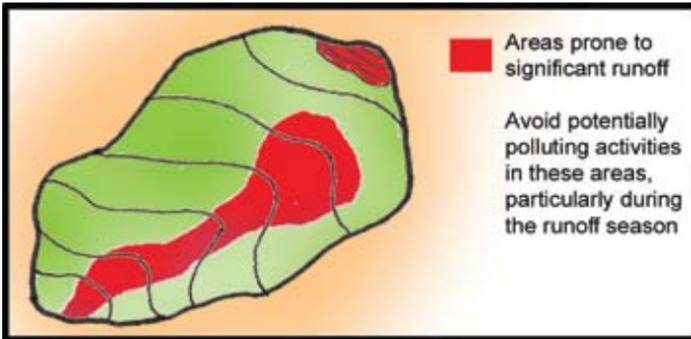
## Buffer functions

1. Slow water runoff and enhance infiltration
2. Trap pollutants in surface runoff
3. Trap pollutants in subsurface flow
4. Stabilize soil
5. Reduce bank erosion

Design Guidelines for Water Quality	Buffer Functions				
	Slow water runoff and enhance infiltration	Trap pollutants in surface runoff	Trap pollutants in subsurface flow	Stabilize soil	Reduce bank erosion
<b>Location and Arrangement</b>					
1.1 Buffers and land management	✓	✓	✓	✓	✓
1.2 Karst landscapes	✓	✓	✓		
1.3 Frozen soils	✓	✓	✓		
1.4 Target buffers in watersheds	✓	✓	✓	✓	✓
1.5 Arrangement near sources	✓	✓	✓		
1.6 Buffer site design	✓	✓	✓	✓	✓
<b>Size and Pollutant Type</b>					
1.7 Variable buffer width	✓	✓	✓		

<b>Design Guidelines for Water Quality</b>	<b>Buffer Functions</b>				
	Slow water runoff and enhance infiltration	Trap pollutants in surface runoff	Trap pollutants in subsurface flow	Stabilize soil	Reduce bank erosion
<b>Size and Pollutant Type (cont.)</b>					
1.8 Effective buffer area ratio	✓	✓	✓		
1.9 Slope and soil type adjustments	✓	✓			
1.10 Buffers for sediment	✓	✓		✓	
1.11 Buffers for pathogens	✓	✓			
1.12 Buffers for nitrogen	✓	✓	✓		
1.13 Buffers for phosphorus	✓	✓			
1.14 Buffers for pesticides	✓	✓	✓		
1.15 Buffers for shallow groundwater			✓		
1.16 Urban runoff and roadsides	✓	✓	✓		
1.17 Buffers and grazing		✓		✓	✓
1.18 Allowances for bank erosion		✓		✓	✓
1.19 Buffer width design tool	✓	✓			
<b>Vegetation</b>					
1.20 Vegetation for removing pollutants	✓	✓	✓		
1.21 Stiff-stemmed grass barriers	✓	✓			
1.22 Vegetation for bank erosion control				✓	✓
1.23 In-Stream pollutant removal		✓			
1.24 Species selection	✓	✓	✓	✓	✓
<b>Management</b>					
1.25 Sediment removal	✓	✓			
1.26 Harvesting for nutrient removal	✓	✓	✓		
1.27 Plant succession	✓	✓	✓		
1.28 Vegetation and traffic	✓	✓			

Additional Design Guidelines that may Benefit Water Quality	Buffer Functions				
	Slow water runoff and enhance infiltration	Trap pollutants in surface runoff	Trap pollutants in subsurface flow	Stabilize soil	Reduce bank erosion
2.1 Matrix primer	✓	✓	✓	✓	
2.2 Patch primer	✓	✓	✓	✓	
2.9 Corridor width	✓	✓	✓	✓	✓
2.11 Aquatic habitat and buffers	✓	✓	✓	✓	✓
2.12 Stream temperature and buffers		✓			
3.1 Buffers and cropland management	✓	✓		✓	
3.2 Windbreaks for wind erosion				✓	
3.3 Herbaceous wind barriers				✓	
3.5 Phytoremediation buffers	✓	✓	✓	✓	
5.7 Buffers and spray drift		✓			



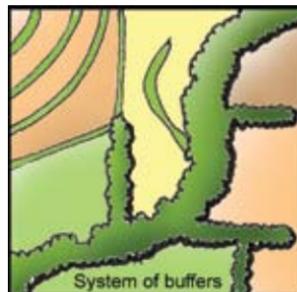
## 1.1 Buffers and land management

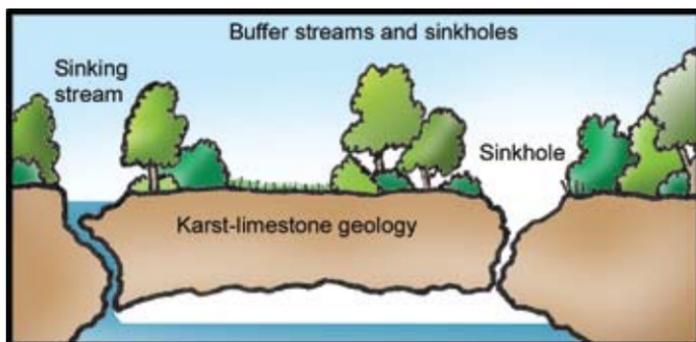
Water quality goals may not be achievable with buffers unless the adjacent land uses are also managed for better water quality. There are many ways that pollutant loads can be reduced from adjacent land uses. Refer to other publications for guidance. See general management considerations.

In some cases, it may be that inappropriate land management practices in just a few areas within a watershed are contributing a majority of the water quality problems. Targeting better land management practices in these few, select areas may yield significant improvements (see section 1.4).

### General management considerations

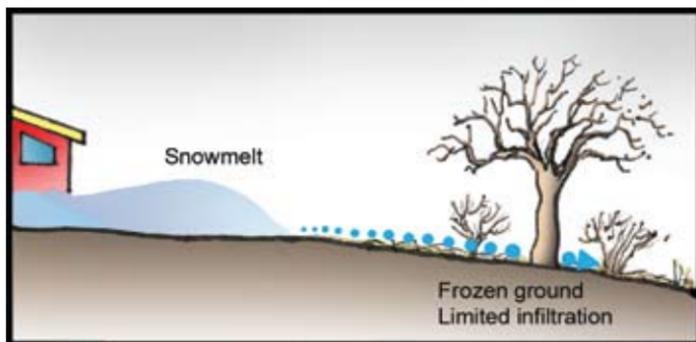
- Manage land to reduce runoff and increase infiltration.
- Maintain vegetative cover as much as possible.
- Avoid potentially polluting activities on areas most prone to generating significant runoff.
- Minimize potentially polluting activities during times of year most prone to generating runoff.
- Use a system of upland buffers to reduce runoff and pollutant load to riparian buffers.





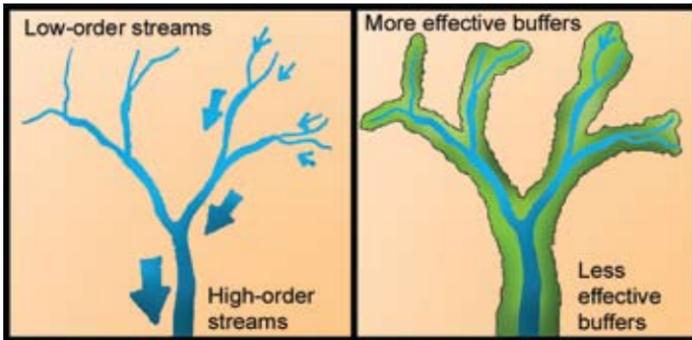
## 1.2 Karst landscapes

Karst or limestone dominated landscapes are particularly susceptible to water quality problems due to the direct and often short connections between surface water and groundwater. Buffers can be used around sinkholes and sinking streams to minimize polluted runoff entering directly into the groundwater system.



## 1.3 Frozen soils

In regions where runoff occurs while the soil is frozen, buffers will be much less effective due to limited infiltration. Other best management practices will need to be used in addition to buffers.

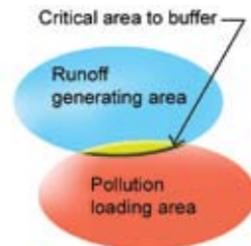


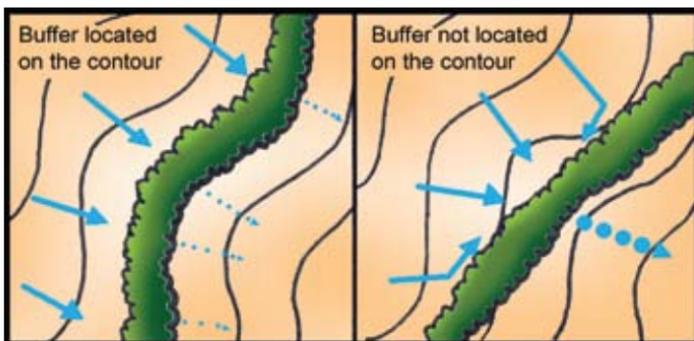
## 1.4 Target buffers in watersheds

Water quality buffers will be more effective in some areas than in others. Targeting buffers to areas that have high pollutant loads and suitable characteristics for pollutant removal will generally have the greatest benefit on water quality.

### General targeting considerations

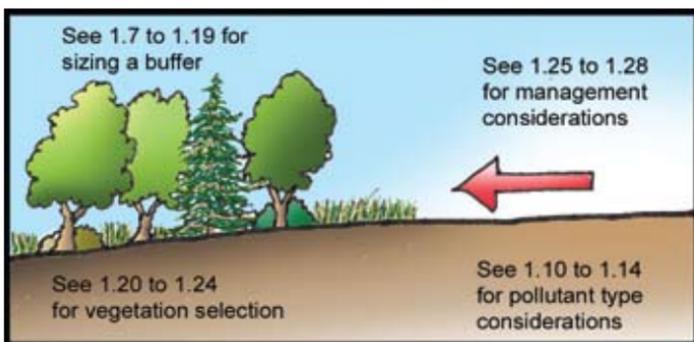
- Riparian buffers will often be more effective along small or low-order streams than larger or high-order streams since most water delivered to channels from uplands enters along low-order streams.
- Groundwater recharge areas, ephemeral channels, and other areas where runoff collects are important areas to buffer.
- In some regions, surface runoff is generated primarily from areas that become saturated during storms. Where these runoff source areas correspond to a pollution loading area, such as a cultivated field, these areas should be buffered.
- Surface runoff from cultivated areas is higher where slopes are steeper and soils are finer-textured. These areas are important to buffer.
- GIS are useful for conducting landscape-scale assessments to target buffers.





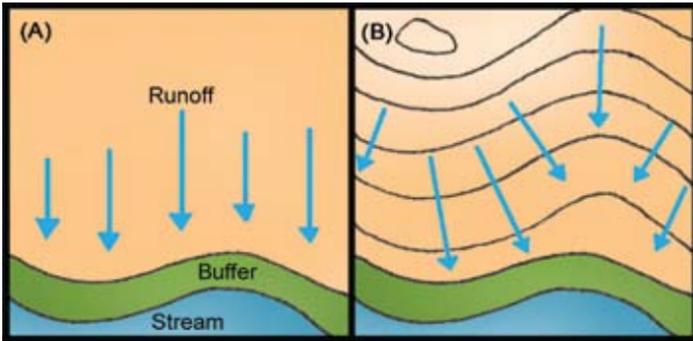
## 1.5 Arrangement near sources

Buffers should be located as close as possible to the pollution source and should be placed along the contour to promote shallow flow across the buffer. If the contour is not closely followed, a buffer may increase concentration of runoff flow and reduce buffer effectiveness. Grass barriers can help spread out concentrated flows (see section 1.21).



## 1.6 Buffer site design

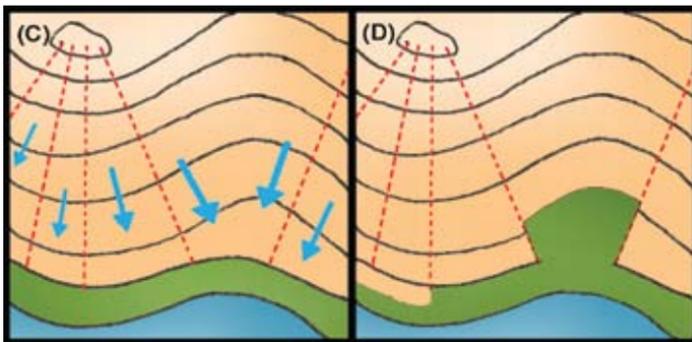
Important design elements for any buffer include its size, the kind of vegetation it contains, and how it is managed. Each of these elements is dictated by site factors including pollutant type and load, the buffer's capacity to trap and transform these pollutants and the desired level of pollution reduction. Use the figure above as a road map to guidelines on site design.



## 1.7 Variable buffer width

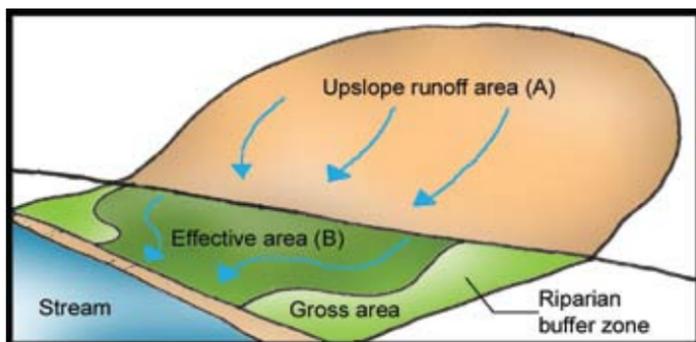
Buffers may have a fixed width where uniform runoff occurs (A). However, runoff is often nonuniform and flow is either diverging or converging due to topography, tillage practices, and other factors (B). A fixed-width buffer will be less effective in these situations.

Instead, buffer width should be variable by widening and narrowing the buffer as runoff loads and buffer site conditions vary.



Runoff areas and corresponding buffer locations to which they flow can be mapped (C). Buffer width can then be modified to account for differences in runoff loads (D). Buffers will need to be wider for upslope runoff areas that are larger and contribute greater loads.

The ratio of the upslope runoff area to buffer area can provide additional design guidance (see section 1.8).



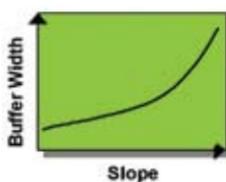
## 1.8 Effective buffer area ratio

The amount of runoff through an area of buffer should be low to achieve high pollutant removal. One consideration is to base the design on a ratio of upslope runoff area (A) to effective buffer area (B). Lower ratios (e.g., 20:1) can provide substantially greater pollutant removal than higher ratios (e.g., 50:1) in many cases. Note that the effective buffer area is the actual pathway that runoff travels to the stream and it may be smaller than the overall gross area of the buffer.

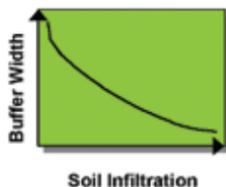
## 1.9 Slope and soil type adjustments

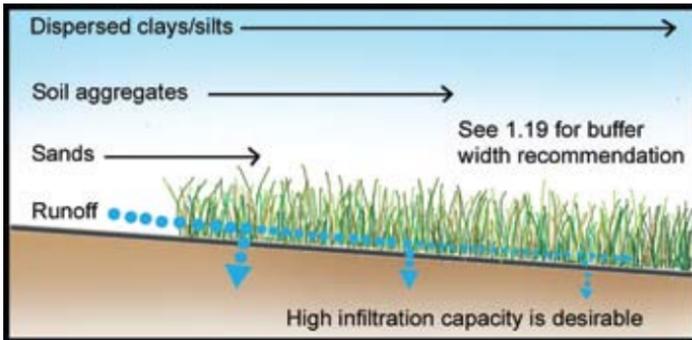
Land slope and soil type have significant impact on the ability of a buffer to remove pollutants from surface runoff.

Steeper slopes reduce performance by allowing greater pollutant transport and less time for infiltration. Steeper slopes will require wider buffers.



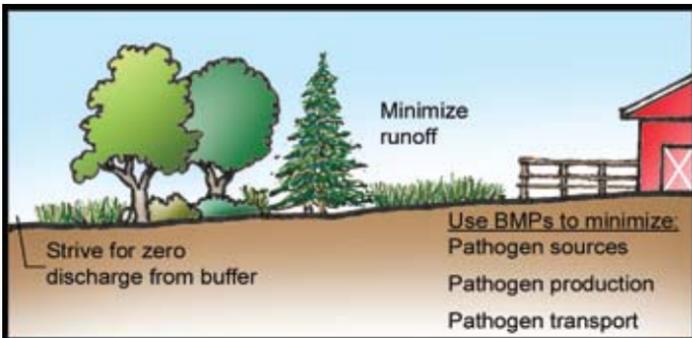
Soils with higher infiltration capacity can reduce runoff to a greater degree than soils having lower infiltration. Soils with lower infiltration capacity will require wider buffers. Finer-textured soils typically have lower infiltration than sandy soils.





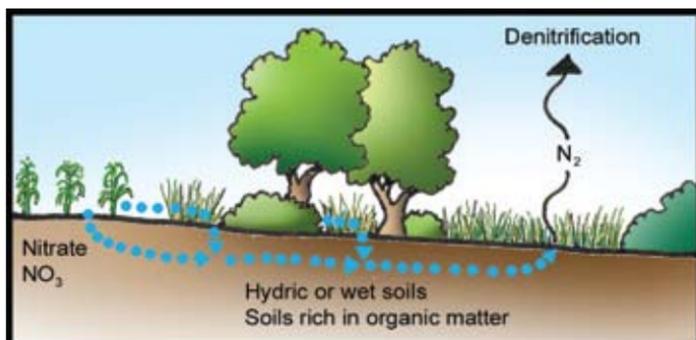
### 1.10 Buffers for sediment

Sediment is the pollutant most effectively removed from runoff by buffers. Coarse-textured sediments will settle out first while finer particles will require wider buffers to be removed. Buffers for sediment trapping should only be used as a final defense. Soils first need to be kept in place as much as possible with sediment and erosion control best management practices. See section 1.25 for managing sediment build-up.



### 1.11 Buffers for pathogens

Buffers can reduce pathogens in surface runoff from urban lands, pastures, manure-applied fields, and confined animal feeding operations but are generally ineffective by themselves to meet water quality standards. Buffers need to be combined with other best management practices to meet standards.



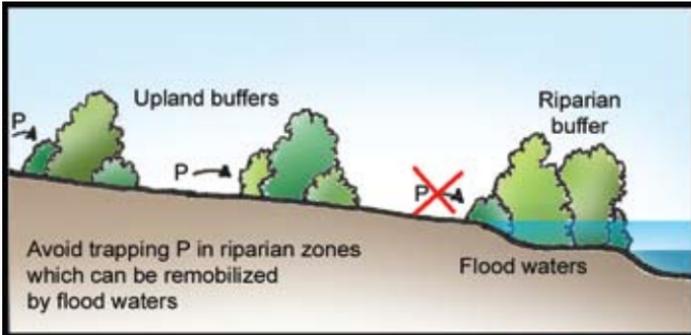
## 1.12 Buffers for nitrogen

Most nitrogen (N) is lost to surface water through overland flow and to groundwater by leaching of nitrate ( $\text{NO}_3$ ). Plant uptake of N generally does not result in permanent removal as N is eventually returned to the soil upon death and decay of plants unless harvested (see section 1.26).

Denitrification is the primary process for permanently removing N with a buffer. In denitrification, anaerobic bacteria transform nitrate to nitrogen gas ( $\text{N}_2$ ) which is released into the atmosphere. Below are some key site characteristics that promote effective denitrification with buffers.

### Key design considerations

- Soils should be rich in organic matter, often provided by decaying plant material.
- Soils need to be wet or hydric.
- Soils should have moderate to high permeability to encourage infiltration and yet should be poorly drained to have anaerobic conditions. Deep coarse sands or gravel may allow dispersion to deeper groundwaters before denitrification occurs.
- Low temperatures and acidic soils will inhibit denitrification.
- See section 1.19 for buffer width recommendations for surface N runoff.
- See section 1.15 for shallow groundwater flow.



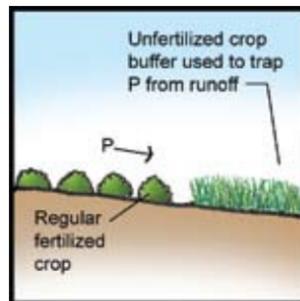
### 1.13 Buffers for phosphorus

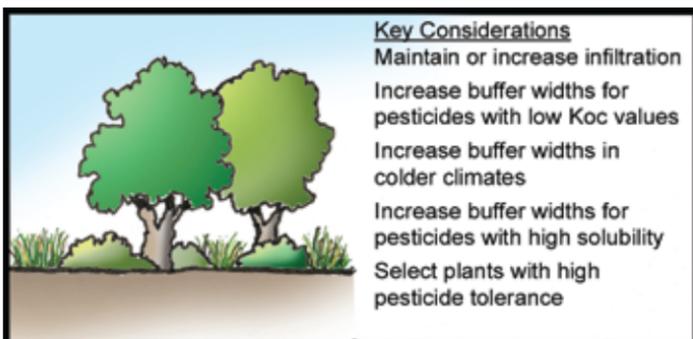
Phosphorus (P) in runoff occurs either as particulate phosphorus or as dissolved phosphorus. Particulate phosphorus is sediment-bound and can be moderately well trapped by deposition in buffers. Dissolved phosphorus must infiltrate with runoff water and be trapped in the soil.

Unlike N which can be released to the atmosphere through denitrification, P will accumulate in the buffer. Once a buffer is saturated with P, it can turn into a source for P. Other best management practices will be necessary to manage phosphorus.

#### Key design considerations

- Avoid trapping P in riparian buffers which can be remobilized by floodwaters.
- See section 1.19 for buffer width recommendations.
- Buffers consisting of unfertilized crops or hayfields can trap and utilize P. Removing this vegetation through harvest may help export P, as well as N, out of the watershed (see section 1.26). Select plants with high nutrient demand.





