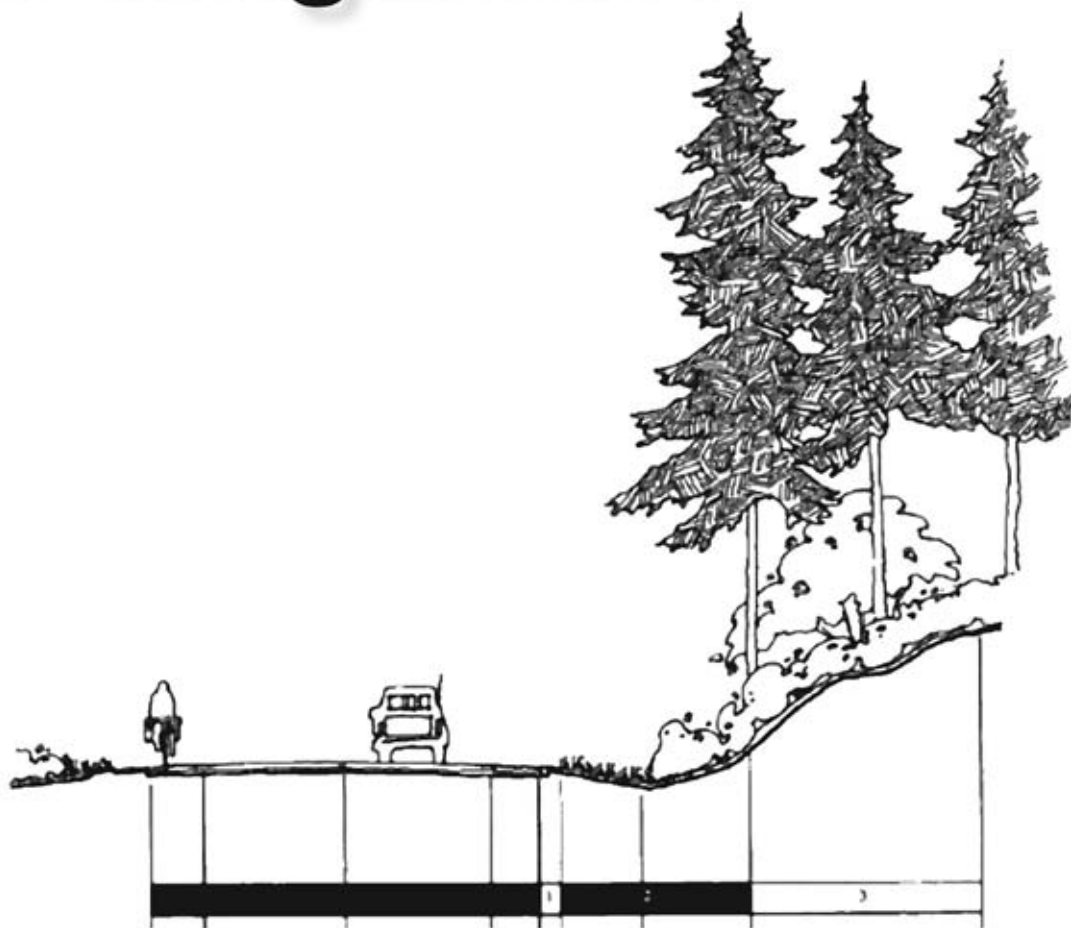


Guidelines for Vegetation Management



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FOREWORD

These guidelines will be of interest to local, regional, state and federal officials as well as other transportation professionals who work with them in dealing with roadside vegetation management. They will be of particular interest to those roadside vegetation managers just beginning their careers. The guidelines provide an overview of current agency practices, recent literature findings, and research on roadside vegetation management. Their primary purpose is to assist roadside vegetation managers in integrated roadside vegetation management decision-making processes into highway project planning, design, construction, and maintenance, as well as to document existing research and practice. Roadside vegetation managers are often faced with problems for which information already exists, in the form of reports and documents, or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated and as a result much of this useful information may go unused by the majority of roadside vegetation managers. These guidelines incorporate the current knowledge and practice of roadside vegetation management. The guidelines also include information extracted from survey responses from 29 state agencies, a glossary that defines technical terms and acronyms, and a compendium of 40 common roadside invasive species, with descriptions of each species, its biology, and common methods of control.

PREFACE

The impetus to writing these guidelines came about from the realization that there was an enormous amount of practical information on roadside vegetation management available but much of it was not being used because it was scattered and unevaluated. The information was dispersed not only in the mainstream literature, but in localized documents and research reports within government agencies. Upon undertaking this task, it quickly became apparent that another major source of the most current practical information on roadside vegetation management was that of the undocumented experience and expertise of roadside vegetation management practitioners. The unselfish cooperation of these individuals has greatly enhanced the utility of these guidelines. These guidelines provide DOT executive managers, middle managers, and supervising practitioners with a toolbox of effective strategies for planning and executing integrated roadside vegetation management programs.

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I.0 INTRODUCTION

To the uninitiated, roadside vegetation management may seem a routine job involving mowing, chopping down trees, and chemical applications. This is far from the truth.

Effective roadside vegetation management requires a high level of expertise and resources to plan, design, construct, and maintain the roadside environment. It requires the vegetation manager to make informed choices among management techniques and to integrate different techniques to achieve the greatest benefits. Such management is known as Integrated Roadside Vegetation Management (IRVM). IRVM involves the planting and establishment of sustainable vegetation on roadsides, and maintaining it through the use of cultural, mechanical, biological, and chemical methods (161, 163, 183).

The roadside vegetation manager today is faced with dwindling resources, increasing environmental and legal constraints, and increasing public pressure to provide safe and aesthetically pleasing roadsides.

Throughout the United States, and the world, roadside vegetation managers face similar challenges and opportunities. This project draws on the long term experience and expertise of these vegetation managers to create guidelines that provide the basic knowledge required to establish a roadside vegetation management program.

The guidelines are intended for any highway agency/organization, but will be particularly useful to those employees just beginning their career and needing to establish or improve their own vegetation management program. We are greatly thankful to the many roadside vegetation managers (from virtually every state) who provided us with literature and their feedback. The development of these guidelines would not have been possible without them.

2.0 EXECUTIVE SUMMARY OF BENEFITS

Before reporting on how to manage roadside vegetation, it is important to understand why it is done. The benefits of roadside vegetation management fall under the following categories:

- Safety
- Economics
- Erosion Control
- Environmental
- Legal and Regulatory Compliance
- Aesthetics
- Sustainable Transportation
- Context Sensitive Solutions
- Other Objectives

The roadside clearly has many different functions and these functions are not always compatible. For example, road safety and fire hazard management might require the removal of some vegetation, whereas environmental and landscape objectives may be to retain roadside vegetation.

To address these conflicts, an appropriate management framework needs to be established. Roadside management practices reflect the legislative obligations, economic pressures, and community values at the time. In the past, less consideration was given to the environmental value of roadside vegetation. Nowadays, roadside vegetation is recognized as an important asset and its management should reflect federal and state government policies including those for biodiversity. Likewise, the aesthetics of the roadside are very important and urban and environmental design is a key factor in new road construction projects. The public expects roadsides to be managed in a safe and environmentally friendly way.

3.0 SCOPE AND ORGANIZATION OF GUIDELINES

These guidelines provide a consistent, coordinated, proactive approach to roadside vegetation management. They are intended to be used as a starting point for a roadside vegetation management program and allow room for variations in state government laws, regulations, guidelines, and regional variation in roadside environments.

The guidelines do not include specific details on vegetation control practices, such as which specific herbicide to use, or which piece of equipment to purchase. Nevertheless, they provide enough information on vegetation management that new managers will generally understand how the various control methods and management structures work.

4.0 OBJECTIVES OF ROADSIDE VEGETATION MANAGEMENT

It is important to understand why we manage roadside vegetation. The benefits of roadside vegetation management fall under the following categories:

- Safety
- Economics
- Erosion control
- Environmental
- Public Relations
- Legal
- Aesthetics
- Other

4.1 Safety

Safety is the top priority in roadside vegetation management. Effective vegetation management reduces the risk of functional or structural failure which may contribute to crashes, injury, or disruption to travel. Effective vegetation management will help limit physical obstruction or restricted visibility and will reduce the severity of run-off-road crashes.

Vegetation Management

Provides a Safe Recovery Zone for Errant Vehicles

Grass is mowed and trees/brush are cut or trimmed along the highway to provide a clear area for errant vehicles to safely return to the highway.

Improves Line of Sight to Obstacles, Rigid and Mobile

The motorist must be able to see other vehicles, signs, fixtures, animals, and people beside the road. Sight distance can be reduced by tall or overhanging vegetation or by vegetation otherwise encroaching on the driver's line of sight. Clear visibility of signs, guardrails, and delineator posts is critical and safety is compromised when vegetation growth is not adequately controlled (129, 183). When visibility of fixtures is impaired, it results in potentially unsafe situations and increased liability to the agency. The available sight distance in the field is measured and compared with minimum standards to determine whether a traffic hazard exists. If the minimum safe stopping sight distance is achieved, then a traffic hazard has been avoided.

Visit the AASHTO bookstore (<http://bookstore.transportation.org>) for current guidelines on sight distance for inter-sections, ramps, etc. In addition, each state also provides line of sight guidelines and specifications.

Removes Hazardous Trees, Tree Limbs, or Brush

While trees are an important roadside asset, they can also pose a major hazard to highway users. Identification and removal or pruning of hazardous trees or brush removes deadly fixed obstacles and reduces the likelihood that trees or limbs will fall and cause property damage, injury, or death to highway users or neighbors to the highway right-of-way.

Reduces Standing Water on Roadways

Standing water on roadways can lead to hydroplaning of vehicles and a subsequent increase in accidents. Vegetation free zones and recovery zones allow for maximum drainage of the road surface with minimum erosion. The type of vegetation can impact soil health and infiltration. In healthy soils, water is rapidly absorbed and in unhealthy soils, water either runs off or remains on the surface. Native grasses and wildflowers adapted to the site are usually deep rooted and provide deeper water channels than the root systems of cool season grasses.

Unmanaged vegetation in roadside ditches can:

- cause water to back up and saturate the road foundation;
- make rubbish removal difficult; and
- cause, after heavy rains, rubbish and debris to accumulate and block drains, flooding the road and making travel unsafe.

Reduces Driver Fatigue with Variety of Changing Aesthetics

Driver fatigue is a major contributor to road accidents. Anything that can reduce driver fatigue will reduce roadside accidents. Landscaping and vegetation has been shown to reduce driver frustration and fatigue (22, 300). Ulrich (1979) found that plants increased positive feelings and reduced fear and anger.

