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An Integrated Approach to Sustainable Roadside Design and Restoration

U.S. Department of Transportation
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The roadside represents the interface between the roadway and the surrounding environment, and plays an important role in protecting the larger ecosystem. Roadsides are dynamic environments that require unique treatments and restoration approaches. This guide presents an integrated and holistic approach to incorporating sustainable solutions into disciplines such as hydraulic design, geotech, aesthetics and vegetation, among others. The intent of this research is not to create a new design process, but rather to incorporate recommendations into the existing design process. The goal is to raise awareness about the trade-offs inherent in designing a sustainable roadside so that these issues are addressed early-on in project development. A checklist of sustainability strategies is included in this guidebook as a tool within the project development process.</td></tr>
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Federal Highway Administration
U.S. Department of Transportation

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ACRONYMS AND ABBREVIATIONS

ADT – average daily traffic

AASHTO – American Association of State Highway and Transportation Officials

BMP – best management practice

BSM – bioretention soil mix

CFT – cross functional team

COV – cone of vision

CSS – context-sensitive solutions

DOR – Department of Roads

DOT – Department of Transportation

EMP – Environmental Mitigation Program

EPA – Environmental Protection Agency

FHWA – Federal Highway Administration

FLH – Federal Lands Highway

FS – Forest Service

ICC – Intercounty Connector

INVEST – Infrastructure Voluntary Evaluation Sustainability Tool

ISO – International Organization for Standardization

IRVM – integrated roadside vegetation management

IVM – integrated vegetation management

LCA – lifecycle assessment

LID – low-impact development

NCHRP – National Cooperative Highway Research Program

NPDES – National Pollutant Discharge Elimination System

NPS – National Park Service

PLD – porous landscape detention

RMNP – Rocky Mountain National Park

SR – State Route

WSRA – Wild and Scenic Rivers Act

DEFINITIONS

CONTEXT SENSITIVE SOLUTIONS	Context sensitive solutions (CSS) is a collaborative, interdisciplinary approach that involves all stakeholders in providing a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources while improving or maintaining safety, mobility, and infrastructure conditions (FHWA, 2007).
ENGINEERING	The profession in which knowledge of mathematical and natural science is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind (Accreditation Board of Engineering and Technology, 1963).
HIGHWAY	Any facility designed to accommodate motorized vehicular transportation. This includes all functional roadway classifications (arterial, collector, local) that accommodate motorized vehicles (FHWA, 2012).
RESTORATION	The return of an ecosystem to a close approximation of its condition prior to disturbance (NRC, 1995).
ROADSIDE	Roadside includes the sides of the road beyond the pavement (travel lanes and shoulders). The area includes the limits of the right-of-way and may extend beyond the right-of-way if public land. The roadside is typically an area disturbed by roadway construction or reconstruction.
SUSTAINABILITY	Sustainability is satisfying basic social and economic needs, both present and future, and the responsible use of natural resources, all while maintaining or improving the well-being of the environment on which life depends (FHWA, 2011).
SUSTAINABLE DEVELOPMENT	With respect to development, the Brundtland Commission of the United Nations succinctly stated that sustainable development is "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs" (United Nations, 1987).
SUSTAINABLE HIGHWAY	FHWA views sustainable highways as an integral part of the broader context of sustainable development. A sustainable highway should satisfy the functional requirements of societal development and economic growth while reducing negative impacts on the environment and consumption of natural resources. The sustainability of a highway should be considered throughout the project lifecycle—from conception through construction (FHWA, 2011).
SUSTAINABLE SOLUTION	A sustainable solution is a specific project activity, feature, or process that accomplishes the goal of promoting sustainability.

EXECUTIVE SUMMARY

The roadside represents the interface between the roadway and the surrounding environment and plays an important role in protecting the larger ecosystem. The intent of this guidebook is to present a comprehensive strategy to address roadside sustainability in the project decision-making process. This guidebook identifies strategies for disciplines to work together early in the process to create innovative, low-maintenance designs that meet a number of goals. These disciplines include:

- **Aesthetics:** The visual integration of transportation facilities into the surrounding landscape; can be defined by multiple variables ranging from natural land forms and human enhanced topography to the design of signage and road safety elements (Texas Department of Transportation, 2009).
- **Geotechnical:** Concerned with the behavior of earth materials; focused on the impact of the roadway to surrounding topography.
- **Hydraulics:** The field of science and engineering dealing with liquids; this guidebook covers concepts such as conveyance systems, channel behavior, and erosion control.
- **Vegetation:** The process of planting on disturbed areas following roadway construction; focused on use of native and natural vegetation.