## 1.14 Buffers for pesticides

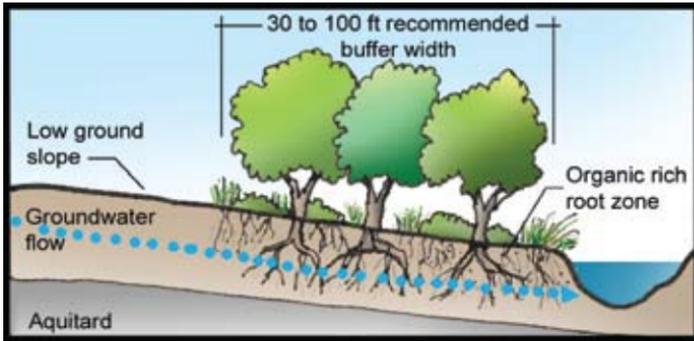
Pesticides in runoff occur either as sediment-bound or in a dissolved form. Dissolved pesticides are generally the most susceptible to leaving an application area and becoming a pollution problem. Pesticide properties can provide some guidance on the mobility of the pesticide.

### Key design considerations

- Some pesticides adsorb strongly to soils while others adsorb weakly as noted by the Koc value or soil adsorption index. See table below for recommendations.
- Pesticides with high water solubilities (e.g., > 30 ppm) will generally require wider buffers.
- Pesticides with longer half lives (e.g., > 30 days) may require wider buffers.
- Other pesticide best management practices should be used in addition to buffers (see sections 5.1 to 5.4).
- See section 1.19 for buffer width recommendations.

Pesticide properties can be found on product labels.

Koc Value Influence on Buffers for Pesticides		
Koc Value	Adsorption and Movement	Buffer Recommendation
< 500	Adsorbs weakly, movement with water	Maximize water infiltration and runoff contact time with soil and vegetation Generally requires wider buffers
> 500	Adsorbs strongly, movement with sediment	Maximize sediment trapping in buffer Narrower buffers may be sufficient



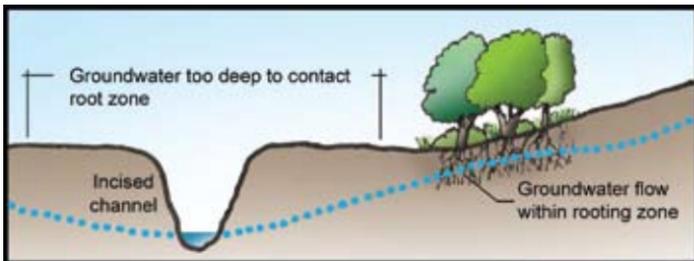
### 1.15 Buffers for shallow groundwater

Buffers may contact shallow groundwater and through various processes, remove some pollutants transported in it.

Nitrate	<i>Removal rates can be &gt; 75 percent</i>
Dissolved phosphorus	<i>Not effectively removed</i>
Pesticides	<i>Limited data at this time</i>

#### Key design considerations

- Shallow groundwater is typically found near streams, lake shores, and wetlands. Buffers are effective where/when shallow groundwater flows toward the stream (and not vice versa).
- Where groundwater emerges as a spring or seep, it may flow across the buffer zone too quickly to be effectively treated. A wider buffer may be necessary to allow for reinfiltration.
- Buffers along deeply incised streams may not intercept groundwater. Groundwater may be shallower in locations farther away from these streams. These areas may be effective locations for buffers to filter groundwater.

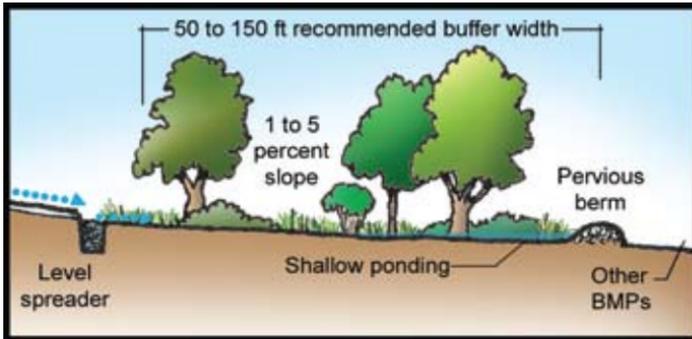


### Key design considerations *(continued)*

- Most nitrate reduction in shallow groundwater occurs within 30 to 100 feet of entering a buffer.
- The greatest nitrate removal occurs on sites where groundwater flow is confined within the root zone (shallower than about 3 feet) by a dense soil layer (aquiclude) or bedrock.
- Select plants with adequate rooting depth to intercept the groundwater flow.
- Select plants tolerant of seasonal water table fluctuations and with higher root biomass.
- Because natural groundwater flow patterns can be very complex, consult with appropriate professionals.
- In areas where groundwater drainage has been augmented with drain tile pipes or ditches, groundwater flow will often bypass buffers untreated. Placing constructed wetlands at the end of tile drains or ditches can help reduce this problem.



Buffers for Shallow Groundwater Pollution	
Variable	Factors Increasing Treatment Potential
Slope	Lower ground slope (0 to 3 percent)
Depth to Water Table	Shallower water table (0 to 3 ft below surface)
Hydric Soils	Present and occupying significant width ( $\geq 30$ feet of buffer width)
Proximity to Source	Buffer closer to the source of pollution
Soil Drainage Class (natural)	Very poorly-, poorly-, and somewhat poorly-drained ratings
Organic Matter	Soils with higher concentrations of organic matter



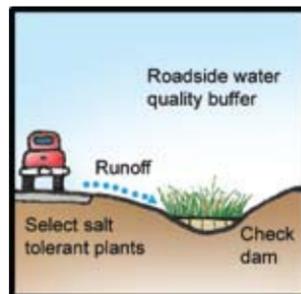
## 1.16 Urban runoff and roadsides

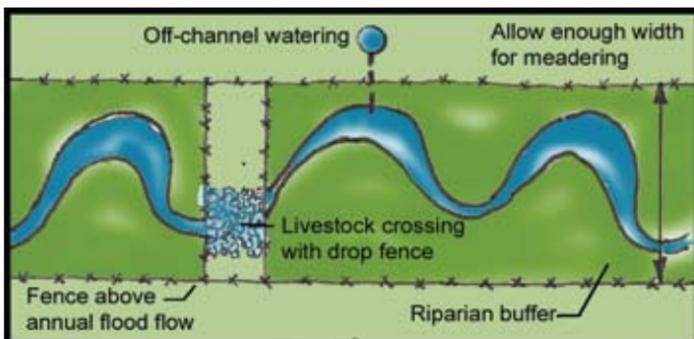
Buffers for urban runoff can be effective for trapping sediment but are generally less effective for dissolved pollutants. Buffers may be ineffective for urban stormwater where high runoff volume converges on and is channeled through the buffer. Buffers need to be designed to prevent flows from inundating or bypassing the buffer.

### Key design considerations

- Buffers are best suited for low to moderate density areas (< 20 percent impervious cover).
- Flow length into a buffer should be < 150 feet for pervious surfaces and < 75 feet for impervious surfaces.
- A level spreader can be used to disperse concentrated flow along the width of the buffer.
- Other best management practices should be used with buffers including low impact development that minimizes impervious cover.

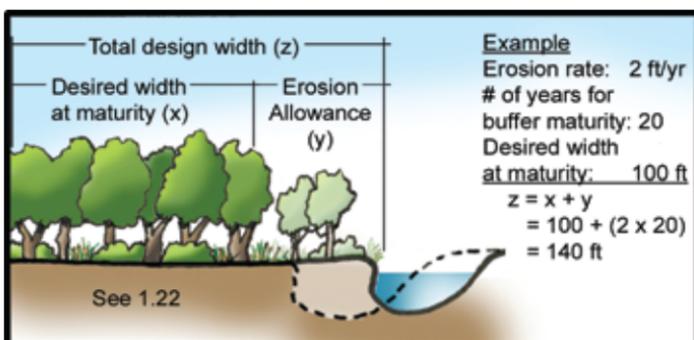
Vegetated roadside buffers can be used to improve water quality by filtering runoff. Use check dams to slow water movement and increase retention time. Select salt tolerant plants where road salt is used.





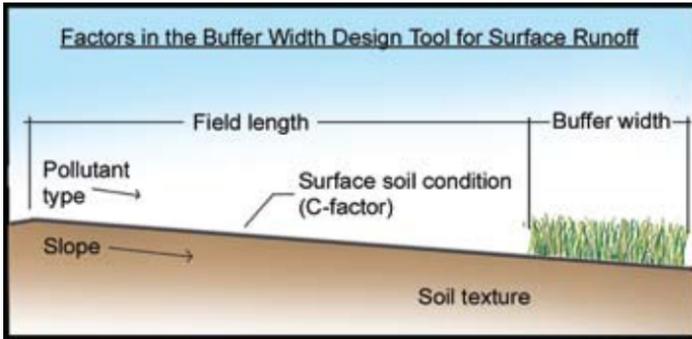
## 1.17 Buffers and grazing

Fencing riparian buffers from pastures is often necessary to protect water quality. Grazing has limited potential for nutrient removal from buffers (see section 1.26) and may accelerate bank erosion. Short duration grazing may be allowed within some riparian buffers. Grazing should not occur when soil is wet, when plants are emerging or setting seed, or when plant cover is limited or stressed by dry conditions.



## 1.18 Allowances for bank erosion

Buffers implemented for reducing streambank erosion may need to include additional width to allow for erosion while vegetation matures to the point where it becomes effective. Mature vegetation may not entirely halt streambank erosion since some erosion is natural. In severely degraded watersheds, vegetation alone will not reduce streambank erosion and other causes will need to be addressed.



## 1.19 Buffer width design tool for surface runoff

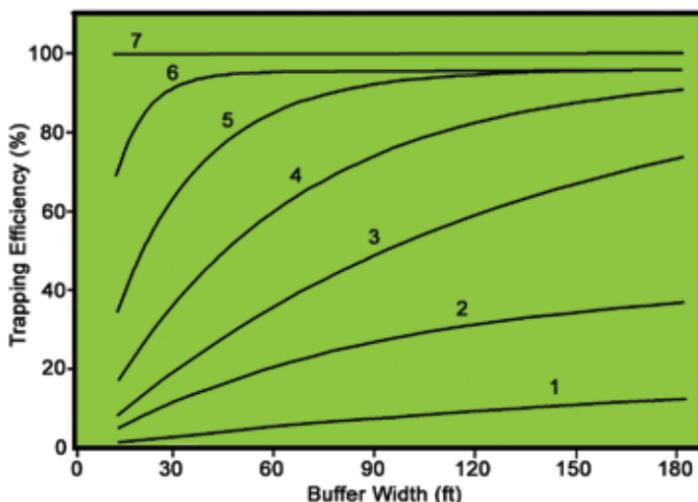
At any given site, the level of pollutant removal from surface runoff depends primarily on buffer width. The graph and tables on the following pages can be used to estimate a buffer width that will achieve a desired level of pollutant removal.

The tool is designed to quickly generate estimates of design width for a broad range of site conditions. Adjustments are made for land slope, soil texture, field size, and soil surface condition. The tool can be used for sediment, sediment-bound pollutants, and dissolved pollutants.

This tool was developed specifically for agricultural runoff but can be applied in a more general way to other land uses as well.

For more information on how this tool was developed, refer to the Frequently Asked Questions section at the end of this guideline.

## Buffer Width Design Tool for Surface Runoff



### Buffer Width Graph

#### Table A - Conditions Corresponding to Each Line in the Graph

Line Number	Field Length (feet)	C-Factor <sup>1</sup>	Slope (%)	Soil Texture <sup>2</sup>	Pollutant Type
7	650	0.5	2	FSL	Sediment
6	650	0.15	2	SiCL	Sediment
5	650	0.5	2	SiCL	Sediment
4	1300	0.5	2	SiCL	Sediment
3	1300	0.5	2	FSL	Dissolved
2	650	0.5	10	SiCL	Sediment
1	1300	0.5	2	SiCL	Dissolved

1. C-Factor of 0.5 represents plowed and disked row crops with moderate residue returned to the soil surface. C-Factor of 0.15 represents conservation tillage and no-till with high residue returned to the soil. C-Factor values for other soil cover management conditions can be found on the next page.

2. FSL = Fine Sandy Loam; SiCL = Silty Clay Loam

**Buffer Width Graph**—The seven lines in the buffer width graph represent seven different site conditions (shown in table 1.19A) that describe the typical range of agricultural sites. The lines divide up the full range of possible pollutant removal levels into convenient increments. Use of this graph amounts to selecting one line that is most appropriate for conditions at a given site.

## How to use the buffer width design tool

1. From table A, identify a reference line number for conditions that most closely resembles one's site.
2. Using table B, select a line number that is higher or lower than the reference line number depending on how one's site conditions and pollutant type differ from those of the reference line. To do so:
  - Add up the pluses and minuses to get the total adjustment.
  - Add the total adjustment number to the reference line number. The result is the appropriate line number to use for determining a buffer design width at one's site.
3. Identify the desired level of pollutant removal, then using the appropriate line in the graph, estimate the corresponding buffer width that will achieve that level.

<b>Table B - Line Selection Adjustment Rules</b>	
Adjustment Rule	
Pollutant Type	3 lines higher (+3) from dissolved pollutants to sediment 2 lines higher (+2) from dissolved pollutants to total P 1 line lower (-1) from sediment to total P 3 lines lower (-3) from sediment to dissolved pollutants
Field Length	1 line higher (+1) for each halving of the field length 1 line lower (-1) for each doubling of the field length
Slope	1 line higher (+1) for each 2.5% lesser slope 1 line lower (-1) for each 2.5% greater slope
Soil Texture	1 line higher (+1) for each soil category coarser 1 line lower (-1) for each soil category finer
C-Factor	1 line higher (+1) for each 0.35 lower C-Factor 1 line lower (-1) for each 0.35 higher C-Factor

**Pollutant Type**

Dissolved pollutants include nitrates, dissolved P, and soluble pesticides

**Field Length**

Length of contributing area to the buffer

**Slope**

Average slope of the buffer and contributing area

**Soil Texture Categories**

Coarse = Sandy loam, sandy clay loam, and fine sandy loam

Medium = Very fine sandy loam, loam, and silt loam

Fine = Clay loam, silty clay loam, and silt

**C-Factor (from Universal Soil Loss Equation)**

Cropland, clean tillage = 1.0

Cropland, plow tillage, low residue = 0.8

Pasture, permanent grass = 0.003

Forest, full canopy = 0.0001

Construction site, no mulch = 1.0

Construction site with secured mulch = 0.1

## Examples using the buffer width design tool

The tables illustrate two examples using the buffer width design tool. In example one, the final reference line after adjustments is 4 while in example two, the final reference line is 1. The dashed lines on the graph below demonstrate how to obtain a buffer design width for the two examples at two particular desired trapping efficiencies.

Example One - Sediment			
Variable	Initial Reference Line	Field Site Condition	Adjustment Rule
Field Length	650 ft	1150 ft	-1
Slope	2.0%	4.5%	-1
Soil Texture	Silty Clay Loam	Loam	+1
C-Factor	0.5	0.5	0
Pollutant Type	Sediment	Sediment	0
Line Number	5		

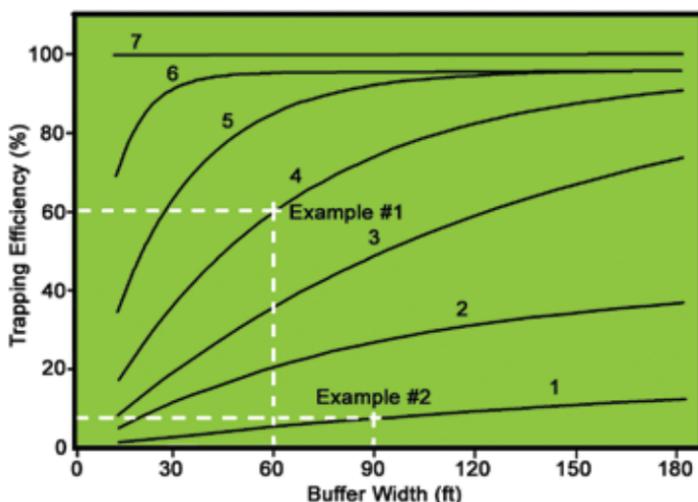
Total Adjustments:  $(-1)+(-1)+(1)+(0)+(0) = -1$

Final Design Line:  $(5) + (-1) = 4$

Example Two - Nitrate			
Variable	Initial Reference Line	Field Site Condition	Adjustment Rule
Field Length	1300 ft	1310 ft	0
Slope	2.0%	5.0%	-1
Soil Texture	Silty Clay Loam	Silt Loam	+1
C-Factor	0.5	0.5	0
Pollutant Type	Sediment	Dissolved	-3
Line Number	4		

Total Adjustments:  $(0)+(-1)+(1)+(0)+(-3) = -3$

Final Design Line:  $(4) + (-3) = 1$



## Buffer width design tool: Frequently Asked Questions

### *How was the tool developed?*

The tool was developed using a complex mathematical model of buffer processes called Vegetative Filter Strip Model (VSFMOD). It computes runoff loads of water and sediment from agricultural fields and their deposition and infiltration within buffers. Using the model, trapping efficiencies for sediment and water were estimated for a range of buffer widths and different combinations of slope, soil texture, field C-factor, and field length that are common in agricultural fields. Other site conditions were held constant (see table below). For more information, refer to Dosskey and others (2008).

Constant Conditions Used for Modeling Simulations	
Factor	Condition
Buffer	Well-established grass Slope and soil texture same as contributing area Runoff is uniformly distributed
Field source	Contour-tilled (P-factor = 1.0) Wet antecedent soil moisture condition
Rainfall	Single event 2.4 inches in 1 hour

### *What are the limitations of this tool?*

This tool does not account for long-term sediment accumulation or long-term fate of dissolved pollutants. These limitations should remind users that the estimated trapping efficiencies are only rough estimates and may decrease over time. By reducing the number of site variables, the tool becomes simpler to use but less accurate than the full VSFMOD model.

### *Can other site factors be accounted for in the design tool?*

Yes, any site condition that would double or halve the field runoff load should dictate an adjustment of one line below and one line above the initial reference line, respectively. To account for different size design storms, a 3.6 inch per hour and 1.5 inch per hour storm would roughly double or halve, respectively, the runoff load compared to the 2.4 inch per hour storm used to generate the reference lines.

## Buffer width design tool: Frequently Asked Questions

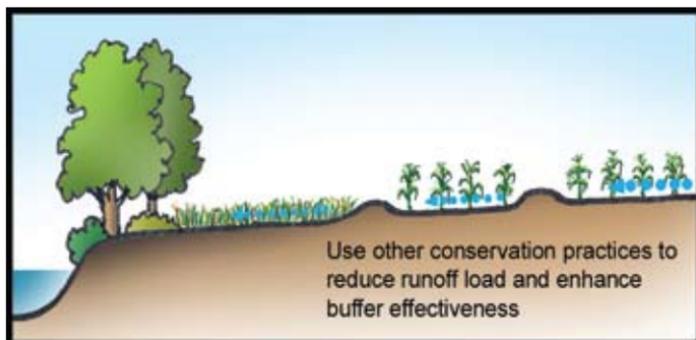
(continued)

*What about extremely narrow buffers < 15 feet?*

Narrow buffers < 15 feet can be effective for sediment removal in some locations. These will be locations that closely resemble conditions for lines 5, 6, and 7 (relatively lower slopes, smaller runoff areas, and permeable soils).

*What if the tool shows that buffers are not particularly effective for my site conditions?*

In some cases, the buffer width estimated to achieve a desired level of trapping efficiency may exceed what a landowner is willing to set aside for a buffer. These situations call for alternative or additional conservation practices to reduce runoff load, a first step in enhancing the effectiveness of any conservation buffer system (see below and section 1.1).

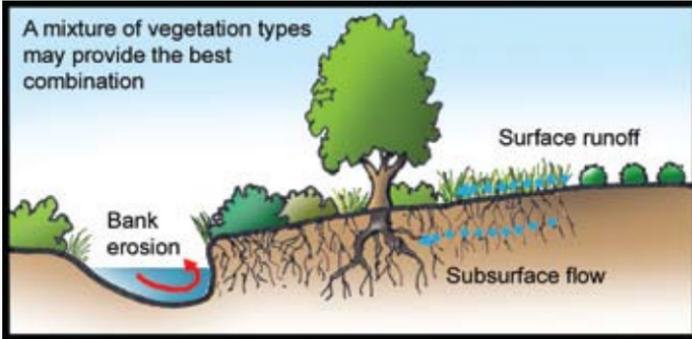


*What if runoff flow is not uniform?*

Non-uniform flow into a buffer in effect increases the runoff load into the portion of the buffer that has contact with the flow, reducing the effectiveness of the buffer. Select a lower line to estimate buffer width for the effective area (see sections 1.7 and 1.8). Grass barriers can help spread out concentrated flow and increase the effective area (see section 1.21).

*What about trees and shrubs?*

The buffer width design tool was developed for dense grass as the buffer vegetation type. Trees and shrubs can be a part of the buffer zone without changing its effectiveness as long as dense groundcover (plants and debris) is present to provide roughness and flow resistance (see section 1.20).



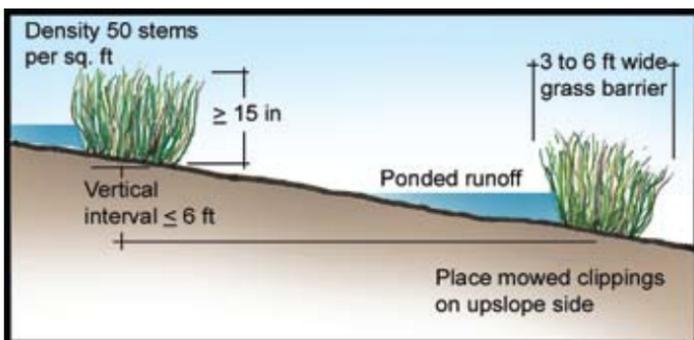
### 1.20 Vegetation for removing pollutants from runoff

Pollutant removal functions of vegetation include reducing flow velocities, increasing deposition and infiltration, and providing nutrient uptake and organic matter for pollutant transformation.

