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# Multifunctional Buffers

## Design Guidelines for Buffers, Corridors, and Greenways

Gary Bentrup and Xinyuan Shi

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## Abstract

Over 80 illustrated design guidelines for multifunctional buffers are synthesized and developed from a review of more than 1,900 research publications. Each guideline describes a specific way that a vegetative buffer can be applied to protect soil, improve air and water quality, support fish and wildlife habitat, augment crop and livestock production, enhance the human environment, or provide recreation opportunities. Vegetated buffers may include those designed as an agroforestry system or those implemented outside of an agricultural setting. These science-based guidelines are presented as easy-to-understand rules of thumb for facilitating the planning and designing of multifunctional buffers in rural and urban landscapes. The online version of the guide includes the reference publication list.

## About the Authors

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## Purpose of This Guide

Multifunctional buffers are strips of vegetation placed in the landscape to influence ecological processes and provide a variety of goods and services (fig. 1). They are known by many names such as *filter strips*, *greenways*, *wildlife corridors*, and *windbreaks*. *Italicized words* in this guide are defined in the glossary.

Environmental objectives or benefits that multifunctional buffers can provide include protecting soil resources, improving air and water quality, and supporting fish and wildlife habitat. Buffers can offer socioeconomic benefits such as augmenting crop and livestock production, enhancing the human environment, and providing recreational opportunities. In addition, buffers can enhance ecosystem resiliency through climate change mitigation and adaptation.

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

The purpose of this publication is to provide a synthesis of this diverse knowledge base into distilled, easy-to-understand design guidelines. This guide is targeted for a wide range of users from land managers to agency staff and technical service providers.

**Figure 1—**Buffers in riparian and upland locations can achieve multiple objectives. Photo by iStock.

## The Guide Online

Over 80 design guidelines were developed from more than 1,900 research articles from disciplines as diverse as agricultural engineering, agroforestry, conservation biology, economics, hydrology, landscape ecology, social sciences, and urban ecology. A separate companion document organizes these articles by guidelines and is available at https://doi.org/10.2737/WO-GTR-108. These references can serve as a valuable resource for additional design information.

An earlier version of this guide ("Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways," published in 2008) is available at https://doi.org/10.2737/SRS-GTR-109. Visit https://www.fs.usda.gov/nac/ to find Spanish, French, Mandarin, Korean, and Mongolian language versions.

## 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. Many gaps still exist in our understanding of buffers and their ecological and socioeconomic functions and impacts.

The user must weave these guidelines together with firsthand knowledge of the site, the landscape, and desired goals to create a design that optimizes objectives and minimizes potential problems.

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

# Planning Multifunctional Buffers

## Types of Buffers

Various terms are used to describe different types of buffers, including filter strip, greenway, *hedgerow, riparian buffer, swale, vegetated waterway,* wildlife corridor, and windbreak, to name a few. These types of buffers may include those designed as an *agroforestry* system or those implemented outside an agricultural setting.

These terms are commonly used in the resource literature and are defined in the glossary. They are often associated with specific resource issues (e.g., water quality with buffers, wildlife with corridors, and recreation and urban aesthetics with greenways). Designing for multifunctionality puts the focus on a project's overarching objectives and the desired buffer functions rather on specific terminology.

## Functions

Multifunctional buffers can improve resource conditions by enhancing certain landscape functions or purposes. Major resource issues that buffers can be designed to address, and their associated functions are listed in table 1 (p. 10).

Most buffers will perform more than one function, even if designed with only one function in mind. Buffer design should consider both intended and unintended functions, which may or may not be desirable. For instance, a plant species used in a buffer might be a host for an undesirable pest or disease.

## Location

Location determines a buffer's proximity to problem conditions in the surrounding landscape. It also determines important site characteristics, such as soil type and slope, that can influence the buffer's effectiveness. One location may be better for one function, while a different location would be better for another function (fig. 2, p. 4).

For instance, upland buffers are generally more effective at removing phosphorus (P) in runoff, whereas riparian buffers can be more effective for nitrogen (N) removal (fig. 2).

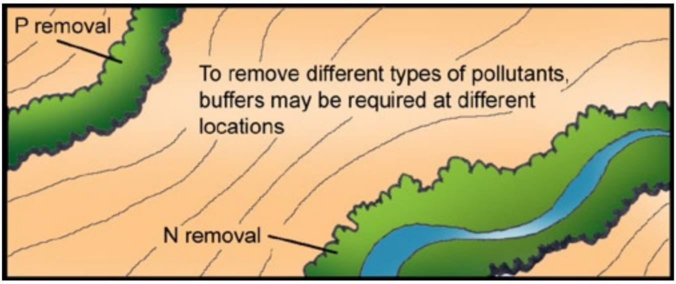



**Figure 2**—Buffer location will determine actual functions.

*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, GIS may identify locations where an objective can be better addressed with a buffer. GIS is particularly useful for identifying locations where a buffer can serve multiple functions.

### Structure

Structural characteristics of a buffer, such as size, shape, and vegetation type, largely determine how well a buffer can function at a given location. These variables can often be designed to achieve desired objectives. These guidelines address many of these design and planning considerations.

### Management

Management activities in and near the buffer will often determine the types of functions the intervention will provide and the performance level in delivering those functions. For example, nutrient management in a field adjacent to a buffer will influence the effectiveness of a buffer to provide water quality benefits. Management activities should consider the suite of desired functions, recognizing that there may be conflicts in management activities that will need to be resolved.

## Systems

Buffers with different designs in various locations can create a buffer system that can achieve multiple objectives.

Addressing multiple objectives and functions is a complex task, since each objective has its own scale and each buffer function operates at its own scale. A planning process using a structured method to organize and ensure that all objectives are addressed produces a landscape plan.

Figure 3 shows a conceptual buffer landscape plan developed through a planning process and illustrates 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.

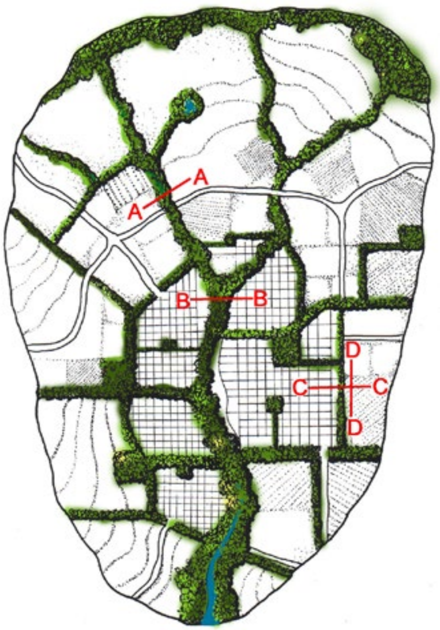
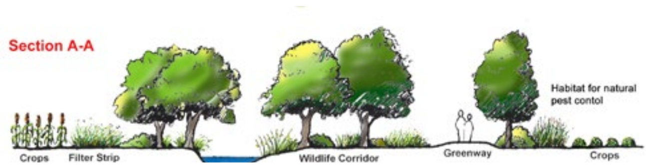


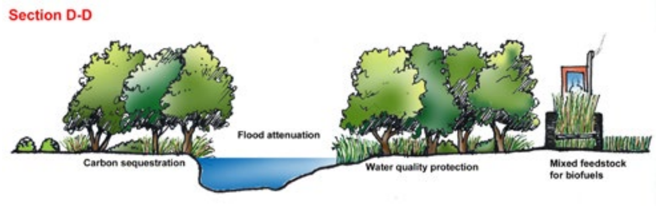

**Figure 3**—Conceptual plan and sections illustrating several types of multifunctional buffers in a watershed. Each buffer accomplishes different sets of functions and objectives.




**Section A-A**: A buffer designed to filter agricultural runoff to reduce a community's treatment cost for drinking water. 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 because the buffer is situated in a built-up area where only city-tolerant wildlife would benefit.


**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. The buffer also provides noise control and protection from agricultural spray. 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 offers aesthetic views at selected locations. The design incorporates other aesthetic considerations to encourage human use. Signage informs residents about conservation measures that protect natural resources.

## Temporal Considerations

Buffers are dynamic systems that change over time as vegetation matures and modifies site and landscape attributes.

This temporal aspect influences the types of functions delivered and the buffer's ability to perform those functions. Planted buffers often require a lag time until the vegetation reaches maturity to provide the desired functions.

For instance, buffers can play an important role in mitigating climate change by sequestering carbon in soils and woody *biomass*. Buffer vegetation can also enhance resiliency to extreme weather events through canopy cover and root systems. Realizing these benefits takes time, and it is important to consider the temporal factors when planning and designing buffers.

Management activities can also be used to address temporal aspects. For example, maintaining vegetation in an early *successional stage* may be advantageous for certain wildlife species requiring this habitat type.

Unplanned disturbances such as a flood event or windstorm may significantly impact the structure and viability of the buffer, ultimately affecting the desired functions. While these types of events cannot be completely avoided, planning and design may help minimize their impact. Relying on multiple practices and systems in addition to buffers can increase the overall resiliency to these events.

Buffers are only one tool in the planner's toolbox. Planners need to be realistic in applying buffers, acknowledging both their strengths and limitations to address resource concerns and management objectives.

**In summary:**

- Consider the landscape context when designing buffers.
- Design each buffer for multiple objectives.
- Develop and integrate systems of buffers where appropriate.
- Be aware of potential unintended effects of buffers.
- Recognize the benefits and limitations of buffers.
- Incorporate temporal considerations.
- Use a planning process.

To begin using this guide, refer to "How to Use This Guide" (p. 9).

## Planning Process

This guide provides science-based guidelines for planning and designing multifunctional buffers. The guidelines are organized into six major resource sections:

1. Water Quality
2. Biodiversity
3. Soils
4. Crops and Livestock
5. Quality of Life
6. Recreation

Buffer objectives and functions have been identified for each resource section (table 1).

A simple step-by-step process is suggested for using the guide effectively (fig. 4). See page 11 for details.

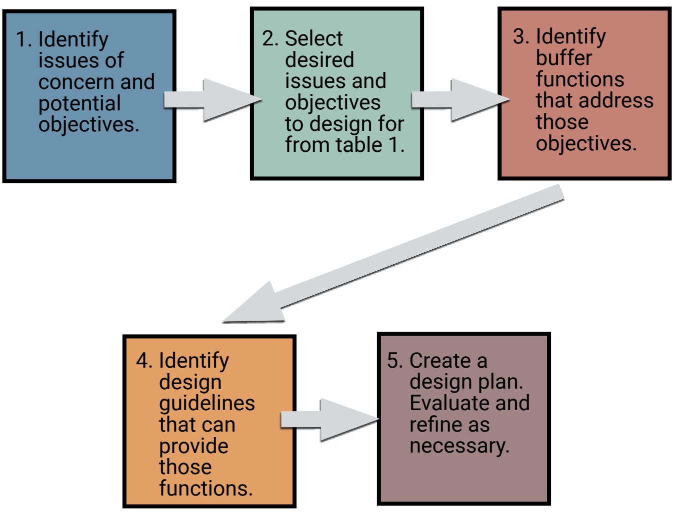



**Figure 4**—Planning process for using the buffer design guidelines.

**Table 1**—Buffer functions that address issues and objectives

| Issue and Objectives | Buffer Functions |
|---|---|
| **Water Quality** | |
| Reduce erosion and runoff of sediment, nutrients, and other potential pollutants<br>Remove pollutants from surface and ground water | Slow water runoff and enhance infiltration<br>Trap pollutants in surface runoff<br>Trap pollutants in subsurface flow<br>Stabilize soil<br>Reduce bank erosion |
| **Biodiversity** | |
| Enhance terrestrial habitat<br>Enhance aquatic habitat | Increase habitat area<br>Protect sensitive habitats<br>Restore connectivity<br>Increase access to resources<br>Shade stream to maintain temperature |
| **Soils** | |
| Reduce soil erosion<br>Increase soil productivity | Reduce water runoff energy<br>Reduce wind energy<br>Stabilize soil<br>Improve soil quality<br>Remove soil pollutants |
| **Crops and Livestock** | |
| Improve yield and reduce pests<br>Provide protection for crops and livestock<br>Increase economic value and crop diversity | Reduce wind energy<br>Affect mesoclimate and microclimate<br>Enhance habitat for pollinators<br>Enhance habitat for pest predators<br>Produce marketable products |
| **Quality of Life** | |
| Create a pleasant and safe environment<br>Protect against natural disasters | Separate human activities<br>Reduce hazards<br>Enhance visual quality and reduce noise<br>Reduce energy consumption<br>Reduce ecosystem disservices |
| **Recreation** | |
| Promote nature-based recreation<br>Reduce negative impacts of outdoor recreation | Increase natural area<br>Protect natural areas<br>Provide a corridor for movement<br>Enhance recreational experience<br>Enhance property values |

1. Identify issues of concern and related objectives (table 1) with assistance from the land manager or stakeholder group using a planning process (figs. 4 and 5). If you are planning to apply for assistance from the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS), refer to page 15 for NRCS resource concerns. Record the objectives (table 2).
2. Based on the identified issues and objectives, select the appropriate buffer functions from table 1 and record these functions.
3. Refer to each resource section and select guidelines that address the desired buffer functions using the guideline-function matrix (fig. 6). Use the additional design guideline-function matrix (fig. 7) to identify guidelines in the other resource sections that may be useful. Record the guideline numbers (table 2).
4. Use the selected guidelines to prepare a preliminary buffer plan. Compromises and tradeoffs may be necessary to address all the objectives and buffer functions.
5. Optional step: Refer to the referenced publications used to develop the guidelines. The companion references document, available at https://doi.org/10.2737/WO-GTR-108, includes more than **1,900** publications that provide additional design information, with more detailed design criteria for specific geographic regions. Use other printed and web-based resources, experts, and personal experience to refine the buffer plan.

**Figure 5**—Identifying issues and desired objectives is the first key step. Photo by Adobe Stock.

**Table 2—**An example table organizing a project's objectives, the desired buffer functions, and the applicable design guidelines

| Objectives | Buffer Functions | Guidelines to Consider |
|---|---|---|
| **Objective 1**<br>Reduce 50 percent of nitrogen from runoff and shallow ground water flow | Slow water runoff and enhance infiltration<br>Trap pollutants in surface runoff<br>Trap pollutants in subsurface flow | 1.1, 1.2, 1.3, 1.10, 1.11, 1.12, 1.13, 1.7, 1.15, 1.20, 1.23, 2.8, 3.1 |
| **Objective 2**<br>Enhance habitat for salamanders to increase local population by 10 percent | Increase habitat area<br>Protect sensitive habitats<br>Restore connectivity | 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 2.12, 2.13, 4.6 |
| **Objective 3**<br>Reduce soil erosion by 50 percent | Reduce water runoff energy<br>Reduce wind energy<br>Stabilize soil | 3.1, 3.2, 3.3, 3.4, 3.6, 4.1 |
| **Objective 4**<br>Produce five woody products for the decorative floral industry | Produce marketable products | 4.11, 4.12, 4.13, 4.14 |
| **Objective 5**<br>Increase biological pest control of aphids and thrips | Enhance habitat for pest predators<br>Affect mesoclimate and microclimate | 3.6, 4.1, 4.2, 4.3 |
| **Objective 6**<br>Enhance the views from the landowner's residence | Enhance visual quality and reduce noise<br>Separate human activities | 5.6, 5.8, 5.9, 5.15, 5.16 |

## Guideline Function Matrix

Figure 6 illustrates how to use the guideline function matrix at the beginning of each resource section. Review the design guidelines associated with the desired functions. The checkmark indicates that the guideline addresses the buffer function at the top of the matrix.

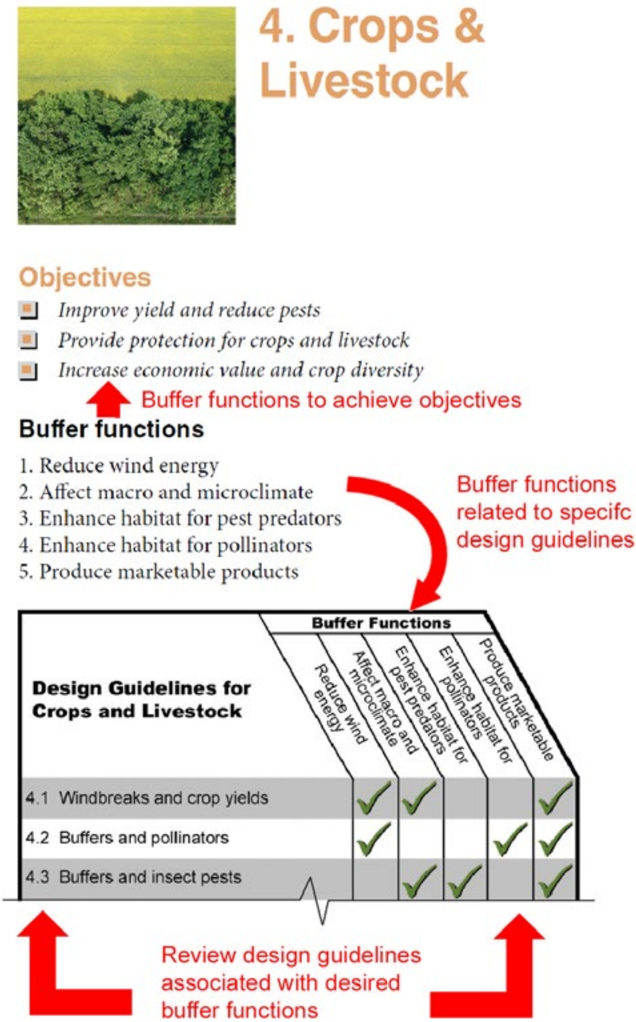
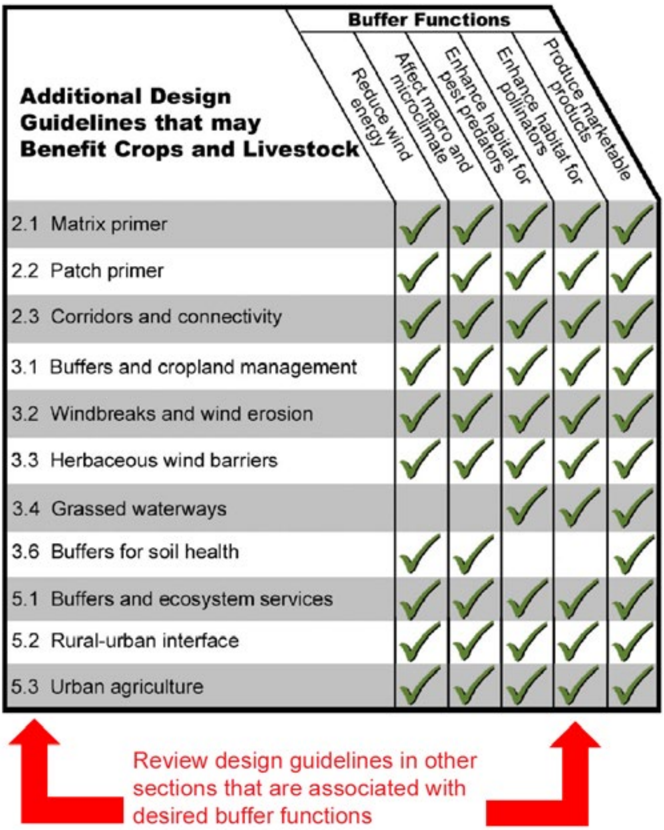



**Figure 6—**An example of a guideline function matrix.

In each resource section, an additional guideline function matrix lists guidelines from other sections that may be applicable (fig. 7). Review these guidelines for further guidance.

These are some of the most relevant additional guidelines for each section, but they do not constitute a complete list. Other guidelines may also apply.



| Additional Design Guidelines that may Benefit Crops and Livestock | Reduce wind energy | Affect macro and microclimate | Enhance habitat for pest predators | Enhance habitat for pollinators | Produce marketable products |
|---|---|---|---|---|---|
| 2.1 Matrix primer | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.2 Patch primer | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.3 Corridors and connectivity | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.1 Buffers and cropland management | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.2 Windbreaks and wind erosion | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.3 Herbaceous wind barriers | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.4 Grassed waterways | | | ✓ | ✓ | ✓ |
| 3.6 Buffers for soil health | ✓ | ✓ | | | ✓ |
| 5.1 Buffers and ecosystem services | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.2 Rural-urban interface | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.3 Urban agriculture | ✓ | ✓ | ✓ | ✓ | ✓ |



**Figure 7**—An example of an additional design guideline function matrix.

## NRCS Resource Concerns

Vegetative buffer practices are often supported by Federal conservation programs that offer technical and financial assistance. USDA NRCS administers many of these programs.

NRCS programs start with the identification of a *resource concern*.

**Resource concern: a condition of the soil, water, air, plant, animal, or energy resource base that does not meet the minimum acceptable standards.**

NRCS identifies seven major resource categories:

1. Soil (table 3)
2. Water (table 4)
3. Air (table 5)
4. Plants (table 6)
5. Animals (table 7)
6. Energy (table 8)
7. Human (table 9)

While this guide follows a different organizational structure for its resource sections, there is significant overlap with NRCS resource concerns.

Tables 3–9 list guidelines based on NRCS resource concerns. If intending to use NRCS assistance, refer to the appropriate tables first. Guideline numbers are hyperlinked to allow for easy navigation. The bookmark tab in this guide will aid going between the tables and the guidelines.

For more information on NRCS, visit: www.nrcs.usda.gov.

**Table 3**—NRCS **Soil** resource concerns and buffer guidelines

| Resource Concern | Guidelines to Consider |
|---|---|
| Sheet and rill erosion | 1.1, 1.2, 1.5, 1.10, 1.11, 1.12, 1.13, 1.19, 1.20, 1.22, 1.23, 3.1, 3.4, 4.11, 4.12, 4.14, 6.4 |
| Wind erosion | 3.1, 3.2, 4.11, 4.12, 4.14 |
| Ephemeral gully erosion | 1.10, 1.11, 1.12, 1.13, 1.19, 1.20, 1.22, 3.1, 4.11, 4.12, 4.14, 6.4 |
| Classic gully erosion | 1.1, 1.2, 1.10, 1.11, 1.12, 1.13, 4.11, 4.12, 4.14, 6.4 |
| Bank erosion from streams, shorelines, or water conveyance channels | 1.14, 1.21, 1.25, 2.8 |
| Subsidence | 1.19, 1.20, 4.11 |
| Compaction | 1.23, 1.25, 4.11 |
| Organic matter depletion | 3.1, 3.2, 3.3, 3.6, 4.11 |
| Concentration of salts or other chemicals | 1.18, 1.19, 3.5 |
| Soil organism habitat loss or degradation | 3.1, 3.2, 3.3, 3.6 |
| Aggregate instability | 1.1, 1.19, 1.20, 3.1, 3.2, 3.3, 3.4, 3.6, 4.11, 4.12, 4.14 |

**Table 4**—NRCS **Water** resource concerns and buffer guidelines

| Resource Concern | Guidelines to Consider |
|---|---|
| Ponding and flooding | 1.1, 1.2, 1.11, 1.12, 1.13, 2.8, 2.12, 5.11, 5.13 |
| Seasonal high-water table | 1.1, 1.2, 1.15, 1.16, 1.19, 2.8, 2.12, 3.2, 3.3, 3.4 |
| Seeps | 1.1, 1.2, 1.4, 1.11, 1.12, 1.13, 1.19, 3.1, 3.2, 3.3, 3.4, 4.11, 4.12, 4.14, 6.3, 6.4 |
| Drifted snow | 3.1, 3.2, 3.3, 4.11, 4.12, 5.2, 5.5, 5.6, 5.12 |
| Surface water depletion | 3.1, 3.2, 3.3, 3.4, 4.5, 4.11, 4.12, 4.14 |
| Ground water depletion | 3.1, 3.2, 3.3, 3.4, 4.5, 4.11, 4.12, 4.14 |
| Naturally available moisture use | 1.1, 1.2, 1.25, 3.1, 3.2, 3.3, 3.4, 4.5, 4.11, 4.12, 5.12 |
| Inefficient irrigation water use | 3.1, 3.2, 3.3, 3.4, 4.1, 4.5 |
| Nutrients transported to surface water | 1.1, 1.2, 1.3, 1.5, 1.7, 1.8, 1.10, 1.11, 1.12, 1.13, 1.14, 1.16, 1.17, 1.18, 1.19, 1.20, 1.21, 1.22, 1.23, 1.24, 1.25, 1.26, 3.1, 3.2, 3.3, 3.4, 3.5, 4.11, 4.12, 4.14, 5.11, 5.13 |
| Nutrients transported to ground water | 1.1, 1.2, 1.3, 1.4, 1.7, 1.8, 1.13, 1.15, 1.16, 1.17, 1.19, 1.20, 1.23, 1.24, 1.25, 1.26, 3.1, 3.2, 3.3, 3.4, 3.5, 4.11, 4.12, 4.14 |
| Pesticides transported to surface water | 1.1, 1.2, 1.3, 1.9, 1.10, 1.11, 1.12, 1.13, 1.16, 1.17, 1.18, 1.19, 1.20, 1.23, 1.26, 3.5, 4.4, 4.6, 4.11, 4.12, 4.14, 5.11, 5.13 |
| Pesticides transported to ground water | 1.1, 1.2, 1.3, 1.4, 1.9, 1.13, 1.15, 1.16, 1.17, 1.19, 1.20, 1.26, 3.5, 4.4, 4.6, 4.11, 4.12, 4.14, 5.13 |

**Table 4** *(continued)*—NRCS **Water** resource concerns and buffer guidelines

| Resource Concern | Guidelines to Consider |
|---|---|
| Pathogens and chemicals from manure, biosolids, or compost applications transported to surface water | 1.1, 1.2, 1.3, 1.6, 1.10, 1.11, 1.12, 1.13, 1.16, 1.17, 1.18, 1.19, 1.20, 1.23, 1.25, 1.26, 3.5, 4.9, 4.11, 4.12, 4.14, 5.11, 5.13 |
| Pathogens and chemicals from manure, biosolids, or compost applications transported to ground water | 1.1, 1.2, 1.3, 1.4, 1.6, 1.15, 1.16, 1.17, 1.19, 1.20, 1.23, 1.25, 1.26, 3.5, 4.9, 4.11, 4.12, 4.14, 5.13 |
| Salts transported to surface water | 1.1, 1.2, 1.3, 1.10, 1.11, 1.12, 1.13, 1.15, 1.16, 1.17, 1.19, 1.20, 1.23, 1.26, 3.5, 5.11, 5.13 |
| Salts transported to ground water | 1.11, 1.2, 1.3, 1.4, 1.13, 1.16, 1.17, 1.18, 1.19, 1.20, 1.23, 1.26, 3.5, 5.13 |
| Petroleum, heavy metals, and other pollutants transported to surface water | 1.1, 1.2, 1.3, 1.10, 1.11, 1.12, 1.13, 1.16, 1.17, 1.19, 1.20, 1.23, 1.26, 3.5, 5.11, 5.13 |
| Petroleum, heavy metals, and other pollutants transported to ground water | 1.1, 1.2, 1.3, 1.4, 1.13, 1.15, 1.16, 1.17, 1.19, 1.20, 1.26, 3.5, 5.13 |
| Sediment transported to surface water | 1.1, 1.2, 1.3, 1.5, 1.10, 1.11, 1.12, 1.13, 1.14, 1.16, 1.17, 1.18, 1.19, 1.20, 1.21, 1.22, 1.23, 1.26, 3.1, 3.2, 3.3, 3.4, 3.5, 4.11, 4.12, 4.14, 5.13, 6.4 |
| Elevated water temperature | 1.1, 1.17, 1.19, 1.25, 1.26, 2.5, 2.11, 2.12, 5.6 |

**Table 5**—NRCS **Air** resource concerns and buffer guidelines

| Resource Concern | Guidelines to Consider |
|---|---|
| Emissions of particulate matter (PM) and PM precursors | 3.2, 3.3, 5.14 |
| Emissions of greenhouse gases (GHGs) | 1.7, 2.8, 3.1, 3.2, 3.3, 3.6, 4.11, 4.12, 4.13, 4.14, 4.15, 5.3 |
| Emissions of ozone precursors | 3.1, 3.2, 3.3, 3.5, 4.3, 5.2, 5.10, 5.14 |
| Objectionable odors | 3.1, 3.2, 3.3, 4.10, 5.16 |
| Emissions of airborne reactive nitrogen | 4.11, 4.12, 4.13, 4.14, 4.15, 5.10, 5.14 |

**Table 6**—NRCS **Plants** resource concerns and buffer guidelines

| Resource Concern | Guidelines to Consider |
|---|---|
| Plant productivity and health | 3.1, 3.2, 3.3, 3.6, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.11, 4.12 |
| Plant structure and composition | 1.19, 1.20, 1.24, 1.25, 4.1, 4.2, 4.3, 4.4, 4.11, 4.12, 4.14, 4.15 |
| Plant pest pressure | 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.11, 4.12, 4.14, 4.15 |
| Wildfire hazard from biomass accumulation | 1.19, 1.24, 1.25, 4.14, 5.10 |

**Table 7—**NRCS **Animals** resource concerns and buffer guidelines

| Resource Concern | Guidelines to Consider |
|---|---|
| Terrestrial habitat for wildlife and invertebrates | 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 2.12, 2.13, 4.2, 4.3, 4.6, 4.11, 4.12, 4.14, 5.2, 5.3, 6.1, 6.2, 6.3 |
| Aquatic habitat for fish and other organisms | 2.1, 2.2, 2.5, 2.7, 2.8, 2.9, 2.10, 2.11, 2.12, 4.6, 6.3 |
| Feed and forage imbalance | 1.25, 4.9, 4.12, 4.15 |
| Inadequate livestock shelter | 4.8, 4.9, 5.6 |
| Inadequate livestock water quantity | 1.25, 4.9, 4.15, 5.6 |

**Table 8—**NRCS **Energy** resource concerns and buffer guidelines

| Resource Concern | Guidelines to Consider |
|---|---|
| Energy efficiency of equipment and facilities | 4.14, 5.2, 5.4 |
| Energy efficiency of farming/ranching practices and field operations | 4.14, 5.2, 5.4 |

**Table 9—**NRCS **Human** resource concerns and buffer guidelines

| Resource Concern | Guidelines to Consider |
|---|---|
| Resource concerns impacting the human environment | 2.1, 2.2, 2.3, 3.2, 3.3, 4.6, 4.10, 4.11, 4.12, 4.13, 4.14, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15, 5.16 |
| Resource concerns impacting outdoor recreation | 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, 6.9 |

# 1. Water Quality

## Objectives

- Reduce erosion and runoff of sediment, nutrients, and other potential pollutants.
- Remove pollutants from surface and ground water.