This guidebook is limited to roadside restoration for roadway rehabilitation projects. Sustainability solutions within the roadway cross-section are included in a companion to this guidebook titled *Integrated Approach for Building Sustainable Roads* (2013). The audience for this guidebook includes practitioners involved in project development, such as the owner's staff, public officials, planners, engineers, designers, and those involved in contractor oversight and management.

The goal of this guidebook is to raise awareness concerning the trade-offs inherent in designing a sustainable roadside so that these issues are addressed early in project planning. A checklist of strategies is included within the discussion of each discipline.

1. Introduction

Current literature shows that the terms “sustainable” and “roadside” are not widely associated with each other. However, with over 4 million miles of paved roadways and associated roadsides in this country, it is important to view them as sustainable places rather than leftover spaces (NRC, 2005).

Sustainable roadsides need to be designed with the intent of integrating successful economic, environmental, and social strategies into the built environment. For purposes of this guidebook, roadsides include the edges of the roadway beyond the pavement (travel lanes and shoulders) extending to the right-of-way line.

The purpose of this guidebook is to recommend strategies to better incorporate sustainability into roadside design considerations. The tools and case studies in this guidebook reflect the full project lifecycle from planning through operations and maintenance. The intent is not to create a new design process but rather to integrate sustainability into existing processes. The goal is to raise awareness about the trade-offs inherent in designing a sustainable roadside so that these issues are addressed early-on in project development.

This guidebook is organized by the disciplines involved in roadside restoration, including aesthetics, geotechnical, hydrology, and revegetation (Figure 1-1). Each discipline section begins with a description of the key requirements typically considered in project development. It then introduces common design trade-offs encountered during roadside restoration decisions and follows with recommendations on how to address trade-offs. Finally, each section ends with a checklist of sustainability measures for the specific discipline. The checklists for each discipline have been compiled into one checklist in Appendix A. This checklist is intended to be used as a tool in the project development process.

It is important to note that roadsides are dynamic environments that require unique treatments and restoration approaches. Approaches that may be appropriate for one project may not be appropriate in a different context. The key is to remain flexible in the selection of sustainability practices to best reflect the needs of an individual project.