Many types of vegetation can provide these functions. A mixture of herbaceous and woody species may provide the best overall combination (see table below). Vegetation selection should also be based on site capabilities and landowner preferences.

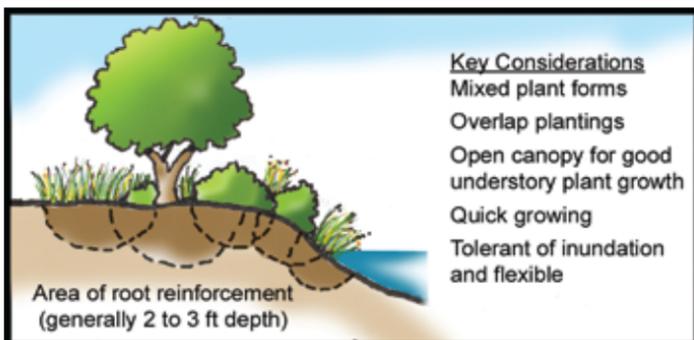
Other factors (e.g., width, slope, location, buffer area ratio, and soils) may play more important roles than vegetation type.

Vegetation Selection for Water Quality	
General Criteria	
Surface runoff	<ul style="list-style-type: none"> <li>High stem and debris density</li> <li>Stiff stems</li> <li>Tolerant of sediment build-up</li> <li>Tolerant of high nutrients levels and other pollutants</li> <li>Actively growing during runoff season</li> </ul>
Subsurface flow	<ul style="list-style-type: none"> <li>Plants with roots that intercept subsurface flow</li> <li>Plants with higher root biomass</li> <li>Tolerant of wet soils and high nutrient levels</li> <li>Avoid N-fixing plants</li> </ul>
Bank Erosion	See 1.18 and 1.22.



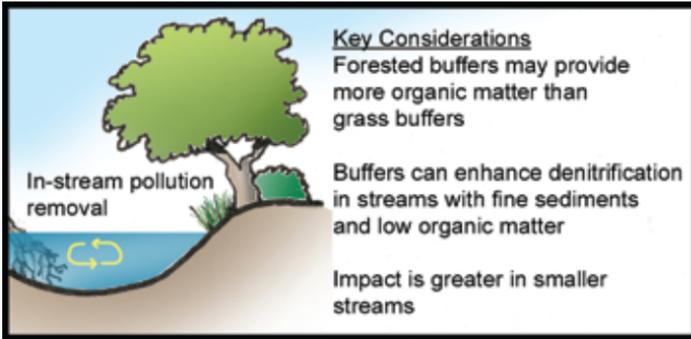
## 1.21 Stiff-stemmed grass barriers

Grass barriers are narrow strips of tall, dense, stiff-stemmed grasses planted perpendicular to the slope. These barriers can slow and pond runoff, promoting infiltration and deposition of sediment. Used mainly where gullies would form on steep land and to slow and disperse concentrated flow.



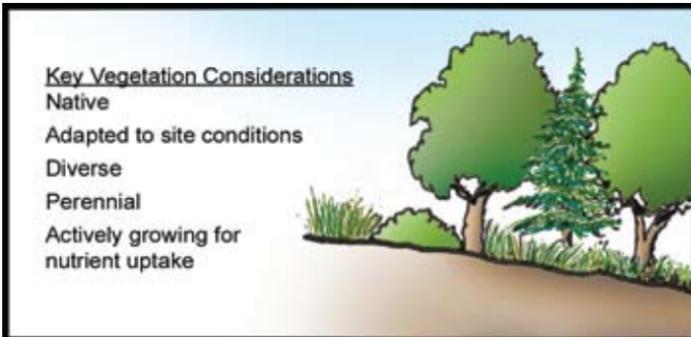
## 1.22 Vegetation for bank erosion control

Herbaceous plants with fibrous root systems are better for protecting banks from surface erosion. Woody species with deeper roots will be better at increasing soil cohesion and reducing mass slope failure. Select woody species that resprout from roots or from broken branches. The best approach is often a combination of plant types.



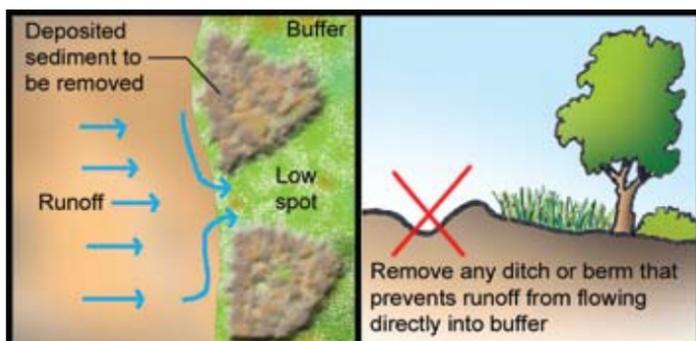
### 1.23 In-stream pollutant removal

Buffers can enhance in-stream processes that remove pollutants carried by streams. Plant debris supports denitrification and pesticide degradation while large woody debris promotes deposition of sediment (see section 2.11). In-stream pollutant removal rates are highly variable. Impact on stream pollution level is generally greater during low flows and in small streams.



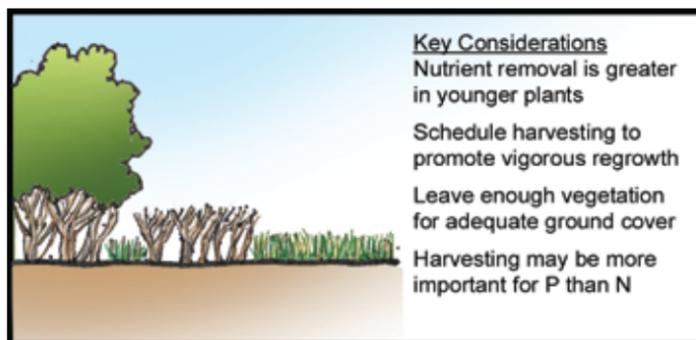
### 1.24 Species selection

Use historical native plant communities to guide vegetation selection, and select species adapted to site conditions. Use a diverse planting mixture to minimize pest and disease problems. Select perennial vegetation to provide permanent cover and to improve infiltration rates over time. Vegetation for nutrient uptake should be actively growing during the runoff season.



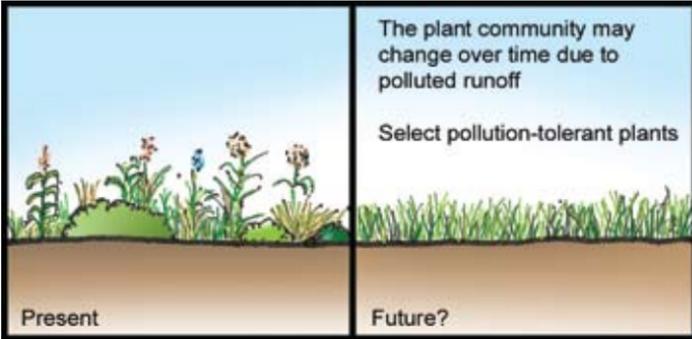
## 1.25 Sediment removal

Sediment trapped in a buffer will change flow into the buffer over time, often resulting in concentrated flows. Periodic removal of accumulated sediment may be necessary. Use erosion control practices in source areas to reduce sediment load and minimize the need for future sediment removal from the buffer. Prevent a ditch or berm from being created along the inflow length of the buffer due to tillage or deposition.



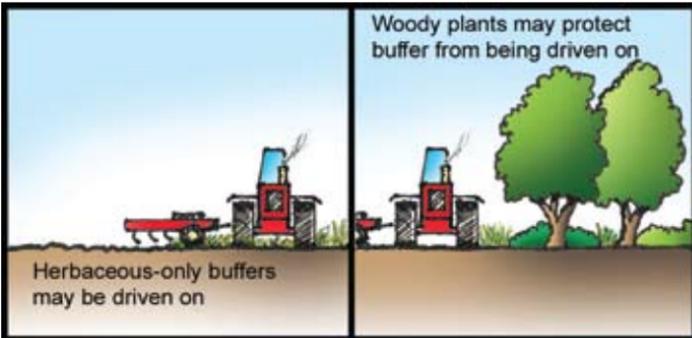
## 1.26 Harvesting for nutrient removal

Harvesting and removing buffer vegetation can encourage plant regrowth and nutrient uptake. Although grazing may be used to remove vegetation, up to 60 to 90 percent of the ingested nutrients will be returned to the system as feces and urine. Harvesting should be considered in context with other management options.



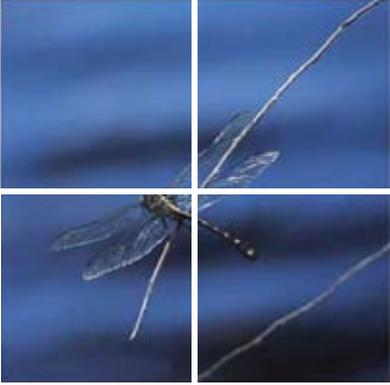
### 1.27 Plant succession

Polluted runoff favors plant species that are more tolerant of pollution and may change the buffer plant community over time. One may need to select plants tolerant of pollutant loading. Over time, trees and shrubs will naturally become established in herbaceous buffers. Periodic tree and shrub removal may be required to maintain dense herbaceous buffers or the desired mix of woody species.



### 1.28 Vegetation and traffic

Traffic in buffers will compact soil, reducing infiltration and vegetation density. Woody vegetation may protect a buffer from being driven on, preventing soil compaction. Herbaceous-only buffers are easier to remove thus making them more vulnerable to changes in land management.







## 2. Biodiversity

### Objectives

- Enhance terrestrial habitat
- Enhance aquatic habitat

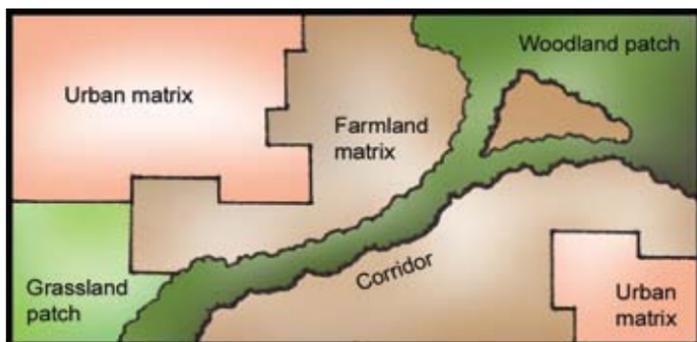
### Buffer functions

1. Increase habitat area
2. Protect sensitive habitats
3. Restore connectivity
4. Increase access to resources
5. Shade stream to maintain temperature

Design Guidelines for Biodiversity	Buffer Functions				
	Increase habitat area	Protect sensitive habitats	Restore connectivity	Increase access to resources	Shade stream to maintain temperature
2.1 Matrix primer	✓	✓	✓	✓	
2.2 Patch primer	✓	✓	✓	✓	
2.3 Corridors and connectivity	✓	✓	✓	✓	
2.4 Corridors versus connectivity zones	✓	✓	✓	✓	
2.5 Corridor network	✓	✓	✓	✓	
2.6 Climate change and corridors	✓	✓	✓	✓	✓
2.7 Stepping stones and gaps	✓	✓	✓	✓	
2.8 Buffers and corridors	✓	✓	✓	✓	
2.9 Corridor width	✓	✓	✓	✓	

<b>Design Guidelines for Biodiversity</b>	<b>Buffer Functions</b>				
	Increase habitat area	Protect sensitive habitats	Restore connectivity	Increase access to resources	Shade stream to maintain temperature
2.10 Edge effects of corridors		✓	✓	✓	
2.11 Aquatic habitat and buffers	✓	✓	✓	✓	✓
2.12 Stream temperature and buffers	✓	✓	✓	✓	✓
2.13 Roads and wildlife crossings			✓	✓	
2.14 Roadside corridors	✓		✓	✓	

<b>Additional Design Guidelines that may Benefit Biodiversity</b>	<b>Buffer Functions</b>				
	Increase habitat area	Protect sensitive habitats	Restore connectivity	Increase access to resources	Shade stream to maintain temperature
1.4 Target buffers in watersheds	✓	✓	✓	✓	✓
1.14 Buffers for pesticides		✓			
3.2 Windbreaks for wind erosion	✓	✓	✓	✓	✓
3.3 Herbaceous wind barriers	✓		✓	✓	
3.4 Grassed waterways	✓		✓	✓	
4.5 Alley cropping	✓		✓	✓	
4.9 Crop pollinator habitat	✓		✓	✓	
5.1 Managing insect pests with buffers	✓		✓	✓	
5.2 Plants that attract beneficial insects	✓		✓	✓	
5.3 Buffers and spray drift		✓			
6.5 Developing an ecological aesthetic	✓	✓	✓	✓	✓
7.1 Trail design and wildlife	✓	✓	✓	✓	
7.2 Flight initiation distance buffers		✓	✓	✓	
7.3 Trails along riparian corridors		✓	✓	✓	✓

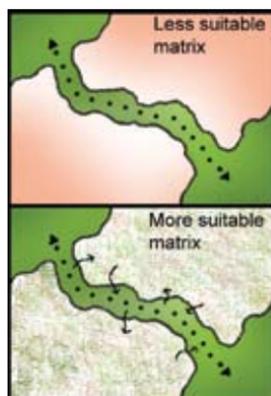


## 2.1 Matrix primer

The role of patches and matrix needs to be considered when designing corridors to enhance biodiversity. In human-dominated landscapes, the matrix is often developed lands (e.g., urban, agriculture) while patches are remnants that have a different plant and animal community than the surrounding area.

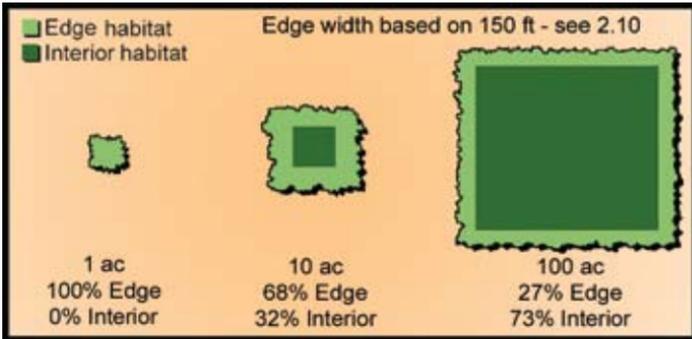
The potential value of corridors to link isolated patches depends on the type and condition of the matrix. A corridor will usually be more valuable in landscapes where the matrix is less suitable for biodiversity.

Below are considerations for managing the matrix for biodiversity. See next page for patch guidelines.



### Key matrix guidelines

- Consider the matrix at multiple spatial and temporal scales.
- Cluster development to protect more open space. Use other smart growth principles where possible.
- Minimize disturbance of natural vegetation.
- Minimize introduction and spread of non-native species.
- Manage disturbances (e.g., haying, earth-moving) to reduce negative impacts.



## 2.2 Patch primer

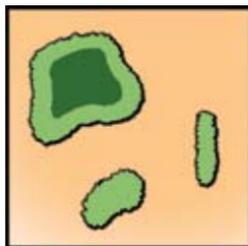
Large patches typically conserve a greater variety and quality of habitats, resulting in higher species diversity and abundance. The larger the patch is, the higher percentage of interior habitat that it will contain. This benefits interior species which are often the most vulnerable to habitat loss and fragmentation.

Minimum patch area requirements for species are highly dependent on species, quality of habitat, and landscape context. The table below provides a summary of patch area requirements. In general, larger animals require larger patches. A biologist should be consulted to refine these ranges.

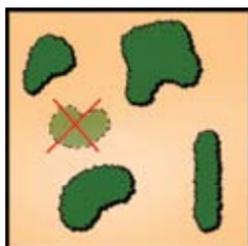
Example Ranges of Minimum Patch Area	
Taxa	Patch Area
Plants	5 to $\geq$ 250 ac
Invertebrates	50 sq ft to $\geq$ 2.5 ac
Reptiles and Amphibians	3 to $\geq$ 35 ac
Grassland Birds	12 to $\geq$ 135 ac
Waterfowl	$\geq$ 12 ac
Forest Birds	5 to $\geq$ 95 ac
Small Mammals	2.5 to $\geq$ 25 ac
Large Mammals	40 ac to $\geq$ 2 sq mi
Large Predator Mammals	3.5 to $\geq$ 850 sq mi

## Key patch guidelines

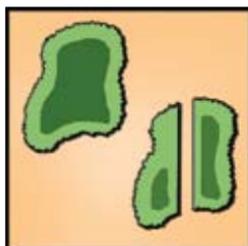
Small patches play a critical role in protecting biodiversity, particularly in areas with limited habitat. Small patches can capture a range of habitat types or unique habitats. Include large and small patches in a plan.



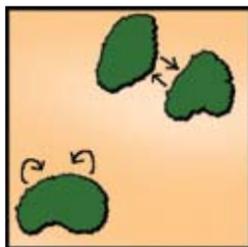
Redundancy is an essential component of ecosystems at all scales. If several patches exist in an area, species may not be seriously threatened or lost if one of the patches is destroyed or degraded.



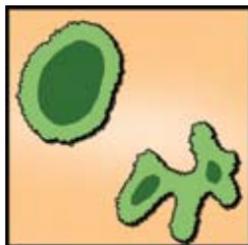
Of two patches having exactly the same area, one fragmented and one unified, the unified patch will be of far greater value. Biodiversity will remain higher and negative edge effects will be reduced.

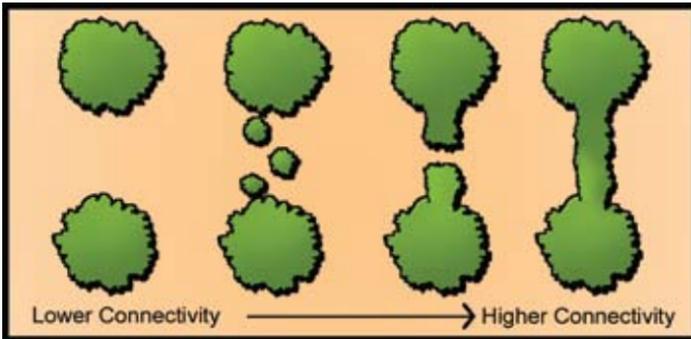


Opportunities for species to interact become greater as the distance between patches decreases. This potential interaction is dependent on species and their movement capabilities.



A less convoluted patch will have a lower proportion of edge habitat and will provide greater benefits for interior species which are often species of concern.





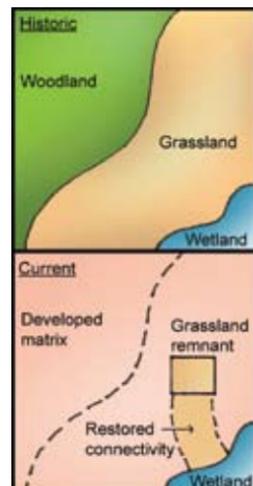
### 2.3 Corridors and connectivity

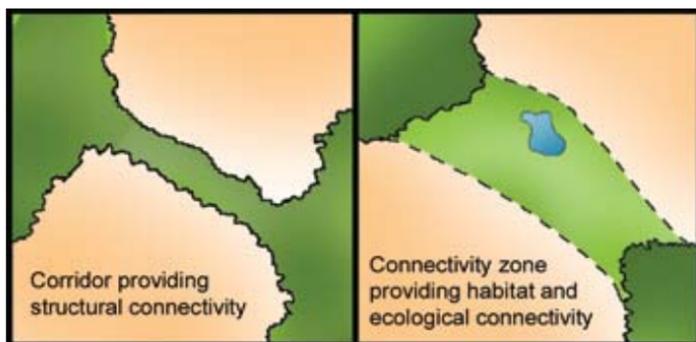
Connecting patches with corridors can benefit biodiversity by providing access to other areas of habitat, increasing gene flow and population viability, enabling recolonization of patches, and providing habitat.

Connectivity can be undesirable or unsuccessful in some cases. Corridors can be dominated by edge effects, can increase risk of parasitism and disease, and can facilitate dispersal of invasive species (see section 2.10). Corridors can be unsuccessful if they do not meet the movement or habitat requirements for the target species.

#### Key design considerations

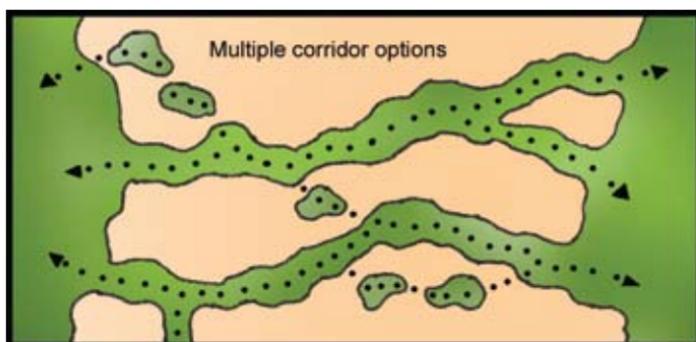
- Design corridors at several spatial and temporal scales.
- Provide quality habitat in a corridor whenever possible.
- Locate corridors along dispersal and migration routes.
- Corridors, particularly regional corridors, should not be limited to a single topographic setting.
- Similarity in vegetation between corridors and patches is beneficial.
- Restore historical connections and generally avoid linking areas not historically connected.





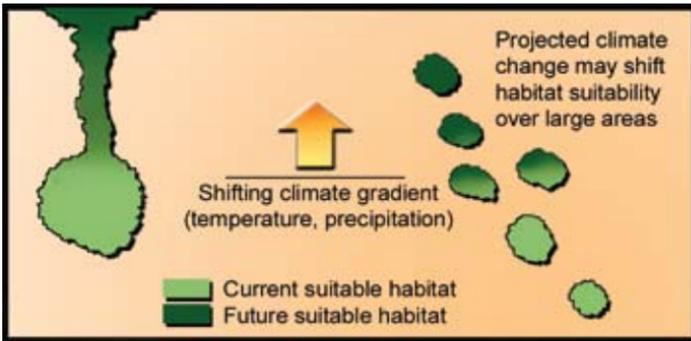
## 2.4 Corridors versus connectivity zones

Avoid limiting corridors to strips of a single vegetation type, rather design corridors as broad connectivity zones. Using this approach, corridors can enhance habitat connectivity by linking the different types of habitat required by a species or ecological connectivity where ecosystem processes are maintained (e.g., climate change, seed dispersal).