Reduces Fire Potential at Pavements Edge

C.C. Wilson (1979) found that 75 percent of all wildfires occur within 10 feet of a road before spreading to grassland and forestland. R.F. Johnson (1963) (307) reported that over 52 percent of man-made fires in California occurred within 33 feet of a road edge. Other studies showed similar results, reinforcing the correlation between roads and wildfire (California Division of Forestry and USDA Forest Service, 1968 [245]). Dry vegetation presents a fire hazard when allowed to grow too close to the travel lane. Wilson (1979) also found that a reduction of fuel (dry vegetation) within the first 10 feet of a roadside greatly reduced the incidence of fire; especially since ignition sources abound, such as tossed cigarette butts, backfiring vehicles, hot exhaust pipes, or a shower of sparks from metal objects scouring the road surface. The fuel source (high and dry grass) and subsequent potential for fire can be reduced through an effective vegetation management program. Roads and well maintained roadsides can provide valuable fuel breaks in fire-prone regions. Bare ground and low growing grass reduce fire intensity, and physical separations of tree crowns prevent fires from spreading at the crown level. These factors improve fire fighter safety and reduce the potential for fires to spread across roads. An increase in width of bare ground and mowed recovery zones have been used by state Departments of Transportation (DOTs) and the U.S. Forest Service as effective fuel breaks. Roads, especially when the roadsides have been treated as fuel breaks, are a preferred location from which to start backfires, often the safest and most successful method of stopping intense fires.

4.2 Economics

A well-cared-for neighborhood can increase property values, keep neighbors happy, reduce costly complaints, and aid business by encouraging travelers to return. An interview-based survey of business owners found that trees and landscaping in neighborhood commercial districts created a pleasant space that attracts people; acts as an outdoor extension of the business' customer service commitment; and can help to develop a distinctive identity for and define the boundaries of a business district, thereby encouraging return visits (313).

Without vegetation management, our roads would rapidly deteriorate. Effective vegetation management practices decrease damage to facilities and structures and reduce maintenance costs. Roadside vegetation management plans support transportation agency efforts to maintain roads and highways at their lowest life-cycle cost. A healthy roadside environment also limits the liability of the governing agency (129).

All aspects of roadside vegetation management impact the economics of maintaining a road.

Vegetation Management Reduces Liability from Visibility Accidents

A well-maintained roadside will increase the motorists' reaction time and enable them to take evasive action from oncoming traffic, vehicles entering the roadway, animals such as deer, and roadside fixtures. Fewer accidents results in less litigation against agencies for negligence.

Vegetation Management Reduces Maintenance Costs

Well-planned, self-sustaining landscapes are easier to maintain and less costly. Sustainable landscapes consist of locally adapted plants that can spread at their own rate to cover roadside areas. They help to reduce annual maintenance costs and improve worker and public safety because they do not require more expensive mowing or even herbicide treatments.

Vegetation Management Protects Highway Assets

Maintained vegetation keeps highway structures from sustaining vehicle hits, accidents, etc. In addition, roots from encroaching vegetation can penetrate and heave road surfaces, and cause failure of the road subsurface (14, 129). Roadside vegetation reduces costly erosion slides and slip out events on roadsides.

4.3 Erosion Control

The most efficient and cost effective form of erosion control is prevention. The most cost effective, environmentally friendly, and aesthetically pleasing form of prevention is the use of vegetation. When properly installed and maintained, vegetation can protect slopes by reducing erosion, strengthening soil, and inhibiting landslides by generally increasing slope stability. Vegetation is often a key factor in the management of stormwater (28, 37, 186).

The use of vegetation to manage erosion and protect slopes is relatively inexpensive, does not require heavy machinery on the slope, establishes wildlife habitat (155), and can improve the aesthetic quality of the roadside.

Helps Maintain Integrity of Shoulder Area

The roadside shoulder slope must be maintained to prevent the erosion and cracking of the roadway surface itself. Grass is the best and least expensive method of preventing erosion on slopes. The root structure of vegetation holds the soil together and the top-growth breaks up the speed and intensity of rainfall droplets and slows the movement of water across the slope.

Prevents Guardrails from Failing

When slopes erode behind rail posts they can fail to hold in place when struck by a vehicle, presenting a safety hazard and a potential lawsuit. In addition, it is costly to replace erosion damaged guardrails. The roots of vegetation keep slopes stable around guardrails and other fixtures.

However, vegetation around guardrails needs to be maintained at a height low enough to allow for visibility and function of the guardrail.

Preserves Stream Banks

Vegetation will control runoff and reduce stream bank erosion. Established vegetation will cover slopes and prevent them from drying out and cracking, exposing them to future erosion events. Increasingly, vegetation management is part of new stream restoration techniques used to protect highways and bridges from erosion. Vegetation is often a key component in designs to slow water and limit or reduce scour.

Prevents Drains from Clogging

Vegetation can limit debris from entering drain grates. Controlled vegetation around drain pipe outfalls will help prevent erosion.

Helps Preserve Wetlands

Vegetation management will limit runoff contaminating surrounding wetlands and help mitigate environmental wetland issues.

4.4 Environmental

Owing to their relatively large area, road networks have a significant effect on the natural environment (88). State DOTs manage over 17 million acres of right-of-way, some of which contain rare ecosystems and endangered species (112, 114).

Roadside management practices reflect the legislative obligations, economic pressures, and community values of the time. In the past, less consideration was given to the environmental value of roadside vegetation. Today, the environment is at the forefront of public concerns (Minnesota Department of Transportation, 2003) (165). Roadside vegetation can significantly improve the environment by improving water quality, managing stormwater, protecting the soil, increasing biodiversity, creating habitat for wildlife, and reducing the number of invasive weeds (Bedard et al., 2000) (11).

Aids in Compliance of Runoff Water Quality Regulations

Regulations enacted by the Environmental Protection Agency (EPA), state agencies, or commissions often hold engineers liable for damage caused by stormwater runoff. Regulations usually require DOTs to maintain slopes for water quality and sediment control. Natural vegetation is the best and least expensive control measure that a DOT

can use to meet regulations. There is a changing trend in land development and stormwater management throughout the United States. It has been called many things, including smart growth, conservation development, and low impact development (LID). LID is alternative, ecologically sensitive design that mimics the way natural areas store and infiltrate rainwater. The LID approach protects local and regional water quality by decentralizing stormwater management and absorbing rainfall throughout the landscape. Low impact development minimizes the amount of impervious surfaces and mitigates the impact of necessary impervious surfaces.

There are a variety of conservation practices that work together to mitigate these effects, such as pervious paving, rain gardens, bioretention cells, bioswales, native landscaping, and soil quality restoration. Bioswales are sometimes a cost effective way to manage stormwater runoff. Bioswales are stormwater runoff conveyance systems that provide an alternative to storm sewers. They can absorb low flows or carry runoff from heavy rains and snowmelt to storm sewer inlets or directly to surface waters. Bioswales improve water quality by enhancing infiltration of the first flush of stormwater runoff and filtering the large storm flows they convey.

Water, Air Quality, and Noise Control

Vegetation can filter and provide cleaner water to streams and wetlands. Roadside vegetation absorbs the carbon dioxide that contributes to global warming, as well as other gases that contribute to urban pollution. Trees combat global warming by absorbing the carbon emitted by vehicles, lowering carbon emissions from fossil fuel-burning plants, and reducing the energy used for climate control in buildings. One tree can remove 26 pounds of carbon dioxide from the atmosphere annually, equaling 11,000 miles of car emissions. Landscape plants, including shrubs and turf, remove smoke, dust, and other pollutants from the air. One study showed that 1 acre of trees has the ability to remove 13 tons of particles and gases annually (291).

Vegetation can absorb sound waves, and significantly reduce unwanted “noise pollution” from traffic and other man made sources of noise. Additionally, in the presence of a breeze, some trees make pleasant sounds of their own. Further, the wildlife attracted to vegetation sometimes results in pleasant natural sounds. These sounds of nature mask and further diminish unnatural noise pollution (300).

Wildlife Habitat

Roadside vegetation provides valuable habitat for insects, birds, and animals. Roadside corridors provide a means for species to exchange genetic material between geographically isolated habitats (305).

4.5 Legal and Regulatory Compliance

While safety is the top priority in roadside vegetation management, legal compliance is the driving force behind the majority of activities conducted on roadsides. Legislation that impacts roadside vegetation management is increasing annually and encompasses mandated control of noxious weeds (127), restriction of mowing times and areas, protection of endangered species, protection of groundwater, and restrictions on the use of herbicides.

In addition, there are serious legal consequences for those that do not manage danger trees or vegetation that restricts visibility. Effective vegetation management programs can be designed to minimize exposure to legal action. Negligence in the maintenance of roadsides exposes transportation agencies to tort law suits. “Tort” is defined very broadly in law as an injury to “one’s person, reputation, or feelings” or damage to “real or personal property.” A principal factor considered by courts in determining whether the highway agency acted reasonably is whether the actions were

in accord with generally accepted vegetation management practices. Trees are the roadside object most often hit and cause more fatalities than any other object. Trees account for 25 percent of all fixed object fatal accidents, causing more than 3,000 deaths per year (99). Trees with a trunk diameter greater than 4 in. will abruptly stop a vehicle and must be considered as hazardous fixed objects when they are near the edge of travel lanes. AASHTO clear zone standards need to be followed regarding the removal of trees. To minimize problems, the clear zone area should be kept clear of tree saplings; as once trees become established, their removal may be resisted by the community (99).

4.6 Aesthetics

While safety and function may be the most important considerations in developing an Integrated Roadside Vegetation Management (IRVM) plan; aesthetics are the end result that the customer (public) sees and considers when they judge if they are getting value for their money (14). Aesthetics plays a big role in most existing agency vegetation management strategies because of this. There is, however, quite a variation in what the public considers a well managed roadside. Public perceptions of a “good looking roadside” can range from a manicured lawn appearance to unmanaged natural vegetation. It is the job of the vegetation manager to strike a balance between these extremes. Roadside vegetation is often effectively used to provide a visual and acoustic screen between roadsides and urban dwellings.

Promotes Tourism

When roadsides look pleasant or are well maintained, they encourage travelers to return to a community or a region. Nice, well maintained vegetation growing along the road can be a source of community pride.

4.7 Sustainable Transportation

“Sustainable transportation” is safe and economical, without depleting natural resources, destroying the environment, or harming human health. Integrated vegetation management contributes to making transport systems more sustainable.

4.8 Other Objectives

There are many other benefits, such as use of vegetation as a snow fence (129). Public relations and community pride are other objectives of roadside vegetation management.

4.9 Context Sensitive Solutions (CSS)

Since economic, scenic, aesthetic, historic, and environmental resources are not isolated elements it is important to consider them as a whole when planning vegetation management strategies. Context sensitive solutions provide the principles and methods to assist in the planning of vegetation management strategies. The Federal Highway Administration defines Context Sensitive Solutions as “a collaborative, interdisciplinary approach that involves all stakeholders to develop a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic, and environmental resources, while maintaining safety and mobility. CSS is an approach that considers the total context within which a transportation improvement project will exist.” For detailed information on CSS, consult NCHRP Report 480, *A Guide to Best Practices for Achieving Context Sensitive Solutions–2002*.

5.0 DETERMINING PROGRAM GOALS AND PERFORMANCE MEASURES

5.1 Mission Statement

Funding is key to a successful program. A mission statement is a great tool to help obtain funding and give direction to the program. The mission statement should be broad and outline the ultimate reason for the program's existence.