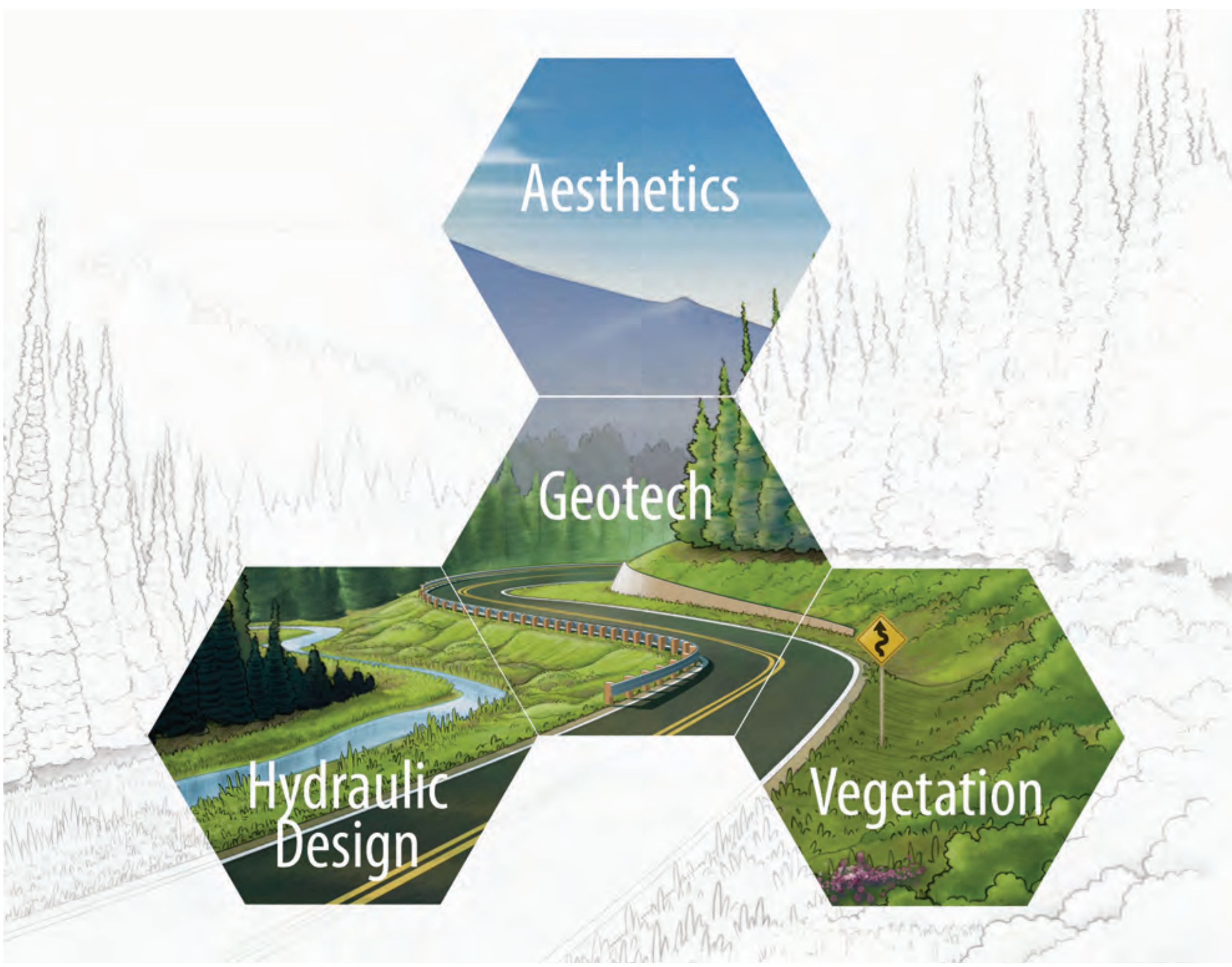


Figure 1-1: Interrelated disciplines involved in sustainable roadside design

1.1 Audience and Scope

The audience for this guidebook is primarily practitioners in the field of transportation in both the public and private sectors—from planning through construction. Interested persons may be involved in any or all of the steps within a project lifecycle. This guidebook introduces a variety of case studies, mainly in rural contexts. However, the "best practices" and "lessons learned" may be applicable to suburban and urban environments as well.

This guidebook serves as a resource for practitioners who seek to improve the roadside environment. Specifically, it is intended to:

- Introduce a culture of sustainability within the world of highway design; one based on the view that sustainability is not an "add-on" task, but rather a holistic and beneficial task, as well as a cost-saving strategy
- Introduce trade-offs in the decision-making process and recommendations for weighing these trade-offs
- Provide recommendations on improving interagency coordination within the existing design process

This guidebook is limited to roadside restoration for roadway rehabilitation projects. For new construction or reconstruction projects, refer to the companion to this guidebook titled *Integrated Approach for Building Sustainable Roads: A Guidebook*. The companion discusses the integration of sustainability into the roadway design process from planning and programming through operations and maintenance (Federal Highway Administration, 2013).

1.2 Safety Considerations

Sustainable roadsides need to be designed with the intent of integrating successful fiscal, environmental, and social strategies into the built environment. An integral part of maintaining a sustainable roadside is the ability to provide safety to users. A safe, sustainable roadside should consider:

- Wildlife and roadside vegetation
- Safe and lasting hydraulic features
- Grading and geotechnical concerns
- Roadside aesthetics

It should be noted that little research has been conducted studying the relationship between sustainability and roadside safety. Designers must look into trade-offs, construction costs, and lifecycle costs in comparison to other roadside elements in order to develop sustainable roadsides. Standards and research through entities such as the National Cooperative Highway Research Program (NCHRP) can assist in selecting appropriate strategies. Each technical section of this guidebook includes a section on safety considerations to show the relationship between safety and sustainability.

2. Principles and Process

This guidebook identifies four of the major disciplines involved in roadside design and provides strategies to consider in enhancing sustainability. The strategies are intended to be integrated into an agency's existing design process, rather than as a separate set of recommendations.[1] Sustainable solutions should be incorporated early in the planning and design processes in order to maximize their value.

1 The FHWA Office of Federal Lands Highway design process is governed by the *FLH Project Design and Development Manual* (PDDM), 2011. References to sections of the PDDM are made throughout this guidebook. http://www.flh.fhwa.dot.gov/resources/manuals/pddm/

2.1 Guiding Principles in Roadside Design

The detailed guidance within this guidebook will vary based on the unique context of the project and type of project (small-scale to large-scale). Overarching recommendations to integrate sustainability into the roadside design process (regardless of scale) include:

- **Adopt** an integrated approach to roadside management (see Context-Sensitive Solutions at right). Create a process through which to coordinate with other disciplines.
    - The process through which meetings and communication best occurs will vary by agency. The key is to ensure that this consistent communication across disciplines happens early and often.
- **Communicate** with stakeholders about their goals, priorities, expectations, and perceptions of the roadside environment.
    - Engaging stakeholders is essential. Project stakeholders may include federal agencies, state departments of transportation (DOT), local jurisdictions, local residents and business owners, recreational users, and other interested parties. Coordination with interested stakeholders should be initiated early in the design process to develop a shared vision and sustainability goals for the project.
- **Educate** staff, contractors, and other personnel involved in all phases of a project (design, construction, operations, maintenance) about the project's sustainability goals and implementation actions.
    - Agency staff need to become the champions for integrating sustainable practices and ensuring that successes are carried forward into future projects. Similarly, the contractor needs to be a partner in ensuring that practices are implemented in the field.