## 2.5 Corridor network

A redundant corridor network may provide multiple pathways for movement, reducing the impact if a corridor is eliminated. However, this increased connectivity could facilitate quicker dispersal of problems such as diseases, parasitism, and invasive species. A corridor network may be a useful approach to encompassing a range of habitats in a region.



## 2.6 Climate change and corridors

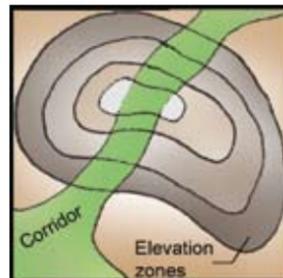
Current and projected climate change may have significant impacts on biodiversity and other resources. Corridors and buffers may potentially affect these impacts in several ways:

1. Reduce greenhouse gases (see sections 4.2, 4.7, and 4.8)
2. Allow species to migrate as climate changes
3. Protect sensitive areas from increased climatic events such as floods and storm surges along coastal areas
4. Provide habitat that offers range of microclimate refugia

Corridors may be of limited value for biodiversity if climate change occurs at a rate too fast to allow for migration and may end up just benefiting species that are highly mobile and adaptable, including invasive species.

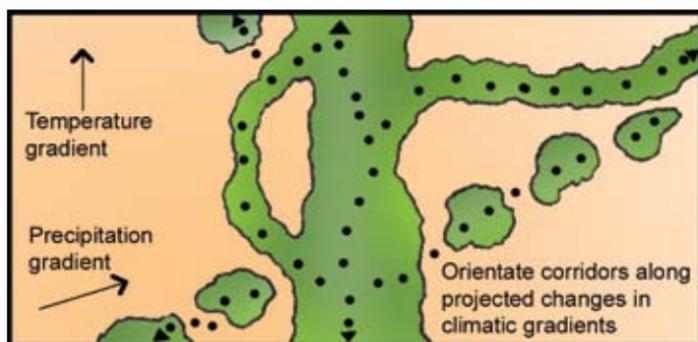
### Key design considerations

- Corridors for climate change may be best suited for landscapes that are less modified by human development.
- Broad connectivity zones may be more effective than distinct and narrow corridors (see section 2.4).
- A strategy of stepping stones and corridors may offer the most opportunities for dispersal and migration (see section 2.7).
- Corridors that cross elevation zones may allow migration in mountainous landscapes.

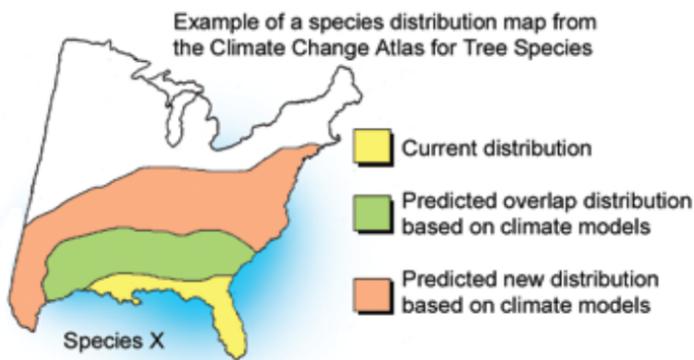


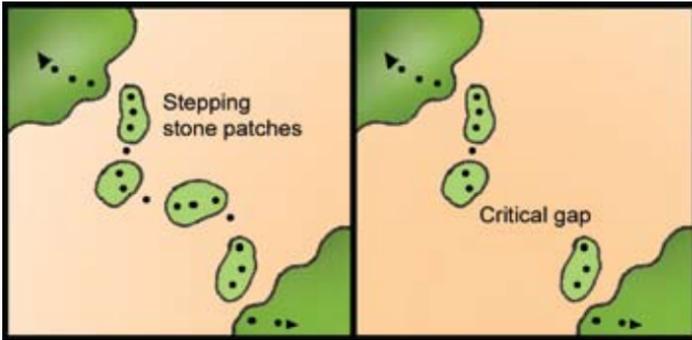
### Key design considerations *(continued)*

- Locate corridors and patches to provide climate refugia at multiple spatial scales.
- Include a range of geological substrates and soils to meet different plant requirements.
- Riparian buffers may help mitigate temperature changes in streams due to climate change (see section 2.12).
- Orientate corridors along projected changes in climatic gradients.



When establishing new, long-term plantings, it may be useful to select plants that may be adapted to the changing climate. Atlases of woody plant distributions under modeled climate change can serve as a guide and may offer insight on which species will require more migration to persist. Search the Web for a climate change atlas for tree species.





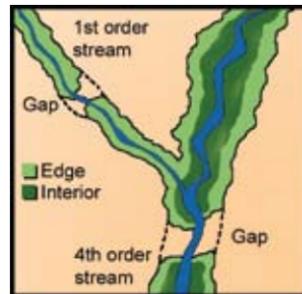
## 2.7 Stepping stones and gaps

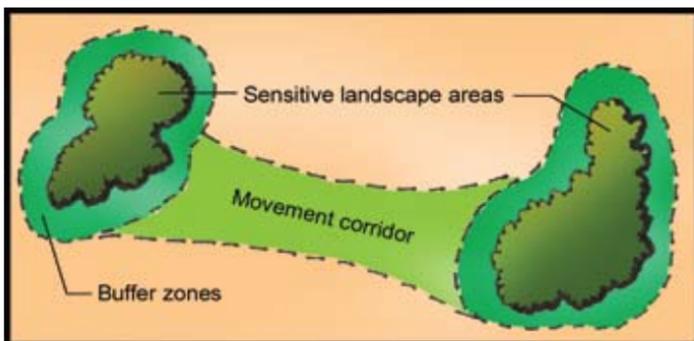
Small patches can serve as stepping stones, allowing for species movement between large patches and are important in fragmented landscapes. However, the loss of a stepping stone can often inhibit movement, increasing patch isolation.

At some point, the distance between stepping stones or a gap in a continuous corridor will exceed a threshold at which a particular species will be unwilling or incapable of crossing. These critical gaps should often be restored.

### Key considerations for managing gaps

- The greater the contrast between the gap and the corridor plant community, the narrower the gap must be in order not to be a barrier.
- Smaller species will generally have smaller gap thresholds.
- Species requiring specialized habitats will have smaller gap thresholds.
- For visually-orientated species, gap thresholds may be determined by the ability to see the next stepping stone or across the gap.
- In riparian corridors, restore gaps in higher order streams first to provide the greatest benefit for biodiversity.



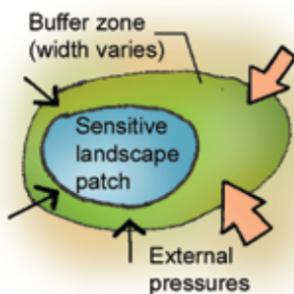


## 2.8 Buffers and corridors

Buffers and corridors are linked together as a conservation strategy. Buffer zones are designated areas used to protect sensitive landscape patches (e.g., wetlands, wildlife reserves) from negative external pressures. Corridors are used to connect the buffered landscape patches.

Buffer zone width should be based on the desired ecological functions, landscape context, and external pressures. Upland buffers of 250 to 1,000 feet around wetlands have been recommended for turtles and amphibians. For wildlife reserves or parks, buffer zones may need to be several miles wide.

Refer to section 2.10 for distances of edge effects. These distances can serve as a guide for creating buffer zones around habitat patches to protect them from edge effects. See section 7.2 for guidance on human activity and buffer zones.

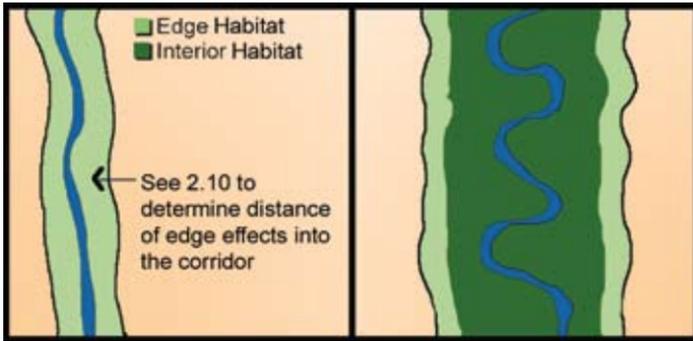


### Key Considerations

Base buffer width on specific ecological functions

Modify buffer width according to landscape context and external pressures

Manage activities within buffer to benefit goals in the landscape patch



## 2.9 Corridor width

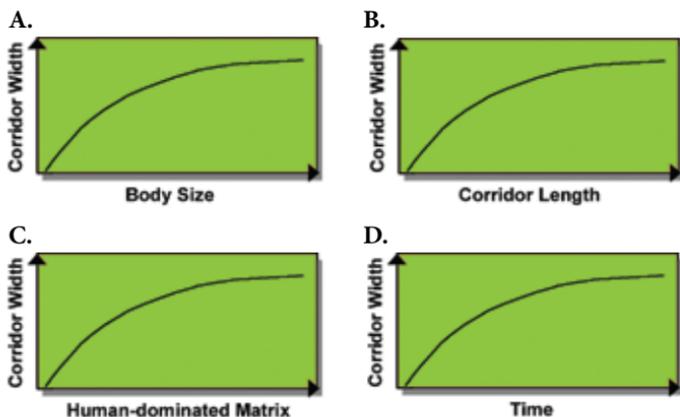
Wide corridors, both upland and riparian, provide greater habitat area with reduced edge effects, while generally promoting more opportunities for species movement. Wider riparian corridors can facilitate stream meandering, providing overall higher habitat quality and diversity.

Many studies have examined the issue of corridor width for certain species. However, many of the studies have not tested a significant range of corridor widths to adequately determine optimal corridor widths. In addition, for a given width, corridor effectiveness will vary with corridor length, habitat continuity, habitat quality, and many other factors.

With those limitations in mind, the bar graph on the next page summarizes research on species movement through corridors. The black bar denotes the suggested minimum corridor width while the gray bar indicates the upper end of recommended widths. These ranges should be refined with a biologist.

Based on this research, some general relationships on corridor width can be inferred (see line graphs).

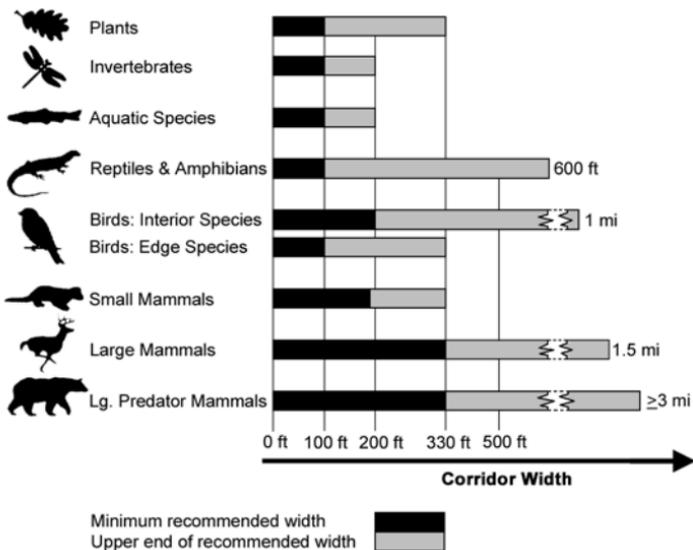
- A. The larger the species, the wider the corridor will need to be to facilitate movement and provide potential habitat.
- B. As the length of the corridor increases, so should the width. Shorter corridors are more likely to provide increased connectivity than long corridors.

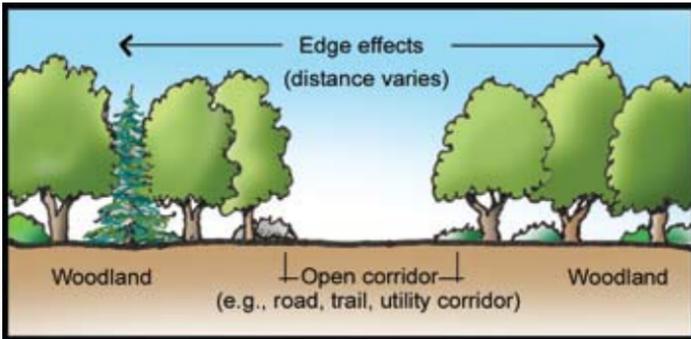


C. A corridor will generally need to be wider in landscapes that provide limited habitat or that are dominated by human use.

D. Corridors that need to function for decades or centuries should be wider. Some functions that require significant time include dispersal for slow-moving organisms, gene flow, and changes to range distribution due to climate change.

**Corridor Width Summary**





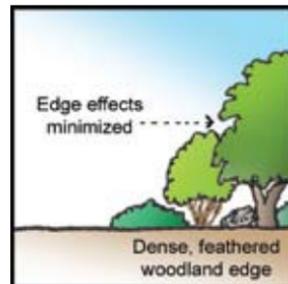
## 2.10 Edge effects of corridors

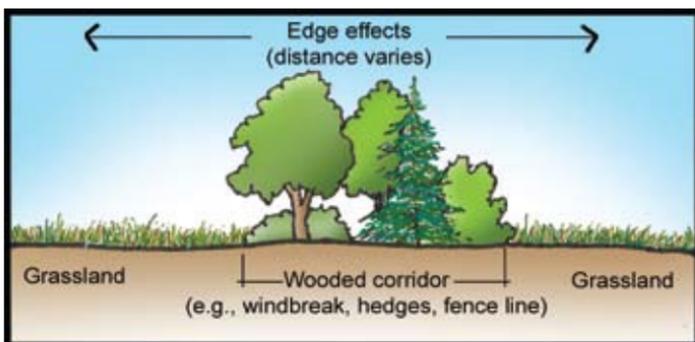
Corridors established in woodlands or grasslands can create negative edge effects that extend into the woodland or grassland. Examples include open corridors cleared for roads in woodlands and hedgerows established in grasslands.

Negative edge effects include increased risk of parasitism or disease, increased risk of predation, adverse microclimate conditions, and competition from invasive species. These factors should be considered when designing corridors.

### Key considerations for reducing negative edge effects

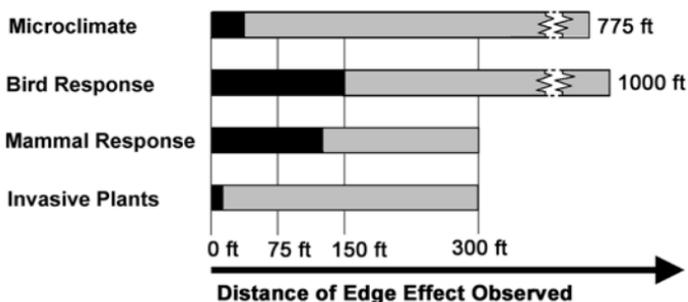
- Locate corridors along existing edges and avoid fragmenting habitat patches.
- Consolidate corridor uses to minimize fragmentation (e.g., combine road and utility corridors).
- In woodlands, create a dense, feathered edge with vegetation to reduce penetration of edge effects.
- Narrower corridors will generally have less edge effects into adjacent habitat.
- If the landscape already consists of patches dominated by edge, a corridor will probably not contribute additional negative impacts.



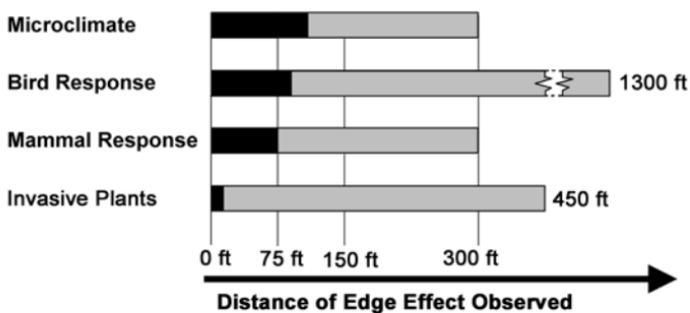


These graphs provide a summary of documented edge effects. These distances can be used for estimating the zone of impact and for designing ways to reduce these impacts.

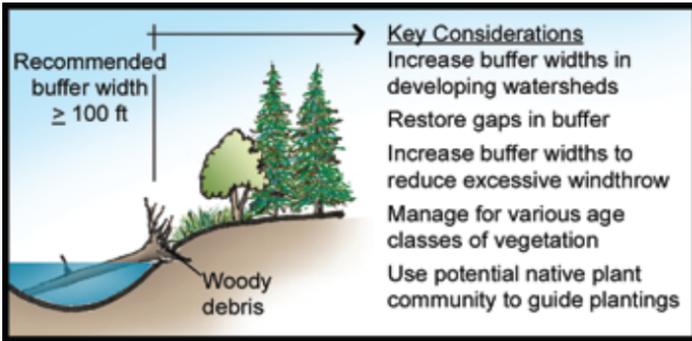
### Open Corridor in Woodland



### Wooded Corridor in Grassland



Minimum distance edge effect observed   
 Maximum distance edge effect observed 



## 2.11 Aquatic habitat and buffers

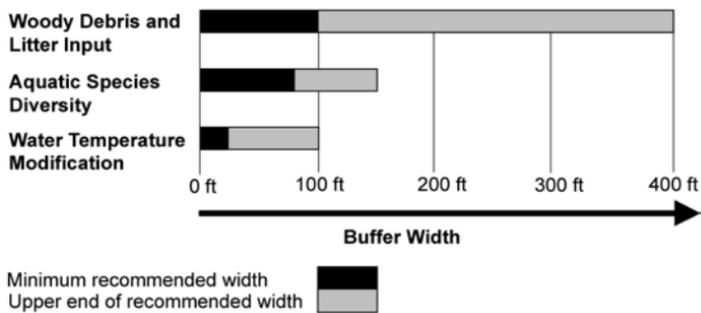
Riparian corridors or buffers influence habitat quality for aquatic species in several ways:

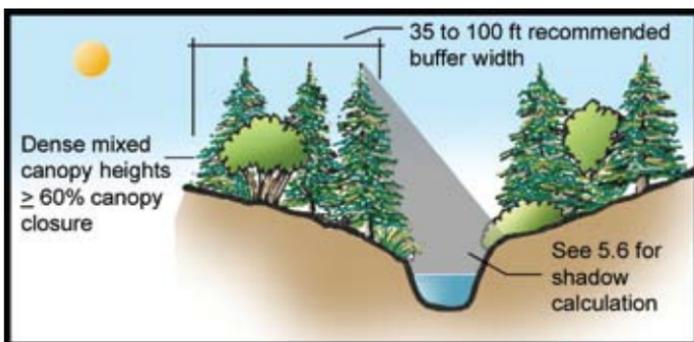
1. Provide woody debris for aquatic habitat structure
2. Maintain in-stream microclimate (see section 2.12)
3. Provide food for aquatic species
4. Protect water quality (see section 1.0)

Riparian buffers may not be able to maintain desirable aquatic habitat quality in watersheds that are highly developed. Other land use management strategies will need to be used as well.

The graph below summarizes some of the research on buffer widths for aquatic habitat functions and can serve as a starting point for design.

**Buffer Width for Aquatic Habitat Functions**





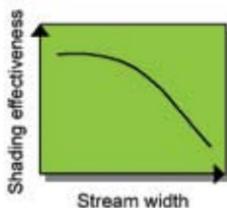
## 2.12 Stream temperature and buffers

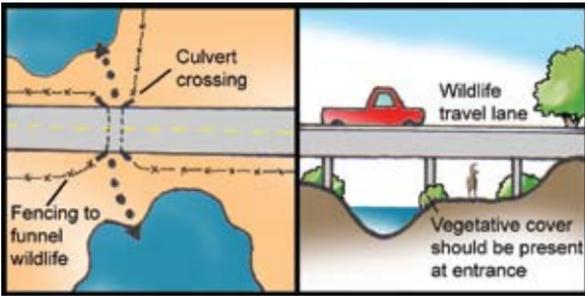
Buffers can help maintain cooler water temperatures in small streams if the vegetation provides adequate shade on the water surface. This can be beneficial for coldwater aquatic species and for water quality.

Stream shade is comprised of topographic shade provided by nearby hills, bank shade, and vegetative shade. Streams with vegetation removed usually have undesirable summer temperature increases from 5 °C to 11 °C. Aspect, channel morphology, and groundwater input may affect temperatures more than buffers.

### Key design considerations

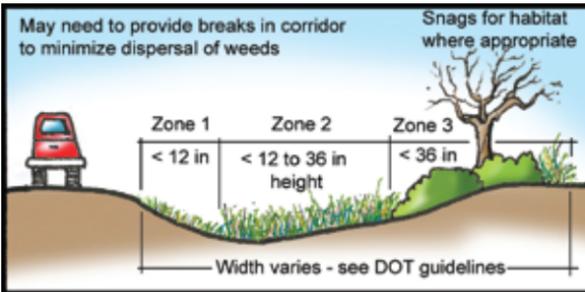
- Incorporate topography and bank shade in the design.
- Trees and shrubs provide the most shade, but unmowed or ungrazed grass buffers can provide shade on streams < 8 feet in width.
- Buffer shading effectiveness decreases as stream width increases.
- Windthrow may be common in buffers retained after timber harvest and wider buffers may be necessary.
- Buffers may need to be wider (150 to 1,000 feet) to maintain other microclimatic factors (e.g., soil temperature, humidity).





### 2.13 Roads and wildlife crossings

When wildlife corridors are bisected by roads, safe passage should be provided through culverts, bridges, and/or overpasses. Landscape-scale assessments can aid in locating wildlife crossings. When using culverts for crossings, include culverts of mixed-sized classes and avoid creating barriers to movement like debris grates. Design guides are available.



### 2.14 Roadside corridors

In areas with limited habitat, roadsides may be beneficial for some species although for others it may be detrimental. Manage vegetation height to maintain visibility to reduce potential vehicle-wildlife collisions. Use native plants and maintain plant vigor by mowing or burning every 3 to 5 years. Burn or mow in blocks to ensure some portion remains undisturbed.