The mission statement should describe what the vegetation manager wants the roadways to look like 10 to 20 years from now. This is the goal that the vegetation manager will be moving towards. In Chapter 4, we discussed the objective of roadside management and the vegetation manager should use those objectives when building their mission statement. Despite the clear benefit of a mission statement, 50 percent of the agencies surveyed (see Appendix A) did not have a written mission statement.

The IRVM plan identifies environmental constraints and gives the vegetation manager flexibility in management methods. For example, New York State Department of Transportation (NYSDOT) uses the following steps in planning their IRVM program:

- Understand pest and ecosystem dynamics
- Set management objectives and tolerance levels
- Compile treatment options
- Account for economic and environmental effects of treatments
- Develop site-specific treatment plans
- Monitor outcomes and revise and adapt management plans

Another IRVM example is from Iowa DOT. They define IRVM as a long term approach to vegetation management that:

- systematically evaluates each area to be managed;
- determines which plant communities best fit the area;
- develops procedures that will encourage, enhance, or reestablish desirable plant communities;
- provides self-sustaining, diversified, visually interesting vegetation;
- keeps safety and an improved environment as priorities; and
- utilizes the most beneficial methods to prevent or correct undesirable situations caused by disturbance or less than optimum vegetative ground cover.

5.2 Establish and Prioritize Goals

After developing a mission statement, it will be necessary to establish goals to help accomplish the mission statement. When establishing goals and objectives, keep in the forefront safety of the public and maintenance staff, the cost of maintenance, the cost of not maintaining the roadside, and the impact on the environment.

There may be conflicts between goals, for instance the use of herbicides to keep costs down and the goal of using less herbicide for political and environmental reasons. The benefit of IRVM is that it gives roadside managers and stakeholders a framework for resolving conflicts. All benefits and costs can be identified as precisely as possible and people can make informed trade-offs, rather than decisions supported only by guesswork or opinions.

Establish Vegetation Management Program Goals

The aim of IRVM is to encourage self-sustaining vegetation and discourage undesirable vegetation with minimal use of herbicides, mowing, tree removal, and other methods. Use the zone concept (see Chapter 8) to break down the vegetation management practices by zone. For example, the long-term aim of IRVM in zones 2–3 is to create stable, low-growing plant communities.

The goals of Iowa DOT's Integrated Roadside Management Plan are to

- Preserve and provide safe, functional, and environmentally improved corridors of travel throughout the state.
- Utilize a long-term integrated management program that promotes desirable self-sustaining plant communities; and encourage plant communities native to Iowa through preservation and re-establishment whenever practical.
- Bring about considerable reduction and possible elimination of the use of chemicals as a control method of undesirable plants.
- Enhance the scenic qualities of the roadsides and their value as wildlife habitat.

To achieve these goals, Iowa DOT outlines the subsequent procedures, which follow a Plan-Do-Check-Act process as follows:

- Inventory the sites to be managed.
- List the existing areas of desirable vegetation as well as those that need improvement.
- Determine the appropriate management methods needed.
- Determine the best time to implement management procedures and see that they are accomplished at that time. Temporary procedures may be needed to preserve an area before permanent procedures can be utilized.
- Evaluate the results periodically.
- Take further measures, if necessary.

Establish Public Relations and Communications Goals

List what is intended to be achieved regarding public relations, and how it will be achieved. Public education, outreach, and a work force that is well trained reduce public complaints and make the agency a good neighbor to landowners next to the right-of-way. The establishment of public relations goals will include public education.

To communicate its IRVM plan, Iowa DOT is committed to

- Develop a public awareness campaign to gain support for integrated management through media, established organizations, seminars, and brochures.
- Develop educational and informational material on IRVM to be presented in seminars and distributed to adjacent landowners, the general public, consultants, and contractors.
- Provide guidelines and directives for contractors and others who seed, plant, and maintain roadsides.

- Prepare and distribute instructions to state, county, and city personnel on preservation of desirable areas and treatment of areas that need improvement.
- Gather, develop, and distribute information with other jurisdictions; seek and share information with other states.
- Encourage research in all aspects of IRVM, i.e., road design for improving IRVM, planting methods, management practices, seed sources, seeding rates, seed mixes, planting equipment, etc.
- Encourage state production of native seeds and plant materials for use in the rights-of-way.

5.3 Balance Cost and Benefits

Once all goals and objectives have been identified, they need to be categorized in order of importance and subjected to a benefit/cost analysis. Chapter 21 is devoted to helping prioritize vegetation management goals.

5.4 Determine Performance Measures

Performance measures of the overall roadside vegetation management program may include the number of citizen complaints, the cost of maintenance, and the vegetation condition (129). Goals that reflect the success of the control activity will be the best for the vegetation managers to follow. When creating goals, it is important to make sure that they are measurable. Many roadside vegetation management activities (e.g., mowing, tree removal, herbicide efficacy, rubbish removal) can be measured. Defining performance measures for each activity will help managers to identify and adjust to strengths and weaknesses in their program. After a rating, review adjustments can be made and funds committed to weaknesses and areas of concern.

Monitoring Performance

Measuring the performance of IRVM is an important step in the cycle of improving vegetation management programs. With performance measures, an IRVM program can be more objectively assessed. Performance-based monitoring insures cost effective management of resources and allows managers to make adjustments that eliminate expenditures on ineffective vegetation control treatments. The cycle includes the gathering of information about the system, planning action based on the information, implementing the plan, gathering information on the outcome of the actions, and repeating to continuously improve the results. An example of an IRVM decision making diagram is presented in Figure 5-1 (296).

Performance-Based Contracting

The “Performance-Based Contract” is increasing in popularity. It is based on the premise that you should get what you pay for—the end result—and not dictate how the end result is achieved. The agency and the contractor agree on the final goal and prepare a contract that enables the agency to accurately measure that outcome through a series of performance measures or benchmarks. This effectively shifts much of the risk from the agency to the contractor. If the work fails inspection, the work is repeated or another strategy is used by the contractor until the work passes inspection—at no extra cost to the agency, hence the shifting of financial risk. Performance-Based Contracting pushes contractors to innovate and find the most efficient method of achieving the desired outcome. The resulting efficiencies benefit everyone in the long run.

Performance-Based Monitoring Procedures

Performance-based monitoring procedures provide a means to determine if contractors have delivered results based on contract specifications. If they do not reach target performance measures then they may incur a penalty; conversely, if they exceed contract specifications they may be paid a bonus. The asset, in this case the roadside vegetation, is evaluated on a regular schedule for measurable conditions, attributes, and quantities agreed upon in the contract. If evaluation is used in conjunction with Global Positioning Systems (GPS) and Geographical Information Systems (GIS), the ratings can be displayed graphically showing where the contractor needs to improve to reach performance targets. The evaluation may be made by the governing agency, the contractor, a combination of both, or an independent assessor.

Establishing a quality assurance plan that describes how the contractor will be measured against the performance standards is the critical part of this contracting method.

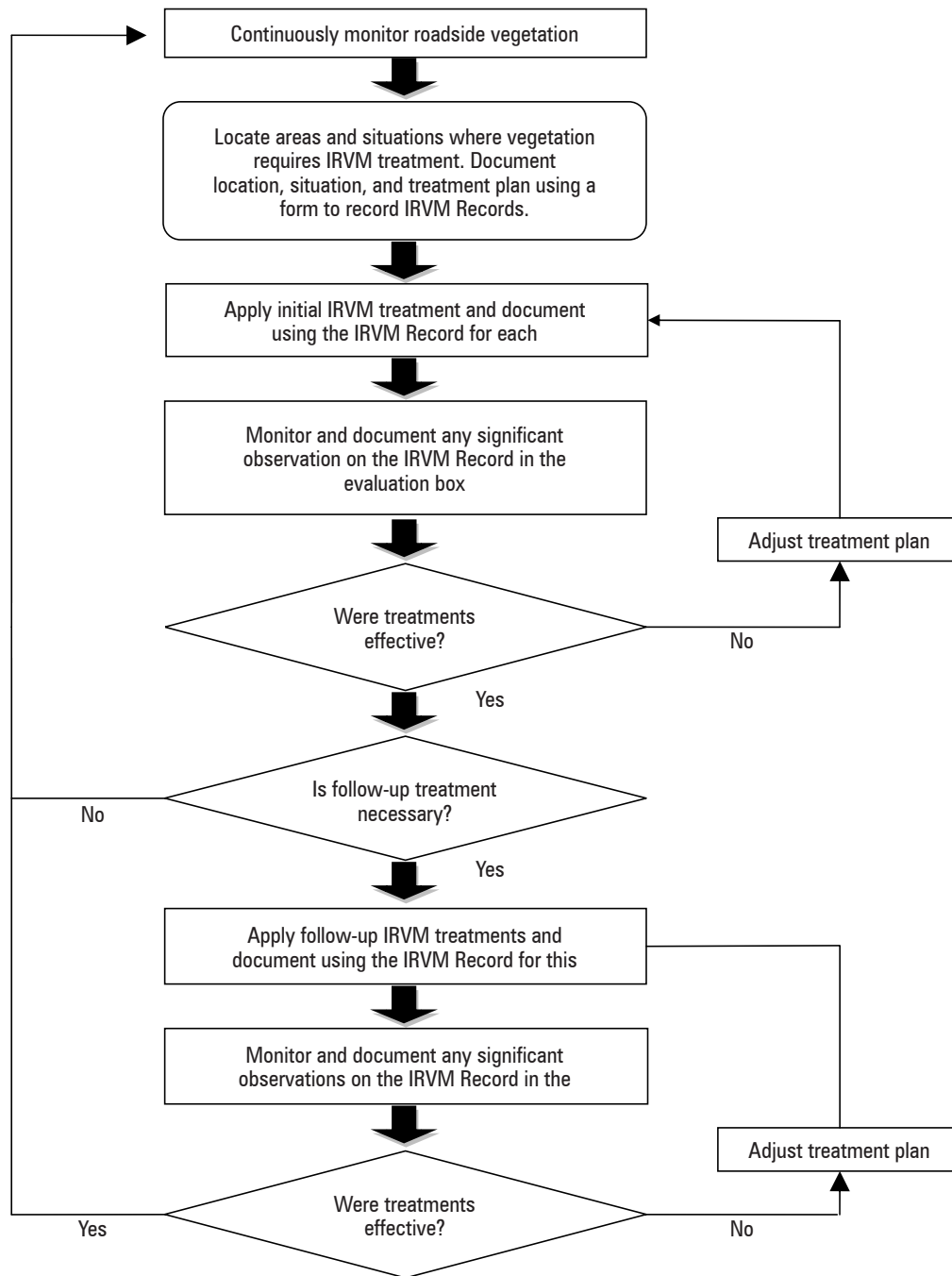


Figure 5-1. Washington State DOT IRVM Decision-Making Process (WSDOT, 1997) (296)

6.0 PUBLIC AND LEGAL ISSUES

6.1 Laws and Regulations Related to Vegetation Management

The Federal government, all states, and some local governments have laws and regulations that pertain to roadside vegetation management practices. Program managers should gather copies of these laws and regulations and study them carefully as the agency must operate within the restrictions set forth in them. Note that these laws and regulations are not static; legislative amendments and court cases constantly modify them. Some of the areas with the greatest changes include herbicide use, water runoff, demands on air and water quality, and invasive species control. A vegetation manager's job includes being aware of and responding to these changing laws, otherwise vegetation management practices may result in litigation.