## Buffer functions

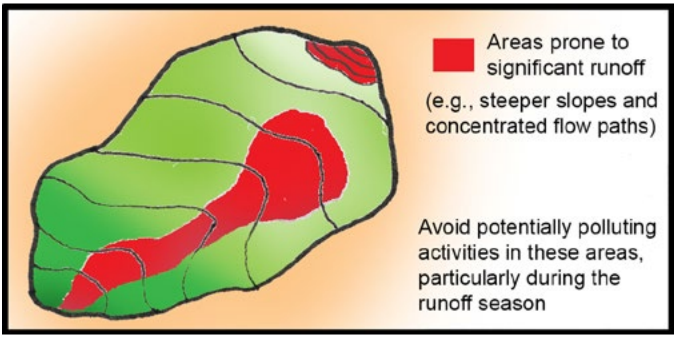
- Slow water runoff and enhance *infiltration.*
- Trap pollutants in surface runoff.
- Trap pollutants in *subsurface flow.*
- Stabilize soil.
- Reduce bank erosion.

| 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 |
|---|---|---|---|---|---|
| 1.1 Buffers and land management | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1.2 Targeted buffers in watersheds | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1.3 Cold climates | ✓ | ✓ | ✓ | | |
| 1.4 Karst landscapes | ✓ | ✓ | ✓ | | |
| 1.5 Buffers for sediment | ✓ | ✓ | | ✓ | ✓ |
| 1.6 Buffers for pathogens | ✓ | ✓ | ✓ | | |
| 1.7 Buffers for nitrogen | ✓ | ✓ | ✓ | | |
| 1.8 Buffers for phosphorus | ✓ | ✓ | ✓ | | |
| 1.9 Buffers for pesticides | ✓ | ✓ | ✓ | | |

| 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 |
|---|---|---|---|---|---|
| 1.10 Buffer width design tool | ✓ | ✓ | ✓ | | |
| 1.11 Variable buffer width | ✓ | ✓ | ✓ | | |
| 1.12 Effective buffer area ratio | ✓ | ✓ | ✓ | | |
| 1.13 Slope and soil type adjustments | ✓ | ✓ | ✓ | | |
| 1.14 Allowances for bank erosion | | ✓ | | ✓ | ✓ |
| 1.15 Buffers for shallow groundwater | | | ✓ | | |
| 1.16 Buffers for tile drainage | | | ✓ | | |
| 1.17 Buffers for in-stream pollutants | | ✓ | ✓ | | |
| 1.18 Buffers for urban and roadside runoff | ✓ | ✓ | ✓ | | |
| 1.19 Vegetation selection | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1.20 Vegetation for removing pollutants | ✓ | ✓ | ✓ | | |
| 1.21 Vegetation for bank erosion control | | | | ✓ | ✓ |
| 1.22 Sediment removal | ✓ | ✓ | | | |
| 1.23 Vegetation and compaction | ✓ | ✓ | | | |
| 1.24 Harvesting for nutrient removal | ✓ | ✓ | ✓ | | |
| 1.25 Buffers and grazing | | ✓ | | ✓ | ✓ |
| 1.26 Buffers and lag time | ✓ | ✓ | ✓ | ✓ | ✓ |

| 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 | ✓ | ✓ | ✓ | ✓ | |
| 2.8 Corridor width | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.10 Buffers for aquatic habitat | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.11 Buffers for stream temperature | | ✓ | | | |
| 2.12 Buffers for wetland habitat | ✓ | ✓ | ✓ | ✓ | |
| 3.1 Buffers and cropland management | ✓ | ✓ | ✓ | ✓ | |
| 3.4 Grassed waterways | ✓ | ✓ | ✓ | ✓ | |
| 3.5 Buffers for phytoremediation | ✓ | ✓ | ✓ | ✓ | |
| 4.6 Buffers and spray drift | | ✓ | | | |

## 1.1 Buffers and Land Management



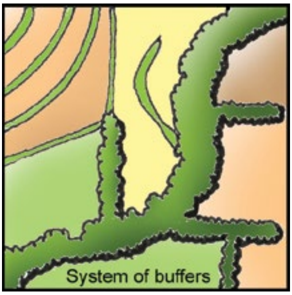

Water quality goals may not be achievable with buffers unless the adjacent land uses are also managed for better water quality. General land management considerations appear below.

In some cases, inappropriate land management practices in just a few areas within a watershed may be contributing to a majority of the water quality problems.

*Targeting* better land management practices in these select areas may yield significant improvements (see 1.2). In other situations, subsurface *tile drains* may circumvent a buffer's effectiveness for water quality improvement (see 1.16).

**General management considerations**

- Manage land to reduce runoff and increase infiltration.
- Avoid potentially polluting activities on areas most prone to generating significant runoff.
- Minimize potentially polluting activities during times of the year most prone to generating runoff.
- Use a system of upland buffers to reduce runoff and *pollutant load* to *riparian buffers*.
- Establish perennial cover in as many areas as possible. If perennial cover is not possible, use low- or *no-till* methods.



Fertilizer application methods can have significant impacts on water quality. Poor application practices can limit buffer effectiveness.

*4R nutrient stewardship* represents one best-management approach for fertilizer application. It promotes the application of the Right source of fertilizer, at the Right rate, at the Right time, and in the Right place. Below are only a few considerations. Consult additional resources when approaching nutrient management.

**Right source considerations**

- Choose fertilizer that matches crop needs and soil characteristics.
- Supply nutrients in plant-available forms or in time-release forms that become available to plants over time.
- Recognize nutrient interactions and promote complementary interactions.

**Right rate considerations**

- Evaluate existing soil nutrients, additional nutrient sources (e.g., compost, manure, crop residues), and remaining plant nutrient demand before calculating fertilizer rate.
- Use the law of diminishing returns where the most economical rate is reached when the last unit of nutrient applied is equal in value to the generated increase in crop yield.

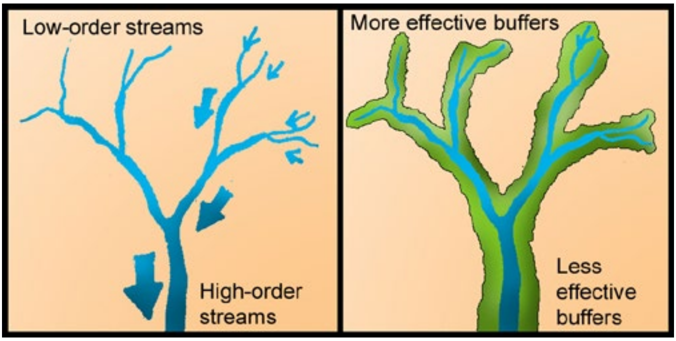
**Right time considerations**

- Apply nutrients when seasonal crop nutrient demand is high.
- Integrate nutrient application with other field operations.
- Consider seasonal and weather conditions. Avoid applying nutrients when soil is *saturated* or during and immediately after precipitation events.

**Right place considerations**

- Apply nutrients in the root zone.
- Evaluate differences in soil nutrient supply and the potential for nutrient loss.
- Maintain crop residue cover and reduce soil disturbance during application.

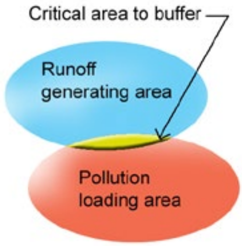
## 1.2 Targeted Buffers in Watersheds




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 for water quality.

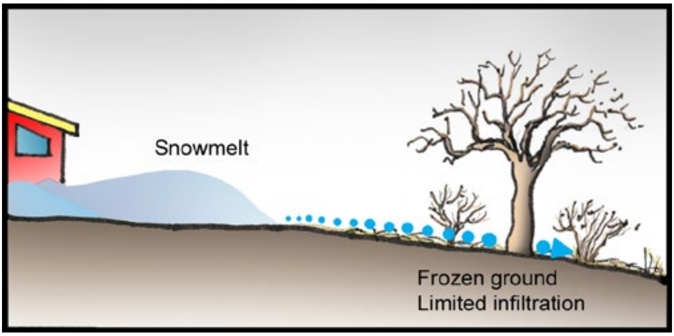
**General targeting considerations**

- Riparian buffers will often be more effective along small or *low-order streams* than larger or *high-order streams,* since most water from uplands enters along low-order streams.
- Consider placing riparian buffers in historic wetland locations.
- *Ground water 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. Areas where runoff sources correspond with pollution loading areas are critical to buffer.




- Areas between disturbance activities (e.g., timber harvest, tillage, urban development) and water channels are also critical to buffer.
- Surface runoff from cultivated areas is higher where slopes are steeper and soils are finer textured. These areas are important to buffer (see 1.13).

## 1.3 Cold Climates



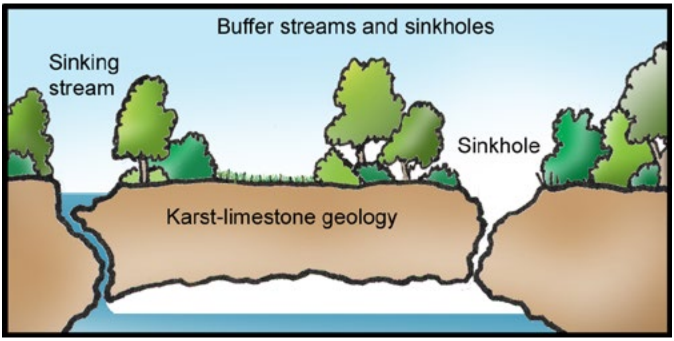

Nutrient loss in colder climates can be more significant than in warmer climates due to the following factors:

1. Frozen ground allows slow or no infiltration.
2. Leaf decay can release nutrients (e.g., phosphorus, see 1.8), and vegetative buffers can become a source of nutrients rather than a sink. Freeze-thaw cycles in early spring and late fall can increase the rate of this breakdown in cold climates.
3. Spring snowmelt significantly increases runoff volume.
4. Rain on snow events can also lead to significant nutrient export during the winter. These types of events are likely to increase with climate change.
5. Vegetation flattened by snow is less effective as a physical barrier to trap *particulate nutrients* and *sediment* in runoff.
6. A shorter growing season limits water and nutrient retention by vegetation.
7. Drifted snow or snow removal piles can include an accumulation of eroded soil and attached nutrients or pollutants.

**Key design considerations**

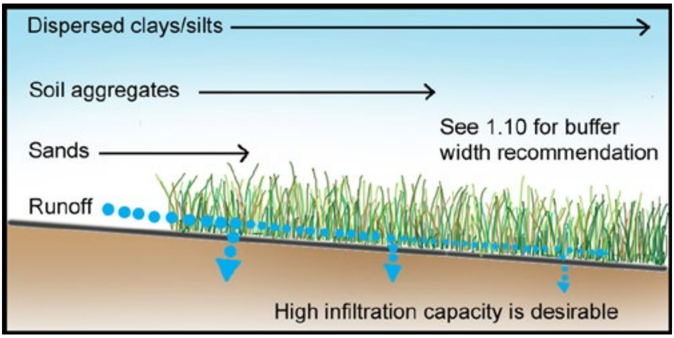
- Select cold-tolerant plant species with stiff stems that avoid being flattened.
- Maximize vegetative cover.
- Design wider buffers than buffers in warmer climates.
- Employ other *best management practices (BMPs)* along with buffers in colder climates (see 1.1).

## 1.4 Karst Landscapes




*Karst* or limestone-dominated landscapes are particularly susceptible to water quality problems because of the direct and often rapid connections between surface water and ground water. Buffers around sinkholes and sinking streams can minimize polluted runoff entering directly into the ground water system.

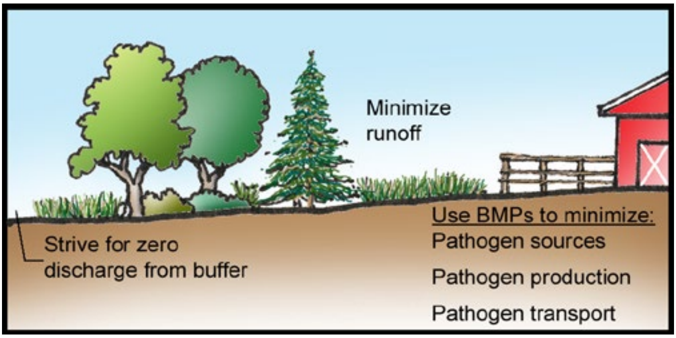
## 1.5 Buffers for Sediment




Sediment is the pollutant most effectively removed from runoff by buffers. Buffers remove sediment by decreasing *flow velocity*, which allows particles to settle. Coarse-textured sediments settle out first, while finer particles require wider buffers to be removed. In general, buffers wider than 20 feet prove effective at removing sediment in most situations (see 1.10).

Buffers for trapping sediment should be a final defense. Soils first need to be kept in place as much as possible with best management practices (see 3.0). Over time, sediment can accumulate and reduce the effectiveness of a buffer (see 1.22).

## 1.6 Buffers for Pathogens




Bacteria, viruses, and protozoa are among some of the harmful *pathogens* that can be transported in runoff from urban lands, septic systems, pastures, manure-applied fields, and confined animal feeding operations. Buffers can reduce pathogens in surface runoff but are generally ineffective by themselves in meeting water quality standards. Buffers need to be combined with other best management practices to meet standards.

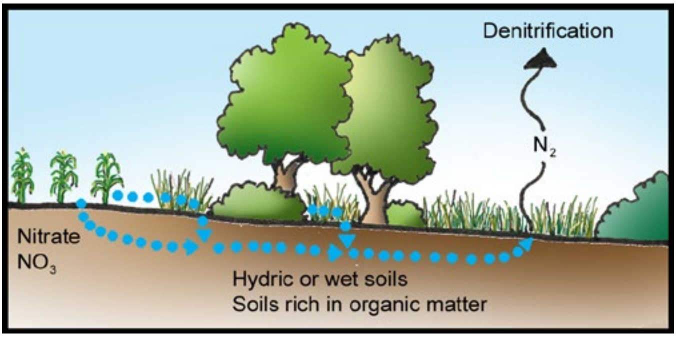
Other best management practices include reducing livestock density, avoiding installing *impervious cover*, removing standing water, and following guidelines for manure applications.

**Key design considerations**

- Select vegetation that reduces runoff velocities and increases infiltration (see 1.20). High runoff velocities can create *concentrated flow* paths, which can bypass existing buffers and/or remobilize previously trapped pathogens.
- Locate buffers downslope of the source.
- Reduce flow velocity by positioning buffers on flat land where they may be more effective at capturing runoff than buffers located on hillslopes.

Vegetation will take time to establish and may not be effective in the first few years (see 1.26). Prioritize other best management practices to reduce pathogen water contamination in the establishment years.

## 1.7 Buffers for Nitrogen




Most nitrogen (N) is lost to surface water through surface runoff and to ground water by leaching of nitrate ($NO_3$). Plant uptake of N generally does not result in permanent removal, as it is eventually returned to the soil when plants decay, unless the plants are harvested (see 1.24).

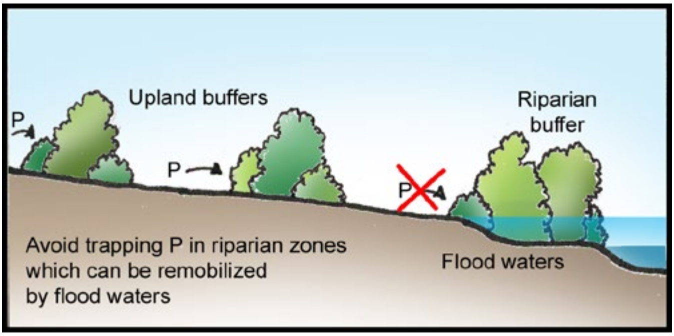
*Denitrification* is the primary process for permanently removing N with a buffer. In denitrification, *anaerobic* bacteria and other microbes transform nitrate into nitrogen gas ($N_2$) which is released into the atmosphere. This can also emit nitrous oxide ($N_2O$), a potent greenhouse gas. However, vegetative buffers tend to emit less $N_2O$ than conventional row crop systems (see 4.13).

**Key design considerations**

- Soils should be rich in organic matter. This is often provided by decaying plant material in the buffer.
- Buffer soils need to be wet or *hydric*.
- Buffers with fine-textured (e.g., clay) soils may be more efficient at nitrate removal than buffers with coarse-textured soils (e.g., sand). Coarse-textured soils have high *hydraulic conductivity,* which reduces water residence times and may also limit the development of anaerobic conditions needed for denitrification.
- Low temperatures and acidic soils inhibit denitrification.
- For sloped terrain, extend the buffer to the *toe slope*. This can enhance denitrification and plant uptake.
- Denitrification improves with higher soil carbon and *soil cohesion*.

- Historic land management practices will affect initial denitrification rate. In general, buffers established on land that was previously pasture will have higher nitrate reduction rates than buffers established on land previously under annual row crop production.
- Road salt runoff can decrease denitrification in riparian buffers. Sodium inputs into high clay soils can produce conditions that favor the production of ammonium nitrogen instead of denitrification.
- Buffers consisting of both *herbaceous* and woody vegetation tend to be more effective than buffers consisting of a single vegetation type.
- See 1.10 for buffer width recommendations.
- See 1.15 for shallow ground water flow.

## 1.8 Buffers for Phosphorus



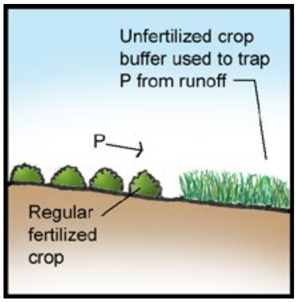

Phosphorus (P) in runoff occurs either as *particulate phosphorus* or as *dissolved phosphorus*. Particulate phosphorus is bound to sediment and can be moderately well trapped by buffers. Dissolved phosphorus must infiltrate the soil with runoff to be trapped.

Unlike N, which can be released to the atmosphere through denitrification, P can only accumulate in the buffer. Once a buffer is saturated with P, it can turn into a source for P. Buffer harvesting and other best management practices will be necessary to manage P (see 1.24).

**Key design considerations**

- Avoid trapping P in flood zones since it can be remobilized by floodwaters.
- Riparian buffers may be more effective at removing N, while upland buffers or *constructed wetlands* (see 1.16) may be more effective at removing P. The decision of buffer type will depend on the target nutrient.


- Other soil management techniques that can be used along with *biomass* removal to reduce P loss from buffers include soil liming and the spreading of P-sorbing agents such as aluminum sulfate, ferric chloride, bauxite residue, and steel slag.
- Buffers consisting of unfertilized crops or hayfields can trap and utilize P. Removing this vegetation through harvest may help export both P and N from the watershed (see 1.24).




- In colder climates, biomass removal should take place before the first frost to reduce increased P loss from vegetation during freeze-thaw cycles (see 1.3).
- Emerging research suggests that inoculating vegetation in riparian buffers with *mycorrhizal fungi* may significantly increase P removal by improving plant P uptake.
- See 1.10 for buffer width recommendations.
- See 1.15 for shallow ground water flow.

## 1.9 Buffers for Pesticides

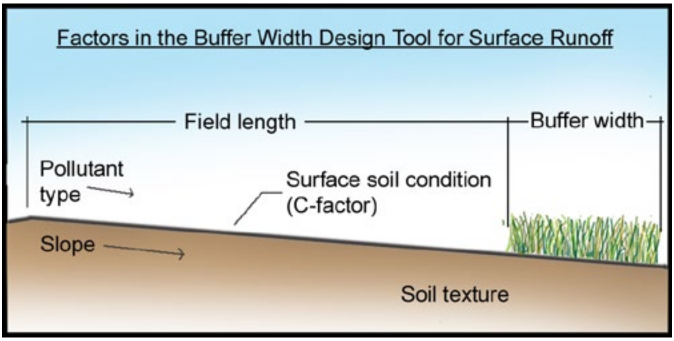
| Koc Value Influence on Buffers for Pesticides | | |
|---|---|---|
| **Koc Value** | **Adsorption and Movement** | **Buffer Recommendation** |
| <500 | Adsorbs weakly, movement with water | Maximize water infiltration and runoff contact time with soil and vegetation. Generally requires wider buffers.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

Similar to N and P, pesticides in runoff occur in either a particulate or a dissolved form. Dissolved pesticides generally have a higher chance of leaving an application area and becoming a problem. Vegetated buffers can be effective at reducing pesticide loss by facilitating the *deposition* of particles, which absorbs pesticides, increasing infiltration, absorbing dissolved forms in the vegetation (see 3.5), and reducing flow volume. However, the final environmental fate of certain pesticides and their metabolites is largely unknown.

**Key design considerations**

- Select plants with high pesticide tolerance.
- Maintain or increase buffer infiltration as much as possible.
- Some pesticides adsorb strongly to soils while others adsorb weakly as noted by the *Koc value* or soil adsorption index.
- Pesticides with high water solubilities (e.g., >30 parts per million [ppm]) will generally require wider buffers.
- Pesticides with a longer *half-life* (e.g., >30 days) may require wider buffers.
- Increase buffer widths in colder climates (see 1.3).
- Most pesticides absorb preferentially to dead organic material. Frequent biomass cutting without removal may increase the effectiveness of the buffer at absorbing pesticides but increase the risk of nutrient leaching. Appropriate timing of biomass removal may achieve both goals (see 1.24).
- Employ other pesticide best management practices in addition to buffers (see 4.2, 4.3, and 4.6).
- See 1.10 for buffer width recommendations.

## 1.10 Buffer Width Design Tool for Surface Runoff




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

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

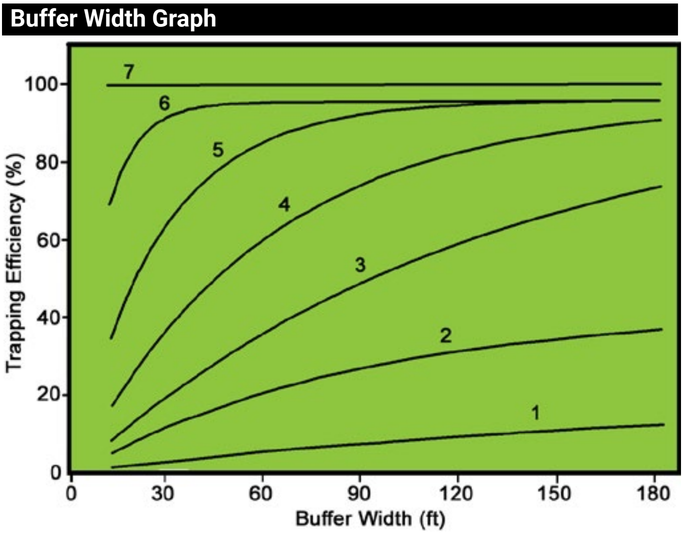
It was developed specifically for agricultural runoff but can be applied in a more general way to other land uses as well.

The tool was developed using a complex mathematical model of buffer processes called Vegetative Filter Strip Model (VSFMOD). For more information on how this tool was developed, refer to the frequently asked questions on page 38.

### Buffer width graph

The seven lines in the buffer width graph represent seven different site conditions (shown in table A) that describe the typical range of agricultural sites. The lines divide the full range of possible pollutant removal levels into convenient increments. To use this graph, select the most appropriate line given your site conditions.

### Buffer width design tool for surface runoff




| Table A—Conditions Corresponding to Each Line in the Graph | | | | | |
|---|---|---|---|---|---|
| **Line Number** | **Field Length** (feet) | **c-factor**[1] | **Slope** (%) | **Soil Texture**[2] | **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.

### How to use the buffer width design tool

1. From table A, identify a reference line number for conditions that most closely resemble the site.
2. Using table B, select a line number that is higher or lower than the reference line number depending on how the site conditions and pollutant type differ from those of the reference line. To do this:
   - 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 the 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.

**Table B—Line Selection Adjustment Rules**

| | Adjustment Rule |
|---|---|
| Pollutant Type | Three lines higher (+3) from dissolved pollutants to sediment<br>Two lines higher (+2) from dissolved pollutants to total P<br>One line lower (-1) from sediment to total P<br>Three lines lower (-3) from sediment to dissolved pollutants |
| Field Length | One line higher (+1) for each halving of the field length<br>One line lower (-1) for each doubling of the field length |
| Slope | One line higher (+1) for each 2.5% decrease in slope<br>One line lower (-1) for each 2.5% increase in slope |
| Soil Texture | One line higher (+1) for each soil category coarser<br>One line lower (-1) for each soil category finer |
| c-factor | One line higher (+1) for each 0.35 lower c-factor<br>One 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

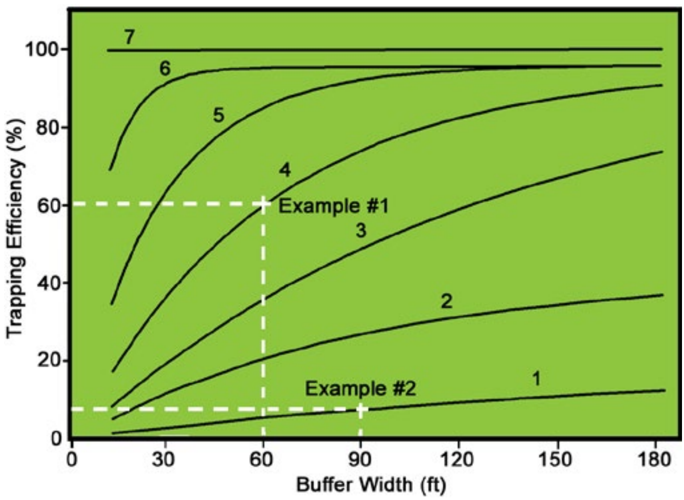
**c-factor** (from Universal Soil Loss Equation)
Cropland, clean tillage = 1.0
Pasture, permanent grass = 0.003
Construction site, no mulch = 1.0
Cropland, plow tillage, low residue = 0.8
Forest, full canopy = 0.0001
Construction site with secured mulch = 0.1

| Example 1—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 2—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



## Frequently asked questions about the buffer width design tool

How was the tool developed?

This tool uses the Vegetative Filter Strip Model (VSFMOD), which 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) in the companion references document, available at https://doi.org/10.2737/WO-GTR-108.

| 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?

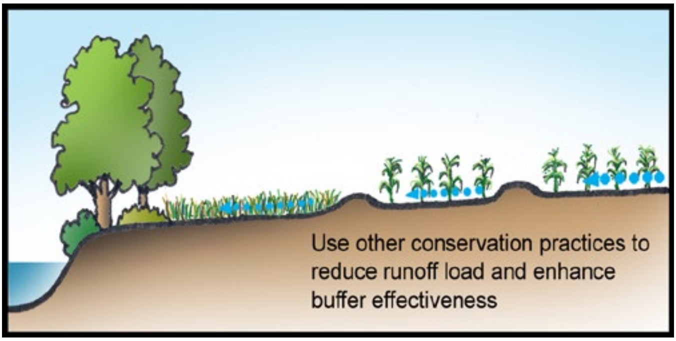
Yes, any site condition that would double or halve the field runoff load should dictate an adjustment of one line below and one line above the initial reference line, respectively. To account for different storm intensities, a 3.6 inch per hour storm would roughly double the runoff load compared to the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

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 gentle slopes, smaller runoff areas, and permeable soils).

What if the tool shows that buffers are not particularly effective for the 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 1.1).



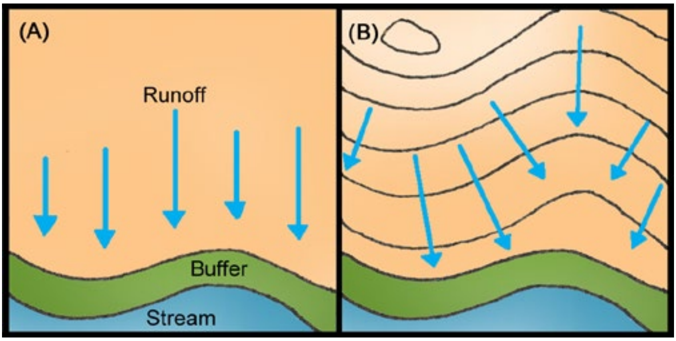

What if runoff flow is not uniform?

Nonuniform flow into a buffer 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 1.11 and 1.12). Grass barriers can help spread out concentrated flow and increase the effective area (see 1.20).

What about trees and shrubs?

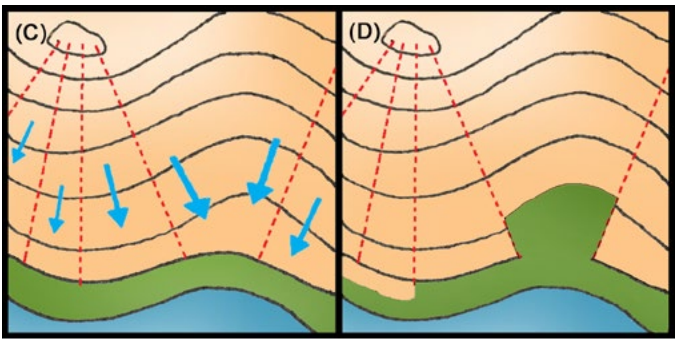
The buffer width design tool was developed for dense grass as the buffer vegetation type. Trees and shrubs can be a part of the buffer zone without changing its effectiveness as long as dense groundcover (plants and debris) is present to provide *roughness* and flow resistance (see 1.19).

## 1.11 Variable Buffer Width




Where runoff is uniform (A), fixed-width buffers can be effective. 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.

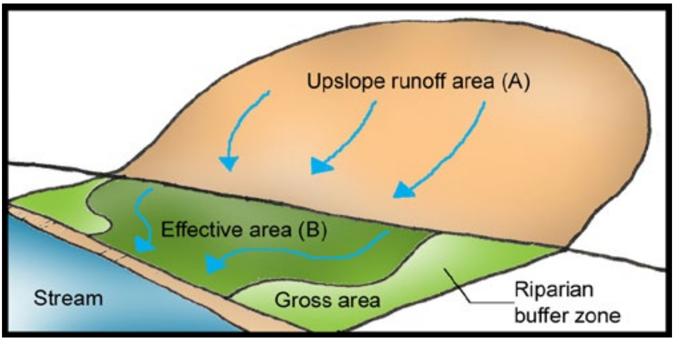
Instead, buffer width should be widened or narrowed as runoff loads and buffer site conditions vary.




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. A similar process can be used for ground water flows in situations where ground water may have a greater impact on water quality than surface flows (see 1.15).

The ratio of the upslope runoff area to buffer area can provide additional design guidance (see 1.12).

## 1.12 Effective Buffer Area Ratio

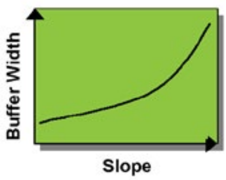



The amount of runoff through an area of buffer should be low to achieve high pollutant removal. One consideration is to base the design on a ratio of upslope runoff area (A) to effective buffer area (B). Lower ratios (e.g., 20:1) generally provide substantially greater pollutant removal than higher ratios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

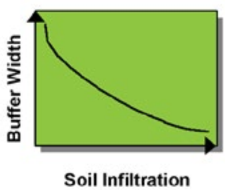
## 1.13 Slope and Soil Type Adjustments

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 (see 1.10).

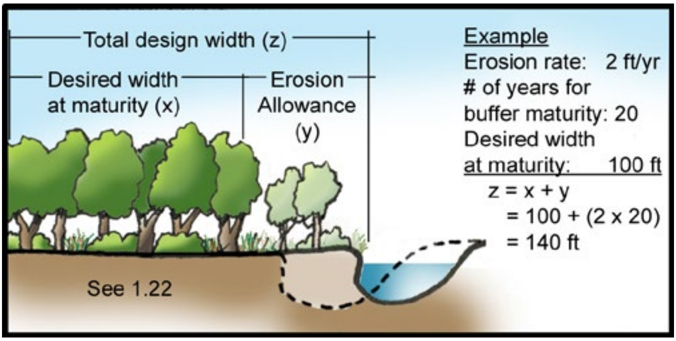



Soils with higher infiltration capacity can reduce runoff to a greater degree than soils with lower infiltration. Soils with lower infiltration capacity will require wider buffers (see 1.10). Finer textured soils typically have lower infiltration than sandy soils.



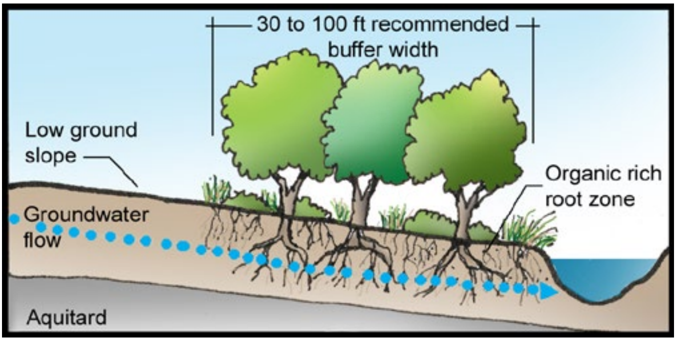

Water Quality

## 1.14 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.

## 1.15 Buffers for Shallow Ground Water

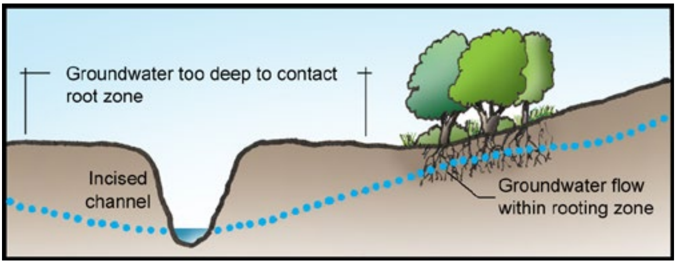



Shallow ground water is typically found near streams, lake shores, and wetlands. Buffers may contact shallow ground water and through various processes can remove some pollutants transported in it.

| | |
|---|---|
| Nitrate | Removal rates can be >75 percent |
| Dissolved phosphorus | Not effectively removed |
| Pesticides | Limited data at this time |

## Key design considerations

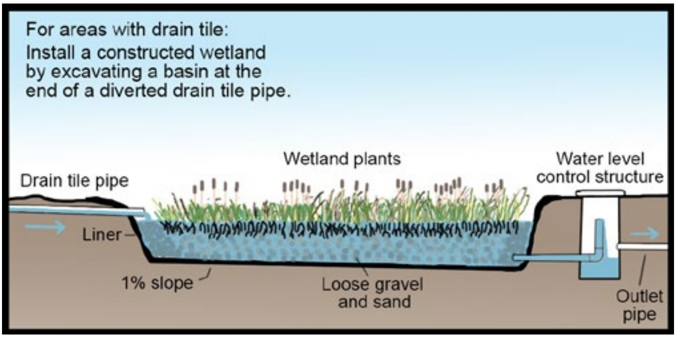
- Use a wider buffer for areas where ground water emerges as a spring or seep, as it may flow across a narrow buffer too quickly to be effectively treated.
- Buffers along deeply incised streams may not intercept ground water. Locate buffers farther away from these streams, where ground water may be shallower.