**Productive  
Soils**







# 3. Productive Soils

## Objectives

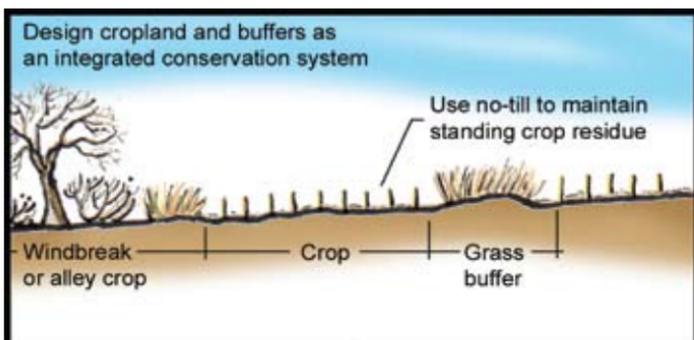
- Reduce soil erosion
- Increase soil productivity

## Buffer functions

1. Reduce water runoff energy
2. Reduce wind energy
3. Stabilize soil
4. Improve soil quality
5. Remove soil pollutants

Design Guidelines for Productive Soils	Buffer Functions				
	Reduce water runoff energy	Reduce wind energy	Stabilize soil	Improve soil quality	Remove soil pollutants
3.1 Buffers and cropland management	✓	✓	✓	✓	
3.2 Windbreaks for wind erosion	✓	✓	✓	✓	
3.3 Herbaceous wind barriers	✓	✓	✓	✓	
3.4 Grassed waterways	✓		✓		
3.5 Phytoremediation buffers	✓	✓	✓	✓	✓

<b>Additional Design Guidelines that may Benefit Productive Soils</b>	<b>Buffer Functions</b>				
	<i>Reduce water runoff energy</i>	<i>Reduce wind energy</i>	<i>Stabilize soil</i>	<i>Improve soil quality</i>	<i>Remove soil pollutants</i>
1.1 Buffers and land management	✓	✓	✓	✓	✓
1.4 Target buffers in watersheds	✓	✓	✓	✓	✓
1.6 Buffer site design	✓		✓		
1.7 Variable buffer width	✓		✓		
1.8 Effective buffer area ratio	✓		✓		
1.10 Buffers for sediment	✓		✓	✓	✓
1.18 Allowances for bank erosion			✓	✓	
1.20 Vegetation for removing pollutants	✓		✓	✓	✓
1.21 Stiff-stemmed grass barriers	✓		✓		
1.22 Vegetation for bank erosion control			✓	✓	
4.4 Windbreaks and crop yields	✓	✓	✓		✓
4.5 Alley cropping	✓	✓	✓	✓	✓
5.10 Waterbreaks	✓		✓		
7.4 Soil erosion and trail recreation	✓	✓	✓		

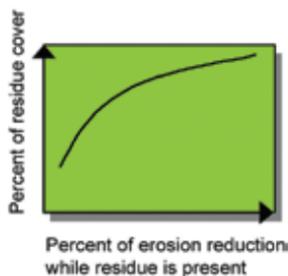


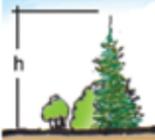
### 3.1 Buffers and cropland management

Buffers can not replace good cropland management. Trapping soil in buffers is ineffective in maintaining soil productivity and can become a long-term maintenance problem. The most effective strategy is combining buffers with appropriate cropland management.

#### Key cropland management considerations

- Establish crop rows on the contour.
- Use conservation tillage or no-till to reduce water and wind erosion. Residue should be left standing and orientated perpendicular to the prevailing wind direction.
- Maintain crop residue to reduce evaporation and increase infiltration. Standing crop residue captures drifting snow and increases soil moisture.
- Use cover crops to provide cover during fallow season.
- Use strip cropping to reduce sediment transport.
- In highly erodible situations, select a perennial crop to maintain cover year around.
- Deliver irrigation water in a manner that minimizes erosion.





**Open Wind Speed 20 mph  
40 to 60% Density**

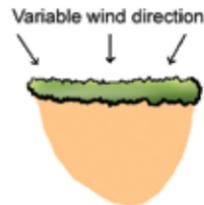
	Downwind Zone of Protection				
h distance from windbreak	5h	10h	15h	20h	30h
miles per hour	6	10	12	15	19
% of open wind speed	30%	50%	60%	75%	95%

### 3.2 Windbreaks for wind erosion

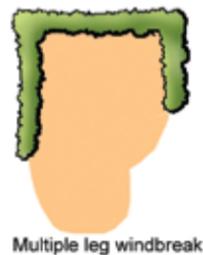
Windbreaks for soil erosion control are usually 1 to 3 rows planted at right angles to prevailing winds. The area protected downwind of a windbreak is a function of the average height and density of the windbreak.

A windbreak protects an area 10 to 15 times the height of the trees. A windbreak density of 40 to 60 percent provides the greatest downwind protection for soil erosion. Choose species foliage and branching characteristics that will achieve the desired density during the critical protection periods.

Single row windbreaks offer limited resilience because a single dead tree can leave a gap in the windbreak. Gaps result in increased wind speeds and reduced protection.



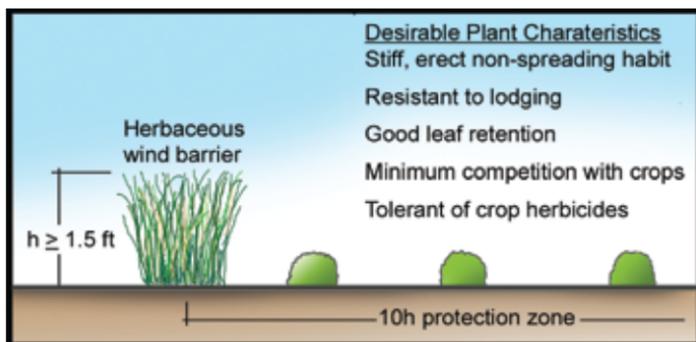
Multiple leg windbreaks provide greater protection than single leg windbreaks.



Locate access roads at the end of windbreaks. Extend windbreaks beyond the area being protected.

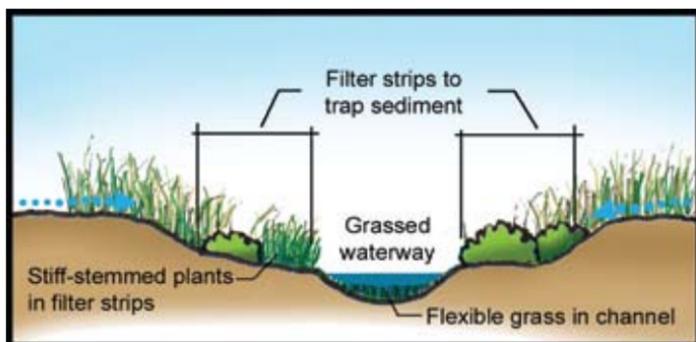
See sections 4.4, 5.7, and 5.8 for other windbreak functions.





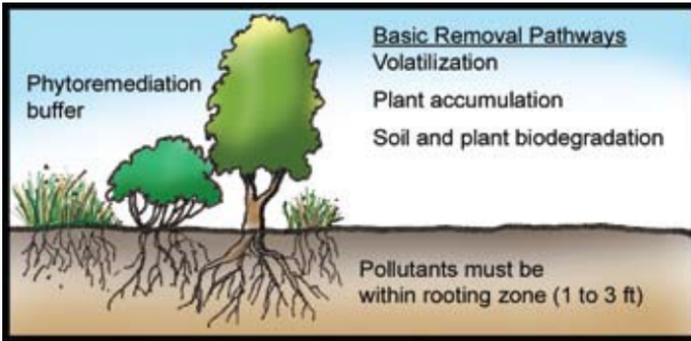
### 3.3 Herbaceous wind barriers

Herbaceous wind barriers are tall, non-woody plants established in narrow strips to reduce soil erosion and protect crops. In general, the same design guidelines in section 3.2 apply to herbaceous-only wind barriers. Herbaceous wind barriers are suitable for situations with height restrictions, such as for use under center pivot irrigation.



### 3.4 Grassed waterways

A grassed waterway is a vegetated channel that carries runoff at a nonerosive velocity to a stable outlet. Grassed waterways can be enhanced by including filter strips to filter runoff and to trap sediment outside of the waterway. Vegetation in the channel should lie down to convey water while vegetation in the filter strips should be tall and stiff to avoid submergence and to filter sediment from runoff.



### 3.5 Phytoremediation buffers

Phytoremediation is the use of plants to clean up soil and water contaminated with metals, solvents, and other pollutants. Phytoremediation buffers can be used to treat brownfields, landfill leachate, mine waste, and other low to moderately polluted sites.

Limitations in using phytoremediation include the length of time required for remediation, pollutants at a level tolerable for the plants used, bioavailability of pollutants, and the level of cleanup required. Consult with appropriate environmental professionals to design an effective system.

#### Key design considerations

- Select vegetation that is fast growing, easy to maintain, and capable of transforming the pollutants to a non-toxic form.
- May need to conduct screening studies and field plot trials to determine suitable plants.
- Avoid monocultures to reduce risk to disease and pests.
- Pollutants need to be within the upper rooting zone. Plants with different rooting types and depths may be used together to treat a greater soil depth. A fibrous root system is usually the most efficient.
- Determine and mitigate potential exposure risks for wildlife.
- Harvesting vegetation and proper disposal may be necessary.







# 4. Economic Opportunities

## Objectives

- Provide income sources
- Increase economic diversity
- Increase economic value

## Buffer functions

1. Produce marketable products
2. Reduce energy consumption
3. Increase property values
4. Provide alternative energy sources
5. Provide ecosystem services

Design Guidelines for Economic Opportunities	Buffer Functions				
	Produce marketable products	Reduce energy consumption	Increase property values	Provide alternative energy sources	Provide ecosystem services
4.1 Buffers and ecosystem services	✓				✓
4.2 Carbon sequestration	✓				✓
4.3 Multi-story cropping in buffers	✓				✓
4.4 Windbreaks and crop yields	✓	✓			✓
4.5 Alley cropping	✓	✓			✓
4.6 Biofuel buffers	✓			✓	✓
4.7 Energy conservation: site		✓	✓	✓	✓
4.8 Energy conservation: landscape		✓	✓		✓
4.9 Crop pollinator habitat	✓				✓

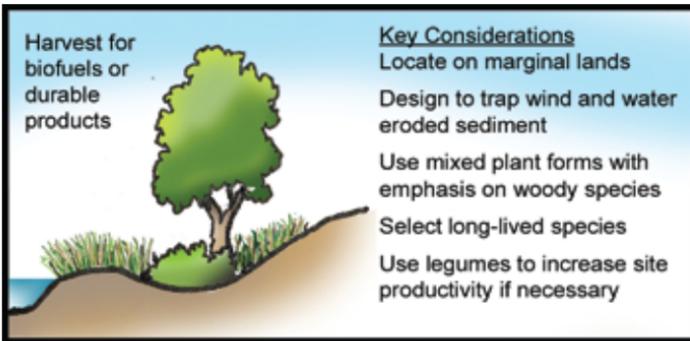
Design Guidelines for Economic Opportunities	Buffer Functions				
	Produce marketable products	Reduce energy consumption	Increase energy values	Provide alternative energy sources	Provide ecosystem services
4.10 Economic impact of trails	✓	✓	✓	✓	✓
4.11 Greenways and property values			✓		✓

Additional Design Guidelines that may Benefit Economic Opportunities	Buffer Functions				
	Produce marketable products	Reduce energy consumption	Increase energy values	Provide alternative energy sources	Provide ecosystem services
3.2 Windbreaks for wind erosion	✓	✓	✓		✓
3.3 Herbaceous wind barriers	✓	✓	✓		✓
3.5 Phytoremediation buffers	✓	✓		✓	✓
5.1 Managing insect pests with buffers	✓				✓
5.8 Windbreaks for livestock	✓	✓	✓		✓
6.2 Windbreaks for odor control				✓	✓
6.3 Air quality buffers				✓	✓
6.4 Buffers for noise control				✓	✓
6.6 Attractive roadside corridors				✓	✓
6.7 Buffers for visual screening				✓	✓
7.5 Trail user preferences				✓	✓
7.6 Trail layout		✓	✓		✓
7.7 Trail access and usage		✓	✓		✓



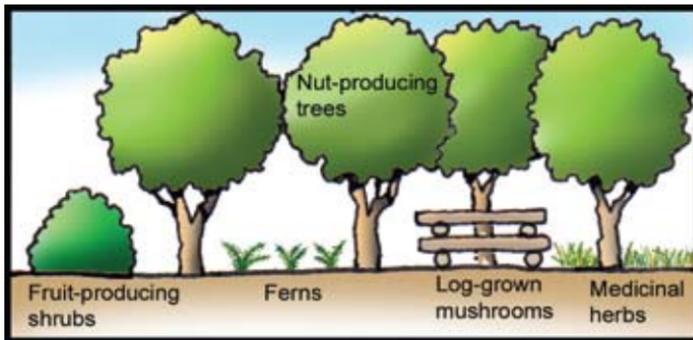
## 4.1 Buffers and ecosystem services

Buffers perform ecosystem services that are valuable for society and landowners. Some services have markets such as hunting and recreational leases based on habitat functions, but many services are difficult to quantify and have limited or no current markets. Some services may develop into markets (e.g., water quality, carbon credits). Above are considerations for designing buffers to maximize ecosystem services.



## 4.2 Carbon sequestration

Carbon sequestered in buffers may be sold in future carbon credit markets. Use trees and other woody plants to store significant carbon aboveground. The largest, more permanent sequestered carbon may be achieved if the vegetation is used for durable products. Soil carbon under buffers can increase through organic matter accumulation and sediment deposition.



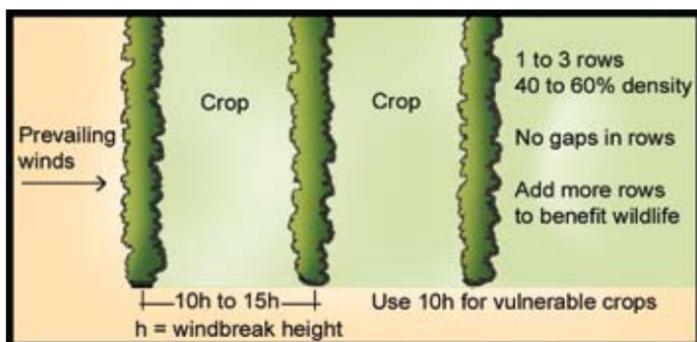
### 4.3 Multi-story cropping in buffers

Useful and marketable products can be grown under tree buffers (see table).

#### Key design considerations

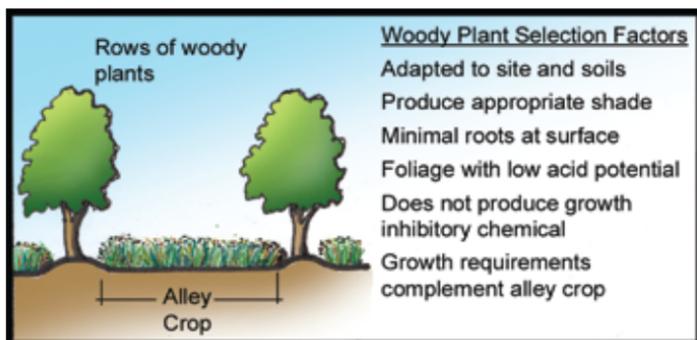
- Select plants that provide multiple benefits.
- Use plants that provide short and long-term products.
- Avoid plants that compete for same resources.
- Utilize the different canopy layers to increase options.
- Avoid plants that compromise other buffer objectives.

Potential Products to Grow in Buffers	
Canopy Layer	Plant/Product
Overstory	Nut-producing trees (e.g., pecans, hazelnut, hickory, pine nuts), Timber (e.g., oak, walnut, maple), Biofuels (e.g., poplar)
Midstory	Syrups (e.g., maple, boxelder), Bark (e.g., cedar, birch), Evergreen boughs, Other wood-derived products (e.g., cedar bedding, oils)
Shrub Layer	Decorative woody florals (e.g., curly willow, red twig dogwood, holly), Berries (e.g., wild plum, juneberry, currants)
Herbaceous Layer	Medicinal herbs (e.g., ginseng, black cohosh, bloodroot), Culinary herbs (e.g., mints, basil), Decoratives (e.g., beargrass, salal, ferns)
Root Zone	Fungi (e.g., truffles, morels)
Vertical Layer	Climbing berries (e.g., raspberry), Climbing vines (e.g., bittersweet), Log-grown mushrooms



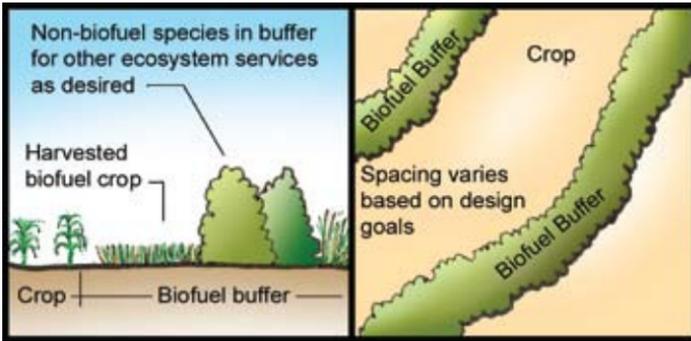
#### 4.4 Windbreaks and crop yields

Windbreaks can increase amount and quality of crop yields by reducing erosion, improving microclimate, retaining moisture, and reducing crop damage by high winds. If prevailing winds are from two directions, windbreaks on two sides may be required. To encourage even distribution of snow across a field for soil moisture, use a density of 30 to 40 percent.



#### 4.5 Alley cropping

Alley cropping is the cultivation of crops grown in between rows of woody plants. Key design considerations include selecting woody plants that provide marketable products, crop timing and management, crop sunlight requirements, and size of farm equipment as it affects spacing requirements. The alley crop can be changed as tree canopy closes over time.



## 4.6 Biofuel buffers

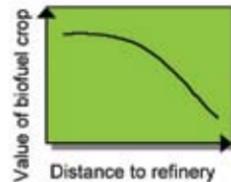
Perennial herbaceous and woody plants can be grown for producing biofuels. Biofuel crops can be used to generate power via co-firing and gasification and can be refined to yield liquid fuels like ethanol, bio-oil, and other products like biodegradable plastics and specialty chemicals.

Biofuel crops grown in buffers can augment larger block plantings of biofuels. Research suggests that it may be possible to produce enough biofuels in buffers to offset the energy required to produce crops in between the buffers.

Hybrid poplar, willows, and switchgrass are the most researched biofuel crops although other species may be suitable (see table). Guides for growing biofuel crops are available.

### Key factors for locating biofuel buffers

- Highly erodible lands are often suitable.
- Other marginal lands may be suitable including flood-prone and nutrient-poor (dependent on plant species).
- Locate to achieve other goals (e.g., crop protection, water quality enhancement).
- Site should be close to a biofuel refinery to minimize transportation.



## Key design considerations

- Perennials provide more benefits than annuals.
- Mixed plantings can provide benefits over monocultures (may need to separate woody and herbaceous biofuel crops).
- Consider planting and harvesting equipment in the layout.
- Select biofuel crops that fit site conditions and that are complementary to natural plant communities in the area.
- Leave some biofuel crop unharvested in a given year to provide other benefits.

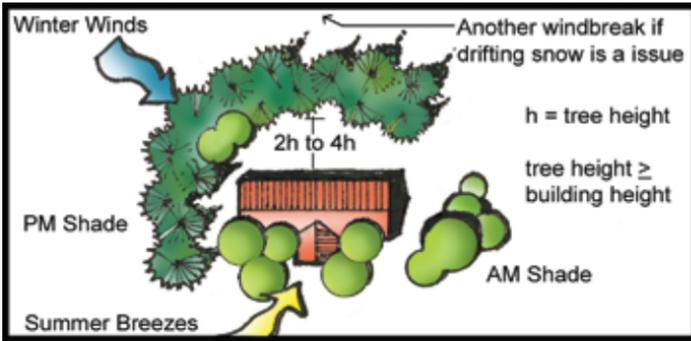
<b>Summary of Current Information on Major Biofuel Crops</b>			
<b>Factor</b>	<b>Poplar (<i>Populus</i> spp.)</b>	<b>Willow (<i>Salix</i> spp.)</b>	<b>Switchgrass (<i>Panicum virgatum</i>)</b>
Current yield <sup>1</sup> (dry tons/acre/yr)	3.1 to 7.0	3.0 to 5.4	4.0 to 6.7
Establishment time	3 years+	3 years+	2 to 3 years+
Pesticide requirements	Low	Low	Low
Fertilizer requirements	Low to Medium	Low to Medium	Very Low
Water demand	Medium	Medium	Low
Establishment cost	Medium	Medium	Low
Plantation longevity	15 to 30 years?	20 to 30 years?	20 to 30 years?
Harvest interval	3 to 10 years	3 to 4 years	Annual
Harvest equipment	Specialized cutter and chipper	Modified forage harvester	Hay baler
Net energy conversion <sup>2</sup>	1:8 to 1:16	1:8 to 1:16	1:4 to 1:14
Erosion rates <sup>3</sup> (tons/acre/yr)	0.09 to 0.9	0.09 to 0.9	0.09

### Notes:

1 Variable yields under unirrigated conditions and low to moderate fertilization.

2 Calculated net energy ratios for biofuels vary greatly due to base assumptions and type of energy produced. For general comparison, corn ethanol results in a net energy ratio of 1:1.6 while soybean biodiesel has a ratio around 1:3.2.