Herbicides

State and federal agencies (e.g., EPA) strictly regulate herbicides and herbicide labels are binding legal documents; not just instructions. Herbicide regulations do not only pertain to their safe handling and use, but also to their transportation. Follow the label when using herbicides to help avoid litigation. Again, make sure that the current herbicide labels are on file, as regulations on herbicide use often change. Refer to current labels and Material Safety Data Sheets (MSDS) at: <http://www.cdms.net/labelsmsds/lmdefault.aspx>.

Some individuals are “hypersensitive” to pesticides that cause little to no reaction in other people. Almost all states have some type of herbicide sensitivity law or regulation and many maintain a registry of hypersensitive individuals that have requested no spraying. Often there is a mandatory process for commercial applicators to provide advance notice to these individuals when an application is to be made within 500 feet of their work, school, or residence. To minimize tort liability, vegetation managers must be careful to abide by application restrictions for the use of herbicides around any hypersensitive individuals. Deal with any hypersensitive request quickly and accurately and document all correspondence associated with the request.

Stormwater

In nature, water usually penetrates into the ground where it can be naturally filtered and cleansed before it enters streams or underground water supplies. When water from rain and snow melt cannot infiltrate into the soil due to manmade impervious surfaces, such as sidewalks, streets, highways, rest areas, and parking lots it results in stormwater. Stormwater can be a problem because it can pick up pollutants (oil, fertilizers, pesticides, soil, trash, and animal waste) and carry them into lakes, rivers, and the ocean. When uncontrolled, stormwater can also cause erosion, slope failures, and produce muddy water that may adversely affect aquatic life.

Structural devices, maintenance procedures, management practices, and activities are used to allow us to manage stormwater to protect beneficial uses, such as swimming, drinking water, recreation, and marine habitat. Structural

features include detention and infiltration ponds, wide grass ditches, swales, rain gardens, catch basins, and culverts. Maintenance operations include keeping highways cleaned of sand, litter, and debris that could make its way into streams and rivers.

Vegetation managers need to be aware of federal and state regulatory permit requirements regarding stormwater. As part of the federal Clean Water Act, Congress established the National Pollution Discharge Elimination System (NPDES), which requires those who discharge stormwater into surface waters to have a “permit.” Under the NPDES, pipes, ditches, and other conveyances that carry runoff from state highways and related facilities are considered municipal storm sewer systems. The agency responsible for stormwater permits varies from state to state, however it is normally an authority such as the “Department of Natural Resources” or the “Department of Ecology.”

6.2 Tort Liability

Many vegetation management activities are inherently dangerous, and the necessity to conduct some of them in traffic amplifies the danger. Inaction by an agency may also send it to court, because uncontrolled vegetation causes many safety problems. Transportation agencies need to be proactive about controlling invasive species to avoid the possibility of being out of compliance with state and federal laws.

When preparing a vegetation management plan, keep in mind that the plan can be used in court against the agency. Have the plan reviewed and approved by legal staff. Lawsuits can arise from many sources, including agency workers, the traveling public, adjacent land-owners, environmental groups, or regulatory agencies.

Some liability may be reduced by contracting some forms of risky work, such as mowing and herbicide application. However, contracting out is not an ironclad protection against liability as an agency is likely to be included in a lawsuit as the contract manager.

While each state has its own regulations, there are a number of federal laws that apply across the United States. Non-compliance with any laws can expose a transportation agency to tort liability. Some of the federal regulations that need to be complied with are listed below.

Environmental Protection Act (EPA)—Safe Drinking Water Act

The objectives of the Safe Drinking Water Act 14 (SDWA) are: the protection of public health by establishing safe limits, based upon the quality of tap water, for contaminants that may have an adverse effect on human health; and the prevention of surface and ground drinking water source contamination.

The Safe Drinking Water Act can be found at <http://www.epa.gov/safewater/sdwa/index.html>.

Clean Water Act

The Clean Water Act is the primary federal law in the United States governing water pollution. The full text of the Act—with amendments through 2006-01-11—is maintained by the California Water Resources Control Board at: <http://www.waterboards.ca.gov>.

Clean Air Act

The Clean Air Act is federal legislation relating to the reduction of air pollution. The clean air act can be found at: <http://www.epa.gov/air/caa>.

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

FIFRA is a federal law that regulates pesticides to protect applicators, consumers, and the environment. FIFRA establishes minimum national standards for the use of pesticides, and regulates the registration, production, and sale of pesticides. FIFRA grants primary, but not exclusive, enforcement responsibility for pesticide use to the states. States retain the authority to regulate the sale or use of any federally registered pesticide or device in the state, but only if state regulations do not permit sale or use of pesticides prohibited under FIFRA. The full text of the FIFRA is located at <http://www.epa.gov/oecaagct/lfra.html>.

Under FIFRA regulations, commercial applicators must keep and maintain routine operational records containing information on kinds, amounts, uses, dates, and places of application of restricted use pesticides. Records must be maintained and kept for a period of two years. This act can be downloaded from <http://www.epa.gov/lawsregs/laws/fifra.html>.

Occupational Safety and Health Act (OSHA)

OSHA is a federal law that was created to protect worker safety and health. The full text of the OSH Act in HTML format is located at <http://www.legalarchiver.org/osh.htm>.

Endangered Species Act (ESA)

The Endangered Species Act is designed to protect critically imperiled species from extinction as a “consequence of economic growth and development untendered by adequate concern and conservation.”

The Endangered Species Act of 1973 can be accessed through U.S. Fish & Wildlife Service at <http://www.nmfs.noaa.gov/pr/laws/esa/text.htm>.

Invasive Species Executive Order: Executive Order 13112

Executive Order 13112 established the National Invasive Species Council. The invasive species executive order can be found at <http://www.invasivespeciesinfo.gov/laws/execorder.shtml>.

Federal Noxious Weed Act

The Federal Noxious Weed Act of 1974 established a federal program to control the spread of noxious weeds. The Secretary of Agriculture was given the authority to declare plants “Noxious Weeds,” and limit the interstate spread of such plants without a permit. The Secretary has the authority to inspect, seize, and destroy products, and quarantine areas, if necessary, to contain or limit the spread of such weeds. This act can be found at <http://wildlifelaw.unm.edu/fedbook/fedweed.html>.

The Migratory Bird Treaty Act

The Migratory Bird Treaty Act implements conventions between the United States, Canada, Japan, Mexico, and Russia for the protection of migratory birds. Birds protected under the Act are not necessarily endangered. The Act provides that, except as permitted by regulation, it is unlawful to pursue, hunt, take, capture, or kill any migratory bird. Violation of the Act is a misdemeanor with penalties including fines up to \$500 and imprisonment up to six months. Federal courts have split on the question of whether intent must be present in order to impose liability under

the Act in cases where birds have been poisoned by pesticides. This act can be found at <http://www.fws.gov/pacific/migratorybirds/mbta.htm>.

6.3 Environmental Stewardship

Environmental stewardship means taking responsibility for and safeguarding human health and the environment to sustain or improve the quality of life for ourselves and future generations. Roadsides constitute a significant percentage of our land, and what we do with them can have great impact on our environment.

Roads and highways often follow streams, coastlines, and other natural landscape features, over and adjacent to many very sensitive and important environmental areas. How the roadside environment is managed is coming under increasing scrutiny by the public, resulting in regulations that vegetation managers must abide by. The more that can be done proactively to protect the roadside environment the better public image the agency will have, and the more leeway it will have to choose how to meet environmental laws, rather than complying with mandated procedures.

Prepare an environmental stewardship plan that will implement practices that improve water quality, protect the soil, increase biodiversity, create habitat for wildlife, and reduce the number of invasive weeds. The environmental stewardship plan should include partnerships with other external stakeholders, such as Ducks Unlimited, the Sierra Club, Native Plant Societies, local watershed groups, and ecosystem protection groups.

6.4 Customer Demands and Expectations

The general public expects a clean, clear, and safe highway for their tax dollars, and may complain when they perceive they are not getting that. The community now also expects improvements in management practices to protect the roadside environment from deterioration. There are increasing demands to restrict highway runoff that affects water quality, air quality, and individuals that are hypersensitive to herbicides (16, 133). Vegetation managers must be concerned about the aesthetics of roadside vegetation and this may include choosing herbicides that do not cause severe visual damage (brown-outs), or trimming trees at times of the year when the trimming will be less noticeable. To provide safe nesting sites for birds, the Migratory Bird Act mandates specific times that roadsides cannot be mowed.

Be aware of customer demands and expectations and either strive to meet them or educate the public to change their expectations. Customer demands and expectations can be modified by public awareness campaigns and other educational initiatives.

6.5 Public Communication and Involvement

For successful implementation of an IRVM plan, the public must be kept informed (14, 129). This can be done through public awareness campaigns using the media, seminars, brochures, agency internet sites, and rest area bulletin boards. Educational and informational literature needs to be developed and distributed to adjacent landowners, the general public, consultants, and contractors.

Another public concern which needs to be taken into consideration is how to manage vegetation when a landowner prefers different controls than the agency does. For example, some people wish to have the right-of-way in front of their property excluded from any kind of chemical application or have dangerous trees remain uncut.

The public needs to be educated on why and how roadsides are managed. They should be informed of the environmental benefits and cost savings associated with self-sustaining low-maintenance roadsides.

6.6 Partnership/Coordination with Stakeholders

It is often a good idea to partner and coordinate with other agencies or neighboring landowners when roadside vegetation management activities affect their programs. Goals for management of roadsides traversing federal and state forests, parks, and game lands can conflict with the stewardship of the landowners. It is best to involve them in the planning phase to increase the chances that they will accept vegetation management activities on or adjacent to their lands. Highways crossing their lands are often authorized by easements with title to the underlying land retained by the landowners.

Easement terms may legally restrict roadside activities. For example, merchantable timber removed from roadsides is required to be cut in standard log lengths and decked for later sale by the Forest Service under terms of easements for state highways on National Forest System lands.

Vegetation management programs can also be greatly enhanced through partnerships with stakeholders. Successful vegetation management programs bring together the public, citizen groups, researchers, and government agencies with an interest in the management of vegetation on roadsides.

Other agencies, such as universities and environmental groups may collaborate on research projects targeted at improving roadside vegetation management practices. Environmental groups, such as Ducks Unlimited, may be a fund source for roadside wetland projects that provide valuable habitat. Stakeholders can be enlisted to educate the public on the benefits of vegetation management in situations where what to the casual observer seems “poorly managed,” is in fact good management intended as wildlife habitat.

Partnering with the public (schools, businesses, service clubs, etc.) to establish “Adopt-a-Highway Programs” not only benefits a roadside program, but also fosters communication and good will between the agency and the community. In many states, courts and prisons can provide offenders sentenced to community service or inmates to help with rubbish removal and manual vegetation control.

These arrangements add staff to the roadside program, but require careful planning and outreach to existing employees and adjoining landowners to address their concerns about job security or personal security. The planning, security, and roadside safety required to utilize community service workers and inmates are a significant cost.