- Most nitrate reduction in shallow ground water occurs within 30 to 100 feet of entering a buffer. The greatest nitrate removal occurs on sites where ground water flow is confined to the root zone by a dense soil layer (*aquitard*) or bedrock.
- Select plants with adequate rooting depth and higher root biomass to intercept ground water flow.
- Select plants tolerant of seasonal water table fluctuations.
- Natural ground water flow patterns can be very complex. Consult with appropriate professionals.

| Buffers for Shallow Ground Water Pollution | |
|---|---|
| **Variable** | **Factors Increasing Treatment Potential** |
| Slope | Lower ground slope (0 to 3 percent) |
| Depth to Water Table | Shallower water table (0 to 3 feet below surface) |
| Hydric Soils | Present and occupying significant width (≥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 |

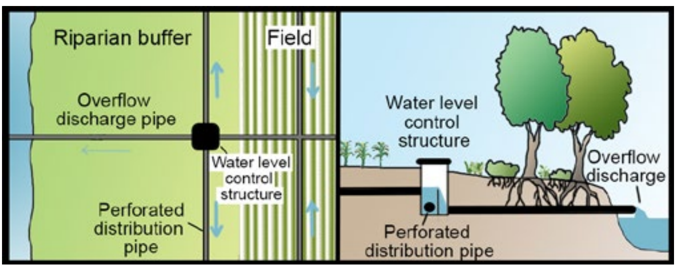
## 1.16 Buffers for Tile Drainage




In areas where ground water drainage has been augmented with drain tile pipes or ditches, ground water flow will often bypass buffers untreated. Placing constructed wetlands at the end of tile drains or ditches can help reduce this problem.

Saturated riparian buffers (SRBs) can also be used. This conservation practice involves redirecting field tile drains to a water level control structure, which is then connected to perforated distribution pipes laid at a depth of 1 to 2 feet and perpendicular to the outlet pipe (approximately parallel to the waterway).

These pipes are installed in the upper edge of a riparian buffer or other vegetated buffer. In this way, SRBs allow tile drainage water, rich in nitrate, to be pushed slowly through buffers where processes like denitrification can occur (see 1.7).

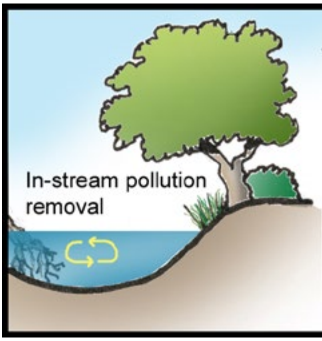



**Key design considerations**

- SRBs should treat 100 percent of the flow from the tile drainage. No tile drain should bypass the system.
- Maximize distribution pipe length. SRBs are more effective with longer distribution pipes.

- Loam soils are best for treating gradual subsurface flow. Water may travel too fast in sandy soils, and clay soils may not allow enough water movement.
- A second distribution pipe can be added mid-buffer to increase water infiltration into the buffer. This has the drawback of reducing the distance contaminated water can move through the buffer and the opportunities for denitrification to occur. It should only be used in instances where the buffer is wide enough (see 1.10) and soil *permeability* is low.
- Denitrification tends to improve with buffer age (see 1.7). When possible, establish new SRBs on sites with existing vegetation.
- The addition of SRB flow may destabilize stream banks. Do not install SRBs in buffers with widths <6.5 feet, or near stream banks >8 feet in height.
- The top 2.5 feet of buffer soils should have >1.2 percent organic matter for denitrification to take place. Woodchips can be added to enhance buffer organic matter.

## 1.17 Buffers for In-Stream Pollutants




Key Considerations

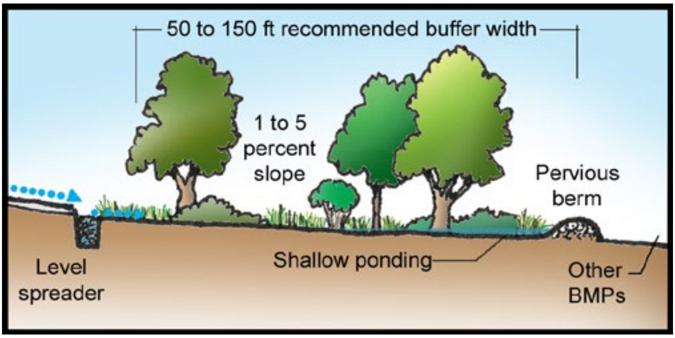
Forested buffers may provide more organic matter than grass buffers

Buffers can enhance denitrification in streams with fine sediments and low organic matter

Impact is greater in smaller streams

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 2.10). In-stream pollutant removal rates vary greatly. Impact on stream pollution level is generally greater during low flows and in small streams.

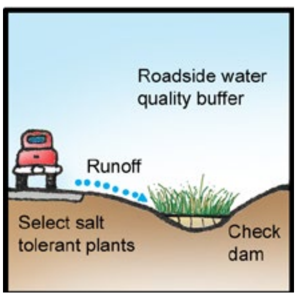
## 1.18 Buffers for Urban and Roadside Runoff




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 channelized through the buffer. In those situations, buffers need to be designed to prevent flows from inundating or bypassing the buffer. Use other best management practices such as minimizing the installation of impervious cover along with buffers.

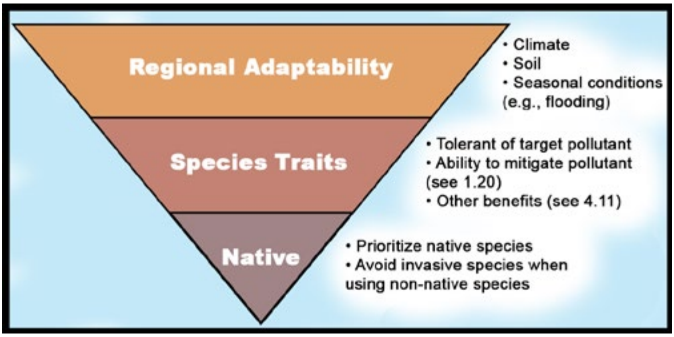
**Key design considerations**

- 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 cover.
- A level spreader can be used to disperse concentrated flow along the width of the buffer.




For road runoff, vegetated buffers such as grass *swales* can be used to improve water quality. Roadside swales >320 feet in length are generally effective at removing most pollutants. In cold climates, select species that are salt tolerant. Vegetation should maintain a height above flow height and a density >80 percent (see 1.20). Use *check dams* to slow water movement and increase retention time.

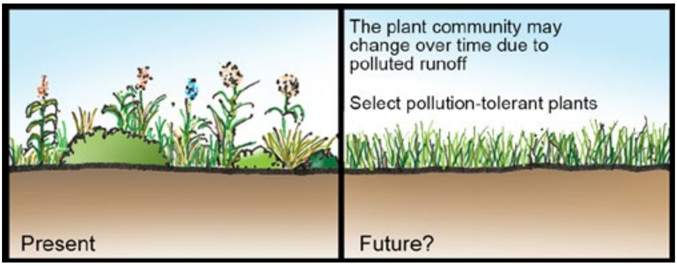
## 1.19 Vegetation Selection




Species suitability is specific to a geographic region. Species that are appropriate for one site may not be suitable for another site. Selection criteria include species traits, adaptability to the region, and target pollutant. Below are other considerations.

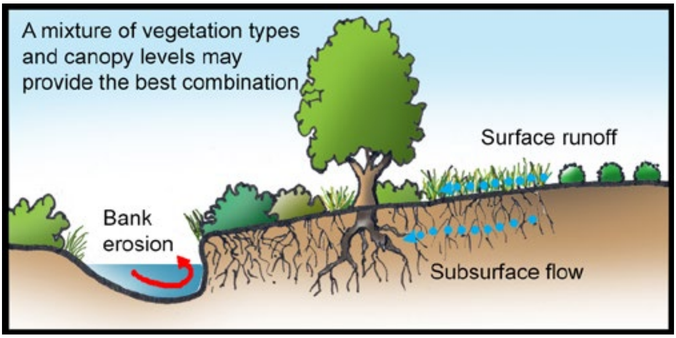
**Key vegetation considerations**

- Use historic native plant communities to guide vegetation selection and select species adapted to site conditions.
- Use a diverse species mixture to minimize pest and disease problems.
- Select perennial vegetation to provide permanent cover and improve infiltration rates over time.




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

## 1.20 Vegetation for Removing Pollutants




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

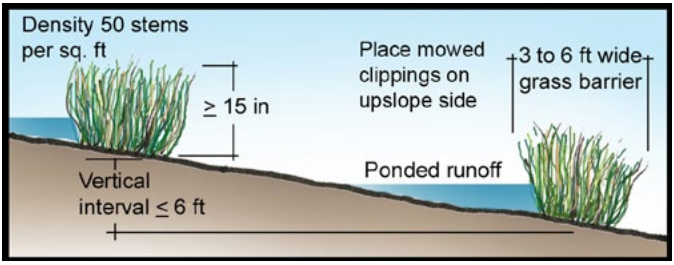
Many types of vegetation can provide these functions. A mixture of herbaceous and woody species may provide the best overall combination (see table below). Also, base vegetation selection on site conditions and landowner preferences (see 1.19).

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

| Vegetation Selection for Water Quality | |
|---|---|
| | **General Criteria** |
| Surface runoff | High stem and debris density<br>Stiff stems<br>Tolerant of sediment buildup<br>Tolerant of high nutrient levels and other pollutants<br>Actively growing during runoff season |
| Subsurface flow | Plants with roots that intercept subsurface flow<br>Plants with higher root biomass<br>Tolerant of wet soils and high nutrient levels<br>Avoid nitrogen-fixing plants |

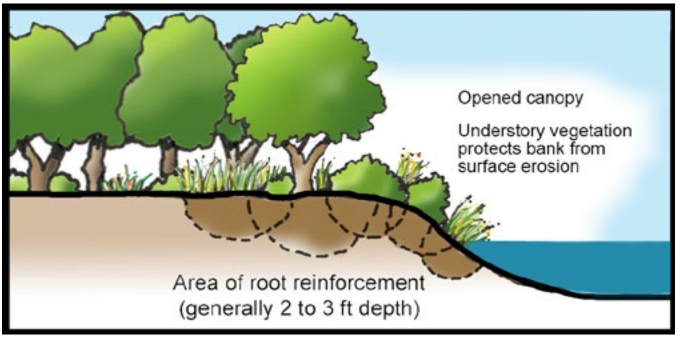
No single buffer or best management practice will be effective at reducing all pollutants. Pollution swapping may occur as one practice introduced to reduce a target pollutant results in the increase of a different pollutant. Consider this risk when choosing buffer vegetation, location, size, and management.

**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. Grass barriers are used mainly where gullies would form on steep land and to slow and disperse concentrated flow.

## 1.21 Vegetation for Bank Erosion Control

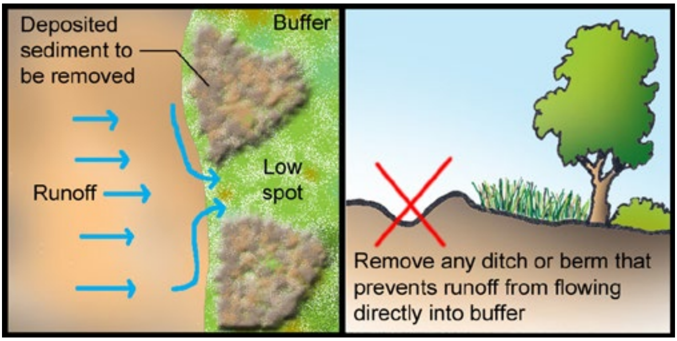



Vegetation reduces bank erosion through its roots. Herbaceous plants with fibrous root systems are better for protecting banks from surface erosion. Woody species with deeper roots will be better at increasing soil cohesion and reducing *mass slope failure*.

**Key vegetation considerations**

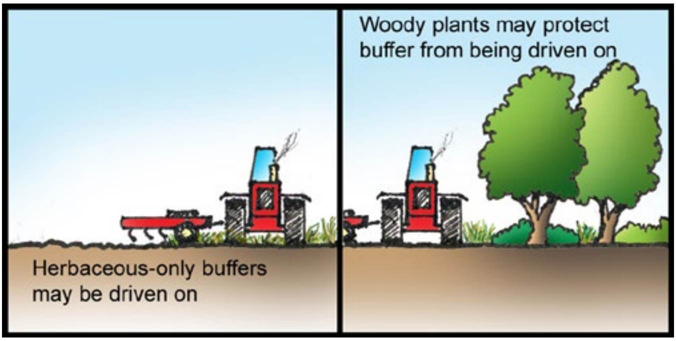
- Select woody species that resprout from roots or from broken branches.
- Use quick-growing plant species with a mixture of forms.
- Use vegetation that is tolerant of inundation and flexible.
- Overlap plantings.
- Open the canopy for good understory plant growth.

## 1.22 Sediment Removal



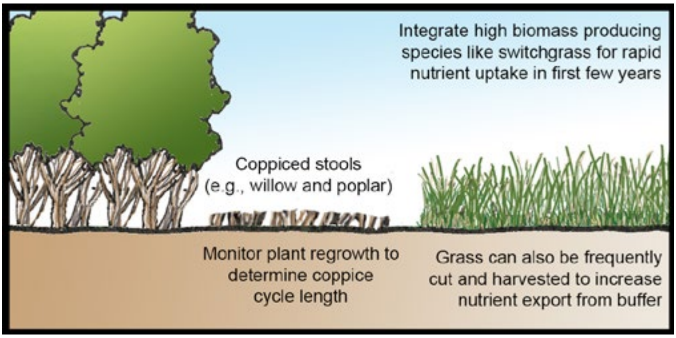

Sediment trapped in a buffer will change flow into the buffer over time, often resulting in concentrated flows. Periodic removal of accumulated sediment may be necessary. Use erosion control practices in source areas to reduce sediment load and minimize the need for future sediment removal from the buffer.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

## 1.23 Vegetation and Compaction




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.

## 1.24 Harvesting for Nutrient Removal



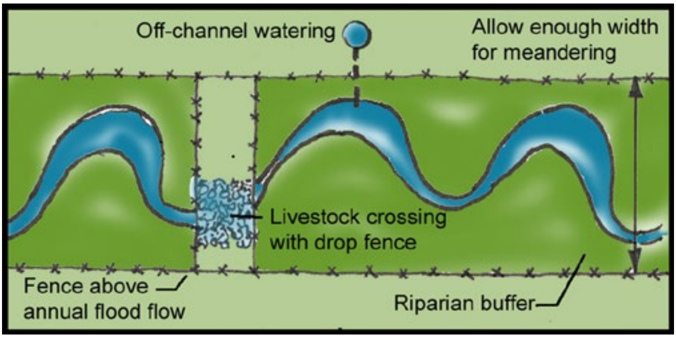

Harvesting and removing buffer vegetation can encourage plant regrowth and nutrient uptake. For certain nutrients such as P that cannot be removed from the buffer through other processes, harvesting may be necessary to ensure buffers do not become saturated and a source of P (see 1.8).

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 (see 1.25). Biomass can be harvested for *fodder*, but it should be cut and carried to livestock at an upland location or at a site where nutrient loading is not a concern and that does not drain to the buffer (see 4.15).

**Key harvesting considerations**

- Test soil before installation to understand baseline conditions and define design considerations. Test soil periodically to ensure that the buffer is meeting goals and harvesting is not depleting soil nutrients.
- Harvesting biomass will reduce other nutrients beyond N and P (e.g., potassium [K], calcium [Ca], magnesium [Mg], sulfur [S], etc.) from the buffer.
- Select fast-growing species (e.g., willow [*Salix* spp.] and poplar [*Populus* spp.]) that are efficient at capturing excess nutrients and can withstand frequent harvesting.
- Leaf and stem biomass contain higher concentrations of N and P than woody biomass.
- Monitor the regrowth of woody vegetation after harvesting. Increase the length of the harvesting rotation if woody vegetation shows decreased *vigor*.
- Avoid harvesting activities when soils are wet.

## 1.25 Buffers and Grazing



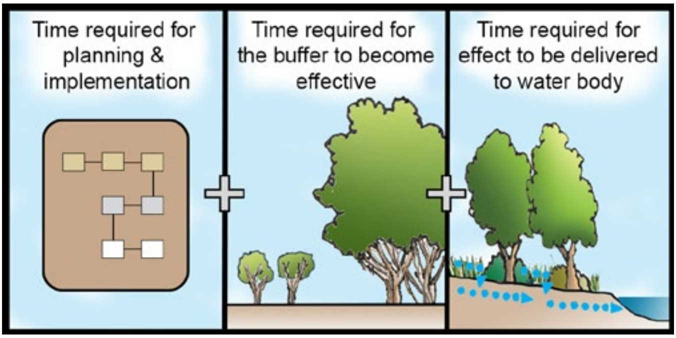

Grazing near or in riparian zones can negatively impact water quality through the following ways:

1. Concentrated livestock can compact soil, which leads to decreased infiltration and increased runoff flows.
2. Compact soils can also lead to a decrease in riparian vegetation, which significantly increases the risk of bank erosion.
3. Increased fecal deposits can introduce harmful microbial pathogens and lead to excess nutrients in riparian zones.
4. Sensitive riparian aboveground and belowground species can be disturbed, further disrupting nutrient cycles in riparian zones.

Fencing riparian buffers from pastures is often necessary to protect water quality. Other best management practices to reduce the harmful pressures of grazing on water systems include reducing stocking rates or altering the distribution of grazing livestock. This can be done by providing alternative water, mineral, and shade sources so that livestock do not gather in riparian zones.

It is not advisable to use grazing as a buffer management practice. Grazing has limited potential for removing nutrients from buffers (see 1.24) 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.

## 1.26 Buffers and Lag Time




Lag time is the time that elapses between the adoption of a practice or change in management practice and the perceived water quality improvement.

It is important to take lag time into consideration when planning and establishing buffers. Depending on the site and target pollutant (see 3.5), the magnitude of lag time may be a few years to decades.

In addition, consider the current and future land cover and land use changes in the watershed, particularly upstream. These changes can affect the performance of the buffer and should factor into the design. These changes should be evaluated in combination with lag time considerations.

For instance, an urbanizing watershed with increasing impervious cover may require wider buffers that are able to handle the increased runoff and flooding that will occur over time (see 5.13).

# 2. Biodiversity



## Objectives

- Enhance terrestrial habitat.
- Enhance aquatic habitat.

## Buffer functions

- Increase habitat area.
- Protect sensitive habitats.
- Restore *connectivity*.
- Increase access to resources.
- 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 Corridor network | ✓ | ✓ | ✓ | ✓ | |
| 2.5 Climate change and corridors | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.6 Stepping stones and gaps | ✓ | ✓ | ✓ | ✓ | |
| 2.7 Buffers and corridors | ✓ | ✓ | ✓ | ✓ | |
| 2.8 Corridor width | ✓ | ✓ | ✓ | ✓ | |
| 2.9 Edge effects of corridors | | ✓ | ✓ | ✓ | |

| Design Guidelines for Biodiversity | Buffer Functions: Increase habitat area | Protect sensitive habitats | Restore connectivity | Increase access to resources | Shade stream to maintain temperature |
|---|---|---|---|---|---|
| 2.10 Buffers for aquatic habitat | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.11 Buffers for stream temperature | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.12 Buffers for wetland habitat | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.13 Roads and wildlife | ✓ | | ✓ | ✓ | |

| Additional Design Guidelines that may Benefit Biodiversity | Buffer Functions: Increase habitat area | Protect sensitive habitats | Restore connectivity | Increase access to resources | Shade stream to maintain temperature |
|---|---|---|---|---|---|
| 1.2 Target buffers in watersheds | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1.9 Buffers for pesticides | | ✓ | | | ✓ |
| 3.2 Windbreaks for wind erosion | ✓ | ✓ | ✓ | ✓ | |
| 3.3 Herbaceous wind barriers | ✓ | ✓ | ✓ | ✓ | |
| 3.4 Grassed waterways | | | | | |
| 4.2 Buffers and pollinators | ✓ | | ✓ | ✓ | |
| 4.3 Buffers and insect pests | ✓ | | ✓ | ✓ | |
| 4.6 Buffers and spray drift | | ✓ | | | ✓ |
| 5.1 Buffers and ecosystem services | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.2 Rural-urban interface | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.8 Ecological aesthetic | ✓ | ✓ | ✓ | ✓ | ✓ |
| 6.1 Trail design and wildlife | ✓ | ✓ | ✓ | ✓ | |
| 6.2 Flight initiation distance buffers | | ✓ | ✓ | ✓ | |
| 6.3 Trails along riparian corridors | | ✓ | ✓ | ✓ | ✓ |

## Landscape Design Concepts

One method of describing landscapes divides a landscape into three basic elements: patches, corridors, and matrix.


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

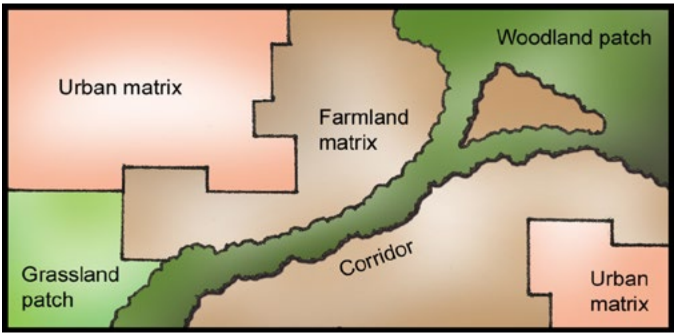
**Corridor:** A linear area with distinct structure, typically supporting certain ecological functions.

**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*. The matrix is often developed lands such as cropland or urban areas.

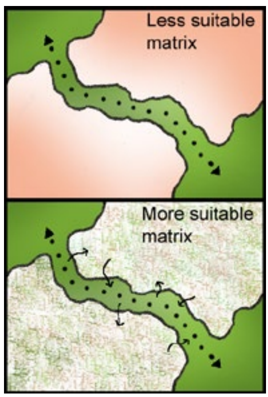
These terms are commonly used in the field of landscape ecology. This section (2.0 Biodiversity) uses these terms to describe best practices and strategies for improving wildlife habitat and biodiversity.

## 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 compared to the surrounding area.

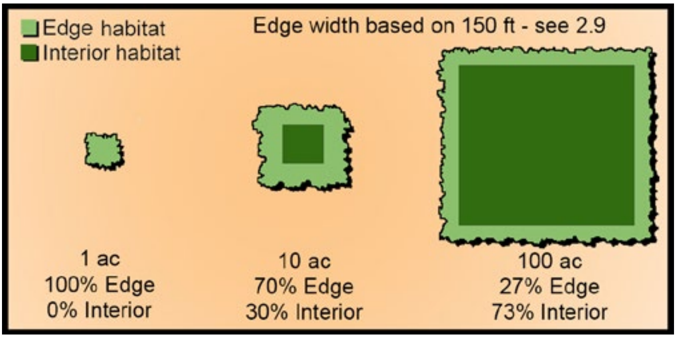
The potential value of corridors to link isolated patches depends on the type and condition of the matrix. A corridor will usually be more valuable in landscapes where the matrix quality is poor and less suitable for biodiversity.




**Key design considerations**

- Consider the matrix at multiple spatial and temporal scales.
- Cluster development to protect natural spaces.
- Minimize disturbance of natural vegetation.
- Minimize introduction and spread of nonnative species.
- Manage disturbances (e.g., haying, earth moving, fire) to reduce negative impacts.
- Compare matrix quality to adjacent patches.
- Certain matrix types may have biodiversity value. Some species may be able to use the matrix as a secondary habitat or food resource.

## 2.2 Patch Primer



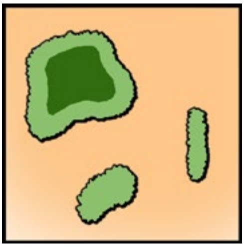

Patches of various sizes and habitat types are important for supporting *species diversity* and *abundance*. Larger patches will have a higher percentage of interior habitat. This benefits *interior species,* which are often the most vulnerable to *habitat fragmentation* and loss. Patches that support a large population can sometimes also have a spillover effect, where the benefits of patches extend beyond their boundaries into the surrounding matrix (see 4.2 and 4.3).

Minimum patch area requirements 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. Consult a wildlife biologist to refine these ranges for the specific situation.

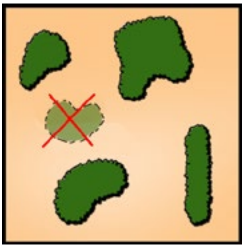
| Example Ranges of Minimum Patch Area | |
|---|---|
| **Taxa** | **Patch Area** |
| Plants | 5 to ≥250 acres |
| Invertebrates | 50 square feet to ≥2.5 acres |
| Reptiles and Amphibians | 3 to ≥35 acres |
| Grassland Birds | 12 to ≥135 acres |
| Waterfowl | ≥12 acres |
| Forest Birds | 5 to ≥95 acres |
| Small Mammals | 2.5 to ≥25 acres |
| Large Mammals | 40 acres to ≥1 square mile |
| Large Predator Mammals | 3.5 to ≥850 square miles |

**Key design considerations**

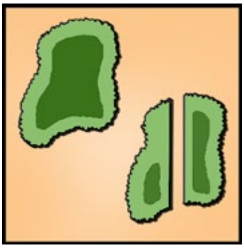
Small patches play a critical role in protecting biodiversity, particularly in areas with limited habitat. Small patches can capture a range of habitat types or unique habitats. Include large and small patches in a plan.



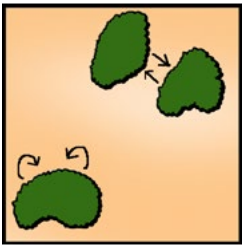
Redundancy is an essential component of ecosystems at all scales. If several patches exist in an area, species may not be seriously threatened or lost if one of the patches is destroyed or degraded.



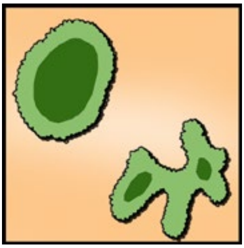
Of two patches with exactly the same area, one fragmented and one unified, the unified patch will be of far greater biodiversity value. Biodiversity will remain higher, and negative *edge effects* will be reduced.



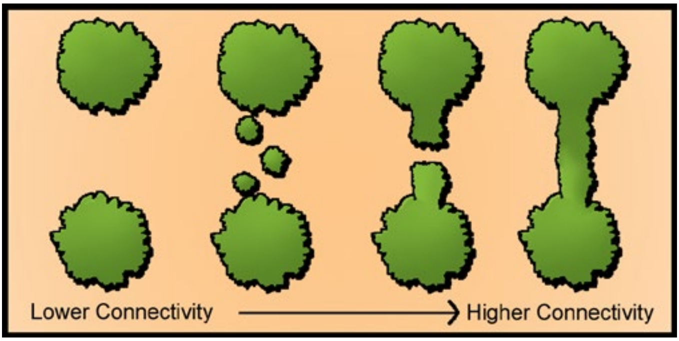
Species have greater opportunities to interact as the distance between patches decreases. This potential interaction depends on the species and their movement capabilities.



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



## 2.3 Corridors and Connectivity



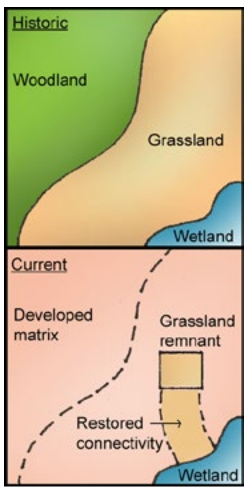

Connecting patches with corridors can benefit biodiversity by providing access to other areas of habitat, increasing *gene flow* and *population viability*, enabling *recolonization* of patches, and providing habitat.

Corridors between patches can increase species movement by up to 50 percent, compared to isolated patches. Corridors are especially important for the movement of *invertebrates* and plants. Other organisms may be able to move through the surrounding matrix.

Connectivity can be undesirable or unsuccessful in some cases. Corridors can be dominated by edge effects, increased risk of *parasitism* and disease, and facilitate *dispersal* of *invasive species* (see 2.9).

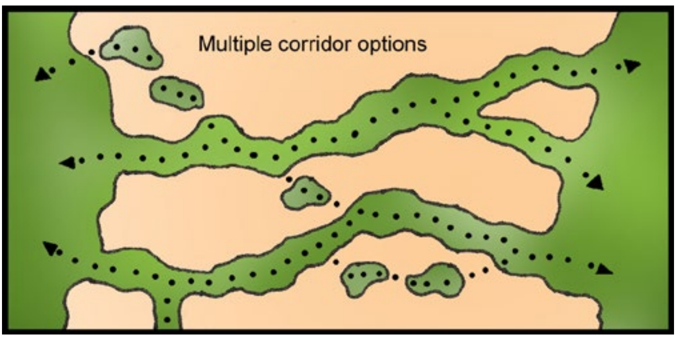
**Key design considerations**

- 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 can be beneficial.



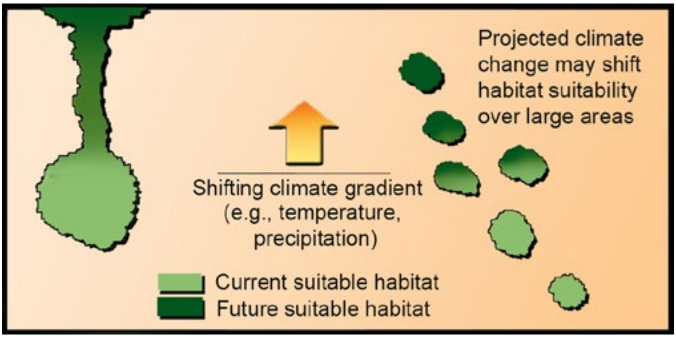
- Restore historical connections and generally avoid linking areas not historically connected.
- Consider the dispersal traits of target species and design corridors to facilitate these traits.
- Identify and remove or work around landscape barriers to species movement.
- If using a mapping system to identify potential corridors, use the highest resolution possible to avoid missing key regional landscape details.
- Avoid facilitating the movement of undesirable species by considering their dispersal traits and identifying existing populations in patches and the surrounding matrix.
- Avoid light pollution near corridors as much as possible.
- Avoid limiting corridors to strips of a single vegetation type. Instead, design corridors as broad connectivity zones.

## 2.4 Corridor Network




A redundant corridor network may provide multiple pathways for movement, reducing the impact if a corridor is eliminated. Having corridor redundancies can also increase the rate of *colonization* of new patches (see 2.2). However, this increased connectivity could facilitate quicker dispersal of problems such as diseases, parasitism, and invasive species (see 2.3 and 2.9). A corridor network may be a useful approach to encompassing a range of habitats in a region.

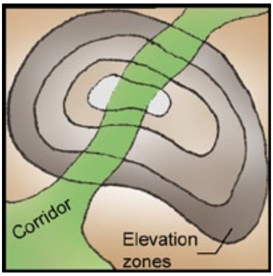
## 2.5 Climate Change and Corridors




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 4.13 and 5.4).
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 (see 5.11).
4. Provide habitat that offers a range of *microclimate refugia*.

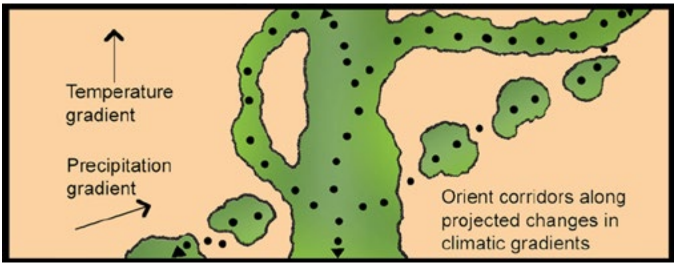
In general, areas with more intact natural habitat have greater climate connectivity compared to areas with fragmented habitat. Prioritizing corridors that facilitate movement through human-dominated regions may have more of an impact in allowing species to adjust to climate change. Corridors are less effective in regions distant from cool mountain ranges or in certain elevated regions where mountaintops can create climate islands.




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 only benefiting species that are highly mobile and adaptable, including invasive species.

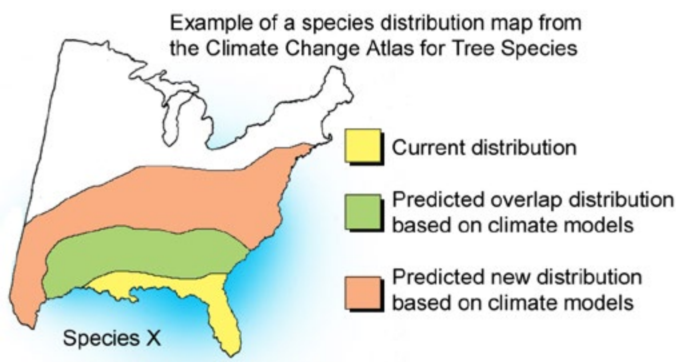
**Key design considerations**

- Corridors for climate change need to ensure the longevity of the corridor.
- A strategy of *stepping stones* and corridors may offer the most opportunities for dispersal and migration (see 2.6).