3 For general comparison, annual crops have erosion rates ranging from 2.0 to 6.7 tons/acre/yr.



## 4.7 Energy conservation: site

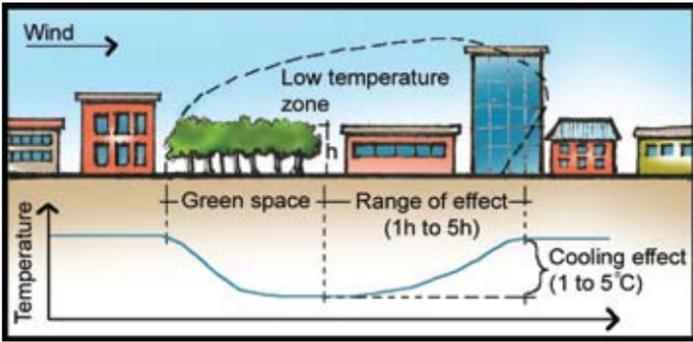
Buffers established with appropriate plants in the correct locations can yield annual energy savings of 10 to 40 percent. The key design issues are to manage for shade and wind.

### Managing shade

- For cooling, maximize shade on west and east walls and roof.
- Trees planted to the southeast, south, or southwest will only shade a building in the summer if they extend out over the roof. These trees should be deciduous and pruned up to allow winter sun into windows.
- Plan for maximum shade at warmest part of year and minimum shade at coldest (see section 5.6).
- Consider the plantings final height and form, branching density, and the leaf-on and -off periods.

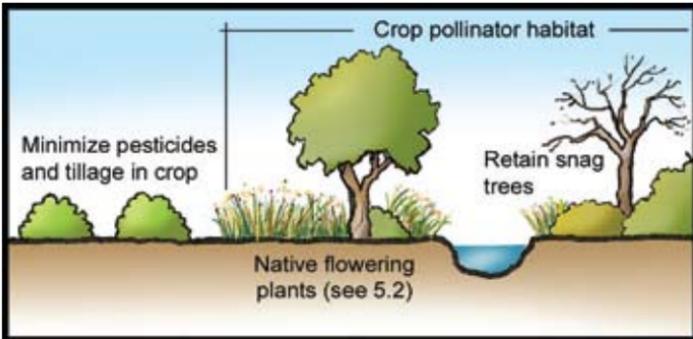
### Managing wind

- For heating, locate a dense evergreen windbreak 2 to 4 tree heights upwind of the building.
- For heating, a windbreak should not be pruned up. Stagger planting rows to prevent gaps in case a tree dies.
- If drifting snow is an issue, locate another windbreak upwind of the first windbreak (see section 5.7).
- For cooling, maintain an open understory to allow for ventilation by summer breezes (which are from a different direction than winter winds—see diagram).



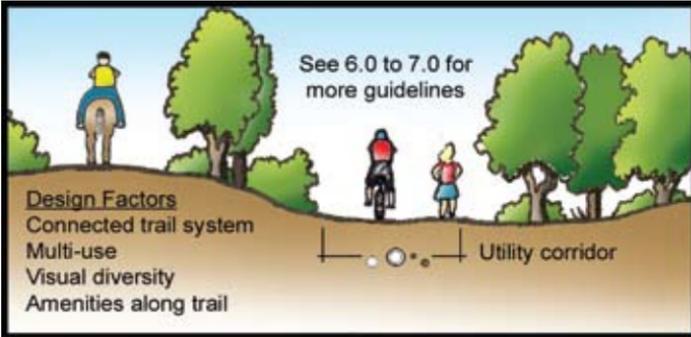
#### 4.8 Energy conservation: landscape

Parks and other green space buffers can reduce energy consumption by lowering adjacent air temperatures. Summer cooling effects of 1 °C to 5 °C can extend 1 to 5 tree heights into the built-up area. To maximize cooling, locate buffers at frequent intervals. Each degree reduction can lower electricity demand for cooling by 2 to 4 percent.



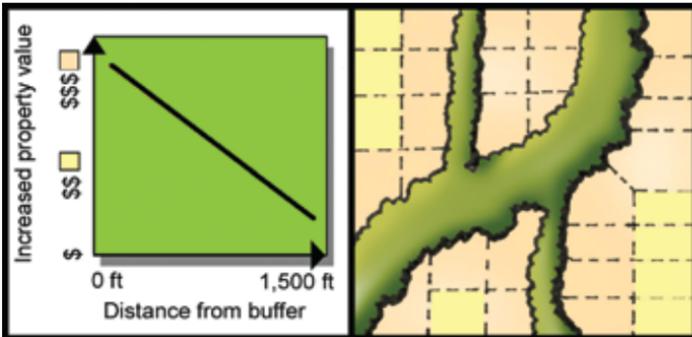
#### 4.9 Crop pollinator habitat

Buffers can provide valuable resources for crop pollinators including shade, nesting sites, water, nectar and pollen, and protection from pesticides (see sections 5.2 to 5.3). Buffers can reduce wind and aid in foraging and pollination efficiency. Ideally, buffers should be < 1,000 feet from the crop.



#### 4.10 Economic impact of trails

Buffers or greenways that include trails can generate economic benefits through increase in property values, tourism, and public cost reduction. Greenways can reduce public costs by serving as utility corridors and protecting high risk areas (e.g., flood prone) from development. Factors increasing trail usage contribute to economic benefits (see sections 6 and 7).



#### 4.11 Greenways and property values

Greenways can increase property values of nearby parcels by 5 to 32 percent. Greenways with desirable visual characteristics and recreational opportunities correspond to higher property values (see sections 6 and 7). Public greenway acquisition and development may be self-financing through the increase in property values and subsequent increase in property taxes.







# 5. Protection and Safety

## Objectives

- Protect from wind or snow*
- Increase biological pest control*
- Protect from flood waters*
- Create a safe environment*

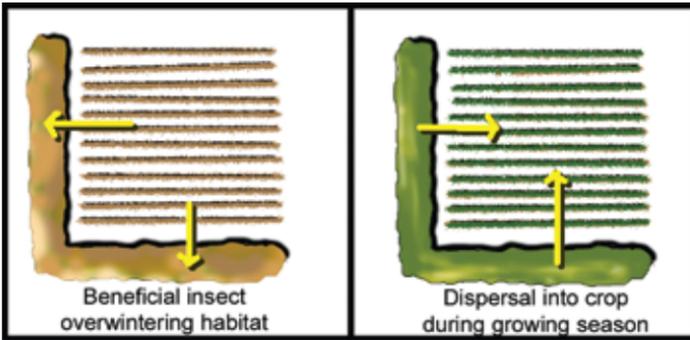
## Buffer functions

1. Reduce wind energy
2. Modify microclimate
3. Enhance habitat for predators of pests
4. Reduce flood water levels and erosion
5. Reduce hazards

Design Guidelines for Protection and Safety	Buffer Functions				
	Reduce wind energy	Modify microclimate	Enhance habitat for predators of pests	Reduce flood water levels and erosion	Reduce hazards
5.1 Managing insect pests with buffers	✓	✓	✓		
5.2 Plants that attract beneficial insects		✓	✓		
5.3 Buffers and spray drift	✓	✓	✓		✓
5.4 Weed control with buffers	✓		✓		
5.5 Buffers and road intersections					✓
5.6 Managing shade		✓			✓
5.7 Managing drifting snow	✓	✓			✓
5.8 Windbreaks for livestock	✓	✓			
5.9 Flood attenuation and buffers				✓	✓

<b>Design Guidelines for Protection and Safety</b>	<b>Buffer Functions</b>				
	Reduce wind energy	Modify microclimate	Enhance habitat for predators of pests	Reduce flood, water levels and erosion	Reduce hazards
5.10 Waterbreaks				✓	✓
5.11 Wildfire defensible buffer zones	✓	✓			✓

<b>Additional Design Guidelines that may Benefit Protection and Safety</b>	<b>Buffer Functions</b>				
	Reduce wind energy	Modify microclimate	Enhance habitat for predators of pests	Reduce flood, water levels and erosion	Reduce hazards
1.18 Allowances for bank erosion				✓	✓
2.2 Patch primer			✓	✓	
2.9 Corridor width			✓	✓	✓
2.13 Roads and wildlife crossings					✓
2.14 Roadside corridors					✓
3.2 Windbreaks for wind erosion	✓	✓	✓		✓
3.3 Herbaceous wind barriers	✓	✓	✓		✓
4.4 Windbreaks and crop yields	✓	✓	✓		
4.5 Alley cropping	✓	✓	✓		
4.7 Energy conservation: site	✓	✓			
4.8 Energy conservation: landscape	✓	✓			
4.9 Crop pollinator habitat	✓	✓	✓		
6.2 Windbreaks for odor control	✓	✓			✓
6.3 Air quality buffers	✓	✓			✓

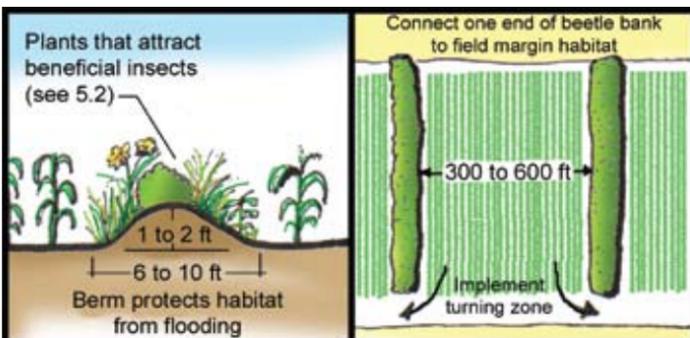


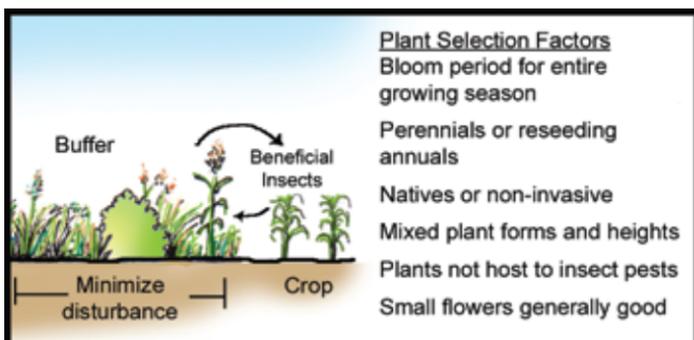
## 5.1 Managing insect pests with buffers

Buffers can provide habitat for beneficial insects that prey on insect pests of crops. To encourage predation, both the life cycle of the beneficial predator and pest should be understood.

### Key design considerations

- Provide plant diversity and structure in the buffer.
- Protect buffer from disturbances (e.g., pesticides, tillage).
- Predation of insect pests generally increases with the percentage of buffer habitat in the area.
- Locate buffers throughout the fields and landscape to encourage dispersal of beneficial insects.
- Buffers may provide habitat for some pest insects but this can be reduced by selecting appropriate plants (see section 5.2).
- Beetle banks are long, planted berms that provide habitat for beneficial insects (see below).





## 5.2 Plants that attract beneficial insects

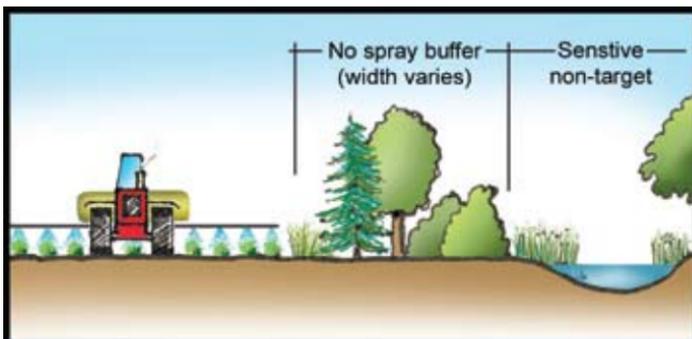
Buffers can be planted with plants to attract beneficial insects that prey on insect pests. Considerations include selecting plants that bloom sequentially throughout the growing season and avoiding plants that enhance pest abundance.

Native plants are preferred because these species attract native beneficial insects and are less likely to become agricultural weeds. The table below provides a list of beneficial insects, the pests the beneficial insects prey on, and the plants or habitats that attract the beneficial insects.

Plants that Attract Beneficial Insects		
Beneficial	Pests	Plants/Habitat
<b>Assassin bug</b> (Reduviidae family)	Many insects including flies and large caterpillars	Permanent plantings for shelter (e.g., windbreaks)
<b>Bees-Butterflies</b> (Many families)	None but important for pollination	Pea, borage, and aster families, milkweeds, butterfly bush, others
<b>Braconid wasp</b> (Braconidae family)	Armyworm, cabbageworm, codling moth, gypsy moth, European corn borer, aphid, caterpillars, and other insects	Nectar plants with small flowers, yarrow, sunflower, cowparsnip
<b>Damsel bug</b> (Nabidae family)	Aphid, thrips, leafhopper, treehopper, caterpillars	Aster family, yarrow, common boneset
<b>Ground beetle</b> (Carabidae family)	Slug, snail, cutworm, Colorado potato beetle, gypsy moth, caterpillars, weed seeds	Amaranth, bunch grasses, permanent plantings for shelter

## Plants that Attract Beneficial Insects

Beneficial	Pests	Plants/Habitat
<b>Hover fly</b> (Syrphidae family)	Aphid	Carrot and aster family (coreopsis, sunflowers, goldenrod), cowparsnip, common boneset
<b>Lacewing</b> (Chrysopidae family)	Soft bodied insects including aphid, thrips, European corn borer, mealybug, scale, mite	Carrot and aster family (coreopsis, sunflowers, goldenrod)
<b>Ladybug beetle</b> (Coccinellidae family)	Aphid, spider mite, European corn borer, mealybug	Aster family, butterfly weed, native grasses, giant hyssop, cowparsnip, yarrow, black locust
<b>Minute Pirate Bug</b> (Anthocorid family)	Thrips, spider mite, leafhopper, corn earworm, small caterpillars, and other insects	Carrot and aster family (daisies, sunflowers, yarrow, goldenrod), blue elderberry, potentilla, giant hyssop, common boneset, and willows
<b>Rove beetle</b> (Staphylinidae family)	Aphid, nematode, flies	Native grasses, permanent plantings for shelter
<b>Spider</b> (Salticidae, Thomisidae, and other families)	Many insects	Carrot and aster family, giant hyssop
<b>Spined soldier bug</b> ( <i>Podisus maculiventris</i> )	Armyworm, sawfly, Colorado potato beetle, Mexican bean beetle	Aster family (sunflowers, yarrow)
<b>Tachinid fly</b> (Tachinidae family)	Cutworm, armyworm, May beetle, gypsy moth, squash bug	Carrot and aster family, amaranth
<b>Tiger beetle</b> (Cicindelidae family)	Many insects	Amaranth, bunch grasses, permanent plantings for shelter
<b>Chalcid wasps</b> (many families including Trichogrammatidae)	Spruce budworm, cotton bollworm, tomato hornworm, corn earworm, corn borer, codling moth	Carrot and aster family (daisies, sunflowers, yarrow, goldenrod), potentilla, giant hyssop, cowparsnip, common boneset



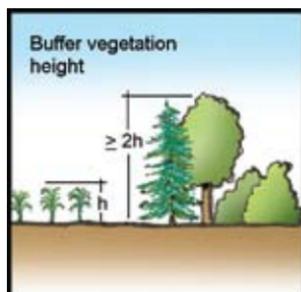
### 5.3 Buffers and spray drift

Buffers can help protect sensitive non-target areas from chemical spray drift. The buffer design is dependent on many variables including spray method, wind, chemical type, and the type of sensitive nontarget.

The adjacent graphs summarize recommendations for buffer widths based on spray method and the type of sensitive nontarget to be protected. Below are general design considerations.

#### Key design considerations

- Use vegetation with fine or needle-like leaves. Broadleaf plants capture less drift but are good for reducing wind.
- Use vegetation tolerant of the chemical being applied.
- Provide a permeable barrier (40 to 50 percent density) to allow air passage. Several rows of vegetation are better than one dense row.
- Buffer should be at least two times taller than the crop.
- Use a mixture of plant forms to ensure no gaps.
- Locate to intercept the prevailing winds and as close as possible to the spray zone.



The black bar denotes the suggested minimum recommended width while the gray bar indicates the upper end of the recommended widths based on current research. This summary should only serve as a starting point for design.

### Sensitive Non-Target



#### Vegetation

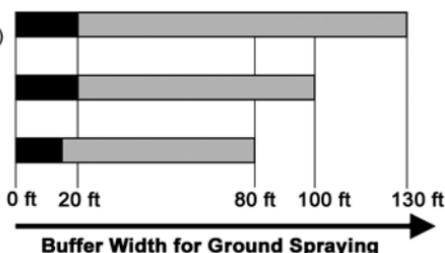
(e.g., seedlings, native veg.)

#### Aquatic

(e.g., wetland, fish)

#### Invertebrates

(e.g., bees, butterflies)



### Sensitive Non-Target



#### Vegetation

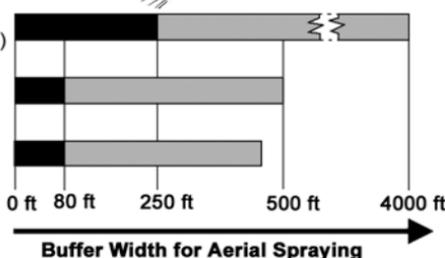
(e.g., seedlings, native veg.)

#### Aquatic

(e.g., wetland, fish)

#### Invertebrates

(e.g., bees, butterflies)



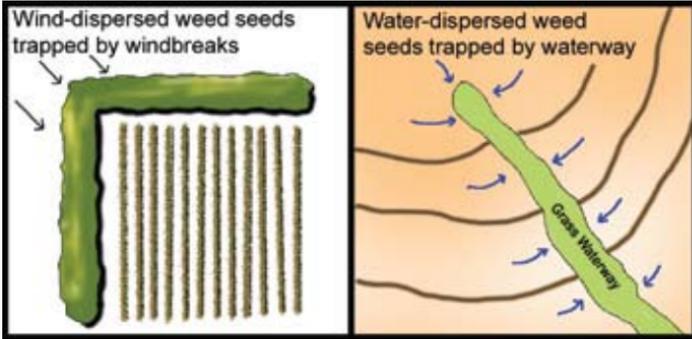
Minimum recommended width



Upper end of recommended width

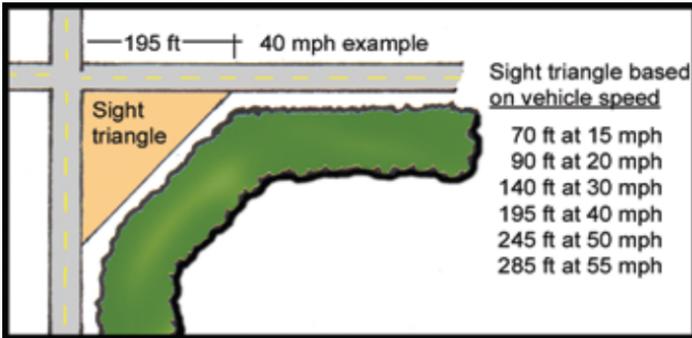
Due to the variability of chemical toxicity, these guidelines need to be used in conjunction with specific management recommendations for the particular chemical in use. Computer models are also available to help calculate spray drift potential and buffer zones.

Buffers should not be a substitute for other safety measures. Additional best management practices for chemical spraying need to be used in conjunction with buffers.



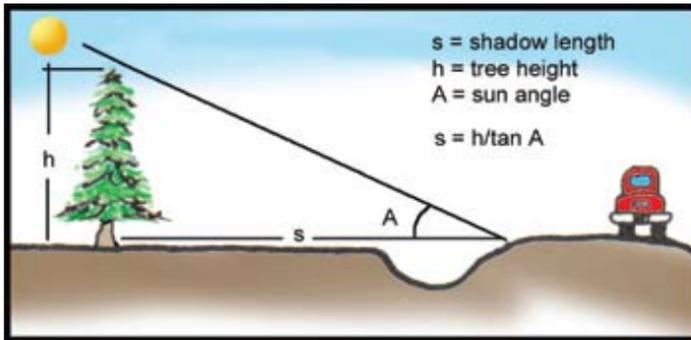
### 5.4 Weed control with buffers

Buffers are usually not a source of weeds and can be used for weed control. Buffers can trap water- and wind-dispersed weed seeds, reducing the area required for weed management. The concentration of weed seeds aids in seed predation by animals. Dense groundcover in a buffer can reduce weed germination.



### 5.5 Buffers and road intersections

At intersections not controlled by stop signs, design buffers to allow for views of oncoming traffic. The sight triangle should be based on vehicle speed. Plant height in sight triangle should be < 3 feet high. Check with agencies to see if there are regulations regarding intersection setbacks.

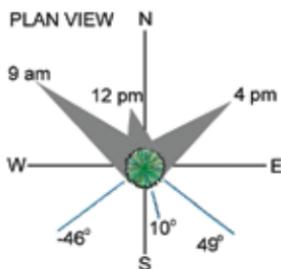


## 5.6 Managing shade

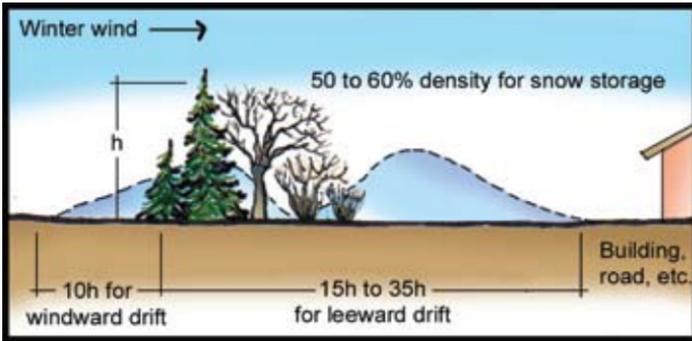
Shade cast by buffers can be a key design factor. For example, where roads are maintained to be free of snow and ice, buffers should be set back from the road to allow sunlight on the road surface. Where roads are maintained with snowpack, constant shade may be desirable to avoid ice. Buffers and their effect on drifting snow should also be considered (see section 5.7).

Use the formula  $s = h / \tan A$  to calculate shadow length. See table 5.6 for an example. Sun angle calculators, available on the Web, will provide the sun angle ( $A$ ) and azimuth angle for a given location based on the date and time.