7.0 INCORPORATING VEGETATION MANAGEMENT AS A PART OF PROJECT DEVELOPMENT, DELIVERY, AND CONSTRUCTION

7.1 Planning (Scoping) Phase

Coordination of Planning, Design, Construction, and Maintenance

Transportation planning activities can occur at the planning stage or early in the design phase. The earlier a vegetation management concern is raised in the planning and design phase, the easier it is to address the concern. If a concern comes to light when design plans are in an advanced stage of detail, it will be more costly and time consuming to change.

In the planning phase, the agency should have good communication between field staff, vegetation management, and planning/scoping staff. With this communication, plans will reflect valuable information about problems and opportunities in the field. This communication also paves the way for ensuring detailed design does not result in features that are more costly to maintain after project completion.

An increasingly valuable tool for bringing vegetation management into planning and scoping are databases and GPS/GIS. Sometimes these resources are in a transportation agency, other times they are in natural resource or regulatory agencies. With this information, planners can look at a project and see if invasive species are within the limits and will add expense for control. They may be able to identify if a large number of hazardous trees will affect project cost and scope.

7.2 Design Phase

A key concept in roadside management is that roadway and roadside design should consider the full life-cycle cost of transportation improvements including the long-term cost of maintenance. The design alternative with the lowest initial construction cost may not be the best solution if this approach will include high recurring maintenance costs. Designers should strive to select design approaches that do not require extensive recurring long-term activities. A second key roadside management concept is that roadway and roadside design should contribute to the safety of DOT maintenance workers by incorporating techniques that eliminate or reduce worker exposure to traffic.

More specifically, these management concepts include the following techniques:

- eliminate the need for recurrent maintenance activities such as vegetation control, herbicide application, pruning, mowing, and graffiti removal;

- facilitate the automation of recurrent maintenance activities such as herbicide application, mowing, and litter collection;
- locate facilities that require recurrent maintenance activity outside the clear recovery zone, or within protected areas;
- provide safe maintenance worker access to facilities that require recurrent maintenance activity.

To implement this second roadside management concept, the following conditions must be considered in roadway and roadside design projects:

- Metal beam guardrail, including standard railing, terminal system end treatments, guard railing at structure approach and departures, and at fixed objects should include vegetation control. For more detailed information regarding placement of vegetation control, consult with both the District Landscape Architect and District Maintenance.
- Thrie beam barrier, which includes single, and double, at structure approach and fixed objects should include vegetation control.
- Unpaved narrow strips often result from the construction of noise barriers or concrete barriers beyond the paved shoulder edge. Unpaved strips 4.5 meters or less in width, parallel and immediately adjacent to the roadway, should be paved to the barrier or wall. Paving these areas eliminates the need for manual vegetation control, and allows automated equipment to remove litter and debris.

In areas of new construction, quality existing topsoil should be stockpiled and spread during the final stages of construction. The native brush should be crushed or chipped and mixed with the stockpiled soil to maximize natural or organic matter in the soil. Since topsoil contains beneficial microorganisms and seed, it is best to stockpile it in shallow windrows and plant with temporary erosion control so that oxygen can penetrate the soil.

Designers should aim to protect as much of the existing vegetation as economically practical, and aim to revegetate with locally adapted species when soil has been disturbed (U.S. Department of Transportation, Federal Highway Administration; U.S. Environmental Protection Agency).

They need to be aware of landform, vegetation, and structures when planning for long-term vegetation management on their roadsides. They should design roadside grades to accomplish operational, environmental, and visual functions. Some of the factors that designers need to consider are water runoff, erosion control, wetland preservation, vegetation, and visual impact (6). Designers should also design medians, shoulders, and other roadside areas so they can be managed safely and efficiently. Maintaining steep slopes, for example, can be costly and dangerous.

Vegetation is often used to blend landform into the surrounding area. Restoration is necessary in areas disturbed by construction. Native or adapted species are selected that are suitable for each zone and compatible with existing surrounding vegetation and expected volunteer growth (117, 294). Structures (noise barriers, retaining walls, utility structures, vegetated earth walls, etc) can be designed to blend with the roadside character, and vegetation is often used to soften their appearance (122).

The selection of locally adapted hardy species that self propagate can greatly minimize roadside vegetation management costs over a project's lifetime.

If the agency has not already done so, it should develop specifications and quality assurance/quality control (QA/QC) processes to reduce the likelihood that equipment, soils, seeds, mulch, or other materials are contaminated with invasive species seeds, roots, or rhizomes.

The long-term success of vegetation in project designs depends on the agency's ability to manage vegetation. Designers should work with maintenance staff to determine if adequate equipment, materials, and staffing are available to maintain vegetation designs.

Design Acceptance

Before construction, designs should be reviewed by the vegetation manager and all stakeholders.

7.3 Construction Phase

The establishment of permanent vegetation is made difficult if the contractor has removed the topsoil and replaced it with nutrient and organic matter deficient subsoils. It is critical to monitor projects during soil removal and replacement and assure that the topsoil is conserved. Try to preserve as much native or natural vegetation during construction.

Erosion on roadside construction sites is a serious problem. Erosion, which produces sediment, is accelerated when soil is disturbed or left bare and exposed to wind and water. The potential for erosion in roadside construction areas can be 100 times greater than on agricultural land and the delivery rate to receiving waters is much higher. Matting may be used to prevent soil erosion until permanent vegetation can be established.

Compaction is the other serious issue facing roadside construction projects. It occurs when soil particles are pressed together. As soil particles are squeezed together, soil density increases and pore space for air and water are reduced. Lack of pore space in the soil reduces water intake and movement throughout its layers. Compaction also limits root growth and the biological diversity of the soil. These problems are compounded when organic matter content is lost by topsoil removal. Soil compaction can lead to low infiltration rates, increased erosion and stormwater runoff, decreased water quality due to more polluted runoff, and increased flooding. Compacted soil is problematic when trying to establish vegetation. It is essential that exposed land and compaction be minimized during roadside construction.

If existing vegetation is being retained or permanent vegetation is being established at the time of construction, then it must be protected from construction operations. Tree guards can be used to help protect limbs and trunks during construction. Agency construction managers should block off an area around brush and trees to protect the trees from damage, and to protect the roots from soil compaction or damage. To calculate the area needed to protect tree roots, use the critical root radius, a formula based on field experience that approximates the extent of a root system. For every inch of tree diameter, it is necessary to protect 1.5 feet of ground beneath the tree; so a 10-inch tree would have a critical root radius of 15 feet, well beyond the edge of the tree crown. If roots, trunks, and limbs are not protected during construction, the damage can make the tree hazardous in the future, threatening traveler safety and requiring staff and money to remove.

Construction inspectors should use specifications and QA/QC processes to ensure contractors are not introducing invasive species to the construction site. Herbicides may be necessary to manage invasive weeds during construction.

Project Acceptance

Final project acceptance should be done jointly by the contractor and the vegetation manager.

7.4. Maintenance Acceptance

Soil improvement and plant establishment must be addressed through the design and construction process before maintenance takes responsibility of the roadside (298).

8.0 ROADSIDE VEGETATION MANAGEMENT ZONES

It is useful to define roadside vegetation management zones for the purposes of planning management activities. The National Roadside Vegetation Management Association (NRVMA) originally developed a zoning system for describing the roadside, a practice which has been widely adopted. Some agencies divide the roadside into three management zones and some into four management zones. A recommended three zone management concept is depicted in Figure 8-1. Approximately half of the agencies surveyed use the zone concept in their vegetation management programs.

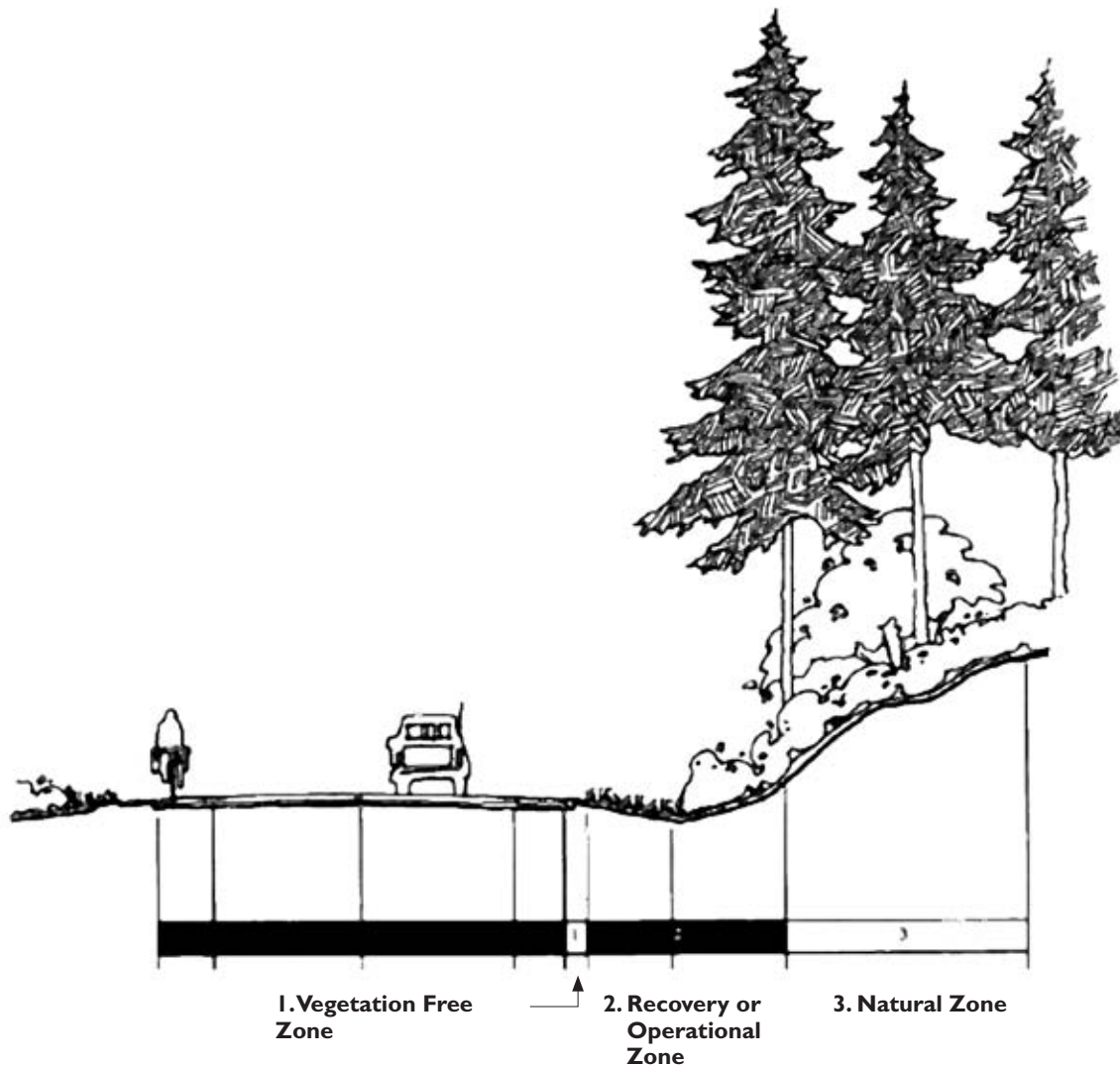


Figure 8-1. Roadside Vegetation Management Zones (diagram adapted from the WSDOT 3 zone system)

8.1 Defining Roadside Vegetation Management Zones

Zone 1—Vegetation Free Zone

Zone 1 is a vegetation-free gravel or paved shoulder, usually maintained as a one to three foot wide strip to provide for maintenance, operational, safety, and pavement and guardrail preservation needs (296). The zone is kept bare to provide surface drainage, reduce the fire potential, provide sight distance for passing and stopping at intersections, and prevent pavement destruction by vegetation. An alternative to keeping zone 1 vegetation free is to manage this zone with 2–6 inches of ground cover. This zone is kept vegetation free through the use of grading, herbicides or vegetation barriers, or is managed so vegetation is kept low to the ground (2–6 inches).