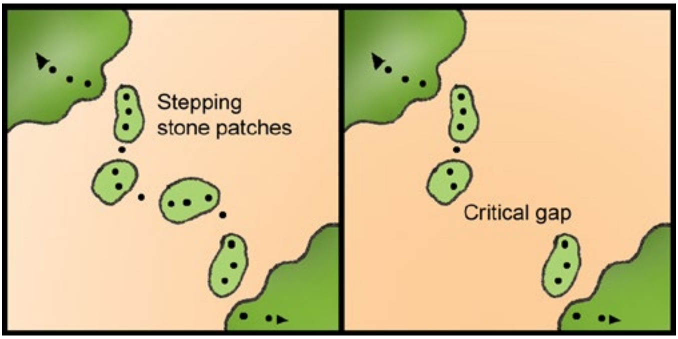



- Orient corridors along projected changes in climatic gradients.
- Locate corridors and patches to provide microclimate refugia at multiple spatial scales.
- Include a range of geological substrates and soils to meet different plant requirements.
- Riparian buffers may help mitigate temperature changes in streams due to climate change (see 2.11).

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.



## 2.6 Stepping Stones and Gaps

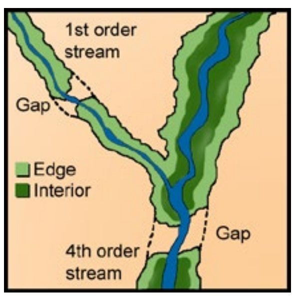



Small patches can serve as stepping stones, allowing for species movement between large patches and are important in fragmented landscapes. However, the loss of a stepping stone can often inhibit movement, increasing patch isolation.

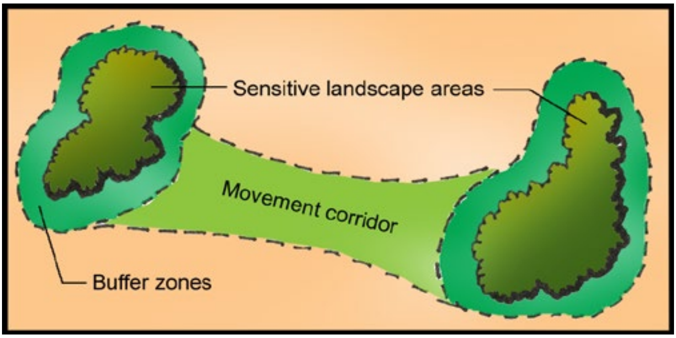
Stepping stones may not always be effective at promoting species movement. For certain species, if the stepping stone is too small, dispersed populations may go locally extinct before being able to produce offspring that can colonize the next patch. If population connectivity is the main goal, corridors may be a better strategy than stepping stones.

**Key design considerations**

- The greater the contrast between the gap and the corridor plant community, the narrower the gap must be to avoid becoming a barrier.
- Smaller animals will generally have smaller gap thresholds.
- Species requiring specialized habitats will have smaller gap thresholds.
- For visually oriented 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.



## 2.7 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 external pressures (e.g., development, agriculture, human traffic). Corridors are used to connect the buffered landscape patches. To facilitate population movement, corridors should be similar to the buffer zone in habitat type and quality (see 2.3).

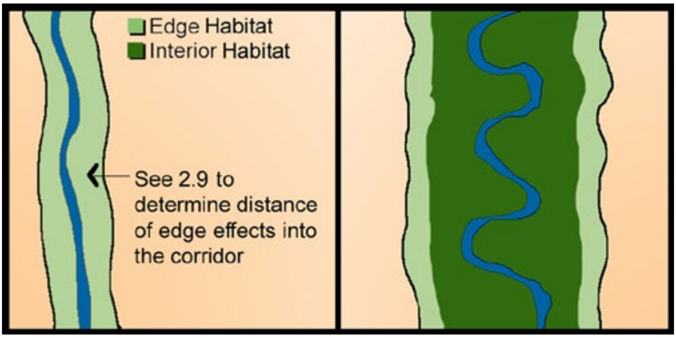
Base buffer zone width on the desired ecological functions, landscape context, and external pressures. Upland buffers of 400 to 1,000 feet around wetlands have been recommended for turtles and amphibians (see 2.12). For wildlife reserves or parks, buffer zones may need to be several miles wide.

**Key design 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.

Refer to 2.9 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 6.2 for guidance on human activity and buffer zones.

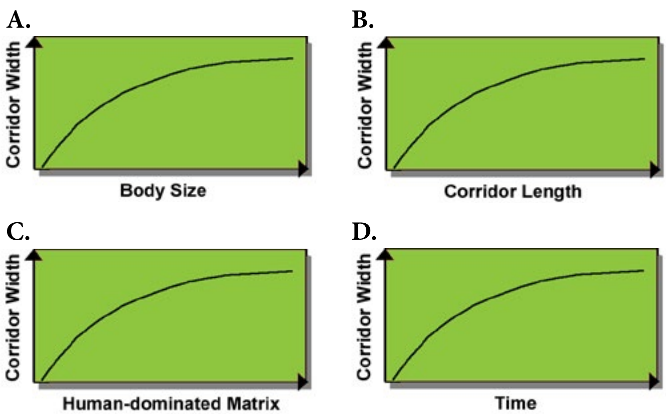
## 2.8 Corridor Width




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 impact 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, which may vary in different settings. For a given width, corridor effectiveness will vary with corridor length, continuity, habitat quality, and many other factors.

Based on this research, the following general relationships on corridor width can be inferred:




(see the next page for graph descriptions)

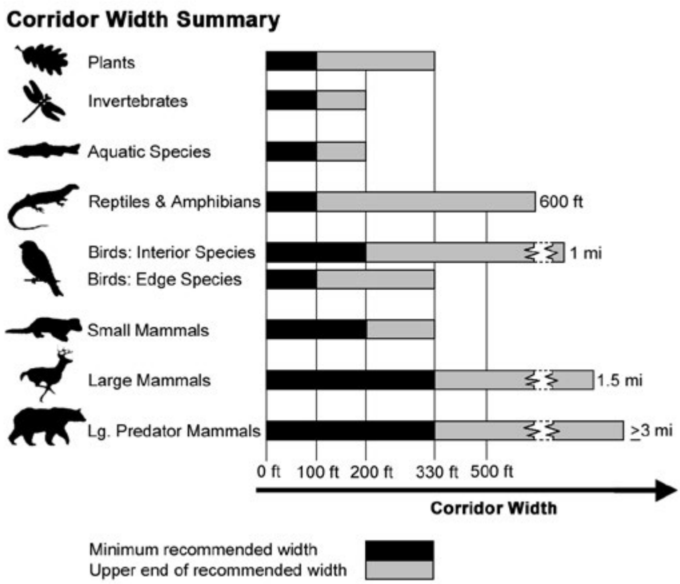
**A.** The larger the species, the wider the corridor will need to be to facilitate movement and provide potential habitat.

**B.** As the length of the corridor increases, so should the width. Shorter corridors are more likely to provide increased connectivity than long corridors.

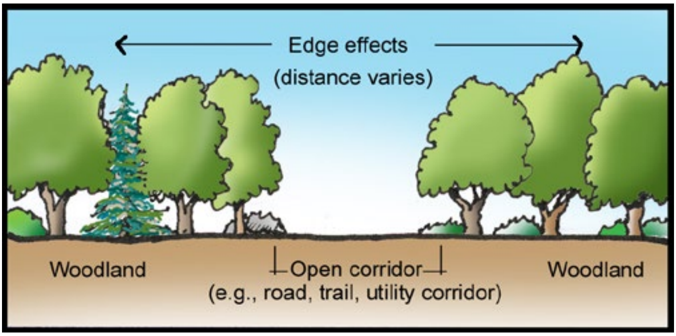
**C.** A corridor will generally need to be wider in landscapes that provide limited habitat or are more intensively used by humans.

**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.

With research limitations in mind, the bar graph below summarizes general findings 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.



## 2.9 Edge Effects of Corridors

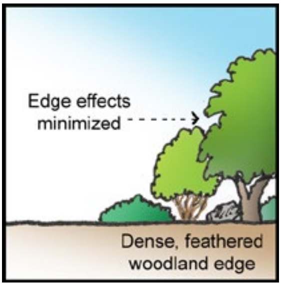


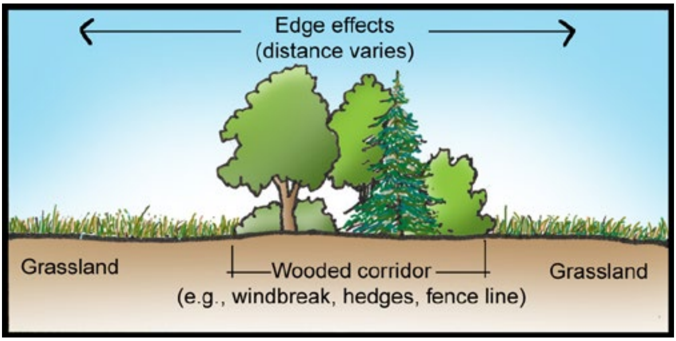

Corridors established in woodlands or grasslands can create edge effects that extend into the woodland or grassland. Examples include open corridors cleared for roads or trails in woodlands and *hedgerows* established in grasslands.

Negative edge effects include increased risk of parasitism or disease, increased risk of *predation*, adverse microclimate conditions, and competition from invasive species. Consider these factors in the corridor design.

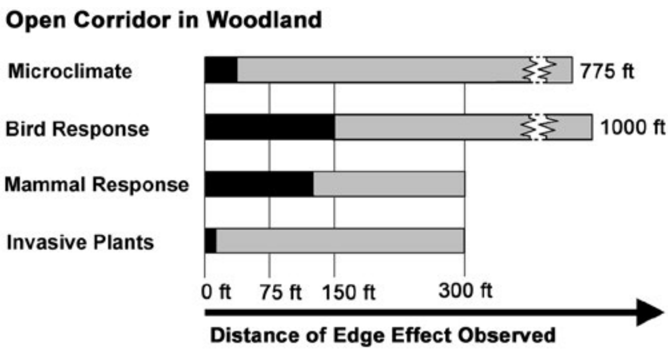
**Key considerations for reducing negative edge effects**

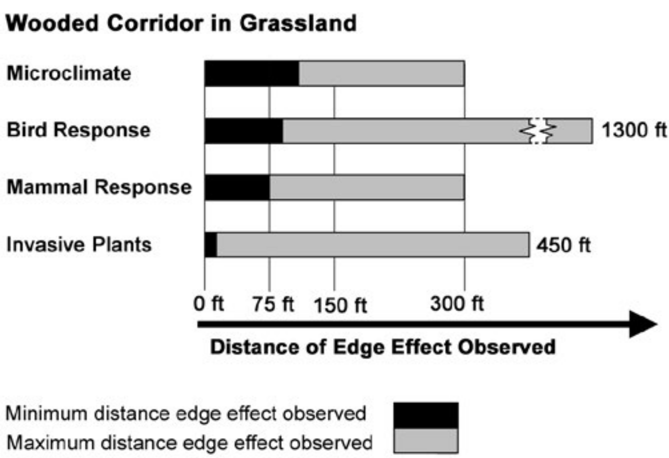
- Locate corridors along existing edges and avoid fragmenting habitat patches (see 2.2).
- Consolidate corridor uses to minimize habitat fragmentation (e.g., combine road and utility corridors).
- In woodlands, create a dense, feathered edge with vegetation to reduce penetration of edge effects.
- Narrower corridors will generally have less edge effects into adjacent habitat, particularly if there is canopy closure.
- If the landscape already consists of patches dominated by edge, a corridor will probably not contribute additional negative impacts.



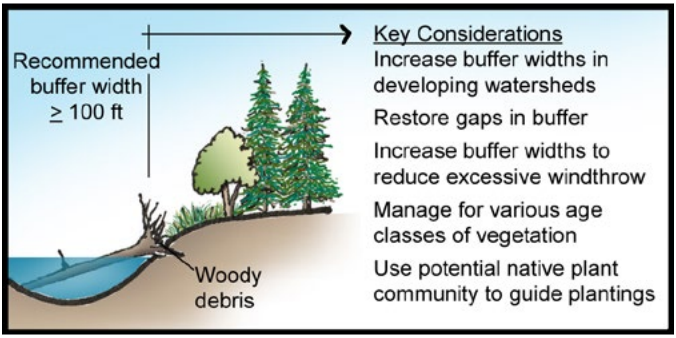



These graphs provide a summary of documented edge effects. These distances can be used for estimating the zone of impact and designing ways to reduce these impacts.



## 2.10 Buffers for Aquatic Habitat

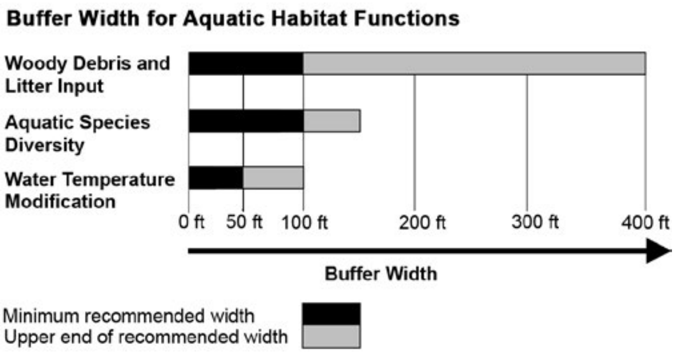



Riparian corridors or buffers influence habitat quality for aquatic species in several ways:

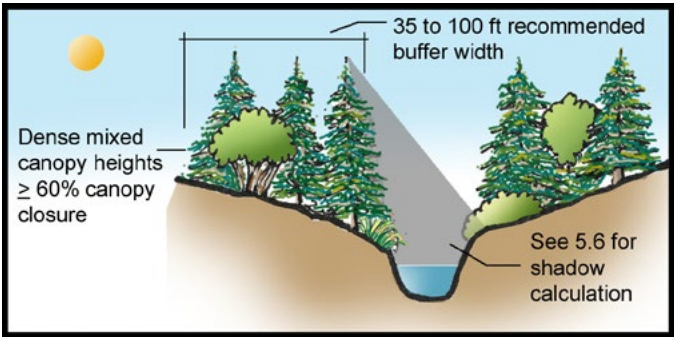
- Provide large woody debris for in-stream habitat structure.
- Maintain in-stream microclimate (see 2.11).
- Provide food for in-stream species through *leaf litter.*
- Protect water quality (see 1.0).

Abrupt changes in the makeup of riparian buffers (i.e., existence or absence of a canopy) can lead to abrupt changes in aquatic communities. If the goal is to promote biological continuity in a stream or river, it is important to establish riparian buffer continuity.

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



## 2.11 Buffers and Stream Temperature



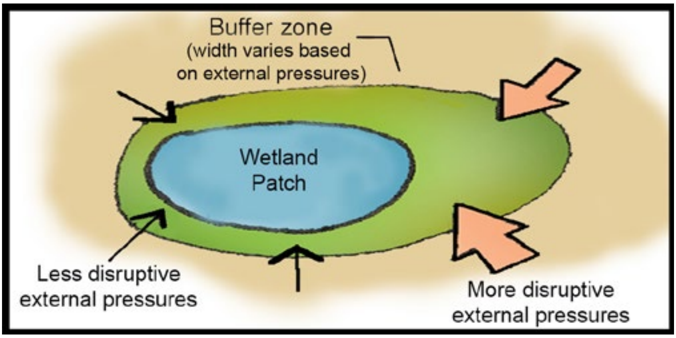

Solar radiation to the surface of the water is the main source of heat energy in riparian zones. Buffers help maintain cooler water temperatures in streams if the vegetation provides adequate shade on the water surface. This can be beneficial for cold-water aquatic species and water quality.

Stream shade is composed of topographic shade provided by nearby hills, bank shade, and vegetative shade. Streams with vegetation removed usually have undesirable summer temperature increases of 9 to 20 °F. Other factors such as *aspect, channel morphology*, surface and subsurface water exchange, and ground water input may affect stream temperatures more than shade. This is especially true for smaller *low-order streams*.

**Key design considerations**

- Buffer shading effectiveness decreases as stream width increases.
- Trees and shrubs provide the most shade, but tall grass buffers can provide shade on streams <8 feet in width.
- Buffer widths for east-to-west streams may be narrower than for north-to-south streams and offer the same shading benefits in the Northern Hemisphere (see 5.6).
- Vegetation establishment should be prioritized on the southern bank of rivers to maximize shading benefits.
- *Windthrow* may be common in buffers retained after timber harvest and wider buffers may be necessary.
- Buffers may need to be wider (e.g., 150 to 1,000 feet) to maintain other microclimatic factors (e.g., humidity).

## 2.12 Buffers for Wetland Habitat

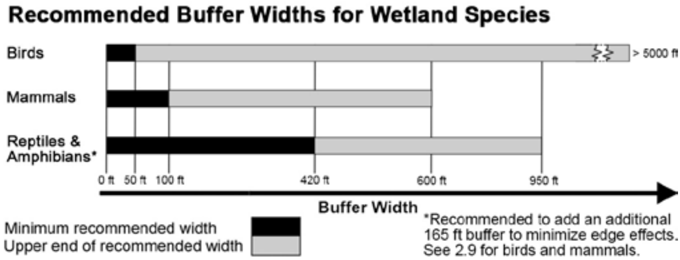



Vegetated buffers can protect wetlands from potential negative impacts of adjacent land use, while also providing critical habitat. Studies have indicated that effective buffer widths around wetlands for wildlife can range from 33 feet to more than 5,000 feet, depending on species.

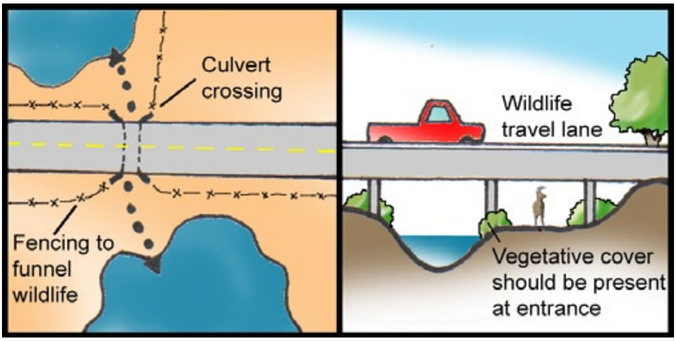
The graph on the next page summarizes the recommended wetland buffer widths for birds, mammals, reptiles, and amphibians.

**Key design considerations**

- Refine buffer width based on target species.
- Design the buffer based on landscape factors and adjacent land uses. Increasing intensity of adjacent land use may require a wider buffer. Width may need to vary around the wetland.
- Allow for wider buffers for pristine or highly valued wetlands.
- Match buffer vegetation to the historic native plant community that was adjacent to the wetland.
- Maintain a diverse array of plant species to allow for greater tolerance to fluctuations in environmental conditions, particularly important because of climate change.




## 2.13 Roads and Wildlife



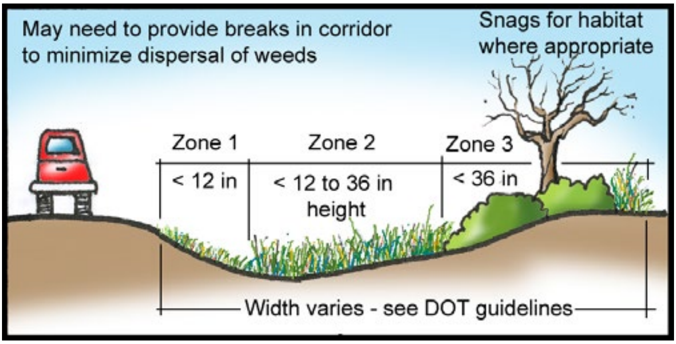

When *wildlife corridors* are bisected by roads, safe passage should be provided through culverts, bridges, and/or overpasses. Crossing structures should be placed in areas of suitable habitat. Landscape-scale assessments can aid in locating wildlife crossings.

When using culverts for wildlife crossings, include culverts of different sizes and avoid installing barriers to movement such as debris grates.

| Types of Wildlife Crossing Structures | | |
|---|---|---|
| **Types** | **Size** (diameter) | **Suitable Wildlife** |
| Pipe culvert | 1 to 6.5 feet | Amphibians and reptiles, small mammals |
| Underpass/bridge | >8 feet | Large mammals, large predator mammals |
| Bridge | 200 to 650 feet | Large mammals, large predator mammals |

## Roadside corridors

In areas with limited habitat, roadsides may be beneficial for some species but detrimental to others. 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.



# 3. Soils



## Objectives

- Reduce soil erosion.
- Increase soil productivity.

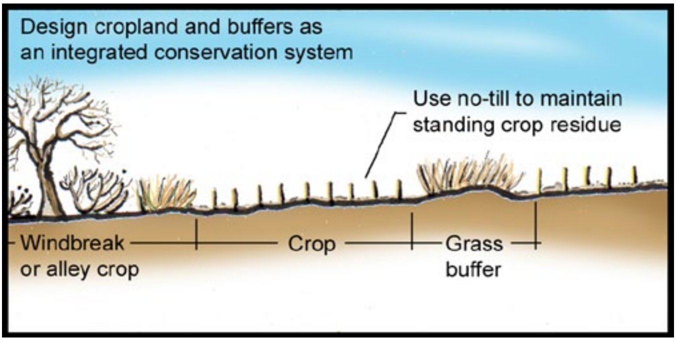
## Buffer functions

- Reduce water runoff energy.
- Reduce wind energy.
- Stabilize soil.
- Improve soil quality.
- Remove soil pollutants.

| Design Guidelines for 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 Buffers for phytoremediation | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.6 Buffers for soil health | ✓ | ✓ | ✓ | ✓ | ✓ |

| Additional Design Guidelines that may Benefit Soils | Buffer Functions: Reduce water runoff energy | Reduce wind energy | Stabilize soil | Improve soil quality | Remove soil pollutants |
|---|---|---|---|---|---|
| 1.1 Buffers and land management | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1.2 Targeted buffers in watersheds | ✓ | ✓ | ✓ | ✓ | ✓ |
| 1.5 Buffers for sediment | ✓ | | ✓ | ✓ | ✓ |
| 1.10 Buffer width design tool | ✓ | | ✓ | | |
| 1.11 Variable buffer width | ✓ | | ✓ | | |
| 1.12 Effective buffer area ratio | ✓ | | ✓ | | |
| 1.13 Slope and soil type adjustments | ✓ | | ✓ | | |
| 1.14 Allowances for bank erosion | ✓ | | ✓ | | |
| 1.19 Vegetation selection | ✓ | | ✓ | ✓ | ✓ |
| 1.20 Vegetation for removing pollutants | ✓ | | ✓ | ✓ | ✓ |
| 1.21 Vegetation for bank erosion control | ✓ | | ✓ | ✓ | |
| 4.12 Alley cropping | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.13 Buffers for flooding | ✓ | | ✓ | | |
| 6.4 Trail degradation | ✓ | ✓ | ✓ | | |

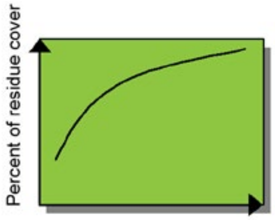
## 3.1 Buffers and Cropland Management




Buffers cannot 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* or at least perpendicular to the slope.
- Use *conservation tillage* or *no-till* practices to reduce water and wind erosion.
- Orient the crop rows perpendicular to the prevailing wind direction when not in conflict with slope (see 1.13).
- 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 the *fallow* season.
- In highly erodible situations, select a perennial crop to maintain year-round cover.
- Use *strip cropping* to reduce *sediment* transport.
- Deliver irrigation water in a manner that minimizes erosion.




Soils

## 3.2 Windbreaks for Wind Erosion


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

| | Downwind Zone of Protection | | | | |
|---|---|---|---|---|---|
| h distance from windbreak | 5h | 10h | 15h | 20h | 30h |
| wind speed (mph) | 6 | 10 | 12 | 15 | 19 |
| % of open wind speed | 30% | 50% | 60% | 75% | 95% |

*Windbreaks* can be an effective strategy for soil erosion control. Windbreaks protect 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.

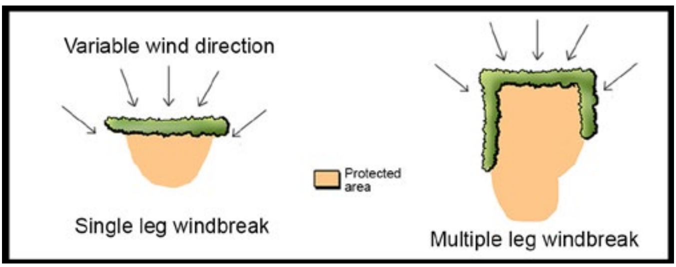
Windbreak density refers to the optical density or the percentage of the view that is filled with trunks, stems, branches, and leaves. The area protected downwind of a windbreak is a function of the windbreak's density, length, width, and height.

| Windbreak Densities | | | | |
|---|---|---|---|---|
| **Density** | **Description** | **Height** | **In-Row Spacing** | **Protection Season** |
| 60%+ | Multiple rows of conifers | Tall | Varies | Year round |
| 60%+ | Multiple rows of trees and shrubs | Medium-Tall | Varies | Year round |
| 60% | Multiple rows of shrubs | Short | 4 feet | Year round |
| 60% | Single row of deciduous trees | Medium-Tall | 12 feet | Growing season |
| 60% | Single row of non-pine conifers | Medium-Tall | <10 feet | Year round |
| 50% | Single row of pine | Tall | <10 feet | Year round |
| 40% | Single row of pine | Tall | >12 feet | Year round |
| 40% | Single row of deciduous trees | Medium-Tall | 14 to 18 feet | Winter season |

Other factors, such as maintaining crop residue, may also enhance windbreak effectiveness. Pair windbreaks with other conservation land management practices to increase their effectiveness (see 1.1 and 3.1).

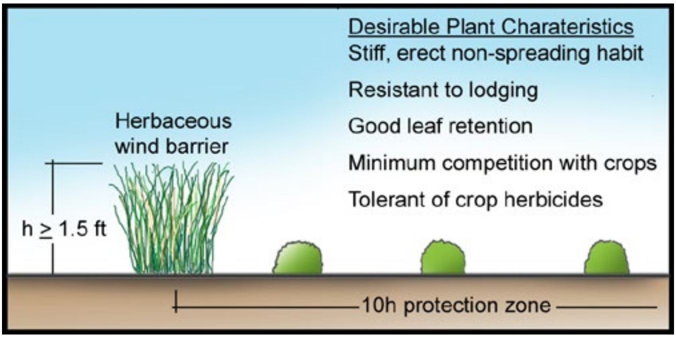
**Key design considerations**

- Orient the windbreak perpendicular to prevailing winds.
- Choose species with foliage and branching characteristics that will achieve the desired density during critical protection periods (e.g., winter).
- Plant multiple tree rows in the windbreak. Single-row windbreaks offer limited resilience because a dead tree will create a gap in the windbreak. Gaps can result in a wind tunnelling effect on the *leeward* side.
- Locate access roads at the end of windbreaks. Extend windbreaks beyond the area being protected.
- Including *conifer* species may be necessary to ensure year-round protection. The canopy density of *deciduous* species will decrease in the winter and reduce their effectiveness as a windbreak.
- In regions where tree establishment may not be possible, windbreaks can be composed of staggered plantings of shrub and/or herbaceous species (see 3.3). This may be especially relevant for arid and semiarid regions.
- Windbreaks with a density <30 percent have very little effect on windspeed.
- Multiple-leg windbreaks provide greater protection than single-leg windbreaks.




See 4.1, 4.5, 4.7, 4.8, 4.9, 4.10, and 5.4 for other windbreak functions.

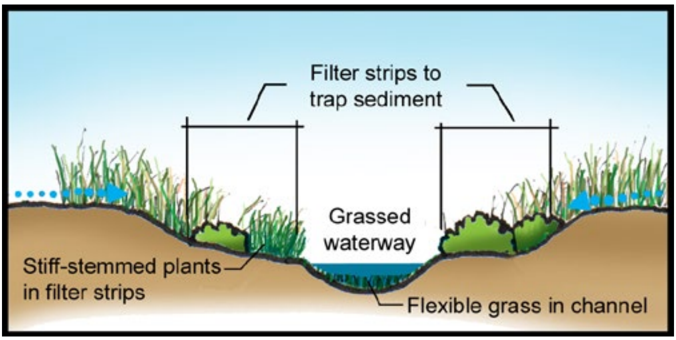
## 3.3 Herbaceous Wind Barriers




*Herbaceous* wind barriers are tall, non-woody plants established in narrow strips to reduce soil erosion and protect crops. In general, the design guidelines in section 3.2 also apply to herbaceous-only wind barriers. Herbaceous wind barriers are suitable for situations with height restrictions, such as under center-pivot irrigation (see 4.5).

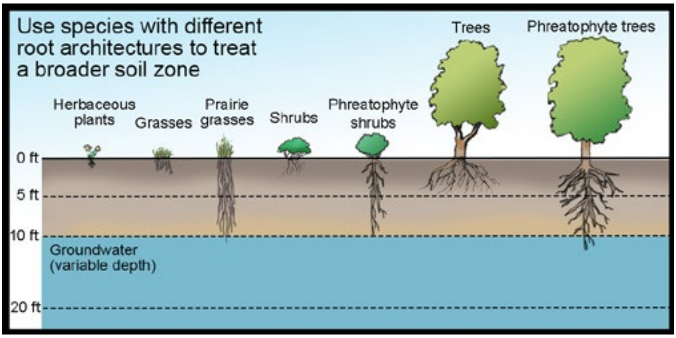
Soils

## 3.4 Grassed Waterways



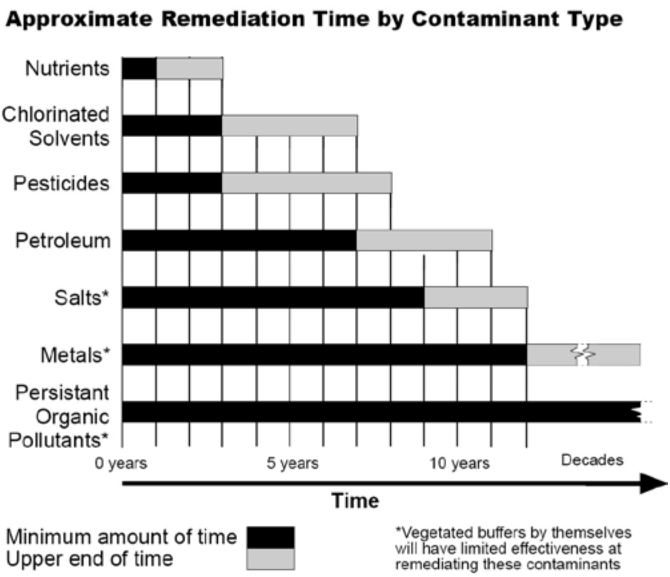

A grassed waterway is a vegetated channel that carries runoff at a nonerosive velocity to a stable outlet. Grassed waterways can be enhanced by including filter strips to filter runoff and trap sediment outside of the waterway. Vegetation in the channel should lie down to convey water, while vegetation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

## 3.5 Buffers for Phytoremediation



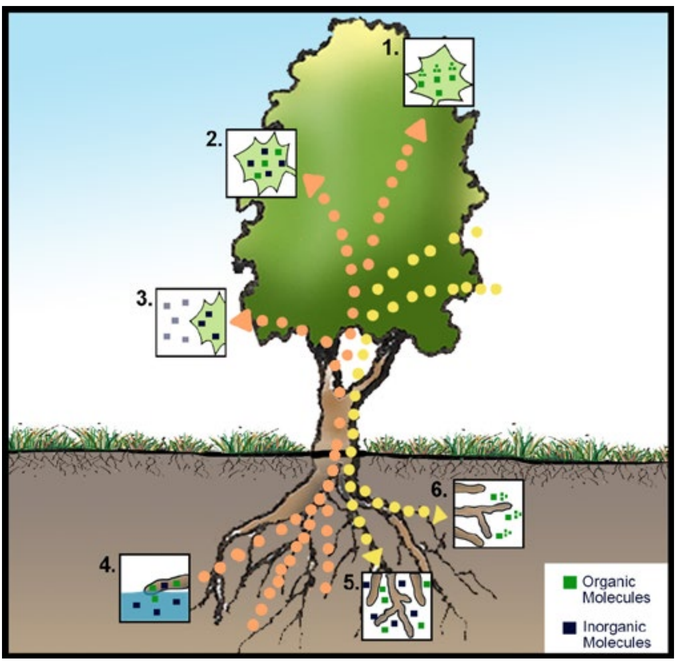

*Phytoremediation* is the use of plants to clean up soil and water contaminated with metals, solvents, and other pollutants. Phytoremediation buffers can treat brownfields, mine waste, and other sites that are low to moderately polluted.