Example: December 21 Sun Path Data				
Longitude 100° West - Latitude 40° North Tree Height = 35 feet				
Time	Sun Angle (A)	tan A	Sun Azimuth (East of South)	Shadow Length (feet)
9:00 AM	9°	0.1584	49°	221
12:00 PM	26°	0.4877	10°	72
4:00 PM	11°	0.1944	-46°	180

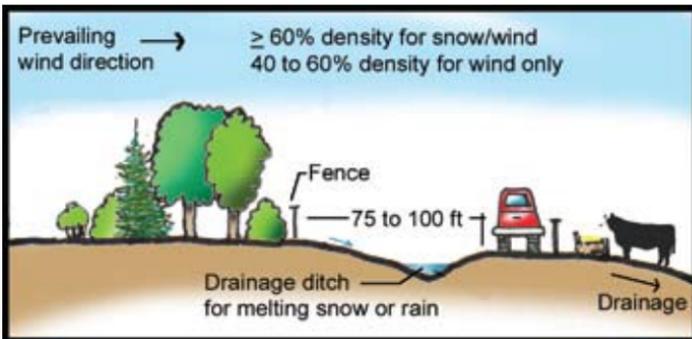


The azimuth angle is used to plot the shadow direction on the ground. Plotting the shadows throughout the day for key times during a year will be useful for designing the buffer (e.g., sections 2.12, 4.4, and 4.7).



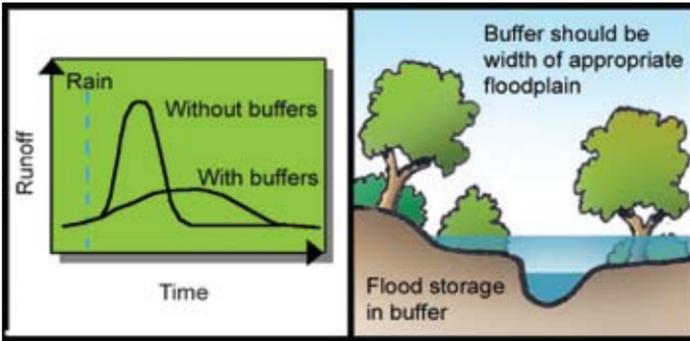
### 5.7 Managing drifting snow

To manage drifting snow, place a windbreak perpendicular to the prevailing winter winds. If the winter winds vary in direction, two windbreaks may be required. Extend the ends of the windbreak 50 to 100 feet beyond the area needing protection. Plant height influences snow storage capacity (i.e., doubling plant height increases snow storage by four times).



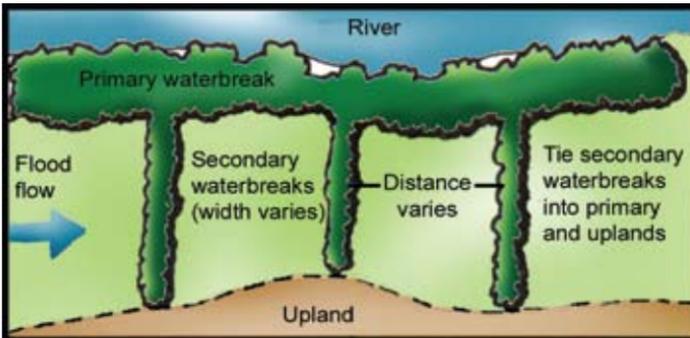
### 5.8 Windbreaks for livestock

Windbreaks located perpendicular to winter winds can protect livestock while allowing cooling summer winds to circulate in the feedlot or pasture. Protect windbreaks from grazing which can reduce windbreak effectiveness. Runoff from feedlot should be directed away from trees and should be treated (see section 1).



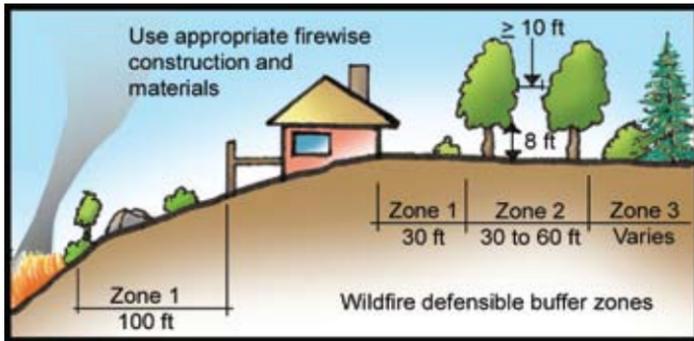
## 5.9 Flood attenuation and buffers

During flood events, riparian buffers and wetlands can slow runoff and absorb excess water. This reduces peak flows and can lessen downstream flooding. Downstream riparian buffers may be more effective in reducing flooding than upstream buffers. Buffer width should correspond to the width of the floodplain of concern.



## 5.10 Waterbreaks

A waterbreak is a system of woody buffers located to manage flooding and encourage sediment deposition. A primary waterbreak is orientated parallel to the river and secondary waterbreaks perpendicular to flood flows. Woody buffers next to levees on the channel side can protect levees from breaching and can reduce damage to levees when they do breach.



## 5.11 Wildfire defensible buffer zones

Buffer zones can be used to reduce fire damage to buildings and sensitive areas in landscapes prone to wildfire.

**Zone 1.** A minimum of 30 feet is needed for firefighters to protect a structure from wildfire. On a slope, increase the distance to 100 feet downhill of the structure. Use low growing and low flammability plants, spaced apart from each other. Remove dead material.

**Zone 2.** Deciduous trees and shrubs and widely spaced conifers may be used in Zone 2. Remove branches within 8 feet of the ground (but no more than 30 percent of the height of the tree) and space trees so that crowns remain at least 10 feet apart at maturity. Remove ladder fuels which are tree limbs and other materials that allow fire to burn into the tree crown.

**Zone 3.** Manage this zone to maintain forest stand health and other landowner objectives. Limit number of dead trees or snags but save some for wildlife (1 to 2 snags per acre).

Check with your local forester for additional guidelines.

### Characteristics of low flammability plants

- Supple moist leaves and water-like, thin sap
- Little or no accumulation of dead vegetation on the plant
- Open and loose branching structure







# 6. Aesthetics and Visual Quality

## Objectives

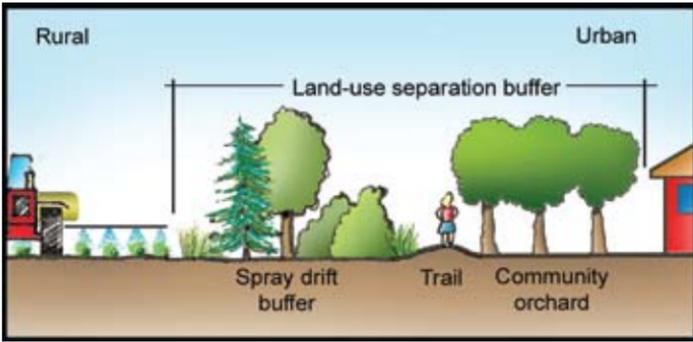
- Enhance visual quality
- Control noise levels
- Control air pollutants and odor

## Buffer functions

1. Enhance visual interest
2. Screen undesirable views
3. Screen undesirable noise
4. Filter air pollutants and odors
5. Separate human activities

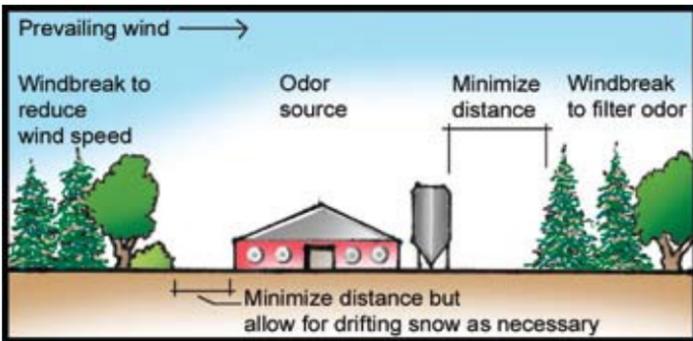
Design Guidelines for Aesthetics and Visual Quality	Buffer Functions				
	Enhance visual interest	Screen views	Screen undesirable noise	Filter air pollutants and odors	Separate human activities
6.1 Rural-urban land use buffer	✓	✓	✓	✓	✓
6.2 Windbreaks for odor control				✓	✓
6.3 Air quality buffers				✓	✓
6.4 Buffers for noise control				✓	✓
6.5 Developing an ecological aesthetic	✓				✓
6.6 Attractive roadside corridors	✓	✓	✓	✓	✓
6.7 Buffers for visual screening			✓		✓

Additional Design Guidelines that may Benefit Aesthetics and Visual Quality	Buffer Functions				
	Enhance visual interest	Screen views	Screen undesirable noise	Filter air pollutants and odors	Separate human activities
2.1 Matrix primer	✓				
2.3 Corridors and connectivity	✓	✓	✓	✓	✓
2.9 Corridor width	✓	✓	✓	✓	✓
2.13 Roads and wildlife crossings	✓				✓
2.14 Roadside corridors	✓	✓	✓	✓	✓
3.2 Windbreaks for wind erosion	✓			✓	✓
3.3 Herbaceous wind barriers	✓			✓	✓
4.10 Greenways and property values	✓	✓	✓	✓	✓
5.1 Managing insect pests with buffers					✓
5.3 Buffers and spray drift				✓	✓
5.4 Weed control with buffers					✓
5.7 Managing drifting snow					✓
5.8 Windbreaks for livestock			✓	✓	✓



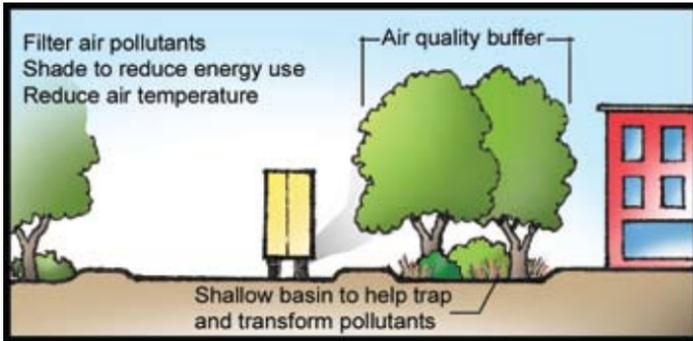
## 6.1 Rural-urban land use buffer

The rural-urban interface is often a zone of tension due to conflicting land uses and management. Use buffers to serve as a physical barrier between these land uses and to provide multiple benefits. Design the buffers to minimize the contentious issues (e.g., spray drift, noise, odor) while providing amenities (e.g., trails, community gardens).



## 6.2 Windbreaks for odor control

Windbreaks can reduce odors from livestock and sewage facilities and other odor-producing sources. Plant buffers with a mixture of tall trees and shrubs, particularly conifers, close to the odor source. Strive for 50 to 65 percent density. A windbreak system around the perimeter is often desirable. See section 6.3 for additional guidelines.



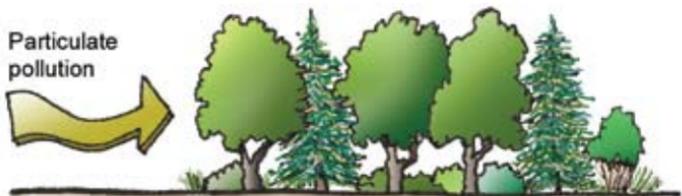
### 6.3 Air quality buffers

Vegetation in buffers can affect local and regional air quality in three main ways: temperature reduction, removal of air pollutants, and energy effects on buildings.

**Temperature reduction.** Lower air temperature due to trees and other vegetation can reduce emissions of many temperature-dependent pollutants.

**Removal of air pollutants.** Plants remove air pollutants by uptake via leaves and by intercepting airborne particles. Pollutants captured by vegetation are often transferred to the soil. While soils and plants will render some pollutants nontoxic, the final destination, form, and impact of the pollutants should be considered.

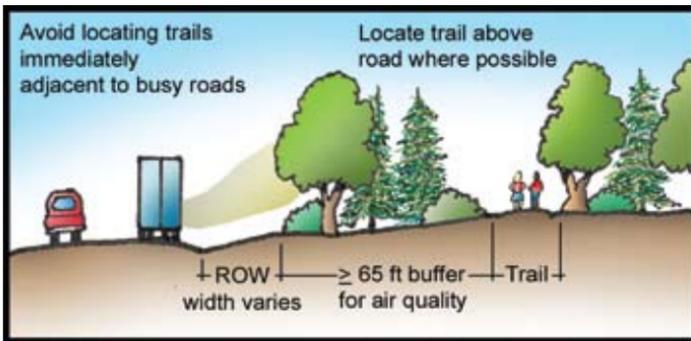
**Energy effects on buildings.** Trees reduce building energy use, lowering pollutant emissions from power plants.



A 65 to 600 ft wide buffer may reduce particulate pollution by 40 to 75 percent although many factors will affect pollutant removal

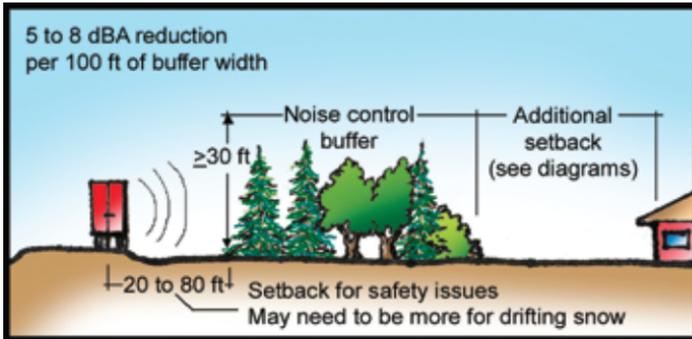
## Key design considerations

- Consider meteorological, topographical, and other landscape-scale factors in locating buffers (e.g., timing of pollution, high concentration spots).
- Plant buffers around and close to air pollution sources.
- Moderately dense buffers are best for pollutant removal.
- Use trees, shrubs, and grasses for multi-level trapping.
- Plant buffers in energy conserving locations (see sections 4.7 to 4.8).



## Plant selection criteria for air pollutant removal

- Evergreen trees can remove more pollutants; however, many conifer species are sensitive to common pollutants.
- Select plants with dense branching and twig structure.
- Leaves with hairy, resinous, and coarse surfaces capture more particles than smooth leaves. Smaller leaves are generally more efficient collectors than larger leaves.
- Herbaceous species may adsorb more gaseous pollutants.
- Use multiple species to minimize risks with low diversity.
- Use long-lived species that require minimal maintenance.
- Select species with pest and disease resistance.
- Select species suitable for the site (e.g., urban environments often have compacted and droughty soils).



## 6.4 Buffers for noise control

Buffers can reduce noise from roads and other sources to levels that allow normal outdoor activities to occur. A 100-foot wide planted buffer will reduce noise by 5 to 8 decibels (dBA). Using a barrier in the buffer such as a landform can significantly increase buffer effectiveness (10 to 15 dBA reduction per 100-foot wide buffer with 12-foot high landform).

Guidelines are provided below for roads. Use the diagrams on the adjacent page to estimate a setback distance from a typical 100-foot wide buffer to achieve an acceptable noise level.

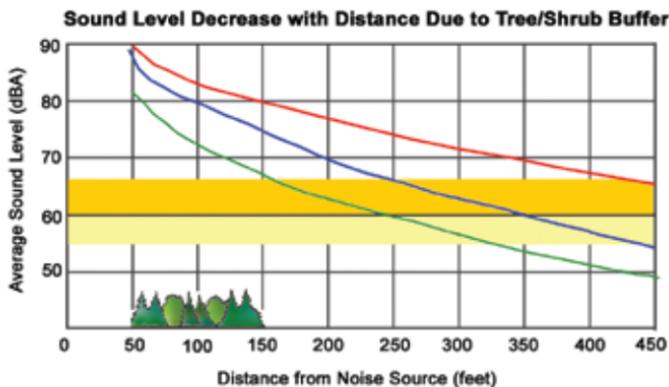
Buffer Guidelines for Noise Reduction Along Roads	
<b>Moderate Speed Road (&lt;40 mph)</b> Plant a 20 to 50-foot wide buffer with the near edge of the buffer within 20 to 50 feet of the center of the nearest traffic lane	<b>High Speed Road (≥40 mph)</b> Plant a 65 to 100-foot wide buffer with the near edge of the buffer within 50 to 80 feet of the center of the nearest traffic lane

### Key design considerations

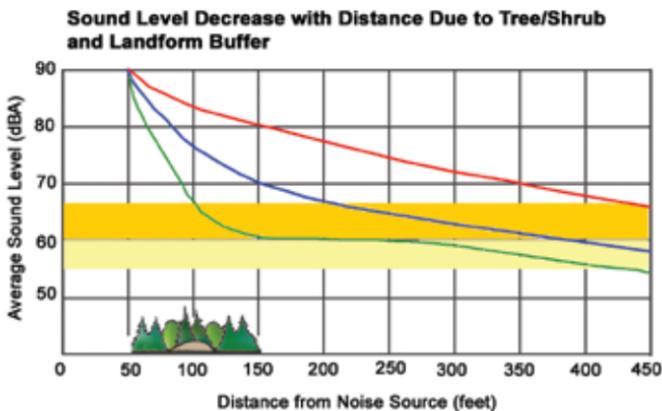
- Locate buffer close to the noise source while providing an appropriate setback for accidents and drifting snow.
- Evergreen species will offer year-round noise control.
- Create a dense buffer with trees and shrubs to prevent gaps.
- Select plants tolerant of air pollution and de-icing methods.
- Natural buffers will be less effective than planted buffers.
- Consider topography and use existing landforms as noise barriers where possible.

## Estimating setback distance from noise control buffers

Example: An outdoor recreational site near a highway needs to be located to meet the desired noise levels of 60 to 65 dBA. If a 100-foot wide tree/shrub buffer is used, the site needs to be 100 to 200 feet behind the buffer. The site can be located immediately behind the buffer if a 12-foot high landform is incorporated into the buffer.

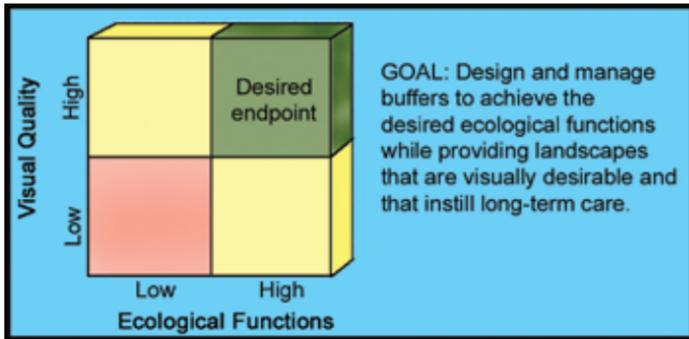


- Control - (No tree/shrub buffer - truck noise at 55 mph)
- Truck noise with 100-ft wide tree/shrub buffer
- Car noise with 100-ft wide tree/shrub buffer



- Control - (No tree/shrub buffer - truck noise at 55 mph)
- Truck noise with 100-ft wide tree/shrub buffer & 4-ft high landform
- Truck noise with 100-ft wide tree/shrub buffer & 12-ft high landform

- 60 to 65 dBA acceptable noise levels for outdoor conversation
- 55 to 60 dBA acceptable noise levels for daytime residential areas



## 6.5 Developing an ecological aesthetic

Many people, regardless of background, prefer similar visual elements in the landscape. Some of these include:

### Commonly preferred visual elements

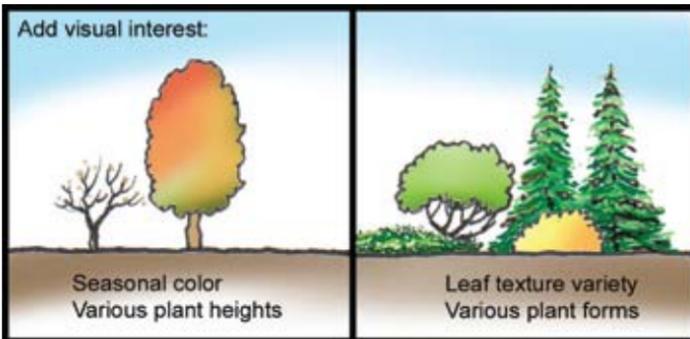
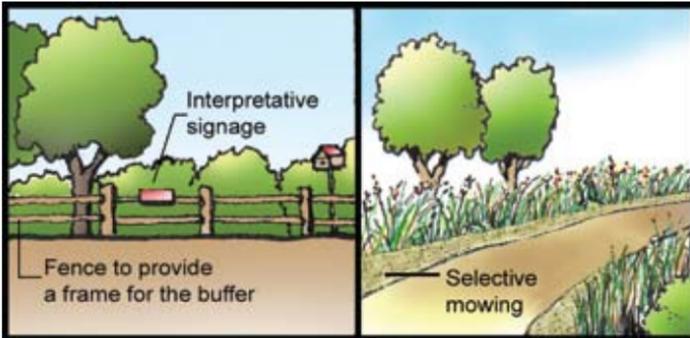
- Waterscapes (e.g., lakes, meandering streams)
- Manicured landscapes
- Savanna or park-like landscapes
- Trees in scale with surrounding features
- Absence of dead and downed wood
- Clean waterways with no or limited woody debris
- Large mature trees and trees with broad canopies
- Spaces defined by edges (e.g., pasture bordered by woods)

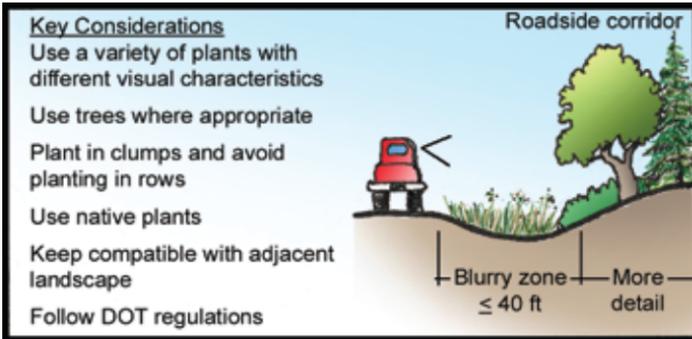
Some of these visual elements are not desirable for achieving goals such as water quality and wildlife habitat. Naturalistic landscapes providing valuable ecological functions are often viewed as untidy and undesirable, while manicured landscapes with limited ecological functions are perceived as demonstrating stewardship and are visually desirable.