Zone 2—Operational Zone

Zone 2 provides sufficient space for the driver of a vehicle to regain control of an errant vehicle and return it to the road.

In addition, Zone 2 is managed to

- maintain sight distance at corners and intersections,
- provide clearance for signage,
- maintain hydraulic capacity of ditches,
- eliminate hazard trees,
- prevent erosion and stabilize the road shoulder, and
- accommodate underground utilities.

This is done by encouraging growth of stable, low-growing, desirable plant communities, removing trees with a trunk diameter greater than 4 inches, and controlling noxious weeds. This zone is managed via mowing, selective herbicide and plant growth regulator use, and some brush control. Grasses and low growing forbs are most suitable for this zone.

Zone 3—Natural Zone

Zone 3 is the natural zone, and is generally maintained as a self-sustaining plant community to minimize erosion as well as the growth of weeds, undesirable trees, and brush (14, 183, 296, 298). The natural zone can be used to conserve and promote native plants and wildflowers, preserve wetlands and wildlife habitat, accommodate utilities, prevent erosion, and blend or screen highway surroundings to ease driver fatigue.

This zone abuts adjacent landowners. When houses or buildings are present, neighbors are likely to press vegetation managers for assistance in removing hazard trees and invasive species. In forests, the natural zone may be managed as “shaded fuel breaks” where tree crowns do not touch, preventing fires from spreading through the tree tops.

Zone Discussion: Conclusion

This zone is maintained as a self-sustaining plant community of native and well-adapted species. This will include trees and shrubs in forested areas. However, if landowners are on the other side of the right-of-way, more intensive management may be required to remove or control noxious weeds, invasive species, unwanted vegetation, or hazardous trees.

On some rights-of-way, an agency may need to prune or remove hazardous trees in Zone 3 that could reach the highway. In many situations, one or more zones do not exist on a roadside. In addition, some roadsides present unique situations where special consideration must be used to manage vegetation, such as rest areas, landscaped areas, environmentally sensitive areas, and areas where neighbors have special concerns.

8.2 Defining Linear Areas

Incorporating the zone concept in a linear environment will allow adjustments in IRVM strategies as the road transitions through different ecoregions. GPS and GIS systems can be an invaluable tool for managing roadside vegetation. This will provide a backbone that can be used to overlay vegetation asset inventory and condition assessments.

8.3 Other Management Areas

There are many areas that do not neatly fit into the zone concept. These include unpaved median strips and auxiliary facilities, such as rest areas, roadside parks, viewpoints, heritage markers, pedestrian and bicycle facilities, wetlands and their associated buffer areas, wetland mitigations, rest areas, overlooks, stormwater treatment facilities, park and ride lots, quarries and borrow sites, entrances, and urban interfaces. It is a good idea to inventory these areas and create written plans for how they will be managed. In developing such a plan, consider how the area relates to adjacent right-of-way and neighboring landowners.

9.0 ESTABLISHING VEGETATION

9.1 Establishing and Maintaining Vegetation

Increased traveler safety, roadside beautification, enhanced wildlife habitat (155), and reducing mowing and herbicide costs are major benefits of establishing and maintaining sustainable vegetation along roadsides. Programs can save a significant amount of money in the long-run if they can select hardy, adapted vegetation that need minimal maintenance and inputs.

Beauty is perceived differently by different members of the public. To many, an attractive roadside consists of a well maintained turf, colorful wildflowers, or locally adapted trees and shrubs that block the view of unsightly roadside facilities. Others find an unmanaged natural habitat for wildlife to be aesthetically pleasing.

Vegetation managers should consider the goals for each road section and develop vegetation management practices that successfully achieve these objectives. Roadside vegetation that is native to the surrounding region, yet still achieves the safety objectives necessary, will most likely provide wildlife benefits and is the best and most self-sustaining strategy. In the agencies surveyed, managers favor grasslands on the roadside because they provide improved visibility and are obstacle-free. Integrated roadside vegetation management encourages a self-sustaining community that minimizes the cost of management by reducing the need for mowing, herbicide usage, or other inputs.

9.2 Weed Management Before Revegetation Efforts

Weed management techniques are necessary to improve the establishment success of native or non-native revegetation efforts in highway rights-of-way programs. In most cases, including a weed management program can be the difference between success and failure for establishing a roadside stand of native species. Roadside revegetation projects that do not incorporate weed management efforts have far greater potential for reverting back to stands of the preexisting weeds. The use of broad spectrum (pre-emergence) and selective (post-emergence) herbicides are the most useful chemical management tools for weed reduction. While pre- and post-plant weed control is needed for establishing revegetation species along roadsides, persistence of these species, once established, can occur with minimal management and provide long-term weed suppression.

The use of integrated management strategies in restoring a stand of desirable roadside species allows for the maximization of different treatment effects. A combination of treatments can provide a broader spectrum of weed control, reduce the risk of selecting for herbicide-resistant weeds, and increase the rate of establishment or regeneration of desirable species along roadsides.

9.3 Native Plants in Revegetation Programs

The natural beauty of wildflowers and native plants can be a powerful promotional tool for roadside programs (126, 153). Most citizens appreciate a natural look in vegetation and often desire to establish natives along roadsides adjacent to their residences. In addition to native species, other non-invasive plants can also be considered in roadside revegetation programs. The best choices for native or non-native roadside vegetation will be the species that suit the needs (e.g., low growing, fire resistant, etc.) and are the best adapted and most competitive on a roadside. The most effective species for roadside vegetation should also be capable of crowding out most other plants and should require minimum management inputs. National Cooperative Highway Research Report 20-5, 33-04, *Synthesis of Highway Practice: Integrated Roadside Vegetation Management* found that the use of native plants in construction or restoration of roadside vegetation patterns was mandated by policy or state laws in more than 40 percent of the reporting states. Information on native or well-adapted, non-native species can be obtained from vegetation experts in the agency or from agencies that work with agriculture, game, forestry, or the environment.

Advantages of Natives

Roadsides dominated by invasive species generally require much higher maintenance, including regular intensive mowing and herbicide treatments, compared to roadsides with more functionally suitable vegetation. Native perennials along highway rights-of-way can have many characteristics that make them a desirable choice in revegetation efforts. In addition to decreasing long-term maintenance costs through a reduced need for herbicides, mowing, and other weed control measures, native species are also aesthetically more attractive to the informed motorist, provide habitat services to the resident wildlife, and stabilize the site by reducing weed growth and disrupting weed corridors. In areas where invasive species are dominated by annuals, native perennials can prevent erosion, reduce fire hazard, provide higher quality forage for native animals, remain green longer into the season, and persist for many years.

Disadvantages of Natives

While native plants are the desired vegetation along most roadsides, they can be difficult to establish and are often poor competitors with invasive or weedy species in their early stages of growth. The conditions that can limit the success of native plant revegetation efforts include topography (steepness, slope, and aspect), soil (shallow, rocky, compacted, and chemical imbalances), climate (region, seasonal variation), existing vegetation (competition, invasion), and continued impacts (traffic, maintenance activities). In addition, revegetation efforts with native species can be more expensive compared to other non-native restoration plants or passive restoration programs. Furthermore, improper selection of native species and inappropriate seeding timing along a roadside can also compromise the success of establishment.

9.4 Sustainable Landscapes

Many state DOTs have conducted roadside revegetation research, but the number of studies on maintenance of sustainable roadside vegetation communities is limited. Successful establishment and sustainable maintenance of revegetation communities is much more likely when roadsides remain undisturbed. Disturbance has a strong negative impact on the persistence of native perennials. Continued disturbance through excessive travel; prolonged inundation; nonselective herbicide applications; roadside grading, disking, and low mowing height; and scalping along road edges, shoulders, swales, and backslope zones can quickly result in dominance by invasive species. Long-term maintenance and management plans should recognize the potential impacts of disturbance on the persistence of native communities along roadsides.

9.5 Choice of Species

Large-Scale Selection Criteria

The zone concept was introduced in Chapter 8 and can be applied to help select the right plant for a specific location. The vegetation requirements for each zone are different, as the plants perform different functions.

Vegetation that is suitable for one zone may not be appropriate for another. For example, in Zone 2, low-growing, self-sustaining grasses and forbs can be most effective and can help reduce maintenance costs. In the northern states, salt tolerant species are desirable because salt is often used on roads for snow and ice control (129, 262). In fire prone areas, the most appropriate choice are plants that stay green in summer months. Plants that fit all program needs are the best choice, including the need to be aesthetically pleasing to the public. The visual impact of low-growing species should be considered when planning revegetation programs. Nurse crops may be useful in the establishment of sustainable vegetation. Once sustainable vegetation is established, it will probably be necessary to adjust herbicide and mowing programs.

Small-Scale Selection Criteria

Each native or non-native plant species used in a revegetation program displays a microhabitat preference for particular roadside topographic positions. Individual species have an optimal microhabitat within the roadside topography. For example, soil moisture availability in roadside topographic zones can vary greatly between the shoulder, backslope, and swale with respect to soil type and moisture availability. The placement of the desired species in the correct area may determine whether the plant can successfully establish. This should be considered when developing a revegetation program.

Before establishing sustainable vegetation, it is wise to assess the conditions of the site under consideration. Some examples that should be assessed include

- existing vegetation,
- soil conditions,
- topography,
- roadway traffic,
- adjacent land use,
- water availability and location,
- amount of uncontrolled vegetation on right-of-way (ROW),
- potential tree hazards, and
- growing season.

These attributes will enable the selection of appropriate planting procedures and maximize the chances for success.

9.6 Revegetation Techniques

Revegetation projects can involve either active or passive restoration methods. Passive restoration utilizes natural recruitment of desirable species from the residual community or seed bank, whereas active restoration requires introducing desirable vegetation into the area through seeding, plug or pole planting, or other methods. Passive

restoration is considerably less expensive, compared to active restoration, but can be limiting in the choice of available species.