Advantages of phytoremediation include its public acceptance and aesthetic appeal and the low cost for establishment and maintenance. Among its limitations are the length of time required for remediation (see graph below) and the limited amount of pollutants that can be effectively remediated by plants alone.



**Mechanisms for phytoremediation include:**

- Phytodegradation or phytometabolism—the uptake of organic contaminants through the roots, which are then broken down in plant tissues or used in plant growth
- Phytoextraction—the uptake of organic or inorganic contaminants from the soil, which are then stored in plant tissue
- Phytovolatilization—the capture and degradation of organic or inorganic contaminants that are then released by the plant into the atmosphere as a gas
- Phytohydraulics—the remediation of organic or inorganic contaminants found in ground water, wastewater, or surface water through plants
- Phytostabilization—the immobilization of organic or inorganic contaminants in the root zone or airborne pollutants on leaf surfaces
- Rhizodegradation—the breakdown of organic contaminants by *root exudates* released by the plant or *soil microorganisms* around the roots



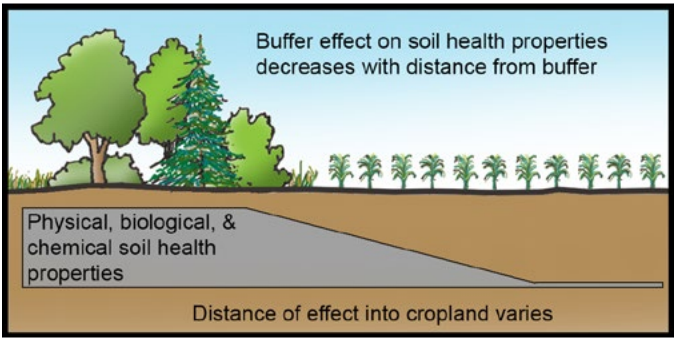

Soils

Phytoremediation can also be enhanced through other agronomic practices such as adding *chelating agents*, reducing soil pH, maintaining soil moisture and *soil organic matter*, and/or adding fertilizer. Consult an agronomist beforehand because improper application could harm soil quality.

**Key design considerations**

- Select species that are fast growing, easy to maintain, and produce abundant *biomass*.
- Species that have higher *evapotranspiration* rates are generally better at capturing contaminants from water (i.e., phytohydraulics).
- Contaminated sites often have degraded soil. Select hardy species tolerant to other conditions such as compaction, soil acidity and salinity, and pests.
- Avoid monocultures to reduce risk of disease and pests.
- Pollutants must be within the rooting zone. Species with fibrous root systems are best to treat contaminants found within the first 5 feet. *Phreatophytes* or species with deep root systems are best to treat contaminants in deeper soils. Plants with different rooting types may be used together to treat a broader zone.
- Determine and mitigate potential exposure risks for wildlife.
- Harvesting vegetation and proper disposal may be necessary, especially in cases where the main remediation mechanism is phytoextraction.
- Phytoremediation systems are complex systems, often with regulatory considerations. Consult with appropriate environmental professionals to design an effective system.

## 3.6 Buffers for Soil Health

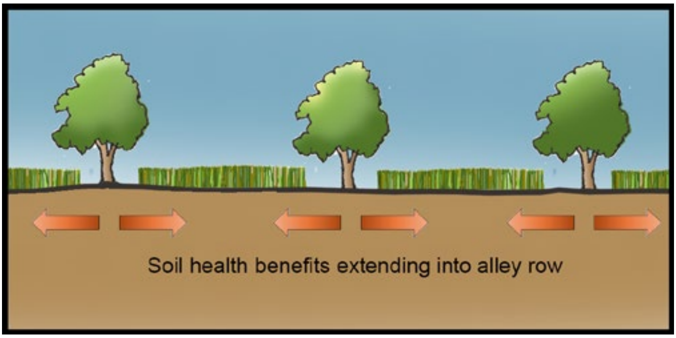



Vegetative perennial buffers have the potential to improve soil health. Transitioning to perennial vegetation can increase soil organic matter, soil microbial activity, nutrient cycling, water-holding capacity, and biomass while reducing *bulk density*. This is due to the reduction of soil disturbance, deeper root systems, and higher species diversity that follows changes in practice from annual row cropping to perennial systems.

**Key design considerations**

- Soil health improvements are concentrated in the rooting zone. Use a mixture of deep-rooted and shallow-rooted species.
- On sloped terrain, buffers can be planted along contours or at a slight grade (i.e., *keyline design*) to improve soil health and reduce soil erosion.
- Clay-rich soils (>33 percent) can accumulate more soil organic matter than soils with a lower clay content (<33 percent).
- Buffers with deciduous tree species generally accumulate more soil organic matter than buffers with coniferous tree species.
- Perennial vegetation in colder climates generally accumulates soil organic matter at a slower rate than in warmer climates.
- A diversity of species in the buffer can enhance soil health properties.

- Minimize or restrict fertilizer and pesticide applications or inputs in the perennial buffer. Using nitrogen-fixing species in the buffer may be beneficial depending on soil nutrient levels.
- Leaving pruned biomass in the buffer may enhance soil health properties over time.
- Alley cropping (see 4.13) or windbreaks (see 3.2 and 4.1) spaced across a field will aid in distributing the soil health benefits. These practices will also reduce soil erosion and help protect soil health improvements.



# 4. Crops and Livestock

## Objectives

- Improve yield and reduce pests.
- Provide protection for crops and livestock.
- Increase economic value and crop diversity.

## Buffer functions

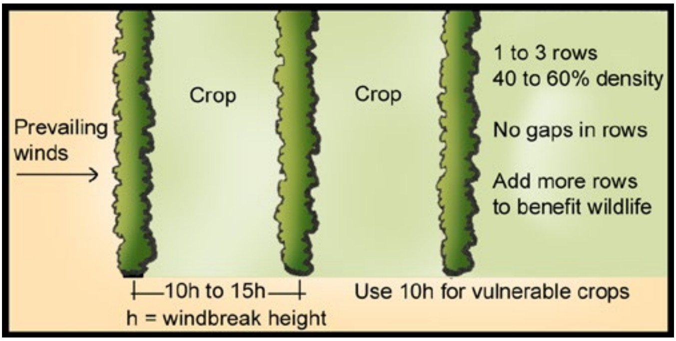
- Reduce wind energy.
- Affect *mesoclimate* and *microclimate*.
- Enhance habitat for pollinators.
- Enhance habitat for pest predators.
- Produce marketable products.

| Design Guidelines for Crops and Livestock | Buffer Functions | | | | |
|---|---|---|---|---|---|
| | Reduce wind energy | Affect meso and microclimate | Enhance habitat for pollinators | Enhance habitat for pest predators | Produce marketable products |
| 4.1 Windbreaks and crop yields | ✓ | ✓ | | | ✓ |
| 4.2 Buffers and pollinators | ✓ | | | ✓ | ✓ |
| 4.3 Buffers and insect pests | | ✓ | ✓ | | ✓ |
| 4.4 Buffers and invasive control | ✓ | | ✓ | | ✓ |
| 4.5 Windbreaks and sprinkler irrigation | ✓ | ✓ | | | ✓ |
| 4.6 Buffers and spray drift | ✓ | ✓ | ✓ | ✓ | ✓ |
| 4.7 Windbreaks for plant disease control | ✓ | ✓ | | | ✓ |
| 4.8 Windbreaks for animal disease control | ✓ | ✓ | | | ✓ |
| 4.9 Windbreaks for livestock | ✓ | ✓ | | | ✓ |

| Design Guidelines for Crops and Livestock | Buffer Functions | | | | |
|---|---|---|---|---|---|
| | Reduce wind energy | Affect meso and microclimate | Enhance habitat for pollinators | Enhance habitat for pest predators | Produce marketable products |
| 4.10 Buffers for odor control | ✓ | ✓ | | | |
| 4.11 Multi-story cropping in buffers | ✓ | ✓ | ✓ | ✓ | ✓ |
| 4.12 Alley cropping | ✓ | ✓ | ✓ | ✓ | ✓ |
| 4.13 Greenhouse emissions and mitigation | | ✓ | | | |
| 4.14 Biofuel buffers | ✓ | ✓ | | | ✓ |
| 4.15 Fodder production | ✓ | ✓ | ✓ | ✓ | ✓ |

| Additional Design Guidelines that may Benefit Crops and Livestock | Buffer Functions | | | | |
|---|---|---|---|---|---|
| | Reduce wind energy | Affect meso and microclimate | Enhance habitat for pollinators | Enhance habitat for pest predators | Produce marketable products |
| 2.1 Matrix primer | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.2 Patch primer | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.3 Corridors and connectivity | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.1 Buffers and cropland management | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.2 Windbreaks and wind erosion | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.3 Herbaceous wind barriers | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3.4 Grassed waterways | | | ✓ | ✓ | ✓ |
| 3.6 Buffers for soil health | ✓ | ✓ | | | ✓ |
| 5.1 Buffers and ecosystem services | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.2 Rural-urban interface | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.3 Urban agriculture | ✓ | ✓ | ✓ | ✓ | ✓ |

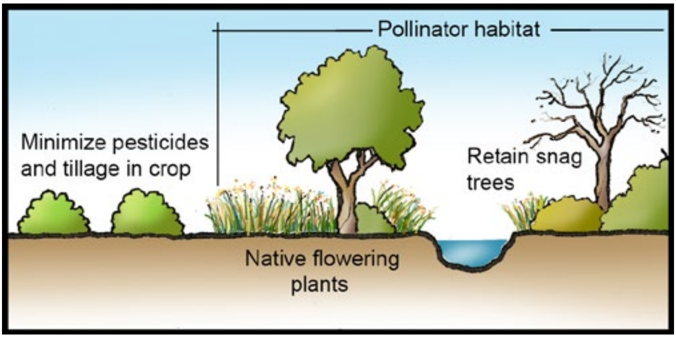
## 4.1 Windbreaks and Crop Yields




*Windbreaks* can increase crop yield and quality by reducing erosion, improving microclimate, retaining moisture, and reducing crop damage from high windspeeds. Windbreaks on two sides may be required if prevailing winds are from two directions. Encourage even distribution of snow across a field with a windbreak density of 30 to 40 percent (see 3.2).

Reductions in yield may occur in the crop rows closest to the windbreak. Minimize yield impacts through root pruning the windbreak adjacent to the crop or planting a shade- and drought-tolerant crop in the competition zone.

## 4.2 Buffers and Pollinators



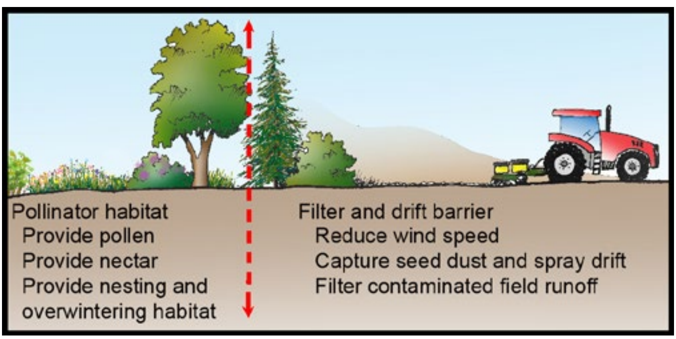

Buffers can provide valuable resources for pollinators and may enhance production of insect-pollinated crops. These resources can include nectar and pollen, nesting and overwintering sites, shade, and access to water. Buffers can reduce wind and aid in foraging and pollinator efficiency (see 4.1). Bees also collect resins and floral oils from trees and other plants to aid in nest construction and provisioning larvae.

**Key design considerations**

- Select a mix of species that will provide nectar and pollen resources throughout the active pollinator season (see 4.3). Flowering trees and shrubs can often provide critical early season resources.
- Avoid using species that flower when pesticides are typically sprayed in the area.
- Poplar (*Populus* spp.), pine (*Pinus* spp.), birch (*Betula* spp.), elm (*Ulmus* spp.), alder (*Alnus* spp.), beech (*Fagus* spp.), and horse chestnut (*Aesculus hippocastanum*) are some of the species that can provide important resins and floral oils.
- Ideally, buffers should be <1,000 feet from the pollinator-dependent crop to facilitate pollinator movement from the buffer into the crop. For large fields, this may require multiple buffers spaced across the field.
- Windbreaks on the windward side of honeybee hives can reduce overwintering losses from cold weather and winds.
- Woody species with soft pithy centers such as sumac, elderberry, and brambles can provide tunnel nesting sites for solitary bees. Retain *snag* trees for nesting sites.

**Protecting against spray drift**

Buffers with plants that don't attract pollinators can serve as a filter and drift barrier to reduce exposure to pesticides and other contaminants harmful to pollinators (see 4.6 and 5.14). These barriers can be used on their own or to protect adjacent pollinator habitat.



## Key design considerations

- Strive for 50- to 60-percent density for the drift barrier. Two rows of evergreens can provide 60-percent density (see 3.2).
- Ideally, the buffer should be at least two times higher than the release height of the spray.
- Fine-leaved, dense evergreen species are effective at intercepting drift due to the large surface area of their leaves or needles throughout the year (see 4.6).
- Spruce (*Picea* spp.), juniper (*Juniperus* spp.), fir (*Abies* spp.), and arborvitae (*Thuja* spp.) are recommended over pines because they have more dense foliage, and the lower tiers of pine canopies can become more open with age. Self-pruning trees are undesirable.
- Species with hairy, resinous, and coarse leaf surfaces capture more particles than smooth leaves.

**North American Trees and Shrubs that Provide Abundant Nectar and/or Pollen**

| Scientific Name/ Common Name | Bloom Time[1] | Region[2] |
|---|---|---|
| *Acer* spp.[3] Maple | Spring to early summer | WCE |
| *Amelanchier* spp.[3] Serviceberry | Early spring to summer | WCE |
| *Amorpha* spp. Leadplant, false indigo | Spring to summer | WCE |
| *Arbutus* spp.[1,3] Madrone | Early spring to summer | WC |
| *Aronia* spp.[3] Chokeberry | Spring to summer | CE |
| *Atriplex canescens* Fourwing saltbush | Spring to fall | W |
| *Baccharis* spp.[4] Baccharis | Summer to fall | WCE |
| *Callicarpa americana* Beautyberry | Early summer | CE |
| *Ceanothus* spp. Ceanothus | Early spring to summer | WCE |
| *Cephalanthus occidentalis* Buttonbush | Summer | WCE |
| *Cercis* spp. Redbud | Spring | WCE |

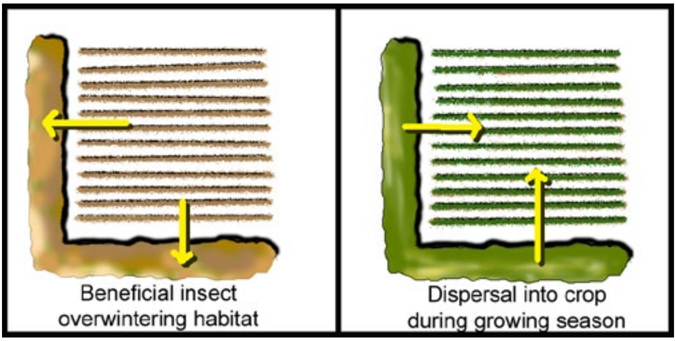
*(Table continues on next page)*

| North American trees and shrubs that provide abundant nectar and/or pollen (*continued*) | | |
|---|---|---|
| **Scientific Name/ Common Name** | **Bloom Time**[1] | **Region**[2] |
| *Chilopsis linearis*<br>Desert willow | Summer | W |
| *Chrysothamnus* spp.<br>Rabbitbrush | Summer to fall | W |
| *Clethra alnifolia*<br>Sweet pepperbush | Summer | E |
| *Crataegus* spp.<br>Hawthorn | Spring | WCE |
| *Dasiphora* spp.<br>Cinquefoil | Spring | WCE |
| *Diospyros* spp.[3]<br>Persimmon | Spring | WCE |
| *Eriogonum* spp.<br>Buckwheat | Summer | WC |
| *Gaylussacia* spp.[3]<br>Huckleberry | Early spring | CE |
| *Gleditsia* spp.[3,5]<br>Honey locust | Spring | WCE |
| *Halesia* spp.<br>Silverbell | Early spring | E |
| *Holodiscus* spp.<br>Oceanspray | Summer | WC |
| *Hypericum* spp.<br>Shrubby St. Johnswort | Late spring | WCE |
| *Ilex* spp.[1,3]<br>Holly, inkberry | Spring | WCE |
| *Itea virginica*<br>Virginia sweetspire | Spring | CE |
| *Liriodendron tulipifera*[3]<br>Tulip tree | Spring | CE |
| *Mahonia* spp.[3]<br>Oregon grape | Spring to early summer | WCE |
| *Nyssa* spp.[3]<br>Blackgum | Spring | CE |
| *Oxydendrum arboreum*<br>Sourwood | Summer | E |
| *Parkinsonia* spp.<br>Palo verde | Spring | WCE |
| *Philadephus* spp.<br>Mock orange | Spring | WCE |
| *Physocarpus* spp.<br>Ninebark | Spring to summer | WCE |

| North American trees and shrubs that provide abundant nectar and/or pollen (*continued*) | | |
|---|---|---|
| **Scientific Name/ Common Name** | **Bloom Time**[1] | **Region**[2] |
| *Prosopis glandulosa*[3] Honey mesquite | Spring to summer | WC |
| *Prunus* spp.[3] Cherry, plum, peach, apricot | Spring | WCE |
| *Purshia tridentata* Antelope bitterbrush | Spring | W |
| *Rhododendron* spp.[4] Rhododendron, azalea | Early spring | WCE |
| *Rhus* spp.[3] Sumac | Spring to summer | WCE |
| *Robinia neomexicana* New Mexico locust | Spring to summer | W |
| *Robinia pseudoacacia*[3,5] Black locust | Spring | E |
| *Rosa* spp.[3] Native roses | Summer | WCE |
| *Rubus* spp.[3,5] Blackberry, raspberry | Spring to fall | WCE |
| *Salix* spp.[3] Willow | Early spring | WCE |
| *Sambucus* spp.[3] Elderberry | Spring to summer | WCE |
| *Sassafras albidum* Sassafras | Spring | CE |
| *Shepherdia* spp. Buffaloberry | Spring | WC |
| *Spiraea* spp. Spirea | Summer | WCE |
| *Tilia* spp.[3] Basswood | Spring to summer | CE |
| *Umbellularia californica* California laurel | Fall to spring | W |
| *Vaccinium* spp.[3] Blueberry, huckleberry | Early spring | WCE |

[1] Flowering times depend on species, location, and environmental conditions, varying from year to year. Consult with local native plant experts to plan for overlapping bloom times.
[2] C = Central; E = East; W = West.
[3] Could provide additional marketable product.
[4] Includes some or all evergreen species.
[5] This species can be invasive or highly aggressive in some parts of the country and should not be planted in those regions.

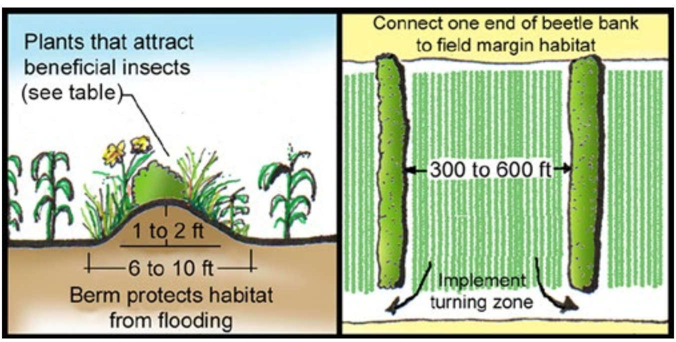
## 4.3 Buffers and Insect Pests




Buffers can be planted with species that attract beneficial insects that then prey on or parasitize insect pests. These beneficial insects can also act as important pollinators. To encourage *predation* and parasitization, both the life cycle of the beneficial predator or *parasitoid* and pest should be understood.

Other considerations include selecting plants that bloom sequentially throughout the growing season and avoiding plants that enhance pest abundance. Native plants attract native beneficial insects and are less likely to become agricultural weeds.

In temperate regions, vegetative buffers can provide overwintering habitat for beneficial insects as well as shelter from extreme temperatures during the summer. Vegetated buffers can include patches of forests, seminatural field margins, hedgerows, vegetative strips, and *beetle banks* (see below). See the next page for key design considerations.



### Key design considerations

- Provide plant diversity in the buffer. Include woody plants to provide structural refuges, wind protection, and alternative prey.
- Include blooming plants to provide nectar and pollen to beneficial insects. These insects tend to prefer small flowers or flowers with an open floral structure.
- Support high vegetative density by cutting vegetation during dormancy every other year or every third year.
- If possible, connect buffers to other existing seminatural patches to increase habitat *connectivity* (see 2.3).
- Protect buffer from disturbances (e.g., pesticides, tillage). Narrow field margins (i.e., <10 feet wide) are particularly sensitive to disturbances like pesticide spraying. Implement no-spray zone buffers in the field immediately adjacent to these buffers to protect their habitat value.
- Encourage predation of insect pests by increasing the percentage of buffer habitat in the area.
- Locate buffers throughout the fields and landscape to encourage *dispersal* of beneficial insects.
- Create structurally diverse buffers, which can provide pest control benefits that extend 600 feet into the field. This effect varies depending on the size of the buffer and plant selection.

| Beneficial Insects and Their Habitat Needs | | |
|---|---|---|
| **Beneficial Insects** | **Pest Prey/Hosts** | **Habitat Needs** |
| **Assassin bug** (Reduviidae family) | Many insects including flies and large caterpillars | Overwinter under leaf litter, low-growing plants, and tree bark; a few drink nectar while waiting for prey on flowers |
| **Braconid wasp** (Braconidae family) | Armyworm, cabbageworm, codling moth, spongy moth, European corn borer, aphid, caterpillars, and other insects | Overwinter within their host; adults drink nectar or honeydew, prefer sheltered edges and areas with minimal wind |
| **Damsel bug** (Nabidae family) | Aphid, thrips, leafhopper, treehopper, caterpillars | Overwinter under mulch, grass thatch, leaf litter |

*(Table continues on next page)*

| Beneficial Insects and Their Habitat Needs (*continued*) | | |
|---|---|---|
| **Beneficial** | **Pests** | **Plants/Habitat** |
| **Ground beetle** (Carabidae family) | Slug, snail, cutworm, Colorado potato beetle, spongy moth, caterpillars, weed seeds | Overwinter in bunch grass clumps, brush piles; omnivorous species may consume seeds, pollen, or detritus in addition to prey |
| **Hover fly** (Syrphidae family) | Aphids, scales, mites, thrips | Overwinter in soil or leaf litter; adults drink nectar and eat pollen, prefer sheltered areas with reduced wind |
| **Lacewing** (Chrysopidae family) | Soft-bodied insects including aphid, thrips, European corn borer, mealybug, scale, mite | Overwinter in leaf litter, under bark; adults drink nectar and honeydew and eat pollen, prefer areas sheltered from wind |
| **Ladybug beetle** (Coccinellidae family) | Aphid, spider mite, European corn borer, mealybug | Overwinter in leaf litter, under bark; adults drink nectar and honeydew and eat pollen |
| **Minute pirate bug** (Anthocorid family) | Thrips, spider mite, leafhopper, corn earworm, small caterpillars, and other insects | Overwinter under bark, leaf litter, grass thatch; drink nectar and plant sap and eat pollen |
| **Rove beetle** (Staphylinidae family) | Aphid, nematode, flies, slugs | Overwinter in bunch grass clumps, brush piles; omnivorous species may eat fungal spores, pollen, or decaying organic matter |
| **Spider** (Salticidae, Thomisidae, and other families) | Many insects | Overwinter in soil, grass clumps, leaf litter, mulch. A few species drink small amounts of nectar in addition to prey |
| **Spined soldier bug** (*Podisus maculiventris*) | Armyworm, sawfly, Colorado potato beetle, Mexican bean beetle | Overwinter under bark, leaf litter |
| **Tachinid fly** (Tachinidae family) | Cutworm, armyworm, May beetle, spongy moth, squash bug | Overwinter within their host; adults drink nectar or honeydew |
| **Soldier beetle** (Cantharidae family) | Many insects | Overwinter in leaf litter, under bark; adults drink nectar and eat pollen |
| **Chalcid wasps** (many families including Trichogrammat-idae) | Spruce budworm, cotton bollworm, tomato hornworm, corn earworm, corn borer, codling moth | Overwinter within their host; adults drink nectar or honeydew, prefer sheltered edges and areas with minimal wind |

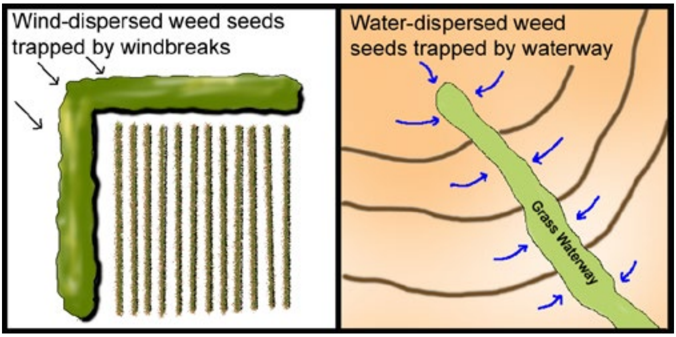
The tables in this guideline can be used together to identify the desired beneficial insects and their associated habitat needs.

To offer the best habitat for beneficial insects, create a diverse buffer that incorporates species from the three groups: wildflowers, trees and shrubs, and bunch grasses.

| Native Plants That Support Beneficial Insects | | |
|---|---|---|
| **Wildflowers** | **Trees and Shrubs** | **Bunch Grasses** |
| *Achillea* spp.<br>Yarrow | *Amorpha* spp.<br>False indigo | *Andropogon* spp.<br>Bluestem |
| *Agastache* spp.<br>Hyssop | *Baccharis* spp.<br>Baccharis | *Aristida* spp.<br>Threeawn |
| *Angelica* spp.<br>Angelia | *Ceanothus* spp.<br>Ceanothus | *Bouteloua* spp.<br>Grama |
| *Apocynum* spp.<br>Dogbane | *Cephalanthus* spp.<br>Buttonbush | *Danthonia* spp.<br>Oatgrass |
| *Arnoglossum* spp.<br>Plantain | *Crataegus* spp.<br>Hawthorn | *Elymus* spp.<br>Wild rye |
| *Asclepias* spp.<br>Milkweed | *Frangula* spp.<br>California buckthorn | *Festuca* spp.<br>Fescue |
| *Coreopsis* spp.<br>Tickseed | *Heteromeles* spp.<br>Toyon | *Koeleria* spp.<br>Junegrass |
| *Eupatorium* spp.<br>Thoroughwort | *Holodiscus* spp.<br>Oceanspray | *Muhlenbergia* spp.<br>Muhly |
| *Gaillardia* spp.<br>Blanketflower | *Prunus* spp.<br>Cherry/plum | *Pseudoroegneria* spp.<br>Wheatgrass |
| *Helianthus* spp.<br>Sunflower | *Rosa* spp.<br>Rose | *Schizachyrium* spp.<br>Little bluestem |
| *Phacelia* spp.<br>Phacelia | *Salix* spp.<br>Willow | *Sorghastrum* spp.<br>Indiangrass |
| *Pycnanthemum* spp.<br>Mountainmint | *Sambucus* spp.<br>Elderberry | *Sporobolus* spp.<br>Sandreed |
| *Silphium* spp.<br>Rosinweed | *Shepherdia* spp.<br>Buffaloberry | |
| *Solidago* spp.<br>Goldenrod | *Spiraea* spp.<br>Meadowsweet | |
| *Zizia* spp.<br>Zizia | *Tilia* spp.<br>Basswood | |

Crops and Livestock

## 4.4 Buffers and Invasive Control

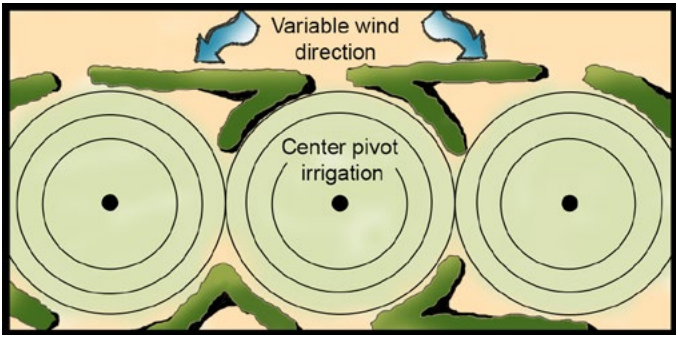



When designed carefully, buffers are usually not a source of *invasive species* or other weeds. They can be used for weed control by trapping water- and wind-dispersed seeds. However, without management, invasive species can become established in buffers. Below are key management considerations to reduce this risk.

**Key management considerations**

- Prioritize species that are native with low invasive potential.
- Learn to identify invasive species common in your area.
- Prioritize invasive species control in buffers impacted by frequent disturbances (e.g., roadsides, *riparian areas*), which can facilitate the spread of these species.
- Focus management efforts on areas near environmentally sensitive areas.
- Use appropriate management techniques (e.g., fire, mowing, grazing) to maintain healthy vegetative cover in the buffer to reduce opportunities for invasive species to become established.
- Inspect the buffer at least annually and prioritize containment and treatment of new invasive species before they become well established.
- Clean mowing equipment to avoid inadvertent transfer of weed seeds.
- Clean and sanitize footwear before and after use or consider dedicating a pair of boots to use only in the buffer. Properly dispose of soil, seeds, plant parts, or invertebrates found during cleaning.

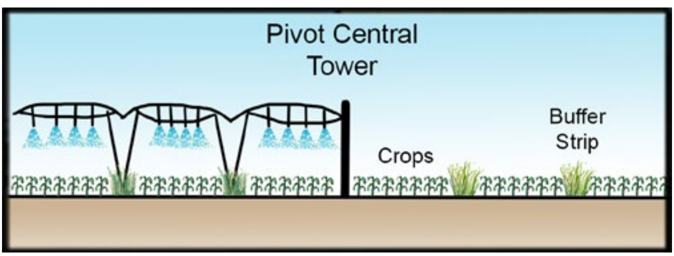
## 4.5 Windbreaks and Sprinkler Irrigation




Windbreaks can improve water use efficiency in sprinkler-irrigated cropping systems. By reducing windspeed, windbreaks reduce *spray evaporation loss* (SEL) and plant *evapotranspiration* rates. Models have shown that windbreaks can reduce annual water usage on farms by 10 to 20 percent.

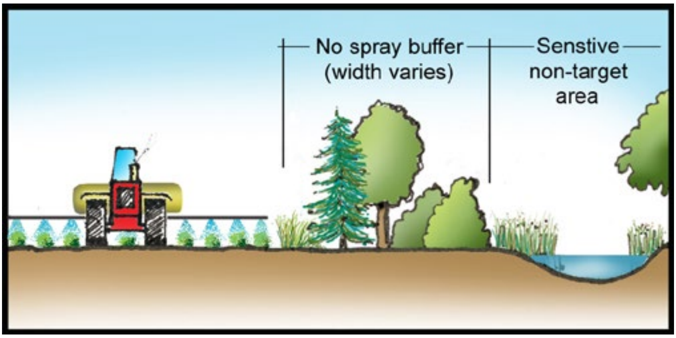
In general, windbreak effectiveness at reducing water loss decreases with distance from the windbreak. Maximum water savings occur within distances of around three to five times the height of the windbreak. Increase windbreak height and windbreak density (see 3.2) to increase water savings.

Woody perennial windbreaks can be incorporated as an edge of field practice. In this case, orient windbreaks perpendicular to prevailing wind direction during the growing season. This may require multiple windbreak legs with variable wind directions. Smaller, *herbaceous* strips can also be planted in the field. In pivot irrigation systems, this may take the form of concentric rings of perennial vegetation.




Other factors such as nozzle diameter size and sprinkler height also impact sprinkler water use efficiency. In general, shorter sprinklers with larger nozzle sizes reduce water usage.