The challenge is to design buffers that achieve the desired ecological functions while providing landscapes that are visually desirable and that instill long-term commitment. The next page provides strategies for addressing this challenge.

## Strategies for enhancing visual preference of buffers

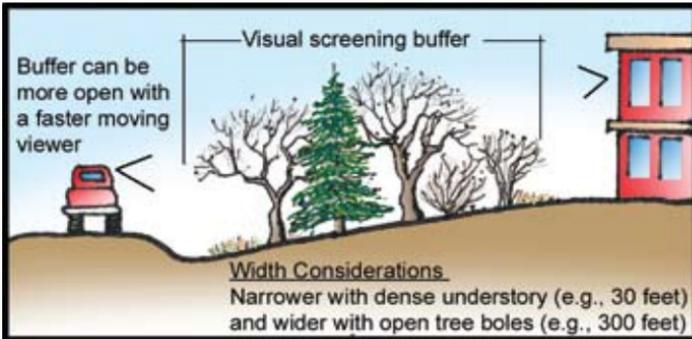
- Design the part of the buffer viewable by the public to be visually pleasing while the interior can be designed to achieve the desired ecological functions.
- Use selective mowing to indicate stewardship without greatly reducing the ecological functions.
- Provide visual frames to contain and provide order around the buffer (e.g., wooden fence).
- Use interpretative signage and education programs to increase awareness and preference.
- Enhance visual interest and diversity by increasing seasonal color and by varying plant heights, textures, and forms.
- Provide simple habitat improvements such as nesting boxes and feeders. Wildlife usually increases visual preference.
- Use bold planting patterns to indicate a designed landscape.





## 6.6 Attractive roadside corridors

Roadside corridors can be designed and managed to create a pleasant driving environment, save maintenance costs, and reduce driver stress. Create visual interest with plant color, texture, form, and height. At speeds over 40 miles per hour, the area that is  $> 40$  feet from the side of the road will have more detail and will be more important visually. See sections 5.5 to 5.7.



## 6.7 Buffers for visual screening

Use dense and multi-layered vegetation, particularly shrubs to screen views. Deciduous plants provide 40 percent less screening than evergreens after leaf fall, so evergreens or a wider deciduous buffer may be necessary for screening year-round. Consider vegetation and viewpoint height in design.







# 7. Outdoor Recreation

## Objectives

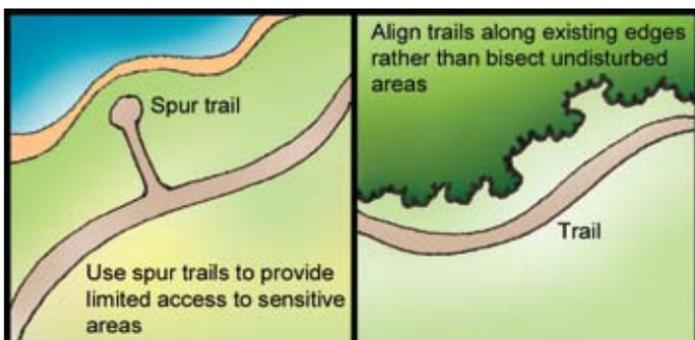
- *Promote nature-based recreation*
- *Use buffers as recreational trails*

## Buffer functions

1. Increase natural area
2. Protect natural areas
3. Protect soil and plant resources
4. Provide a corridor for movement
5. Enhance recreational experience

Design Guidelines for Outdoor Recreation	Buffer Functions				
	Increase natural area	Protect natural areas	Protect soil and plant resources	Provide a corridor for movement	Enhance recreational experience
7.1 Trail design and wildlife	✓	✓	✓	✓	✓
7.2 Flight initiation distance buffers	✓	✓	✓	✓	✓
7.3 Trails along riparian corridors	✓	✓	✓	✓	
7.4 Soil erosion and trail recreation		✓	✓		✓
7.5 Trail user preferences				✓	✓
7.6 Trail layout	✓			✓	✓
7.7 Trail access and usage				✓	✓
7.8 Greenways and public safety					✓

<b>Additional Design Guidelines that may Benefit Outdoor Recreation</b>	<b>Buffer Functions</b>				
	Increase natural area	Protect natural areas	Protect soil and plant resources	Provide a corridor for movement	Enhance recreational experience
1.18 Allowances for bank erosion		✓	✓		
1.22 Vegetation for bank erosion control		✓	✓		
2.1 Matrix primer	✓	✓	✓	✓	✓
2.3 Corridors and connectivity	✓	✓	✓	✓	✓
2.8 Buffers and corridors	✓	✓	✓	✓	✓
2.9 Corridor width	✓	✓	✓	✓	✓
2.10 Edge effects of corridors		✓		✓	
2.11 Aquatic habitat and buffers	✓	✓	✓	✓	✓
2.13 Roads and wildlife crossings		✓		✓	
3.1 Buffers and cropland management			✓		
3.2 Windbreaks for wind erosion	✓		✓	✓	
4.10 Economic impacts of trails				✓	✓
6.4 Buffers for noise control				✓	✓
6.5 Developing an ecological aesthetic				✓	✓
6.7 Buffers for visual screening				✓	✓

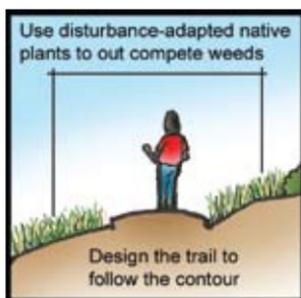


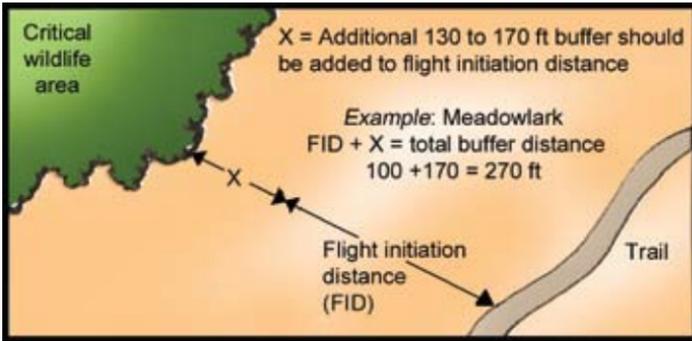
## 7.1 Trail design and wildlife

Trails can be designed to minimize human disturbance impacts on wildlife. Factors influencing short-term impacts include: type of species and flushing distance, type and intensity of human activity, time of year and time of day, and type of wildlife activity. Consult with wildlife experts for guidance.

### Key design considerations

- Align trails along or near existing human-created or natural edges rather than bisecting undisturbed areas (see section 7.3).
- Keep a trail and its zone of influence away from specific areas of known sensitive species.
- Avoid or limit access to critical habitat patches.
- Provide diverse trail experiences so that trail users are less inclined to create trails of their own.
- Use spur trails or dead-end trails to provide access to sensitive areas because these trails have less volume.
- Generally, concentrate activity rather than disperse it.
- Keep trail construction impact as narrow as possible.
- Concentrate weed control at road and trail crossings, trailheads, and riparian areas.
- See section 7.2 for buffers based on flight initiation distance.





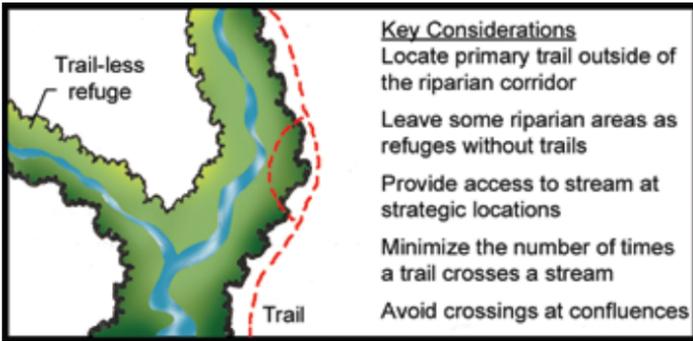
## 7.2 Flight initiation distance buffers

Fight initiation distance (FID) is the distance at which an animal will start to move away from an approaching threat such as a trail user. FID has been recorded for a variety of species and these distances may serve as general guidelines for establishing buffers from critical wildlife areas (see table 7.2).

These distances are based on being approached by a single person on foot. Groups of people may require wider buffers. Many other factors influence FID and a wildlife biologist should be consulted.

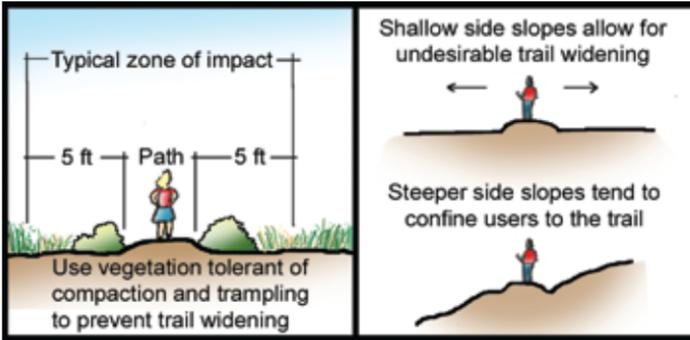
Flight Initiation Distance		Flight Initiation Distance	
Species	Flight Distance (feet)	Species	Flight Distance (feet)
Mule Deer	490 to 820	Golden Plovers	660
Pronghorn	770	Great Blue Heron	660
Elk	280 to 660	Merlin	60 to 600
Bison	330	Prairie Falcon	60 to 600
Golden Eagle	345 to 1280	Great Egret	330
Rough-legged Hawk	175 to 2900	Meadowlark	100
Bald Eagle	165 to 2900	Robin	30

Note that FID is the distance at which the animal begins to evade a threat; an additional setback should be added to the FID to create a buffer that will minimize wildlife disturbance. An additional 130 to 170 feet has been recommended as the additional buffer distance.



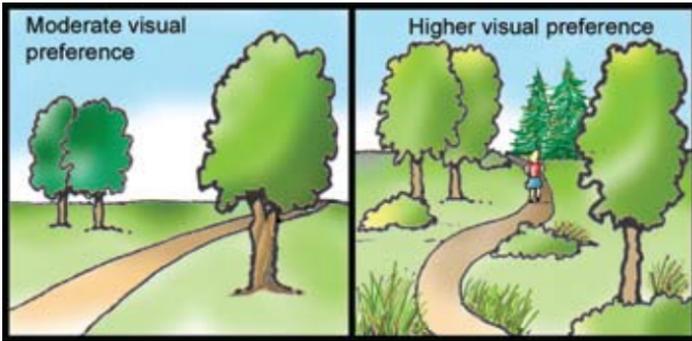
### 7.3 Trails along riparian corridors

Riparian corridors are critical areas for many ecological functions which can be negatively impacted by poorly designed and managed recreational trails. To minimize impacts and maintenance issues, locate the primary trail to the outside of the riparian corridor and then provide access to the riparian area at strategic points.



### 7.4 Soil erosion and trail recreation

Reduce soil erosion by locating trails on soils with low erodibility (e.g., coarse-textured, low organic matter, low soil moisture). Design trails to follow the contour. Use waterbars and other measures to route runoff away from trail. Bridge wet soils and avoid steep slopes. Consider using trail surface materials like mulch or crushed gravel to reduce erosion.

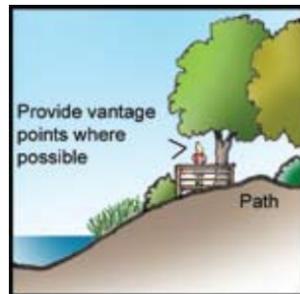


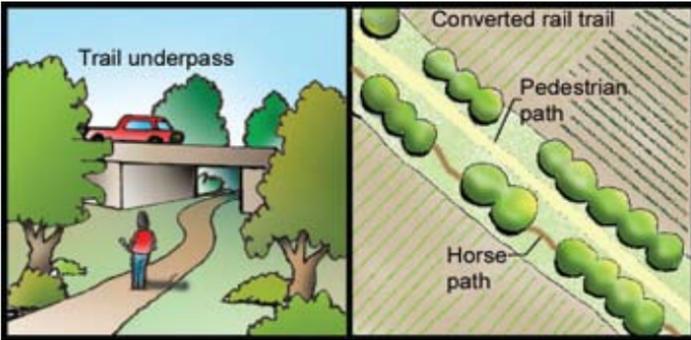
## 7.5 Trail user preferences

Preference studies have identified attributes that trail users find desirable in greenway trails. These attributes can be used to enhance the recreational experience and increase trail usage.

### Key design considerations

- Trails passing through several types of plant communities are generally more preferred.
- Incorporate waterscapes and historical or cultural elements where possible (e.g., old stone walls, canals).
- Trails passing through open areas with few trees or distinct features are less preferred. A mixture of open and enclosed areas is desirable.
- Create a sense of mystery through a curvilinear path alignment.
- Incorporate other preferred visual elements (see section 6.5).
- Provide trails that are connected, accessible to users, and that encourage multiple uses (see sections 7.6 to 7.8).
- Design trails to reduce exposure to noise and air pollution (see sections 6.3 and 6.4).
- Create vantage points where users can view wildlife, other trail users, or interesting features.



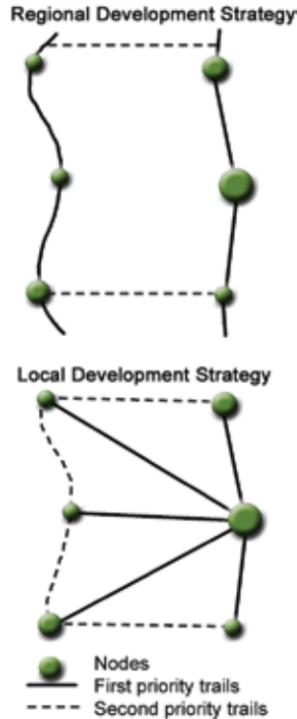


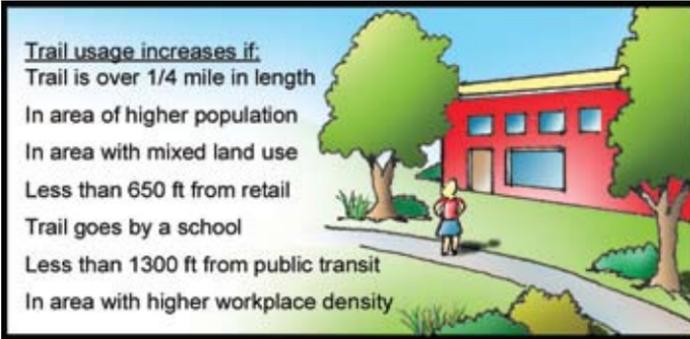
## 7.6 Trail layout

A connected trail systems offers a more pleasant, safe, and continuous recreational experience than unconnected trails. Design trails to provide safe passage across potential barriers such as roads (e.g., through trail bridges and underpasses). Abandoned railroad lines may be converted to trails, often serving as an important regional trail in an area.

Regional trails are often developed as the backbone of a trail system of which local trails can connect. In urbanized areas, a local development strategy for trails may be a more useful approach than a regional strategy. Local trails can more consistently meet users' everyday needs for recreation, commuting, and access to nature (see diagram).

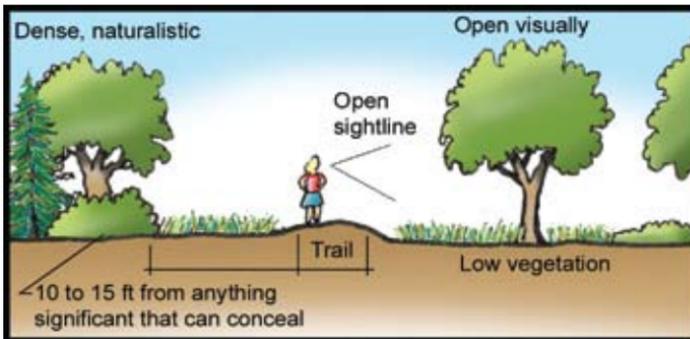
The nodes represent origin-destination points such as parks and places of work. In the regional strategy, regional trails are built first and then secondary connections are made. In the local strategy, a series of local trails are developed first to provide more options for pedestrian use.





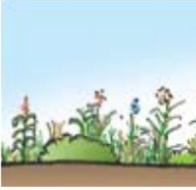
## 7.7 Trail access and usage

As a general guideline for local trails, the target population should be < 5 miles from the trail and 1 mile if the group is an older population. For regional trails, people may be willing to travel 15 or more miles to use a greenway trail. Accommodate multiple modes of travel but consider separating conflicting use (e.g., biking and horseback riding).



## 7.8 Greenways and public safety

Greenway trails have documented low crime rates compared to other developed land uses. Vegetation can be managed to reduce the perception of fear or crime. Dense, naturalistic vegetation along one side of a trail is not perceived as unsafe as long as the other side is visually open. Provide 100 feet of both forward and rear visibility on trails where possible.



# Glossary of Terms

**anaerobic:** without oxygen.

**aquitard:** an underground bed or layer of soil, rock, or clay that is too dense to allow easy passage of water.

**best management practices (BMPs):** structural or nonstructural methods that prevent or reduce the movement of sediment, nutrients, pesticides, and other pollutants from the land to surface or ground water.

**bioavailability:** the degree to which pollutants in contaminated soil are available for biodegradation.

**bole:** the trunk of a tree.

**buffer:** a linear patch. The buffer's linear shape may help the buffer perform certain functions, such as screening undesirable views and increasing habitat connectivity.

**buffer area ratio:** the ratio of upslope runoff-contributing area to buffer area that the runoff flows into.

**carbon sequestration:** the removal of carbon dioxide from the atmosphere.

**c-factor:** the ratio of soil loss from land under a specific crop and management system to soil loss from continuously fallow and tilled land.

**concentrated flow:** runoff that accumulates or converges into well-defined channels.

**connectivity:** the ease with which organisms and materials can travel between two points.

**conservation tillage:** a system of crop production in which the soil is disturbed as little as possible.

**corridor:** a linear patch. The corridor's linear shape may help the corridor perform certain functions, such as screening undesirable views and increasing habitat connectivity.

**denitrification:** bacterial reduction of nitrite to gaseous nitrogen under anaerobic conditions.

**deposition:** the geological process by which material is added to a landform or land mass.

**dispersal:** the process or result of organisms or particles spreading from one place to another.

**ecosystem services:** consumable and non-consumable services that an ecosystem provides to humans.

**edge effects:** the ecological effects that result when two or more habitat types meet at an interface. Edge can occur naturally or artificially, and artificial creation of edge can have negative impacts if it alters ecological processes.

**filter strip:** strip or area of vegetation used for removing sediment, organic matter, and other pollutants from runoff and wastewater.

**Geographic Information System (GIS):** a system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data.

**groundwater recharge:** inflow of water to a groundwater reservoir from the surface.

**hydric soil:** a soil formed under conditions of saturation or flooding, where these conditions last long enough during the growing season so that anaerobic conditions develop in the upper part of the soil.

**karst:** an area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams, and caverns.

**koc value:** a measure of how tightly a pesticide binds or sticks to soil particles. The larger the Koc, the more strongly the pesticide is held to soil organic matter and the less likely it will leach.

**impervious cover:** any hard surface material such as roof tops, asphalt, or concrete that limits infiltration and induces high runoff rates.

**infiltration:** the downward entry of water into the soil or other material.

**leachate:** a liquid that has come in contact with or been released from waste.

**mass slope failure:** the downslope movement of material on an unstable slope.

**matrix:** the background within which patches and buffers exist.

**migration:** the periodic passage of groups of animals from one region to another for feeding or breeding.

**parasitism:** a relationship between two species of organisms in which one benefits at the expense of the other, without killing it.

**patch:** a relatively small area that has distinctly different structure and function than the surrounding landscape.

**pathogens:** microorganisms that can cause disease in other organisms or in humans.

**permeability:** the ability of a material to allow the passage of a liquid.

**phytoremediation:** the use of plants to clean up soil and water contaminated with metals, solvents, and other pollutants.

**porosity:** a measure of the void spaces in a material.

**predation:** the act of capturing another organism for use as food.

**refugia:** locations in which species have persisted while becoming extinct elsewhere.

**riparian areas:** transitional areas between those characterized by terrestrial and aquatic ecosystems. Riparian areas are distinguished by gradients in bio-physical conditions, ecological processes, and biota.

**sensitive non-target areas:** areas adjacent to chemical spray application areas and considered off-limits to spray drift.

**soil cohesion:** the ability of a soil to hold itself together.

**stepping stones:** small patches of habitat that allow for species movement between large patches.

**targeting:** focusing preservation, conservation, or other management practices on specific portions of the landscape where they will have the greatest benefits.

**windthrow:** uprooting of trees by wind.

**Bentrup, G.** 2008. Conservation Buffers—Design guidelines for buffers, corridors, and greenways. Gen. Tech. Rep. SRS-109. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 110 p.

Over 80 illustrated design guidelines for conservation buffers are synthesized and developed from a review of over 1,400 research publications. Each guideline describes a specific way that a vegetative buffer can be applied to protect soil, improve air and water quality, enhance fish and wildlife habitat, produce economic products, provide recreation opportunities, or beautify the landscape. These science-based guidelines are presented as easy-to-understand rules-of-thumb for facilitating the planning and designing of conservation buffers in rural and urban landscapes. The online version of the guide includes the reference publication list as well as other buffer design resources @ [www.bufferguidelines.net](http://www.bufferguidelines.net).

**Keywords:** Buffer, conservation planning, conservation practice, corridor, filter strip, greenway, riparian, streamside management zone, windbreak.



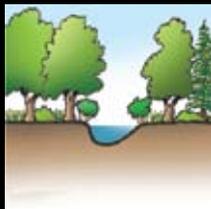
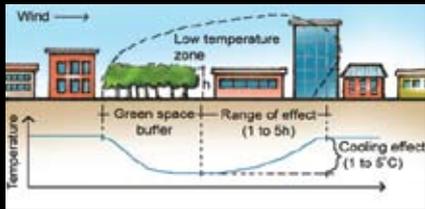


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