Revegetation methods can also be important in the potential success of a project. Woody species from stem cutting can be established by pole plantings, but the site must have available water for a long enough period to allow root development and establishment. Perennials can also be introduced through plug planting, but again, they must have adequate water to allow establishment. These two techniques can be expensive, but under the right conditions will have a high potential for success. For species that require seeding into the sites, this can be accomplished by broadcast, drill, or hydroseeding. Of the three techniques, broadcast seeding is the easiest and least expensive, but also has the lowest probability of success. Drill seeding has the highest degree of success, but is more difficult to accomplish along roadsides. In addition, the seeding method cannot be used in rocky soils or in areas with rugged terrain. Hydroseeding is the most common method of revegetating by seed and generally includes a mixture of water, seed, fertilizer, and mulch material. While this technique can be used in most situations and is more expensive compared to broadcast seeding, it has a much higher rate of success. The most appropriate technique to use in a revegetation program will depend on the site conditions, species desired, and seasonal timing.

10.0 BASIC PLANT BIOLOGY

10.1 Integrated Roadside Vegetation Management (IRVM)

Integrated Roadside Vegetation Management (IRVM) begins with planting and establishment of sustainable vegetation, and uses cultural, mechanical, biological, and chemical methods to maintain that vegetation (161, 162, 183). To create an effective IRVM plan, it is essential to inventory and assess the current condition of vegetation on roadsides. Roadsides vary dramatically from site to site and IRVM plans are most effective when site specific (45).

IRVM aims to establish and maintain desirable plant species and remove undesirable species. To do this it is important to identify the species being managed, and understand the biology of the vegetation system to be managed. Knowledge of the response of the species within the system to herbicides, mowing, and other control measures will greatly assist in the selection of detailed management practices.

Weed prevention and erosion control are two primary objectives of roadside maintenance, and both can be accomplished through the use of native grasses and wildflowers or other adapted vegetation (U.S. Department of Transportation, Federal Highway Administration) (117, 126, 129).

A weed is a plant growing where it is not wanted. From a roadside vegetation manager's perspective, a plant with any of the following characteristics can be considered a weed:

- any plant which causes a decline in the predominant roadside desirable grass species;
- any plant which, because of its height, creates a sight distance problem;
- any plant which causes destruction of any road surface, bridge, or other roadside structure;
- any plant which has negative significance in the agriculture industry; and
- any plant which has been included on the state's Noxious Weed List.

10.2 Biology of Weeds

Understanding the basic biology of weeds can be critical to developing effective short- and long-term management programs. A simple definition of a weed is a plant that has negative economic, health, or aesthetic value. For right-of-way weeds, their impact can be associated with the function and maintenance of the right-of-way, obstructing vision of signals, signs, crossroads, and other cars; preventing inspections; creating fire hazards; causing communication and power interruptions; providing cover for rodents; and restricting drainage into ditches and channels.

The majority of troublesome weeds in the United States are not native to the areas they inhabit; however, even native plants can be roadside weeds if they are in the wrong place. Non-native weeds have arrived either intentionally as ornamentals, food sources, forage species, and as erosion control, or accidentally as contaminants of seed, soil, clothing, and equipment. Most weeds were introduced from Europe, but many weeds are native to other continents.

Their introduction and distribution along rights-of-way has largely been associated with human movement, primarily via movement of vehicles, equipment, and soil.

Most states have regulatory lists of weeds referred to as noxious weeds. These can be weeds of agricultural areas, natural areas, or rights-of-way. Other lists, without regulatory authority, are published by various organizations, particularly non-profits such as the Exotic Pest Plant Councils or Invasive Plant Councils. These inventories of invasive weeds can overlap with the state noxious weed lists or contain plants not found on state lists.

Plant biology covers many different disciplines, including plant classification, anatomy, morphology, physiology, genetics, and ecology. Weed managers can use information from all of these disciplines to develop more effective weed control methods. This chapter provides the most pertinent information on the biology of weeds to assist in developing weed control strategies.

10.3 Weed Classification

There are several ways to classify plants, depending on the utility of the classification system. For the botanist, classification based on ancestral similarity is most useful. For the gardener, perhaps classification based on growth form or life history is more important. For the wildland manager, systems based on the habitat of the species are more practical. Weed managers and right-of-way applicators, however, should be familiar with all of these classification systems, as each will be useful in planning control measures. Some different methods of classifying weeds are discussed below.

Ancestral Relationship

Taxonomists classify plants based on their ancestral relationship so that species evolutionarily related are generally classified in hierarchical groups, such as family, genus, and then species. There are higher levels of classification, but these are rarely used by anyone except professional systematists. From a practical standpoint, it is important to know the family of the weed to be controlled, for example: a grass (Poaceae), sedge (Cyperaceae), legume (Fabaceae), mustard (Brassicaceae), composite (Asteraceae), etc. Control strategies, particularly with selectivity of herbicides, can be very much related to the family of the target weed.

The family, genus, and species of a weed can be found in floras of a particular region. Some floras are very broad, such as the *Flora of North America*, others can be very regional. Floras can include all species within an area, including native and non-native plants; others can be very specific and include only weedy species. Typically, flora of states or regions can assist in identification of a plant by including dichotomous keys. A dichotomous key is a tool that can allow the user to determine the identity of plants. It consists of a series of choices that lead the user to the correct name of a given plant. "Dichotomous" means "divided into two parts." These keys are hard to use for untrained vegetation managers or even botanists. Weed floras often contain color photos, which are much easier to use for identification, but may not always be accurate because they are not usually complete. More recently, computer-based identification systems have been developed for weeds. These are considerably easier to use by practitioners compared to dichotomous keys.

Generalized categories can also be very useful for right-of-way managers. For example, classification systems that include ferns or fern-like species, grasses, sedges, broadleaf forbs, vines, shrubs, and trees are loosely based on taxonomic relationships, although vines and woody species are very diverse taxonomically.

Fern and Fern-Like Species

These species are more primitive evolutionarily than flowering plants. They reproduce by spores or creeping rhizomes. In general, though not always, these species are perennials that prefer moist habitats, particularly the horse-tails or scouring rushes (*Equisetum* spp.).

Grasses

Grasses are monocots, one of two major groups of flowering plants, typically having one seed leaf, that produce only one obscure cotyledon (the primary or rudimentary leaf of the embryo of seed plants) after germination. Grasses represent the most important group of plants in the world, not just as weeds, but also as food sources. They are characterized by having narrow and upright leaves with parallel veins. Annual grasses all have a fibrous root system, and the vast majority of perennial grasses have either creeping rhizomes, stolons, or are bunchgrasses. The growing point of grasses is generally close to the soil surface and this can play an important role in the activity of various weed control tools, including mowing, other form of physical removal, and herbicides. Grasses can also be categorized as “cool” or “warm” season based on their typical peak growth season.

Sedges

Sedges resemble grasses. Some have triangular stems, such as the nutsedges, but others have no leaves, or leaves (e.g., bulrushes) or stems that can resemble grasses. Sedges often grow in moist or even wet soils and can be annuals or perennials. Perennials can produce tubers or spread by creeping rhizomes.

Broadleaf Forbs

Broadleaf forbs are dicots; usually with two conspicuous leaf-like cotyledons visible shortly after germination. Unlike grasses, they usually have broader leaves with a net-like venation pattern. The growing points of broadleaf species can be close to the soil surface when plants grow as rosettes, but are more often in the axis of the leaves above the soil. This can influence the effectiveness of mowing or herbicide control programs because these meristems are more susceptible to damage from these techniques. Broadleaf forbs can be annuals with fibrous or taproot systems, or perennials with many different vegetative reproductive structures. Broadleaf forbs do not have woody stem tissues and typically die back to the ground each winter.

Vines

Vines can be either herbaceous or woody broadleaf species. Although most are perennials, some can be annuals. They are characterized by having twisting stems or structures on the stem that allow them to cling to objects. This allows them to grow and climb on poles, signs, signals, fence posts, other vegetation, and roadside structures.

Woody Species

Woody plants can be classified as either shrubs (brush) or trees. Shrubs have multiple stems, none of which are dominant, whereas trees have a single dominant stem and typically grow taller than shrubs. Both, however, have woody stem material with bark. All woody species are perennial, but some remain green year round while most are deciduous during the winter months. Woody species can also include conifers, such as pines and firs.

10.4. Life Cycle

Weeds and other plants are often classified by how long they survive. This can be very important in developing a management program. The primary categories include annuals, biennials, and perennials.

Annuals

Annuals complete their life cycle from germination to death in less than one year. Annual weeds are the most important in agricultural systems. Annual weeds normally reproduce from seed, and are often heavy seed producers, particularly in climates with a long growing season. Annuals can be further classified as **winter** or **summer** annuals, depending on the time of year they germinate. Winter annuals germinate in the fall or early winter, and flower and set seed in the spring to early summer. There are exceptions to this, however. Yellow starthistle is a winter annual that flowers towards the end of the summer or even fall. Summer annuals germinate in the spring or early summer and set seed in late summer to fall. In milder climates, winter and summer annuals can overlap and many species can act as both. Annuals are often easier to control than perennials, but seedbanks can persist for very long periods, requiring continuous efforts over many years.

Biennials

Biennials live longer than one year but less than two. During the first year, they germinate and grow vegetatively, often into a rosette. Biennials usually overwinter as a rosette, which can often lead to their confusion as annuals. Vegetative growth resumes in the spring and floral initiation begins. After flowering and seed production, plants senesce (mature) and die. Biennials are often large plants when mature, and have large, fleshy roots. Some annual plants can act as biennials in mild climates and persist into the second year. There are no grasses with a biennial life cycle. Control efforts are more effective when directed at the first year growth, but these rosettes may be difficult to see, so often control is initiated after the plants have bolted (become reproductive) in the second year.

Perennials

Perennials are plants that live longer than two years and may reproduce several times before dying. They can appear as annuals in the first year after emergence and at this time they are much easier to control. However, they quickly develop underground storage organs that allow them to survive through the winter. Some perennials reproduce only by seed. These plants generally have thick, fleshy taproots where food reserves are stored, and have the potential to regenerate into a new plant if the shoot portion of the plant is removed. They are also characterized by new growth occurring each year from the same root system.

Many herbaceous perennial species reproduce by rhizomes, tubers, stolons, bulbs, corms, or budding roots, in addition to sexual reproduction. Like seed, vegetative propagules (roots, stems, stolons, bulbs, etc. that can give rise to new plants) also can be moved from site to site by vehicles and roadside implements.

Woody perennials are characterized by stems which persist from year to year and undergo secondary thickening. Woody perennials are common in non-crop and forest areas. In some cases, mechanical removal of the stems will not result in removal of a woody plant. However, these species are generally not considered weedy or invasive. Most invasive woody perennials have the ability to resprout from the base and quickly take over the area, often becoming even more widespread.

10.5 Growth Stages

All plants go through four growth phases, including the seedling, vegetative, reproductive, and mature stages. The seedling phase extends from the appearance of the first cotyledons to the first few true leaves. Plants in this stage are most vulnerable to weed control techniques. For example, the cuticle layer is thin so herbicides can more readily penetrate, and the root systems are smaller and easier to kill. Rapid growth of the plant occurs in the vegetative

stage. In this phase, photosynthesis rates are high, as is water uptake. Perennials are developing their vegetative reproductive structures during the vegetative stage. In some cases, particularly with annuals, plants become more difficult to control compared to the seedling stage. During the reproductive stage, vegetative growth is limited as resources are being used to produce flowers, fruit, and seeds. Water and photosynthetic products (sugar) are being directed to these structures rather than the roots and underground structures. During this phase, control of perennials is difficult with systemic (translocated) herbicides, as little chemical will reach the below ground reproductive structures. At the mature stage, growth has stopped and plants are often translocating energy molecules to the below ground reproductive structures in perennials. This is the ideal time to apply systemic herbicides, as a higher percentage will move to the below ground structures for activity in the following spring. In comparison to perennials, annual plants are senescing and dying during this period and control methods are not needed unless designed to reduce fire hazard or provide access to an area.