## 4.6 Buffers and Spray Drift



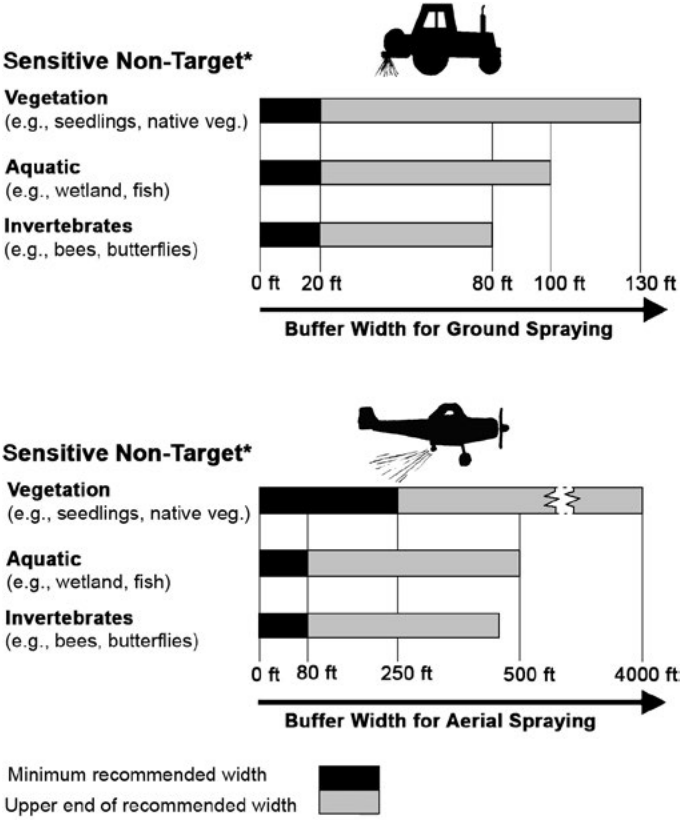

Buffers can help protect *sensitive nontarget areas* from chemical spray drift. The buffer design depends on many variables including spray method, wind direction and speed, chemical type, and the type of sensitive nontarget area.

**Key design considerations**

- Use vegetation with fine or needlelike leaves. Broadleaf plants capture less drift but are good for reducing windspeed.
- Use vegetation tolerant of the chemical being applied.
- Repeated applications of pesticides or fertilizers can change the plant community composition of buffers and lower species diversity over time.
- Provide a permeable barrier (10- to 40-percent *porosity*, see 3.2) to allow air passage. Several rows of vegetation are better than one dense row.
- Vegetation should be at full leaf stage during spray application.
- Use a mixture of plant forms and heights to eliminate gaps.
- Locate buffer to intercept the prevailing winds and as close as possible to the spray zone.
- No-spray zones can also be used in the crop field next to the field edge to reduce the amount of *spray drift*.
- Rain events may wash off accumulated pesticides in *riparian buffers* and contribute to higher pesticide concentrations in adjacent water bodies. Wider buffers may be useful to enhance pesticide mitigation (see 1.9).

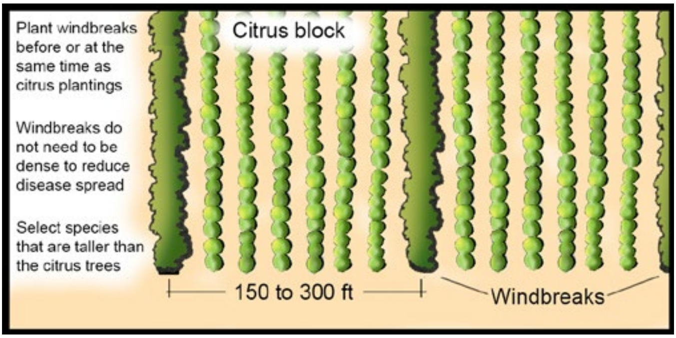
The graphs below summarize recommendations for buffer widths based on spray method and the sensitive nontarget area to be protected. These are general design considerations and should only serve as a starting point for design.

While studies are limited, buffer width recommendations for spraying with an *unmanned aerial vehicle (UAV)* would likely fall between ground and aerial spraying recommendations.




*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.

## 4.7 Windbreaks for Plant Disease Control




Windbreaks can protect certain crops against disease. Currently, the majority of research focuses on windbreaks as an effective control against citrus canker (*Xanthomonas citri*). This is a bacterial disease that significantly impacts citrus trees and causes leaves and fruit to drop early. The disease is typically controlled with copper sprays, but season-long applications of copper can damage fruit quality.

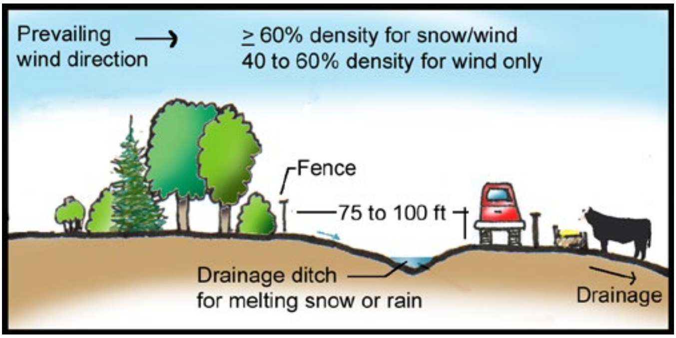
Windbreaks can act as an additional strategy for disease control and protect orchards by reducing the frequency of high windspeeds that increase citrus canker spread in the orchard. To be an effective barrier, windbreaks need to be four to five times taller than the crop trees.

Windbreaks are a preventative strategy and can only reduce disease spread. They are mostly ineffective when planted in already diseased orchards. Although research is limited, windbreaks may be useful for controlling other plant diseases.

## 4.8 Windbreaks for Animal Disease Control

Windbreaks may have the potential to reduce the airborne transmission of animal viruses such as pathogenic avian influenza. Scientific evidence is very limited at this time, and there could be unintended consequences. Windbreaks should not be relied on as a *best management practice* for this function but rather as a possible supporting strategy. Older windbreaks have been shown to be better for this function. Given the pathways for airborne transmission, air quality guidelines could be useful to consider (see 5.14).

## 4.9 Windbreaks for Livestock




Windbreaks can be designed to protect livestock from temperature extremes and severe weather events. Usually this takes the form of offering shade in the open pasture during the summer and protecting a smaller area that serves as an outdoor feedlot during the winter.

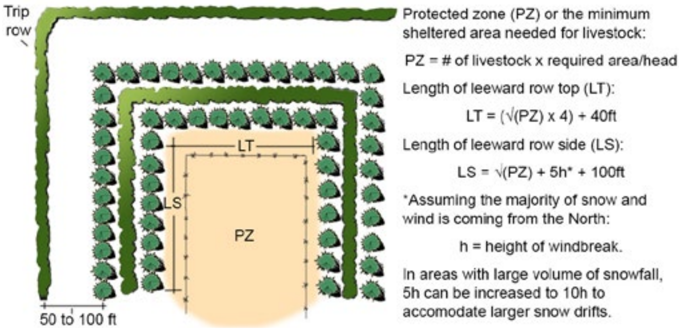
**Winter shelter**

In regions that experience harsh winter conditions, windbreaks can be designed to provide natural shelter for livestock, alleviating winter winds and trapping snow drift. Farmers with animals protected by windbreaks have reported significant savings in feed costs, reduced calf and lamb mortality, and increased milk production.

**Key design considerations**

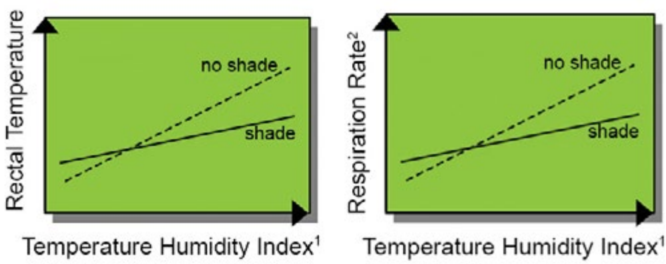
- Orient windbreak perpendicular to prevailing winter winds. In regions where the wind varies in direction, install a second leg for added protection.
- Ideal windbreak density is 60 to 80 percent for livestock protection. In general, this can be achieved with three to five rows that include a conifer row.
- In regions that experience severe winter storms, install five to seven rows for adequate protection.
- Extend the windbreak 100 feet past the desired zone of protection to account for snow drift at the ends.
- Install a trip shrub row 30 to 50 feet outside the first windward row to reduce snow deposition on the *leeward* side.

- Install drainage to redirect runoff away from the feeding area. Runoff should also not drain through the windbreak since concentrated nutrients can impact tree health.
- Fence around the windbreaks to prevent livestock access.
- Locate the feed bunk away from the leeward row 5 to 10 times windbreak height to avoid snow drift on the leeward side and still stay within the zone of protection.



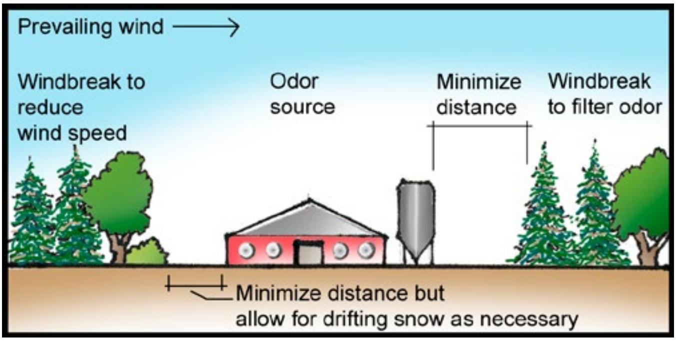

### Shade

In the summer months, windbreaks and other tall structures offer important sources of shade in the feedlot or pasture. Weight loss, idleness, and reduced milk production are all effects of heat-stressed livestock. In severe conditions, heat stress can also lead to livestock mortality. Depending on the tree species used, windbreaks can also serve as an additional *fodder* source (see 4.15).




[1] Temperature Humidity Index (THI) is a measure of the combined effects of temperature (T in °C) and relative humidity (RH). The formula for calculating THI is: THI = 0.8T + RH(T - 14.4) + 46.4.
[2] Respiration rate (breaths per minute) is an important indicator of livestock heat stress. A healthy nonstressed cow will have a respiration rate of 26 to 50 breaths per minute.

## 4.10 Buffers for Odor Control

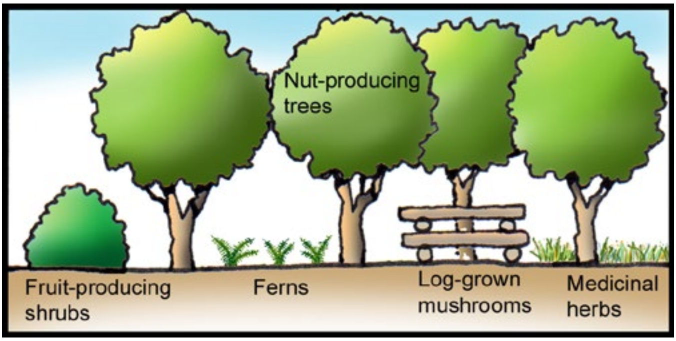



Windbreaks and other vegetation can also act as buffers for livestock odor. In these instances, windbreaks located around livestock housing can modify microclimate conditions and increase dispersion of odors through air turbulence. They can also trap the chemical particles of different odors. See 5.14 for additional air quality guidelines.

**Key design considerations**

- Position windbreaks downwind of the livestock production unit, close to the odor source.
- Establish dense and high vegetative windbreaks with a mixture of tall trees and shrubs. Optimal density is 50 to 65 percent (see 3.2).

## 4.11 Multistory Cropping in Buffers




Multistory cropping is an *agroforestry* practice that involves growing and cultivating compatible plants that fill different *niches* on the same piece of land.

Trees planted in these buffers can provide marketable products. Other products can also be cultivated under the tree canopy.

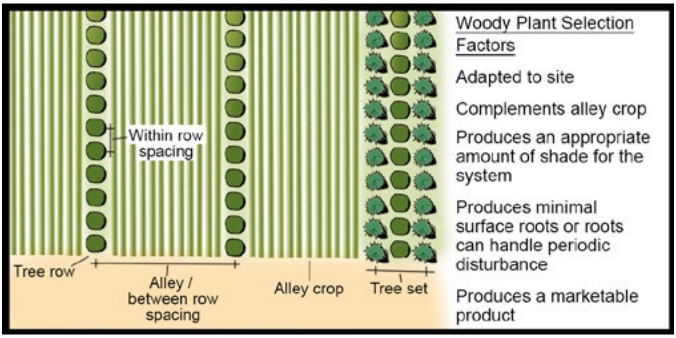
**Key design considerations**

- Select plants that provide multiple benefits and plants that provide short- and long-term products.
- Avoid plants that compete for the same resources.
- Avoid plants and associated management activities that compromise other buffer objectives.
- Install pathways for ease of access.

The following table shows products with reported markets that can be cultivated in a multistory cropping buffer. This is not an exhaustive list. Many other species and potential products can be cultivated in buffers.

| Potential Products to Grow in Buffers | | |
|---|---|---|
| **Canopy Layer** | **Product** | **Species** |
| Overstory | Nuts and oil | Chestnut, oak, pecan, walnut, pine |
| Overstory | Timber | Maple, oak, walnut, pine |
| Overstory | Syrup | Maple, walnut, birch |
| Midstory | Biofuel | Poplar |
| Midstory | Fruit | Apple, cherry, mulberry, pawpaw, peach, persimmon |
| Midstory | Decoratives | Apple, birch, cedar |
| Shrub layer | Biofuel | Willow |
| Shrub layer | Fruit | Aronia, blueberry, brambles, currants, elderberry, gooseberry, plum, serviceberry |
| Shrub layer | Nuts and oil | Hazelnut |
| Shrub layer | Decoratives | Dogwood, forsythia, holly, willow, witchhazel |
| Herbaceous layer | Botanicals and herbs | Ginseng, mint, nettle, ramps, St. Johnswort |
| Herbaceous layer | Decoratives | Beargrass, salal, ferns |
| Root zone | Botanicals and tubers | Black cohosh, bloodroot, ginseng, mayapple, Solomon's seal |
| Root zone | Fungi | Morels, truffles |
| Vertical layer | Fruit | Arctic kiwi, grape |
| Vertical layer | Fungi | Log-grown mushrooms, shiitake, oyster, lion's mane |

## 4.12 Alley Cropping

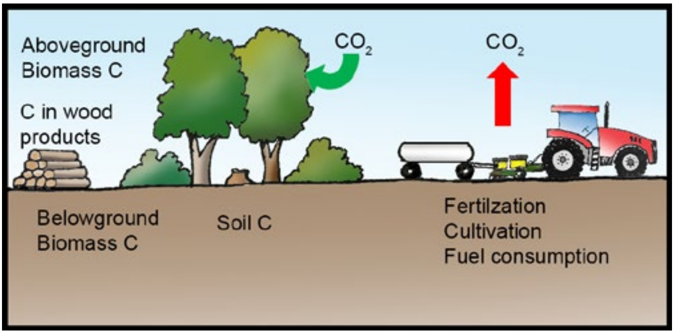



Alley cropping is an agroforestry practice involving the cultivation of crops grown in between single or multiple rows of woody plants. The woody plant rows are composed of trees or shrubs that are meant to produce a medium- to long-term product. Typically, the alley crop is an annual crop that produces a short-term product while the trees and shrubs mature. This has the benefit of diversifying farm income, reducing soil erosion, improving microclimate and soil health, and enhancing wildlife habitat.

**Key design considerations**

- Alley widths should be a multiple of the width of farm equipment.
- Include adequate headland to accommodate equipment turning radius.
- If soil erosion is not an issue, orient rows north to south to reduce shade competition.
- In cases where slope and erosion may be an issue, rows can be oriented along *contours* to reduce soil erosion (see 1.13).
- Some plants produce *allelopathic* chemicals. If incorporating these plants into the alley crop system, pair them with plants that are not susceptible to the allelopathic chemical.
- Consider growth of woody plants over time and potential aboveground and belowground competitive interactions. Management may include pruning and thinning to reduce shade competition and/or ripping to reduce root competition.

## 4.13 Buffers and Greenhouse Gas Mitigation




Buffers can help mitigate climate change impacts due to excess greenhouse gases (GHGs) in the Earth's atmosphere. Buffers can sequester carbon. They can also reduce GHG emissions since areas occupied by buffers are typically exempt from fertilizer application and other agronomic practices, such as tillage and pesticide applications, that contribute to GHG emissions.

| Buffers for Greenhouse Gas Mitigation | | |
|---|---|---|
| **Greenhouse gas (GHG)** | **Primary sources in agricultural systems** | **Mitigation potential with buffers[1]** |
| Carbon dioxide ($CO_2$) | Fuel consumption, fertilization, cultivation (leading to loss of soil C) | High (through C sequestration) |
| Nitrous oxide ($N_2O$) | Fertilization, manure management | Low to moderate |
| Methane ($CH_4$) | Enteric fermentation, manure management, rice cultivation | Low to moderate |

[1] Based on current science, an estimate on the ability of a buffer to reduce a specific GHG.

### Carbon dioxide ($CO_2$)

Perennial buffers, particularly with woody species, can help offset $CO_2$ emissions. Woody buffers sequester carbon (C) by using $CO_2$ for photosynthesis and storing C above ground in trunks and branches, as well as below ground in roots and soil. Perennial buffers are not a replacement for native forests in terms of *carbon sequestration*. For instance, *hedgerows* generally sequester more carbon than annual cropping systems but less than *secondary forests*.

### Key design considerations

- Select large, long-lived woody species for long-term storage and fast-growing species for quicker storage.
- Use native woody species that are low maintenance and disease resistant. In areas of greatest wildfire risk, use fire-resilient species (see 5.10)
- Minimize short-lived species that are small at maturity.
- Broadleaf trees may have a greater ability to accumulate soil C when compared to *coniferous* trees.
- Wider buffers with additional rows of woody vegetation can store more C.
- A diverse mixture of plant species will generally support higher soil C storage and will likely be more resilient to disturbance.
- Longer term C sequestration can be achieved if the biomass is converted to durable wood products through sustainable forestry.
- Buffers added to sites with depleted soil C, such as annual croplands, will sequester more soil C than sites with higher soil C, such as pastures.
- Buffers that decrease wind and water erosion can help protect and reduce the loss of soil C.
- Reduce soil disturbance and tillage to maintain soil C.
- Avoid nitrogen fertilizer application in the buffer and reduce fertilizer application rate in adjacent cropland or pasture to minimize $CO_2$ emissions from soils (see 1.1).

### Nitrous oxide ($N_2O$)

Agricultural soils are a primary source of $N_2O$ emissions. Since $N_2O$ cannot be sequestered like $CO_2$, reducing emissions is the only way to mitigate effects of $N_2O$. Buffers can help decrease $N_2O$ emissions by reducing the concentration of inorganic nitrogen (N) in soils. Buffers can also lower $N_2O$ by reducing the need for N inputs.

### Key design considerations

- Upland buffers can help mitigate $N_2O$ emissions by capturing and using nitrates that would otherwise contribute to $N_2O$ emissions.

- Avoid nitrogen fertilizer application in the buffer and reduce fertilizer application rate in adjacent cropland or pasture (see 1.1).
- While nitrogen-fixing plants may help reduce the need for N inputs, a buffer with a high proportion of nitrogen-fixing species may contribute to $N_2O$ emissions.
- Select species with high N requirements to utilize any excess. Native or hybrid poplar (*Populus* ssp.) and willow (*Salix* spp.) species are particularly effective.
- Use a mix of vegetation types to increase root depth and density and provide soil C. $N_2O$ emissions are generally lower if the soil C-to-N ratio is >25.
- While flooded areas can sometimes be a source of $N_2O$ emissions, riparian buffers should have an overall net benefit by reducing nitrates that would otherwise contribute to $N_2O$ emissions.

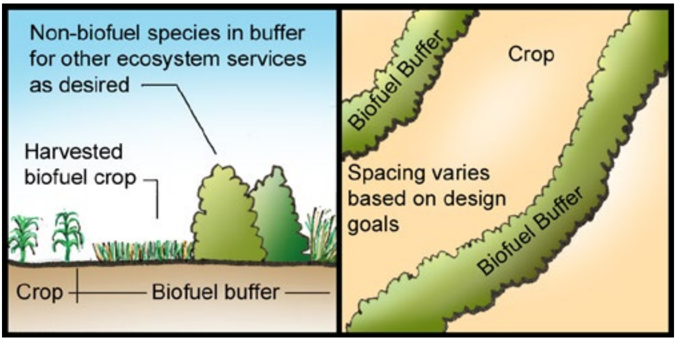
**Methane ($CH_4$)**

Agricultural soils can be a sink or source for $CH_4$ emissions. Buffers can help take up excess soil moisture, increase *soil organic matter,* and decrease soil *bulk density*, all of which create a favorable environment for reducing $CH_4$ emissions from soils.

**Key design considerations**

- Upland and riparian areas can be a sink for $CH_4$ emissions. Sites that are frequently flooded may be a source of $CH_4$ in some cases.
- Use a mix of vegetation types in the buffer to support conditions for reducing $CH_4$ emissions.
- Reduce soil disturbance and tillage to maintain a favorable environment for reducing $CH_4$ emissions.
- Avoid nitrogen fertilizer application in the buffer and reduce fertilizer application rate in adjacent cropland or pasture (see 1.1).
- Reduce soil compaction in and adjacent to the buffer (see 1.23)

## 4.14 Biofuel Buffers




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

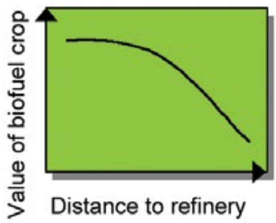
Biofuel crops grown in buffers can augment larger block plantings of biofuels. Research suggests that it may be possible to produce enough biofuels in buffers to offset the energy required to produce crops in between the buffers.

Consider the land use history when locating biofuel buffers. Converting certain types of land to biofuel buffers may increase greenhouse gas emissions and result in a tradeoff of *ecosystem services* (see 5.1). For instance, converting an existing perennial grassland to a single biofuel crop field would negatively impact biodiversity.

**Key design considerations**

- Highly erodible lands can be suitable when management activities are tailored to minimize soil disturbance.
- Other *marginal lands* may be suitable, including flood-prone and nutrient-poor sites (depending on plant species).
- Locate to achieve other goals (e.g., crop protection, wildlife habitat, forest products, recreational services).
- Perennial biofuel crops may yield better than annual crops when grown on marginal lands.

- Mixed plantings can provide benefits over monocultures, but woody and herbaceous biofuel crops may need separation.
- Consider planting and harvesting equipment in the layout.
- Select biofuel crops that fit site conditions and complement natural plant communities in the area.
- Leave some biofuel crop unharvested in a given year to provide other ecological benefits.
- Adding fertilizers and organic amendments can increase *biomass* production. Ensure the nutrients do not leach into surface or ground water (see 1.0).
- The site should be close to a biofuel refinery to minimize transport. A biofuel buffer located too far from a refinery may not be profitable or effective at reducing overall energy usage.




- Harvesting time can significantly affect biomass quality. In general, harvest in the late winter to minimize mineral concentrations in the biomass, improve plant nutrient cycling, and reduce soil greenhouse gas emissions.

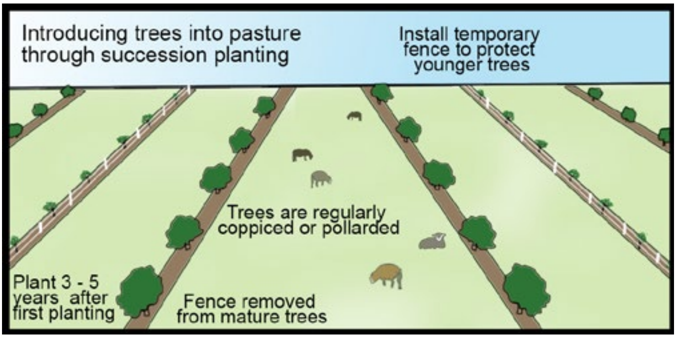
Many biofuel crops may not be native to the area where they are cultivated and could become invasive. Adopt strategies to mitigate the potential of becoming invasive, such as focusing on low-risk crops, cultivating in nonsensitive habitats, considering the plant's dispersal strategies and locating plantings away from potential transportation corridors, and minimizing harvest disturbance.

Hybrid poplar, willows, and switchgrass are the most-researched biofuel crops in temperate regions. Other species may also be suitable. Below is a table of current information on these major biofuel crops.

| Summary of Current Information on Major Biofuel Crops | | | |
|---|---|---|---|
| **Factor** | **Poplar** (*Populus* spp.) | **Willow** (*Salix* spp.) | **Switchgrass** (*Panicum virgatum*) |
| Current yield[1] (dry tons/acre/year) | 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 | Low to Medium |
| Water demand | Medium | Medium | Low |
| Establishment cost | Medium | Medium | Low |
| Plantation longevity | Possibly 15 to 30 years | Possibly 20 to 30 years | Possibly 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[2] | 1:8 to 1:16 | 1:8 to 1:16 | 1:4 to 1:14 |
| Erosion rates[3] (tons/acre/yr) | 0.09 to 0.9 | 0.09 to 0.9 | 0.09 |

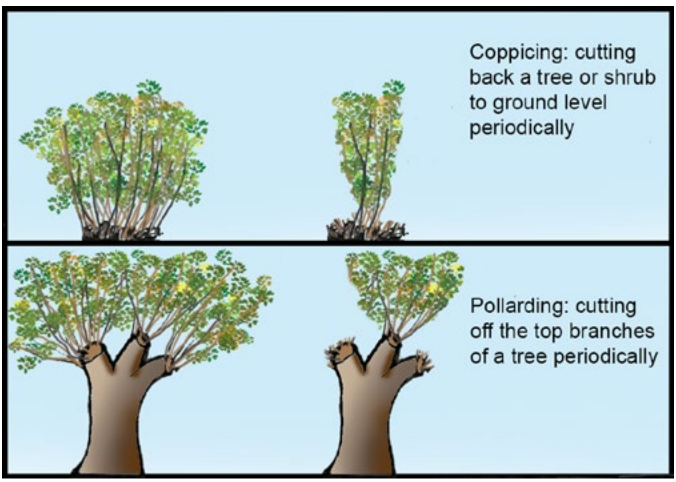
[1] Variable yields under unirrigated conditions and low to moderate fertilization.
[2] Calculated net energy ratios for biofuels vary greatly due to base assumptions and type of energy produced. For general comparison, corn ethanol results in a net energy ratio of 1:1.6 while soybean biodiesel has a ratio around 1:3.2.
[3] For general comparison, annual crops have erosion rates ranging from 2.0 to 6.7 tons/acre/year.

## 4.15 Fodder Production

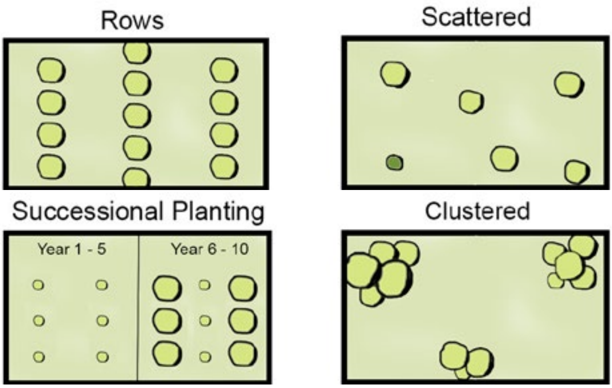



Leaves and small twigs from certain tree and shrub species can serve as a supplemental feedstock for livestock consumption, especially during times of feed shortages. This fodder can often be high in crude protein, minerals and vitamins, and secondary compounds that can have medicinal properties.

Fodder species can be planted into a pasture or along the pasture edges and can be harvested to provide fresh fodder to livestock or stored as *silage* for later feeding. Depending on the species, harvesting can involve *coppicing* or *pollarding* methods (see image below). Since harvesting for fodder will occur during the growing season, care must be taken not to reduce the *vigor* of the plant by harvesting too much biomass at one time. Other management practices may include fencing or tree shelters to protect the saplings during establishment.



A few examples of planting patterns for fodder production are shown below. There are many ways to incorporate trees into pasture that are not limited to the examples shown.




**Key vegetation considerations**

- Ideal tree fodder species should produce quality forage, be easy to establish, and maintain high productivity under repeated cutting and browsing.
- Trees and other woody perennials do not recover from browsing and/or repeated cutting as quickly as grasses. Include adequate rest times for fodder trees to recover. Fodder coppice and pollard schedules typically range from 2 to 7 years.
- The nutritional value of tree fodder is typically higher earlier in the growing season, but fodder volume increases later in the growing season.
- Competition between trees and forage in pasture typically reduces total forage yields but improves forage nutritional quality.
- Livestock may need to be trained to consume tree fodder.
- Trees in the pasture may also provide other benefits for livestock (see 4.9) and an additional income source (see 4.11).

The table on the next page shows the palatability of certain tree species for different livestock. Research in tree fodder palatability and nutrient profiles is limited and sometimes contradictory. Use a cautious approach when introducing livestock to new tree fodders.

| Livestock Tree Fodder Palatability | | | | |
|---|---|---|---|---|
| **Tree Species** | **Cattle** | **Sheep** | **Goats** | **Horses** |
| *Acer* spp.[1]<br>Maple[1] | X | X | X | |
| *Alnus* spp.[2]<br>Alder[2] | X | X | X | X |
| *Betula* spp.<br>Birch | X | X | X | X |
| *Corylus* spp.<br>Hazel | X | X | X | X |
| *Fagus* spp.[2]<br>Beech[2] | X | X | X | |
| *Fraxinus* spp.<br>Ash | X | X | X | X |
| *Glenditsia triacanthos*[3]<br>Honey locust[3] | X | X | X | |
| *Morus* spp.[4]<br>Mulberry[4] | X | X | X | X |
| *Populus* spp.<br>Poplar | X | X | X | X |
| *Prosopis glandulosa*[3]<br>Honey mesquite[3] | X | X | X | |
| *Quercus* spp.[5]<br>Oak[5] | X | X | X | |
| *Robinia pseudoacacia*[6]<br>Black locust[6] | X | X | X | |
| *Salix* spp.<br>Willow | X | X | X | X |
| *Tilia* spp.<br>Linden | X | X | X | X |
| *Ulmus* spp.<br>Elm | X | X | X | |

[1] Contentious. Red maple (*Acer rubrum*) is considered toxic. Hybrids and other closely related maples may also be toxic.
[2] Not toxic but low palatability.
[3] Most of the literature is focused on pods as a fodder source. Leaves are not thought to be toxic but may not be palatable.
[4] White mulberry (*Morus alba*) is well studied and has a high crude protein content. Mulberry fruit is also highly nutritious and valued as alternative livestock feed.
[5] Contentious. Young leaves and acorns are toxic.
[6] Contentious. Bark, leaves, and seeds may be toxic.

In addition to leaf fodder, nuts and fruits from certain tree and shrub species can provide supplemental feed for *ruminants* and *monogastric livestock*. For example, hogs can eat fallen chestnuts (*Castanea* spp.), walnuts (*Juglans* spp.), and hazelnuts (*Corylus* spp.), while poultry, hogs, and some ruminants can consume fallen fruit such as mulberries (*Morus* spp.), apples (*Malus* spp.), and persimmon (*Diospyros* spp.). Each specific plant crop and livestock combination should be carefully investigated to ensure compatibility and livestock safety.

Livestock consumption of fallen nuts and fruit can also be used as a strategy to control pest and disease issues in orchards and other tree crop systems. Food safety guidelines need to be followed to ensure that the nut or fruit crop for human consumption is not contaminated by livestock manure.

# 5. Quality of Life

## Objectives

- Create a pleasant and safe environment.
- Protect against natural disasters.