10.6 Anatomical and Morphological Structures

There are many different types of plant cells that perform a variety of different functions. When plants reach maturity, some cells are still living (contain cytoplasm), while others are dead. All nonliving parts of plants, including cell walls, intercellular spaces, and nonliving cells, are called the apoplast, while all living portions of the plant, including the cytoplasm of living cells, are called the symplast. In general, water and other soluble compounds can flow freely through apoplastic regions of a plant, while flow into symplastic regions is regulated by the cell membrane. To kill a plant, the symplast must be disrupted. Herbicides exert their effect on plants by disrupting specific cellular and molecular sites and processes.

The process by which herbicides move in plants is dependent on the chemical properties of the specific herbicide. Some herbicides move primarily in the apoplastic tissues; which typically means the xylem. Others move in the symplast, or phloem. All phloem mobile herbicides also have the ability to also move in the apoplast.

Phloem Mobile Herbicides

Phloem mobile herbicides move in the same manner as carbohydrates (sugars). After carbohydrates have been produced in the leaves, they must be transported to zones of either use or storage. The translocation of carbohydrates within plants is explained by the source-to-sink theory, in which “sources” are areas of production (photosynthetically active leaves), while “sinks” are actively growing shoot tips. Sinks include developing fruit, flowers, or seeds; actively respiring roots; or underground storage structures such as rhizomes, bulbs, or other vegetative reproductive structures. Certain foliar-applied herbicides that are able to penetrate the plant cuticle must enter the symplast by passing into the cytoplasm of epidermal cells; from there they may be translocated throughout the plant by way of the phloem.

In early spring, when new shoots are being produced from perennial root systems, underground organs may act as a source, as food substances are translocated to actively growing parts of the plant. During flowering, which requires large amounts of energy, stored underground carbohydrate reserves are generally at their lowest point. Later in the year, when leaves are producing carbohydrates for storage, the same organs may act as a translocation sink. Winter dormant periods are when stored reserves are highest. This seasonal cycling of translocation and stored food reserves is important to consider in weed control, for it regulates both movement of herbicides throughout a perennial plant and regeneration of shoots following damage to roots.

For control of annual plants, the movement of systemic herbicides is not as critical, but for control of perennials it can mean the difference between poor and excellent control. The best control of perennials is generally achieved when phloem mobile (systemic) herbicides are applied while the carbohydrates are translocating to the below ground reproductive tissues. This usually occurs after flowering and reproduction in late summer or early fall.

Xylem Mobile Herbicides

When stomata remain open on the leaf surface, CO₂ uptake can occur for photosynthesis. However, open stomata also allows loss of water vapor. This process, called transpiration, regulates the temperature of the leaf, which is cooled as water evaporates. However, as more and more water is lost through open stomata, stomata eventually close to prevent too much water loss. The need for CO₂ for photosynthesis must be balanced with the loss of H₂O through transpiration. As a result, relatively large amounts of water must be supplied to plants from the roots for maximum productivity.

Long-distance transport of water, mineral nutrients, and xylem mobile herbicides in plants occurs in response to water-potential gradients produced by transpiration. As water evaporates from a plant surface, more water moves to that surface to fill the deficit, effectively pulling water and dissolved substances through the plant from the soil to the leaves.

Water, nutrients, and soil-applied herbicides enter roots through root hairs and move towards the vascular cylinder largely through apoplastic walls and spaces. At a layer of cells called the endodermis, however, movement of any water solution through cell walls is restricted by a waxy-like structure called the Casparian strip. Water, minerals, and herbicides must move across the cell membrane into the cytoplasm of the cells in order to reach the xylem. Thus, everything entering the vascular tissue, including herbicides, must first pass through the filtering process of the cell membrane before it can be transported throughout the plant. Once past the waxy barrier, water and nutrients move into the xylem tissue and are transported apoplastically upward through the plant. Although water is used by plants for metabolic processes, growth, and storage, most of the water that moves through plants is lost through transpiration. Since water is primarily transported to the leaves, most herbicides that translocate in the xylem act on processes that occur in leaves. The most common of these processes is photosynthesis. For this reason, the majority of xylem mobile herbicides are photosynthetic inhibitors.

10.7 Plant Growth and Development

Plant growth is characterized by both cell division and cell elongation. These generally occur in the root and shoot meristems. The differentiation of cells into specific tissue types also occurs near the meristems. Herbicides that prevent growth must ultimately accumulate near the meristems. These types of herbicides are nearly always translocated in the phloem.

Plant development occurs just after cell elongation and is where cells become organized into the tissues that will function in mature plants. This can be epidermal tissues, vascular tissues, photosynthetic cells, or other cell types. The most critical time in the life cycle of a weed is from germination to establishment.

Seeds and Germination

Even during storage, a seed is a living unit composed of three basic parts: an embryo, a source of food (endosperm or cotyledons), and an external covering, or seed coat. Food is usually stored in the cotyledons of dicots and the endosperm of monocots. As long as the seed is relatively dehydrated, it remains dormant. It is alive, but all meta-

bolic processes are occurring at very slow rates. To activate the plant embryo, seeds of most species need only to be saturated with water and placed in a suitable environment.

This process is called germination and occurs in the soil. Most weed seeds, in contrast to crop seeds, also require light for germination, which therefore occurs at or near the soil surface. Once the microenvironmental conditions that allow germination to proceed are met, further events occur within the seed that allow the seedling to develop. Germination of the seed is characterized by the emergence of the root. During the early development of the seedling, the energy is obtained from the endosperm and the cotyledons, but after the development of the first true leaves, the plant gets its energy from the environment by photosynthesis and the roots now absorb water and minerals from the soil. While dry seeds in the soil are difficult to kill, there are many steps in the process of germination that may be disrupted.

Growth

As the seed germinates, the emergence of the primary root, or radicle, from the seed usually occurs first in both dicots and monocots, followed by the expansion of the seedling shoot. Both organs grow rapidly. Both the root and shoot tip have meristems where new cells are continually produced by cell division. Rapid growth of both the root and the shoot of a seedling occur with the elongation of newly produced cells from the meristem in a process called primary growth. As the plant grows, specific zones develop immediately behind the meristems that are physically and physiologically different, in a process called differentiation. The cells in these zones become specialized into tissues and organs to perform specific functions. Throughout the life of the plant, primary growth continues by means of cells that are continually produced in the meristems. Following primary growth, additional cells are produced in many dicot plants from the vascular cambium, a cell layer between the xylem and phloem, resulting in an increase in diameter of roots and stems. This type of growth, called secondary growth, is characteristic of perennial plants, especially woody ones. Stems of monocots are primarily herbaceous, while those of dicots may be either herbaceous or woody.

Emergence and Establishment

Shoot emergence patterns from the soil are of two principal types. Epigeal emergence, typical of many dicots, occurs when cotyledons are carried above the soil surface during emergence, while hypogeal emergence, typical of grass plants, occurs when cotyledons remain below the soil surface during emergence. In most dicots, within a short time after germination the shoot apex is elevated completely above the soil surface. In monocots, the shoot emerges from the soil with the apex and surrounding leaves encased in a sheath, called a coleoptile. Unlike dicots, the internodal regions do not elongate immediately and the shoot apex remains close to the ground. The shoot apex of monocots typically lengthens just before flowering. Thus, at the seedling stage, the meristems of most dicots are exposed above the soil surface, while those of monocots are well protected at the base of the plant. These characteristics are important to consider in weed control, particularly herbicide placement decisions.

10.8 Environment and Plant Growth

The environment of a plant is the summation of all living (biotic) and nonliving (abiotic) factors that affect the growth, development, and distribution of the plant. The biotic portion of the environment includes microbes, animals, and other plants, whereas the abiotic components include soil, water, nutrients, and climatic conditions. The environment is often divided into the macroenvironment and the microenvironment. The macroenvironment is the broadscale regional environment, which includes many aspects of soil and climate such as overall light intensity, precipitation patterns, and temperature. The microenvironment is the smaller-scale aspect of the environment that is influenced by the presence of objects (rocks, soils, and other vegetation) and by topography.

Factors in the environment that influence plant growth are usually divided into two categories, resources and conditions. Environmental resources are consumable and include light, CO₂, water, nutrients, and oxygen. In contrast, environmental conditions such as temperature, soil pH, and soil bulk density (compaction) are not directly consumed. Plants respond directly to the resources and conditions in their surrounding microenvironment. Thus, the physiological and morphological characteristics of plants will vary according to the specific microenvironments in which they occur. Even though the macroenvironment may be relatively constant from year to year, the microenvironment often is not; thus, plant responses can be expected to vary from growing season to growing season. This phenomenon must be kept in mind, especially when considering weed management practices, since these also must be tailored to the microenvironment and the desired plant response.

10.9 Factors Influencing Plant Growth

Water

All plants require water for growth. While most of our crops can only be grown when irrigation is provided, right-of-way weeds and other invasive species can survive on natural rainfall. In non-irrigated settings, water is probably the most limiting resource for plant growth in much of the United States, particularly the western states. In dry years or in dry locations, desirable species are barely able to survive in the absence of weeds. When weeds are present, survival is often drastically reduced.

In addition to its importance in nearly all plant biochemical processes, most notably photosynthesis, water also transports dissolved nutrients to the leaves, and sugars to the growing points or storage organs. Drought can not only impact all these processes, but can also reduce the activity of herbicides. When transpiration and photosynthesis are reduced, water movement from the soil to the leaves and sugar movement from the leaves to the growing points are also reduced. These are the two major pathways of herbicide movement. As such, little herbicide can translocate to the site of activity in the plant, thus, control of the weed will be greatly reduced.

Temperature

Like water, temperature can influence many plant functions; including water loss through transpiration, evaporation of herbicide solution on the leaf surface, germination, and plant growth. Evaporation is affected by both temperature and humidity. Plant growth typically increases when temperatures increase, and decreases when temperature falls.

Optimal plant growth occurs between 50–100°F (10–38°C). High and low temperature extremes also determine the latitude that a plant can grow and survive. Short seasons with a high number of frost days can restrict the distribution or robustness of some species, whereas the lack of frost can limit the survivability of other species.

Relative Humidity

Plants exposed to high relative humidity do not typically need to protect against water loss to the degree of plants in low humidity environments. As such, they often have leaves that are more succulent and with a thinner waxy layer. Transpiration rates are low under such conditions. Maximum growth generally occurs in areas where plants are exposed to high heat and high humidity. This is why tropical and subtropical areas are often so lush with vegetation. Herbicides applied foliarly can more easily penetrate leaf surfaces in high relative humidity. This increased penetration occurs because spray droplets do not evaporate as fast on the leaf surface. This allows more time for the herbicide to enter the leaf.