## Buffer functions

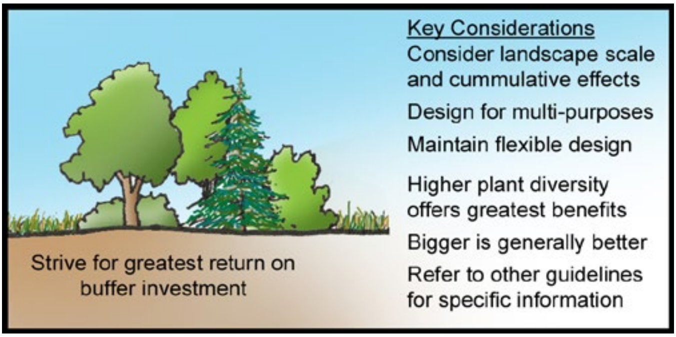
- Separate human activities.
- Reduce hazards.
- Enhance visual quality and reduce noise.
- Reduce energy consumption.
- Reduce *ecosystem disservices.*

| Design Guidelines for Quality of Life | Buffer Functions: Seperate human activities | Reduce hazards | Enhance visual quality and reduce noise | Reduce energy consumption | Reduce ecosystem disservices |
|---|---|---|---|---|---|
| 5.1 Buffers and ecosystem services | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.2 Rural-urban interface | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.3 Urban agriculture | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5.4 Energy conservation | | | | ✓ | ✓ |
| 5.5 Buffers and road intersections | | ✓ | | | |
| 5.6 Buffers and shade | | ✓ | ✓ | ✓ | ✓ |
| 5.7 Buffers and pollen | ✓ | ✓ | | | ✓ |
| 5.8 Ecological aesthetic | ✓ | ✓ | ✓ | | ✓ |
| 5.9 Attractive roadside corridors | ✓ | ✓ | ✓ | | ✓ |

| Design Guidelines for Quality of Life | Buffer Functions: Seperate human activities | Reduce hazards | Enhance visual quality and reduce noise | Reduce energy consumption | Reduce ecosystem disservices |
|---|---|---|---|---|---|
| 5.10 Wildfire defensible buffer zones | ✓ | ✓ | | | ✓ |
| 5.11 Coastal zone protection | ✓ | ✓ | | | ✓ |
| 5.12 Living snow fences | | ✓ | ✓ | ✓ | ✓ |
| 5.13 Buffers for flooding | ✓ | ✓ | ✓ | | ✓ |
| 5.14 Buffers for air quality | ✓ | ✓ | ✓ | | ✓ |
| 5.15 Buffers for noise control | ✓ | ✓ | ✓ | | ✓ |
| 5.16 Buffers for visual screening | ✓ | | ✓ | | ✓ |

| Additional Design Guidelines for Quality of Life | Buffer Functions: Seperate human activities | Reduce hazards | Enhance visual quality and reduce noise | Reduce energy consumption | Reduce ecosystem disservices |
|---|---|---|---|---|---|
| 2.1 Matrix primer | | ✓ | ✓ | | ✓ |
| 2.2 Patch primer | | ✓ | ✓ | | ✓ |
| 2.3 Corridors and connectivity | ✓ | ✓ | ✓ | | ✓ |
| 2.8 Corridor width | ✓ | ✓ | ✓ | | ✓ |
| 2.13 Roads and wildlife | ✓ | ✓ | ✓ | | ✓ |
| 3.2 Windbreaks for wind erosion | ✓ | ✓ | ✓ | | ✓ |
| 3.3 Herbaceous wind barriers | ✓ | ✓ | ✓ | | ✓ |
| 3.5 Buffers for phytoremediation | ✓ | ✓ | ✓ | ✓ | ✓ |
| 4.10 Buffers for odor control | ✓ | ✓ | ✓ | | ✓ |
| 4.11 Multi-story cropping in buffers | | ✓ | ✓ | ✓ | ✓ |
| 4.12 Alley cropping | | ✓ | ✓ | ✓ | ✓ |
| 4.13 Greenhouse emissions and mitigation | | ✓ | | ✓ | ✓ |

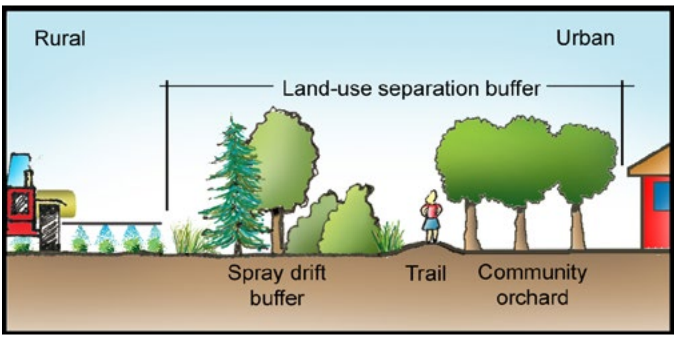
## 5.1 Buffers and Ecosystem Services




Buffers perform *ecosystem services* that are valuable for society and landowners. Some services have markets such as hunting and recreational leases, but many services are difficult to quantify and have limited or no current markets. Other services may develop into markets (e.g., carbon credits).

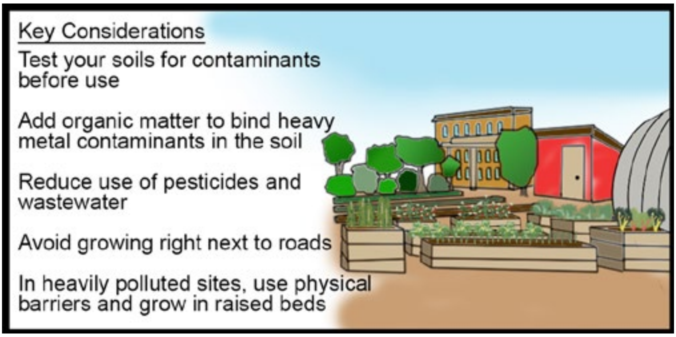
Establishing buffers can also lead to tradeoffs in ecosystem services. Consider interactions between different ecosystem services and develop management strategies that maximize complementary interactions while reducing competitive interactions and ecosystem disservices.

## 5.2 Rural-Urban Interface




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

## 5.3 Urban Agriculture




Urban agriculture is considered a part of *green infrastructure* and involves growing food and/or other agricultural products at a small scale within the urban landscape.

Urban agriculture can be implemented at abandoned lots, public spaces, schools, or private property. These sites act as important buffers that provide ecosystem services and protect natural resources in the city. They also contribute to local food security and community development.

Higher levels of pollutants in the air, soil, and water can be found in urban and semi-urban environments due to the presence of increased traffic, *impervious cover*, buildings, and industry. These pollutants can accumulate in and/or on the edible parts of food crops. Consider this carefully before attempting to grow food in urban centers.

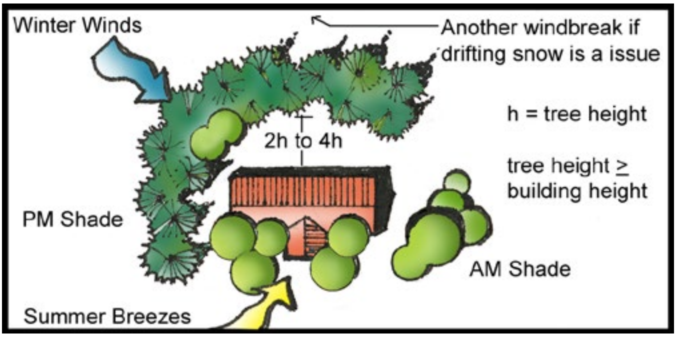
Woody perennials can also be added to urban agriculture systems. Emerging research provides some evidence that woody species accumulate fewer toxins in their fruit compared with vegetable crops. This is highly variable and depends on other factors such as the concentration of the pollutant, the type of pollutant, and the species.

See 3.5 for phytoremediation.

See 5.1 for ecosystem services.

See 5.4 for energy conservation.

## 5.4 Energy Conservation




### Site scale

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

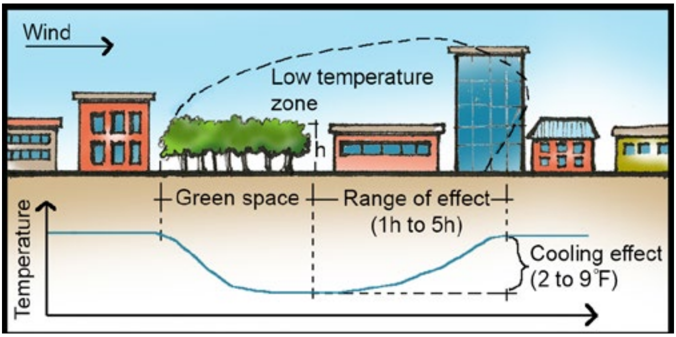
### Managing shade

- 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 the warmest part of year and minimum shade at coldest (see 5.6).
- Consider the planting's final height and form, branching density, and the leaf-on and -off periods.

### Managing wind

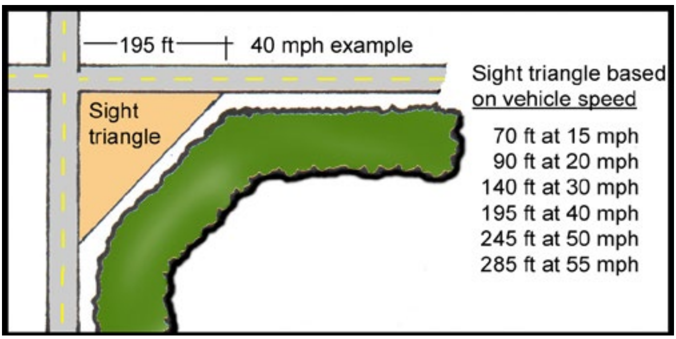
- For reducing heat loss, locate a dense *coniferous windbreak* two to four tree heights upwind of the building. The lower branches of trees in the windbreak should not be pruned. Stagger planting rows to prevent gaps in case a tree dies.
- If drifting snow is an issue, locate another windbreak upwind of the first windbreak (see 5.12).
- For cooling, maintain an open understory to allow for ventilation by summer breezes, which may be from a different direction than winter winds (see diagram).

**Landscape scale**



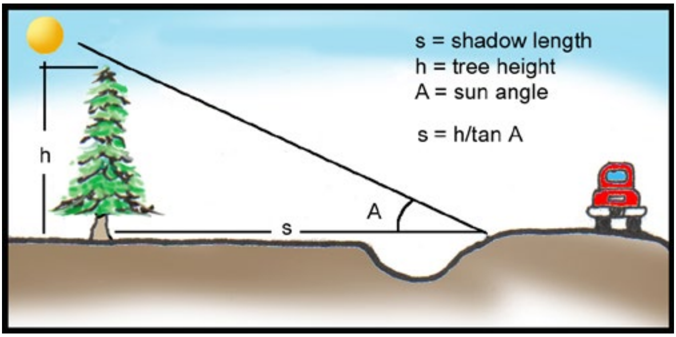

Parks, greenways, and other green space buffers can reduce energy consumption by lowering adjacent air temperatures. Summer cooling effects of 2 to 9 °F can extend one to five tree heights into the built-up area. To maximize cooling, locate buffers with large, canopied trees at frequent intervals. Each degree reduction can lower electricity demand for cooling by 2 to 4 percent.

## 5.5 Buffers and Road Intersections




At intersections, particularly those not controlled by stop signs, design buffers to allow for views of oncoming traffic. Base the sight triangle on vehicle speed. Keep plant height in the sight triangle at <3 feet. Check with agencies regarding regulations for intersection setbacks.

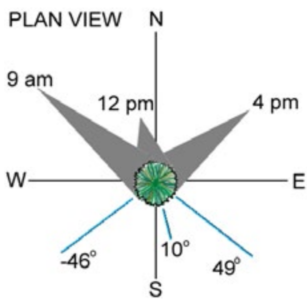
## 5.6 Buffers and Shade




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 5.12).

Use the formula s = h / tan A to calculate shadow length where (s) is shadow length, (h) is tree height, and tan A is the tangent of the sun angle (A) . See the table below for an example. Sun angle calculators, which provide the sun angle (A) and *azimuth angle* for a given location based on the date and time, are available online.

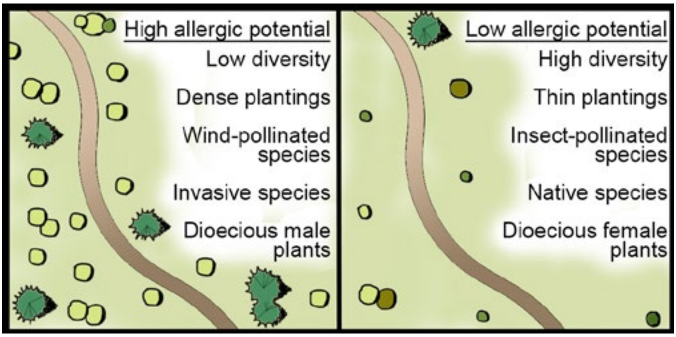
| Example: December 21 Sun Path Data<br>Long. 100° W, Lat. 40° N Tree Height (h) = 35 feet | | | | |
|---|---|---|---|---|
| **Time** | **Sun Angle** (A) | **Tan A** | **Sun Azimuth** (East of South) | **Shadow Length (s)** (feet) |
| 9 a.m. | 9° | 0.1584 | 49° | 221 |
| 12 p.m. | 26° | 0.4877 | 10° | 72 |
| 4 p.m. | 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 various buffers (see 2.11, 4.1, and 5.4).

Quality of Life

## 5.7 Buffers and Pollen



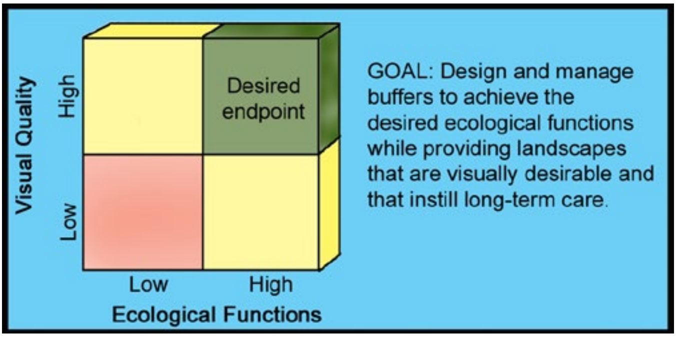

While plants in urban environments can have many benefits, they can also be a source of pollen, causing allergic reactions or asthma attacks. Pollen can also interact with other air pollutants and result in a greater impact on human health. Careful selection of low-allergenic species with appropriate buffer design for urban air quality (see 5.14) can reduce these negative impacts.

The Ogren Plant Allergy Scale measures the allergenic potential of 5,000 plant species. Safest and least allergenic plants are ranked at 1 while the most allergenic plants are ranked at 10. This resource can help with appropriate urban plant selection. Below are other species selection and design considerations.

**Key design considerations**

- Avoid planting male individuals of *dioecious* species.
- Avoid planting wind-pollinated species.
- Plant diverse species.
- Control *invasive species* and limit plantings of exotic species to reduce the chances of causing new pollen allergies.
- Employ suitable pruning practices to reduce pollen production.
- Respect planting distances and avoid dense plantings.
- Consult local botanists and other experts to select suitable species.

## 5.8 Ecological Aesthetic




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

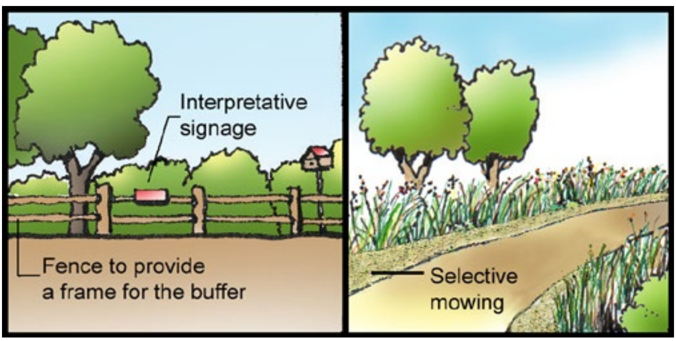
- Waterscapes (e.g., lakes, streams)
- Manicured landscapes with an absence of overgrown vegetation
- Savanna, park-like, or open landscapes
- Trees in scale with surrounding features
- Absence of dead and downed wood
- Clean waterways with no or limited woody debris
- Large mature trees and trees with broad canopies
- Spaces defined by edges (e.g., pasture bordered by woods)
- Auditory elements that match the visual landscape (e.g., birdsong paired with wooded landscapes or water sounds in riparian zones)

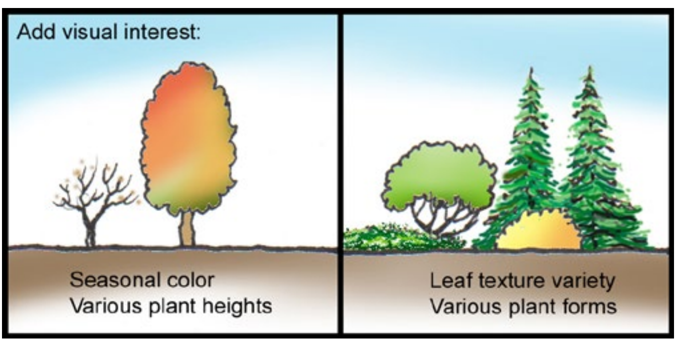
Some of these visual elements are not desirable for achieving goals such as water quality and wildlife habitat. Naturalistic landscapes providing valuable ecological functions are often viewed as untidy and undesirable, while manicured landscapes with limited ecological functions are perceived as demonstrating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

The challenge is to design buffers that achieve the desired ecological functions while providing landscapes that are visually desirable and instill long-term commitment.

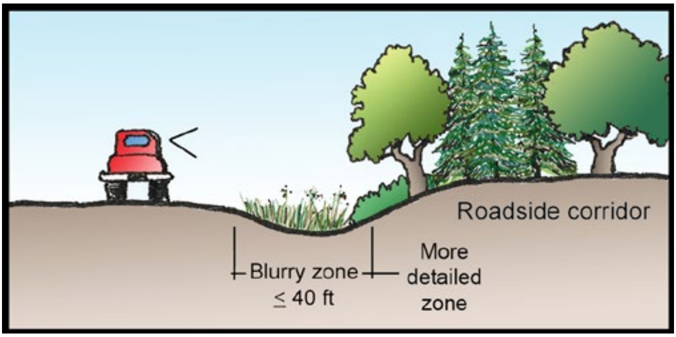
**Strategies for enhancing visual preference of buffers**

- 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 varying plant heights, textures, forms, and flowering and fruiting patterns.
- Provide simple habitat improvements such as nesting boxes and feeders. Wildlife usually increases visual preference.
- Use bold planting patterns to indicate a designed landscape.



## 5.9 Attractive Roadside Corridors



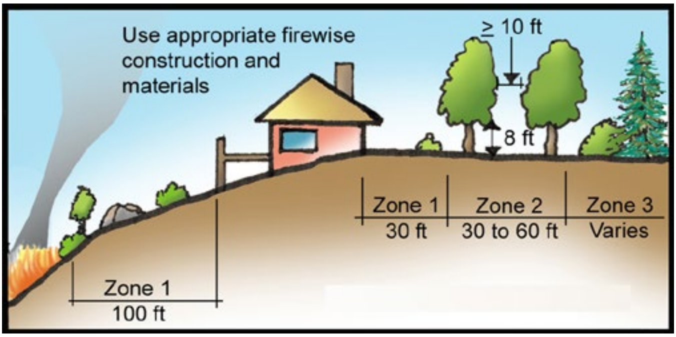

Roadside corridors can be designed and managed to create a pleasant driving environment, save maintenance costs, and reduce driver stress.

At speeds over 40 mph, the area that is >40 feet from the side of the road will have more detail and be more important visually.

**Key design considerations**

- Create visual interest by using a variety of plants with different visual characteristics (e.g., color, form, and texture).
- Plant in clumps and avoid planting in rows.
- Use native plants.
- Keep roadside corridors compatible with adjacent landscape.
- Select plant species that have low maintenance.
- Select plant species with high salt tolerance in areas where roads are treated with salt.
- Avoid planting tall trees or shrubs in the zone immediately adjacent to the roadside. This will improve visibility and reduce the potential of wildlife-vehicle collisions.
- Follow local Department of Transportation regulations.
- See 5.5 for road intersections.
- See 5.6 for shade considerations.
- See 5.8 for aesthetic appeal.
- See 5.12 for snow protection.

## 5.10 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 plants, spaced apart. Remove dead material through prescribed burning, targeted grazing, or mechanical techniques.

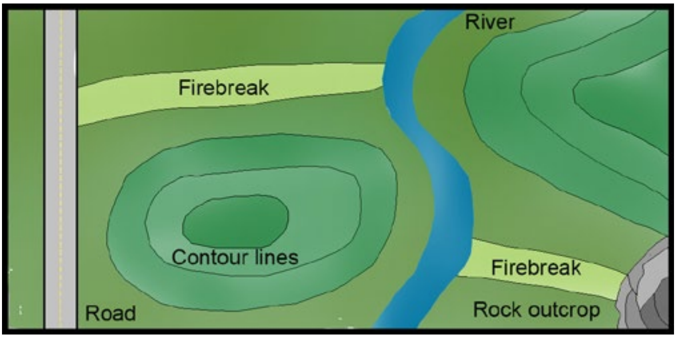
**Zone 2**—Deciduous trees and shrubs and widely spaced conifers may be used in Zone 2. Remove branches within 8 feet of the ground (but no more than 30 percent of the height of the tree) and space trees so that crowns remain at least 10 feet apart at maturity. Remove ladder fuels (e.g., tree limbs that allow fire to climb into the tree crown). Consider firefighting equipment accessibility when planting in this zone.

**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 (one to two snags per acre).

Check with your local forester for additional guidelines.

**Characteristics of low-flammability plants**

- Supple, moist leaves and waterlike, thin sap
- Little or no accumulation of dead vegetation on the plant
- Open and loose branching structure
- Slow to ignite
- Only sustains burning for a short time

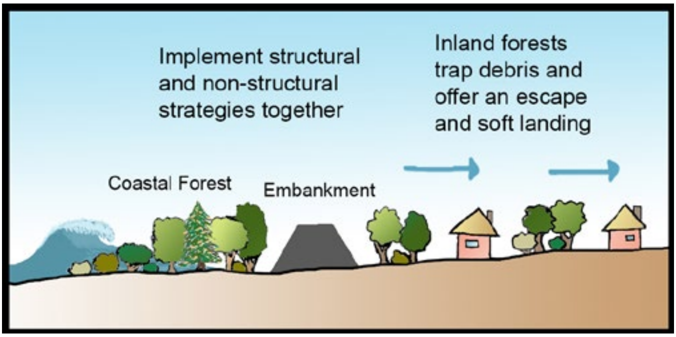



At the landscape scale, firebreaks can be used to reduce the spread of wildfire and help manage prescribed fires. These buffers can consist of fire-resistant vegetation, nonflammable materials, bare ground, or a combination.

**Key design considerations**

- Design firebreaks to be of sufficient width and length to contain the expected fire.
- Use landscape features such as water bodies, rock cliffs, and roads to augment firebreaks for greater effectiveness.
- Locate firebreaks near ridge crests and valley bottoms, where fuels and *topography* may help reduce fire intensity. Avoid locating firebreaks in midslope positions when possible.
- Locate firebreaks on the *contour* to minimize soil erosion and use appropriate erosion-control measures.
- Identify the expected wind direction(s) and install firebreaks on the side of the area to be protected.
- Use available decision-support tools such as g*eographic information systems (GIS)* and models to guide the planning and layout of firebreaks.
- Use plants with low flammability characteristics and manage the fuel load as necessary.
- Use caution when incorporating overhead electric line rights-of-way into a firebreak. Electric lines can be hazardous because carbon in the smoke may conduct electricity, causing a discharge similar to lightning.
- Install firebreaks in a manner that supports vehicle and fire suppression equipment.

## 5.11 Coastal Zone Protection



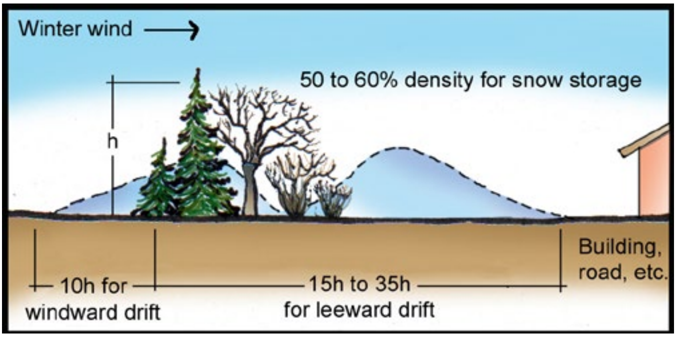

Coastal zones are made of unique habitats in the transition between sea and land. These areas are prone to erosion and high pollution and are hotspots of human development. Incorporating buffers into coastal zone management can mitigate the negative impacts of human development and protect sensitive habitats. Apply wider buffers around areas of concern (see 1.11).

Coastal forests can also buffer against tsunamis and tidal waves. By themselves, forest buffers are largely ineffective against waves higher than 30 feet. Nonstructural (e.g., vegetation) and structural (e.g., embankments) strategies should be implemented together to create more effective protections against larger tsunamis and tidal waves.

**Key design considerations**

- Select species tolerant of coastal conditions (e.g., salt spray, saltwater intrusion, soil salinization, wind, and flooding).
- Limit fertilizer application in coastal zones.
- Eliminate gaps in coastal zone buffers. Water flow accelerates as it moves through the gap and can lead to increased risk and damage directly behind the gap.
- Inland forests made of deciduous species can trap debris and act as a means of escape for people carried inland by waves.
- Use trees that will have large trunk diameters (>1 foot) at maturity. Trees with smaller trunk diameters can more easily break under the force of waves and be a source of debris.
- Interplant shorter and taller trees together in the coastal forest to increase *hydraulic resistance*.

## 5.12 Living Snow Fences



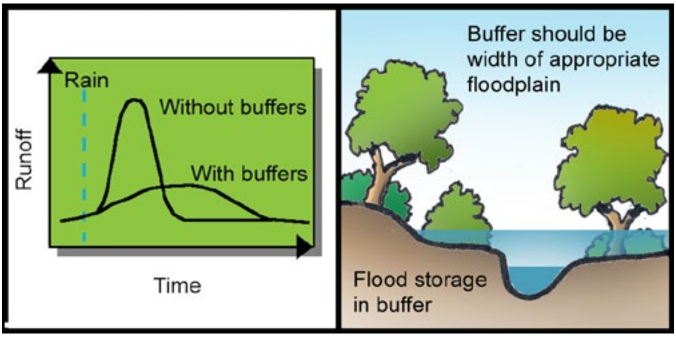

In temperate regions, drifting snow can cause road accidents and damage property. Structural snow fences constructed from wood, metal, or plastic can be built as barriers to mitigate drifting snow. However, they can be expensive to install and maintain.

Living snow fences offer a cost-effective way to manage deposition of blowing and drifting snow. They can be composed of tree and shrub rows or corn left standing over the winter.

**Key design considerations**

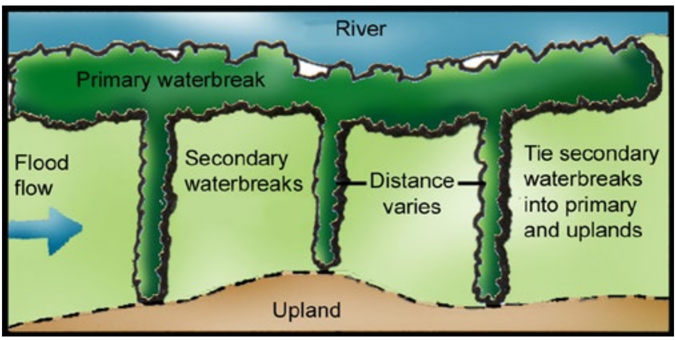
- Establish living snow fences perpendicular to the prevailing winds. If winter winds vary in direction, two fence legs may be required.
- Plant height influences snow storage capacity. Doubling plant height can more than quadruple snow storage.
- Extend the ends of the living snow fence 50 to 100 feet beyond the area needing protection.
- Densities around 50 percent are most effective at trapping snow (see 3.2).
- Living snow fences will take time to establish. Select fast-growing species to reduce establishment time.
- After establishment, living snow fences require very little maintenance compared to other structural snow fences and can last several decades, depending on the species.
- Certain species that are suitable for living snow fences (e.g., willow [*Salix* spp.]) may also provide useful products (see 4.11).

## 5.13 Buffers for Flooding



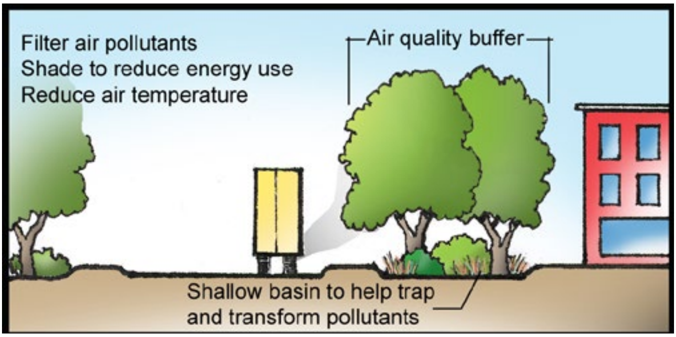

During flood events, riparian buffers and wetlands can slow runoff and absorb excess water. This reduces *peak flows* and can lessen downstream flooding. Downstream riparian buffers may be more effective in reducing flooding than upstream buffers, but both areas benefit from buffers for stormwater mitigation.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

**Waterbreaks**




A waterbreak is a system of woody buffers located to manage flooding and encourage *sediment deposition*. A primary waterbreak is oriented 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 reduce damage to levees when they do breach.

## 5.14 Buffers for Air Quality




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 temperature-dependent pollutants (i.e., ground-level ozone).

**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 can help reduce building energy use and lower pollutant emissions associated with energy production (see 5.4).


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

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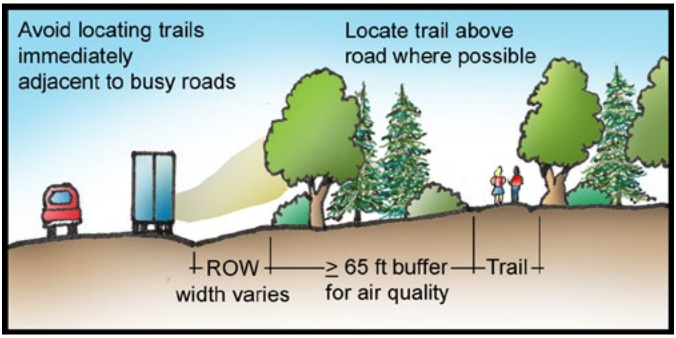
**Key design considerations**

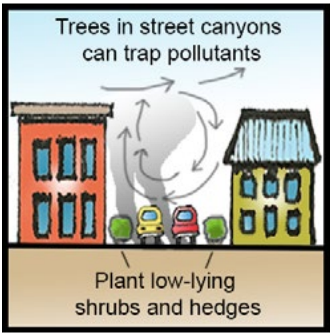
- Consider spatial and temporal factors in locating buffers (e.g., timing of pollution, high concentration spots).
- Plant buffers around and close to air pollution sources.
- Buffers are not 100 percent effective. Pollutant particles can still travel through the buffer. Avoid locating gathering spots in the immediate *leeward* side of the buffer.
- Moderately dense buffers are best for pollutant removal.
- Use trees, shrubs, and grasses for multilevel trapping and structural diversity.
- Plant buffers in energy-conserving locations (see 5.4).




**Plant selection criteria for air pollutant removal**

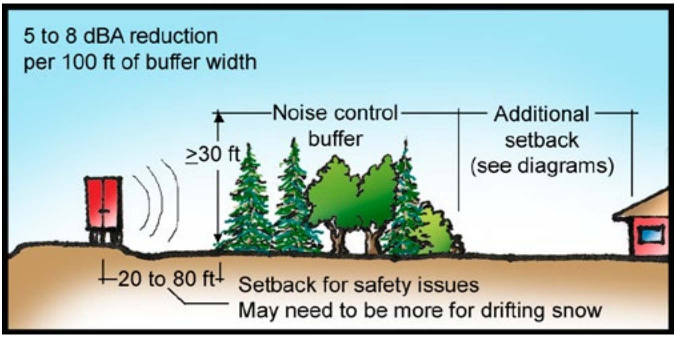
- Conifers can remove more pollutants than deciduous species, but many conifer species are sensitive to common pollutants.
- Select plants with dense branching and twig structure.
- Leaves with hairy, resinous, and coarse surfaces capture more pollutants than smooth leaves. Smaller leaves are generally better at capturing pollutants than larger leaves.
- *Herbaceous* species may absorb 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 drought-prone soils).

**Buffer effects in the built environment**




- Trees in an open road environment can improve air quality, but trees placed in street canyons can reduce windspeed and trap pollutants in the canyon.
- Low (i.e., 6.5 to 8 feet tall) and permeable hedges should be used in street canyons instead of tall trees.
- If trees are already established in street canyons, keep canopy size, planting density, and tree height to a minimum through thinning and pruning.
- Vegetation can be a source of air pollutants through pollen allergens and other organic compounds. Consider potential allergens when selecting species (see 5.7).

## 5.15 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).

The table below shows guidelines for moderate- and high-speed roads. Use the diagrams on the next 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 | |
|---|---|
| **Moderate-Speed Road (<40 mph)** | **High-Speed Road (≥40 mph)** |
| 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. | 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. |

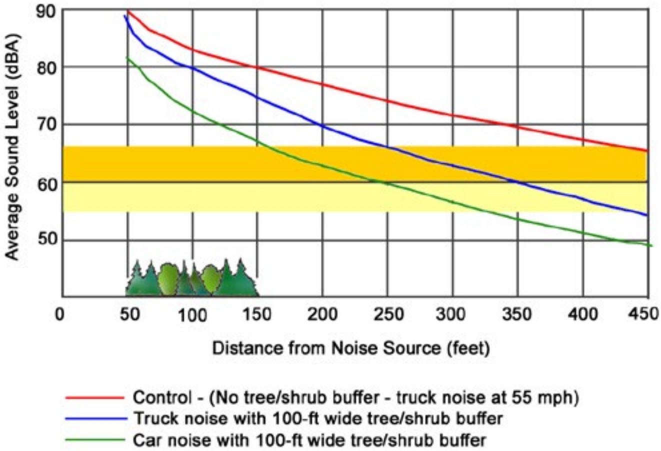
**Key design considerations**

- Locate buffer close to the noise source while providing an appropriate setback for accidents and drifting snow.
- Conifers offer year-round noise control, but deciduous species may be more effective at noise control during the growing season.
- Dense buffers with a *porosity* of 5 percent or less are the most effective at noise control.
- Select plants tolerant of air pollution and deicing methods.
- Natural buffers are less effective than planted buffers.
- Consider topography and use existing landforms as noise barriers where possible.
- Buffer length can also affect noise control. Buffers longer than 165 feet tend to have a stable noise control effect.
- Buffers may take several years to establish and provide the desired noise reduction. Immediate relief may be achieved by tilling the soil. *Leaf litter*, shrubs, and herbaceous vegetation may also contribute to short-term noise control.
- Potted plants can be placed in different arrangements to determine the effectiveness of certain designs and plants at noise control before transplanting.
- Densely vegetated buffers may improve perceptions of noise reduction even if actual noise reduction is minimal.
- Vegetative buffers are generally more effective at reducing higher frequency noise (i.e., >4000 Hz) than low-frequency noise (i.e., <100 Hz).

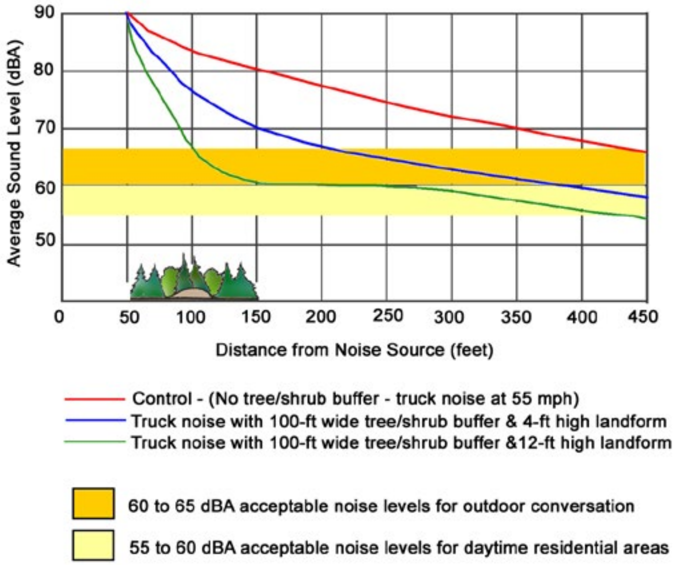
**Estimating setback distance from noise control buffers**

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.

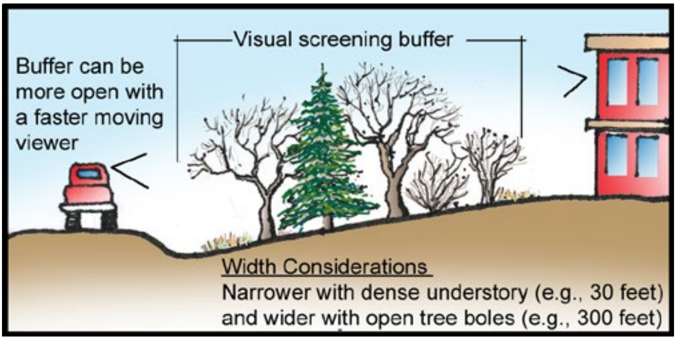
**Sound Level Decrease with Distance Due to Tree/Shrub Buffer**




**Sound Level Decrease with Distance Due to Tree/Shrub and Landform Buffer**



## 5.16 Buffers for Visual Screening




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

# 6. Recreation

## Objectives

- Promote nature-based recreation.
- Reduce negative impacts of outdoor recreation.

## Buffer functions

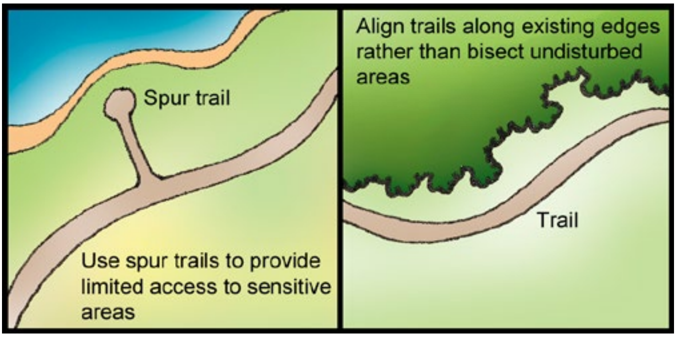
- Increase natural area.
- Protect natural areas.
- Provide a corridor for movement.
- Enhance recreational experience.
- Enhance property values.

| Design Guidelines for Recreation | Buffer Functions | | | | |
|---|---|---|---|---|---|
| | Increase natural area | Protect natural areas | Provide a corridor for movement | Enhance recreational experience | Enhance property values |
| 6.1 Trail design and wildlife | ✓ | ✓ | ✓ | ✓ | ✓ |
| 6.2 Flight initiation distance buffers | ✓ | ✓ | ✓ | ✓ | |
| 6.3 Trails along riparian corridors | ✓ | ✓ | ✓ | ✓ | ✓ |
| 6.4 Trail degradation | | ✓ | ✓ | ✓ | ✓ |
| 6.5 Trail user preferences | | ✓ | ✓ | ✓ | ✓ |
| 6.6 Trail layout | ✓ | ✓ | ✓ | ✓ | ✓ |
| 6.7 Trail access and usage | | | ✓ | ✓ | ✓ |
| 6.8 Greenways and public safety | | | | ✓ | ✓ |
| 6.9 Economic impact of trails | | | | ✓ | ✓ |

Recreation

| Additional Design Guidelines that may Benefit Recreation | Buffer Functions: Increase natural area | Protect natural areas | Provide a corridor for movement | Enhance recreational experience | Enhance property values |
|---|---|---|---|---|---|
| 1.14 Allowances for bank erosion | | ✓ | ✓ | | ✓ |
| 1.21 Vegetation for bank erosion control | | ✓ | ✓ | | ✓ |
| 2.1 Matrix primer | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.3 Corridors and connectivity | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.7 Buffers and corridors | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.8 Corridor width | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.9 Edge effects of corridors | | ✓ | ✓ | | |
| 2.10 Buffers for aquatic habitat | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2.13 Roads and wildlife | | ✓ | ✓ | ✓ | |
| 3.1 Buffers and cropland management | | ✓ | ✓ | | |
| 3.2 Windbreaks for wind erosion | ✓ | | ✓ | ✓ | |
| 5.8 Developing an ecological aesthetic | | | ✓ | ✓ | ✓ |
| 5.15 Buffers for noise control | | | | ✓ | ✓ |
| 5.16 Buffers for visual screening | | | | ✓ | ✓ |
| 6.9 Economic impacts of trails | | | | ✓ | ✓ |

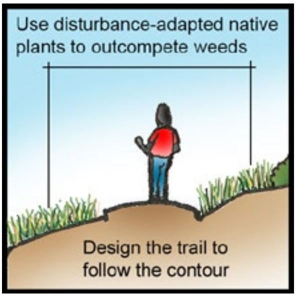
## 6.1 Trail Design and Wildlife



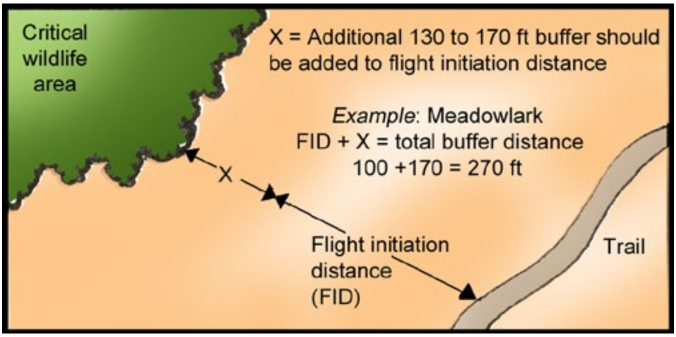

Trails can be designed to minimize human disturbance impacts on wildlife. Factors influencing short-term impacts include type of species and *flushing distance*, type and intensity of human activity, time of year and time of day, and type of wildlife activity. Consult with wildlife experts for guidance.

**Key design considerations**

- Align trails along or near existing human-created or natural edges rather than bisecting undisturbed areas (see 6.3).
- Keep a trail and its zone of influence away from areas with sensitive species. Limit access to critical habitat patches.
- Use *spur trails* or dead-end trails to provide access to sensitive areas.
- Encourage visitors to stay on trails through education, appropriate signage, and vegetative barriers.
- Concentrate activity rather than disperse it. In trail-heavy areas, prioritize restricting access and restoring habitat.
- Restrict trail building to a short time during a season when species of concern are less sensitive. Keep the trail construction zone as narrow as possible.
- Concentrate weed control at road and trail crossings, trailheads, and *riparian areas.*



## 6.2 Flight Initiation Distance Buffers



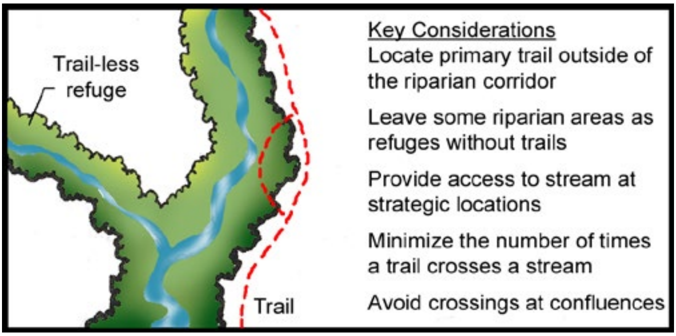

Flight initiation distance (FID) is the distance at which an animal will start to move away from an approaching threat such as a trail user. FID (also called flushing distance) has been recorded for a variety of species; these distances may serve as general guidelines for establishing buffers from critical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

These distances are based on being approached by a single person on foot. Groups of people may require wider buffers. Wildlife may also become habituated to human presence. Wildlife in urban or high-disturbance areas generally have a lower FID than the wildlife in rural or low-disturbance areas.

| Flight Initiation Distance | | | |
|---|---|---|---|
| **Species** | **Flight Distance** (feet) | **Species** | **Flight Distance** (feet) |
| Mule Deer | 490 to 850 | 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 1,280 | Great Egret | 330 |
| Rough-Legged Hawk | 175 to 2,900 | Meadowlark | 100 |
| Bald Eagle | 165 to 2,900 | Robin | 30 |
| Grizzly Bear | 68 to 515 | Black Bear | 32 to 82 |
| Wolves | 55 to 1,600 | Cougar | 165 to unknown |

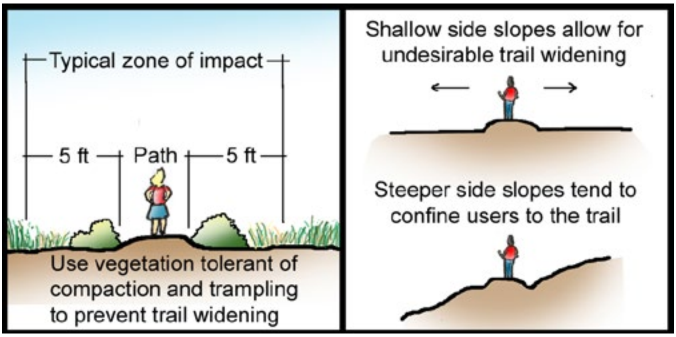
Note that FID is the distance at which the animal begins to evade a threat. An additional setback should be added to the FID to create a buffer that will minimize wildlife disturbance. An additional 130 to 170 feet has been recommended as the additional buffer distance.

## 6.3 Trails Along Riparian Corridors



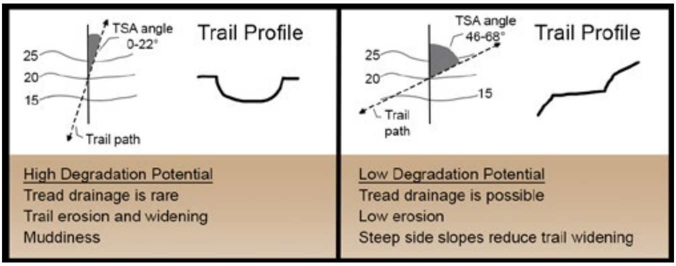

Riparian corridors are critical areas for many ecological functions that can be negatively impacted by poorly designed and managed recreational trails. To minimize impacts and maintenance issues, locate the primary trail to the outside of the riparian corridor and then provide access to the riparian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

## 6.4 Trail Degradation




Recreational activities (e.g., hiking, bicycling, backpacking, horseback riding, etc.) can degrade trails. Common impacts include vegetation loss, trail widening, muddiness, and soil compaction and erosion. While some degradation cannot be avoided, severe impacts can be prevented through appropriate trail design.

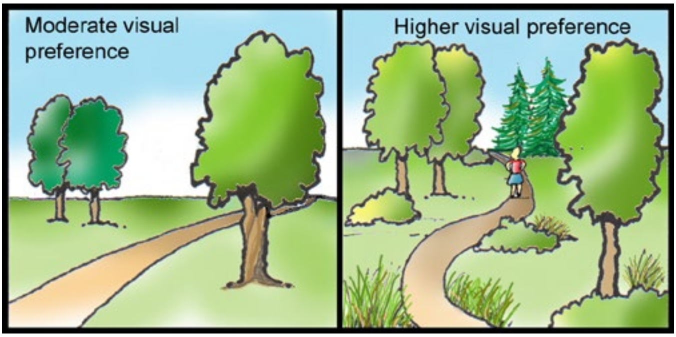
One of the most important design factors impacting trail degradation is *trail slope alignment* (TSA). In general, a higher TSA results in a lower potential for trail degradation (see next page).




**Key design considerations**

- Locate trails on soils with low erodibility (e.g., coarse textured, low organic matter, low soil moisture).
- Avoid locating trails in floodplains. Locate trails in low valleys above flood levels.
- Design trails to follow the *contour*. Situating trails along hillsides can lead to reduced soil erosion and discourage off-trail movements.
- Thin soils over bedrock usually have the lowest erodibility. If steep or climbing trails are necessary, locate them on rocky terrain.
- Use *waterbars* and/or other measures to route runoff away from trails.
- Harden high-use trail surfaces (e.g., mulch, gravel, boardwalk) to reduce erosion.
- Restrict horse and all-terrain vehicle (ATV) use to hardened trails and/or trails with high trail slope alignment angles (i.e., >48°).
- Restore vegetation adjacent to trails. Seed or replant abandoned trails.
- See 5.8 for ecological aesthetics.
- See 6.2 for wildlife flight initiation distances.
- See 6.3 for riparian trails.
- See 6.5 for user preferences.
- See 6.6 for trail layout.

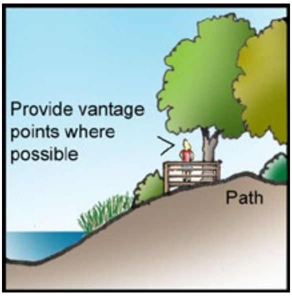
## 6.5 Trail User Preferences




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.

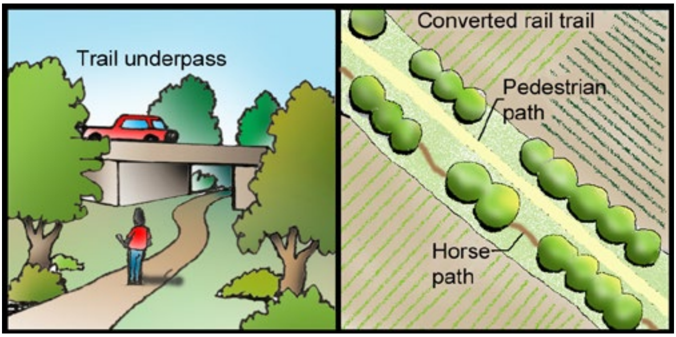
**Key design considerations**

- Users generally prefer trails that pass through several types of plant communities.
- 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 desirable. Users prefer a mixture of open and enclosed areas.
- Curving paths are more stimulating than linear paths.
- Incorporate other preferred visual elements (see 5.8).
- Provide trails that are connected, accessible to users, and encourage multiple uses (see 6.7).
- Design trails to reduce exposure to noise and air pollution (see 5.14 and 5.15).
- Create vantage points where users can view wildlife, other trail users, or interesting features.
- Continued trail management will be needed to reduce negative perceptions of human impact (e.g., litter) and mitigate trail degradation (see 6.4).



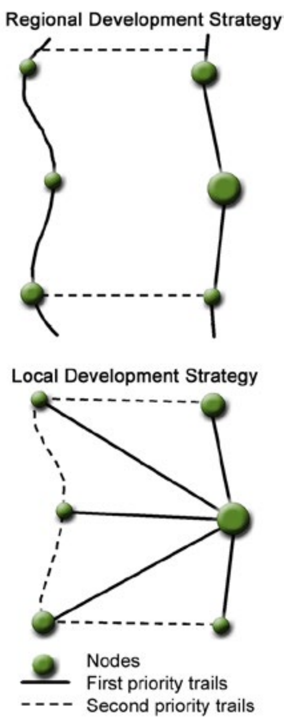

Recreation

## 6.6 Trail Layout



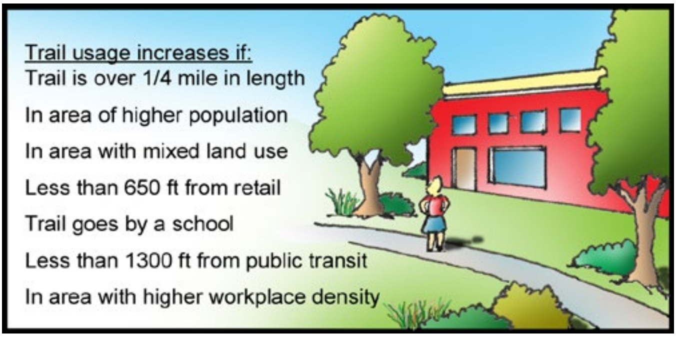

A connected trail system offers a more pleasant, safe, and continuous recreational experience than a series of unconnected trails. Design trails to provide safe passage across potential barriers such as roads (e.g., through trail bridges and underpasses). Abandoned railroad lines may be converted to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

Regional trails are often developed as the backbone of a trail system to 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).



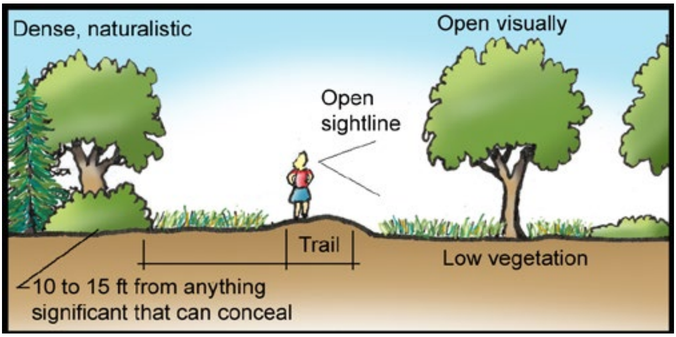

The nodes represent origin-destination points such as parks and workplaces. In the regional strategy, regional trails are built first and then secondary connections are made. In the local strategy, a series of local trails are developed first to provide more options for pedestrian use.

## 6.7 Trail Access and Usage



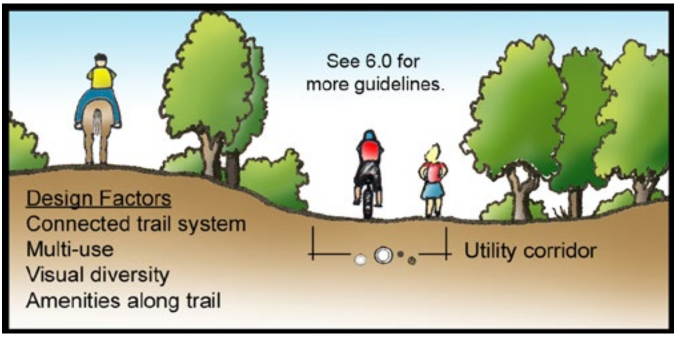

As a general guideline for local trails, the target population should be <5 miles from the trail, and <1 mile if the group is an older population. For regional trails, people may be willing to travel 15 or more miles to use a greenway trail. Accommodate multiple modes of travel but consider separating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

## 6.8 Greenways and Public Safety



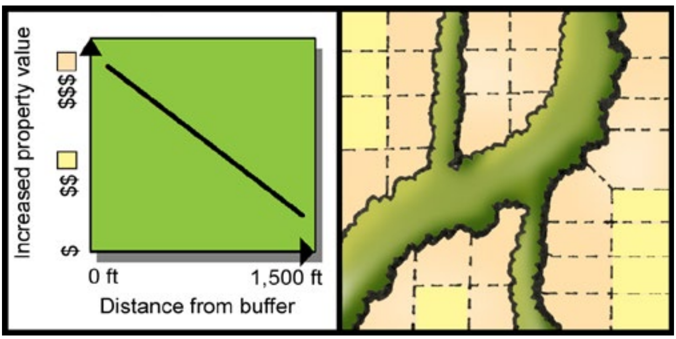

Greenway trails have documented low crime rates compared to other developed land uses. Vegetation can be managed to reduce the perception of fear or crime. Dense, naturalistic vegetation along one side of a trail is not perceived as unsafe as long as the other side is visually open. Provide 100 feet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

## 6.9 Economic Impact of Trails

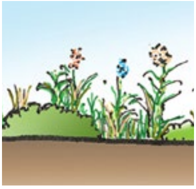



Buffers or greenways that include trails can generate economic benefits through increase in property values, tourism, and public-cost reduction. Greenways can reduce public costs by serving as utility corridors and protecting high-risk areas (e.g., flood prone) from development. Factors increasing trail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

**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. Public greenway acquisition and development may be self-financing through the increases in property values, property taxes, and tourism.



# Glossary

**agroforestry**: the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits.

**allelopathy (or allelopathic)**: the suppression of growth of one plant by another due to the release of chemicals that impact growth, survival, and reproduction.

**anaerobic**: without oxygen.

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

**aspect**: the compass direction that a slope is facing.

**azimuth angle:** the horizontal angle measured clockwise between the sun and the northern cardinal direction.

**beetle bank**: a berm or mound planted with native grasses and/or wildflowers in an agricultural field. Beetle banks are used to support predatory beetle populations as a form of pest control.

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

**biofuel**: fuel produced from living matter or biomass.

**biomass**: the living material of a plant.

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

**bulk density:** dry weight of soil divided by its volume. High bulk density can indicate compacted soils.

**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.

**channel morphology**: the shape and pattern of a water channel.

**check dam**: a small barrier constructed across a natural or man-made channel, swale, or ditch to reduce runoff velocity and erosion.

**chelating agent**: a chemical compound that binds to metal ions.

**colonization**: the occupation of a habitat by a population of species.

**concentrated flow**: runoff that accumulates or converges into small, shallow channels.

**conifer (coniferous)**: a classification of trees and shrubs with needle-shaped leaves that are typically retained year round.

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

**conservation tillage**: a method of crop production in which the soil is disturbed as little as possible (see no-till).

**constructed wetland:** an artificial wetland installed to treat contaminants in water.

**contour**: a series of lines drawn on a topographic map that symbolize elevation.

**coppice**: the periodic cutting back of trees or shrubs to ground level.

**deciduous**: a classification of trees and shrubs that shed leaves annually.

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

**deposition**: referring to sediment deposition. The settling out or laying down of sediment carried by wind, water, or ice.

**dioecious**: plant species that possess either male or female reproductive organs, not both. Monoecious plants possess both male and female reproductive organs.

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

**dissolved nutrients (phosphorus or nitrogen)**: nutrients that have become dissolved in water. Vegetative buffers are less effective at capturing dissolved nutrients than particulate nutrients.

**ecosystem disservices:** ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human well-being.

**ecosystem services**: positive consumable and nonconsumable 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 desired ecological processes.

**edge habitat**: habitat that occurs at the boundary between two different habitat types.

**ephemeral channel**: temporary, small water channels that occur during or for a short time after precipitation or snowmelt events.

**evapotranspiration**: the combined processes of evaporation and plant transpiration that moves water from the land surface to the atmosphere.

**fallow**: the practice of leaving agricultural land uncultivated to replenish fertility and soil moisture.

**filter strip (or buffer strip)**: a narrow band of herbaceous vegetation used to reduce water pollution.

**flow velocity**: the speed at which a fluid travels in a certain direction.

**flushing distance (or flight initiation distance)**: the distance between an animal and a human when the animal flees.

**fodder**: livestock feed.

**4R nutrient stewardship**: a framework for nutrient management that focuses on achieving crop goals while also emphasizing sustainability. 4R nutrient stewardship stands for right source, right rate, right time, and right place.

**gene flow**: the movement of genetic material from one population to another.

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

**green infrastructure**: a system of natural vegetation and green technologies designed and implemented to provide ecosystem services, typically in the built environment.

**greenway:** a corridor of undeveloped land in or near an urban area dedicated to recreation or conservation.

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

**habitat fragmentation**: the process where parts of large, continuous habitats are destroyed, resulting in smaller, isolated habitat patches.

**half-life**: the time required for a substance to halve in quantity.

**herbaceous**: a plant that produces no woody material. Can be annual or perennial.

**hedgerow**: a row of shrubs or small trees, typically planted or maintained to denote a boundary.

**high-order streams**: larger streams or rivers characterized by wider channels, deeper water, and slower flow rates compared to smaller streams.

**hydraulic conductivity**: a measurement of how easily water can pass through soil.

**hydraulic resistance**: a measurement of the resistance that occurs as water flows through or past certain objects.

**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.

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

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

**interior species**: species that prefer or can only survive in habitat found in the patch middle, away from the edge.

**invasive species**: a nonnative animal or plant species that has a significant negative impact on the local ecosystem.

**invertebrates**: an animal without a backbone (e.g., insects).

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

**keyline design**: a landscaping technique to capture water and enhance beneficial use. Design revolves around the "keyline" or the contour line where the slope goes from concave to convex. Subsequent rows are designed parallel to the keyline.

**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.

**leaf litter**: plant debris that has recently fallen to the ground and has not yet decomposed.

**leeward**: the sheltered side behind a windbreak.

**low-order streams**: the smallest and uppermost channels in a river network, typically defined as first- to third-order streams.

**marginal lands**: land that has low agricultural capability and can create ecosystem disservices when under cultivation.

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

**mesoclimate:** the climate at an intermediate geographic scale, such as a downtown district, neighborhood, large park, or farm.

**microclimate**: the localized climate of a small area.

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

**monogastric livestock**: animals with a single-compartment stomach.

**mycorrhizal fungi**: fungi that can form a symbiotic relationship with plants, referred to as mycorrhizae. Mycorrhizal fungi can exist separate from the fungus-root and are often cultured/inoculated as fungal spores and/or hyphae.

**niche**: the physical and environmental conditions that an organism requires. Niche also includes an organism's role in the ecosystem.

**no-till**: a conservation farming practice that involves the cultivation of crops or pasture without tilling the soil.

**parasitism**: a relationship between two species of organisms in which one benefits at the expense of the other.

**parasitoid:** a parasitic organism, typically an insect, whose young develop on or in another host organism and will eventually kill the host.

**particulate nutrients (phosphorus or nitrogen)**: solid particles of nutrients that have not been dissolved in solution (see dissolved nutrients). Vegetative buffers are relatively effective at capturing particulate nutrients.

**pathogens**: microorganisms that can cause disease in other organisms or in humans. Examples include *E. coli* and *Salmonella* spp.

**peak flow**: the maximum flow rate of discharge to a stream after a storm event.

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

**phreatophytes**: deep-rooted plants that usually have part of their root system in the water table.

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

**pollard**: selective cutting or pruning of tree branches that have reached a certain height to keep the tree at that height.

**pollutant load**: the amount of pollutant in a body of water.

**population viability**: the ability of a population to survive, successfully reproduce, and avoid extinction.

**porosity**: a measure of the void spaces (i.e., holes) in a material or buffer.

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

**recolonization**: repopulation of a habitat by a species that previously colonized it.

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

**resource concern:** a condition of the soil, water, air, plant, animal, or energy resource base that does not meet the minimum acceptable standards.

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

**riparian buffer**: a vegetated corridor of land near a waterway that is planted or maintained to primarily protect water quality.

**root exudates**: organic substances produced by plant roots and secreted into the root zone.

**roughness (or surface roughness)**: the irregularity in elevation of an area of terrain.

**ruminant livestock**: animals that chew cud and have a four-chambered stomach.

**rural-urban interface**: the transitional landscape between urban and rural areas.

**secondary forest**: a forest or wooded area that has regenerated naturally after human disturbance.

**saturated**: referring to buffers. Soaked, holding as much water or dissolved nutrients as possible.

**sediment**: the solid substances that are transported by wind or water.

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

**silage**: green fodder compacted and stored in airtight conditions, without first being dried, to ferment. It is typically used as animal feed in the winter.

**snag**: a standing tree that is dead or dying. Snags are valuable habitat for wildlife.

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

**soil microorganisms**: the microscopic living organisms in soil, which include bacteria, fungi, viruses, archaea, and protozoa.

**soil organic matter (SOM)**: the part of the soil made of decomposing plant and animal tissues. Soil organic carbon (SOC) is a primary component (58 percent) of SOM.

**soluble**: the ability of a solid substance (solute) to be dissolved in a liquid (solvent).

**species abundance**: the number of individuals of a species in a given area. This is one metric of biodiversity.

**species diversity**: the number of different species in a given area. This is one metric of biodiversity.

**spray drift**: the unintentional deposition of chemical sprays outside of the target area.

**spray evaporation loss (SEL)**: the amount of sprinkler irrigation water that evaporates before contacting the soil.

**spur trail**: a type of trail that branches off from the main trail and leads to a dead end, viewpoint, campsite, or summit.

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

**stream meandering** : a type of stream that runs snakelike through the landscape. Water flowing along the outside of the curves tends to move faster than the inner curves, causing the stream bed to be deeper along the outside curves.

**strip cropping**: a type of farming that involves growing different crops in alternating strips to reduce soil erosion.

**subsurface flow**: the belowground flow of water.

**successional stage:** a distinct phase where a particular set of flora and fauna species dominates a community following a disturbance, gradually changing over time as new species arrive and adapt to the evolving environment, eventually leading to a climax community if left undisturbed.

**swale**: a sunken channel (natural or artificial) between ridges. Swales are usually wetter and host different vegetation than the surrounding area.

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

**tile drain**: a type of drainage system that removes excess water from the shallow root zone in agricultural soils using pipes buried in the ground.

**toe slope**: the bottom of a slope or the part where the slope levels out.

**topography**: the shape of the surface of the land.

**trail slope alignment (TSA)**: the angle degree measurement between the trail path and the prevailing landform slope.

**unmanned aerial vehicle (UAV)**: an aircraft, commonly known as a drone, without any human pilot, crew, or passengers on board.

**vigor**: the health and thriftiness of a plant.

**vegetated waterway (or grassed waterway)**: a natural or artificial channel with appropriate vegetation to carry surface runoff and minimize erosion.

**waterbar**: a linear trail feature (e.g., ridge) that is installed to reduce trail erosion.

**wildlife corridor**: a strip of habitat connecting wildlife populations that would otherwise be separated by human development or agriculture.

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

**windbreak (or shelterbelt)**: a linear planting of one or more rows of trees or shrubs designed to offer protection from wind.

**Bentrup, Gary; Shi, Xinyuan.** 2025. Multifunctional buffers: design guidelines for buffers, corridors, and greenways. Gen. Tech. Rep. WO-108. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 162 p. https://doi.org/10.2737/WO-GTR-108.

Over 80 illustrated design guidelines for multifunctional buffers are synthesized and developed from a review of more than 1,900 research publications. Each guideline describes a specific way that a vegetative buffer can be applied to protect soil, improve air and water quality, support fish and wildlife habitat, augment crop and livestock production, enhance the human environment, or provide recreation opportunities. Vegetated buffers may include those designed as an agroforestry system or those implemented outside of an agricultural setting. These science-based guidelines are presented as easy-to-understand rules of thumb for facilitating the planning and designing of multifunctional buffers in rural and urban landscapes. The online version of the guide includes the reference publication list.

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