CONTEXT-SENSITIVE SOLUTIONS (CSS)

CSS is a collaborative, interdisciplinary, holistic approach to the development of transportation projects (FHWA, www.contextsensitivesolutions.org). It involves all stakeholders, including community members, elected officials, interest groups, and affected local, state, and federal agencies. CSS puts project needs and both agency and community values on a level playing field and considers all trade-offs in decision making. CSS should be incorporated into decisions related to the roadside—not simply for aesthetics but for the overall function and character of the facility.

INFRASTRUCTURE RATING SYSTEMS

A number of green infrastructure rating systems have evolved over the past few years to measure the concept of sustainable transportation. Each rating system has different applications and review processes. FHWA has created the web-based FHWA Sustainable Highways Self-Evaluation Tool, referred to as INVEST (Infrastructure Voluntary Evaluation Sustainability Tool). INVEST represents a collection of best practices to measure sustainability during the system planning, project development, and operations and maintenance phases. Many of these credits extend beyond the planning phase to the roadside restoration phase, including lifecycle cost analysis, habitat restoration, protection of riparian habitats, ecological connectivity, recycle and reuse of materials, contextual site vegetation, and others.

- **Promote** sustainability awareness and education.
  - Implement a public outreach process to educate roadway users and nearby residents/businesses about the project's sustainability features and the benefits of sustainable design.
- **Plan** for the life of a project; compare the full lifecycle costs of different strategies and approaches.
  - Roadway design and construction decisions are complex and interwoven. In recent years, infrastructure rating systems have evolved with an emphasis on measuring transportation sustainability. Criteria within these systems pertain to the roadside environment. In addition, specific programs, such as FHWA's RealCost software, can help calculate not only construction costs but long-term maintenance costs of different choices.[2]
- **Consider** project impacts within the context of global considerations, such as climate change.
  - Climate variability is linked to transportation decision-making. The difficulty for the science and transportation communities is in accurately projecting the extent to which climate will change. In turn, the projections need to help determine how to best protect and adapt transportation infrastructure to withstand the impacts associated with an increase in climate variability.

CLIMATE VARIABILITY IMPACTS

The idea that the Earth's climate is changing has become widely accepted within the scientific community, and there is strong evidence that many changes to the climate are already taking place. Rising sea levels, increased average global temperatures, increased heat waves, and an increased intensity of storm events have already been observed and are projected to become more extreme over the course of the 21st century.

Long-term changes in climate conditions could significantly affect how transportation facilities are designed, constructed, operated, and maintained. Sea-level rise could threaten coastal infrastructure, such as coastal highways, railroads, and ports. Extended heat waves could cause pavement to buckle. Increased frequency of the freeze/thaw cycles has the potential to significantly affect pavement lifespan and designs. Strategies to address climate change include assessing the risks and impacts that projected climate variability could have on existing assets and how climate variability could be incorporated into the planning and design of new assets. (Assessing the Impact of Climate Variability on Transportation Infrastructure, 2012).

2 FHWA RealCost software is available at: http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm.

2.2 Roadside Considerations in Each Project Phase

There are four major phases to roadway design, which are described in greater detail in the companion to this guidebook titled *Integrated Approach for Building Sustainable Roads* (2013):

- Planning and Programming
- Design
- Construction
- Operations and Maintenance

The four phases are shown in Figure 2-1. Sustainability considerations for roadsides need to be part of each project phase. A set of recommendations to enhance sustainability are included under each phase below.

Phase 1: Planning and Programming

- **Understand the project context.** Evaluate and document the attributes of the roadside environment that make it unique.
- **Evaluate existing conditions.** Existing roadside vegetation, hydraulic patterns, topography, and aesthetic features need to be understood in the planning phase.
- **Develop roadside sustainability goals.** Site opportunities and constraints must feed into the development of sustainability goals for the roadside. Goals should be realistic and a system should be developed to track progress.

Phase 2: Design

- **Design roadside elements to meet sustainability goals.** Test and implement innovative practices to meet sustainability goals.

Phase 3: Construction

- **Revisit and revise the roadside maintenance plan.** Maintenance plans should be "living documents" that continue to be revisited and updated as the project moves through design, construction, and operations.
- **Minimize construction impacts and mimic natural conditions.** The construction process should focus on minimizing impacts to the roadside environment, particularly with site establishment and grading, erosion, dust, noise, and air quality impacts.

Phase 4: Maintenance and Operations

- **Track maintenance activities.** Tasks, responsibilities, and time frames need to be identified in the construction process and then tracked through operations. Detailed information should be collected to understand the successes and limitations of different sustainability strategies.
- **Modify strategies in the field.** The implementation of best practices in sustainability should remain flexible enough to be modified if needed during operations.

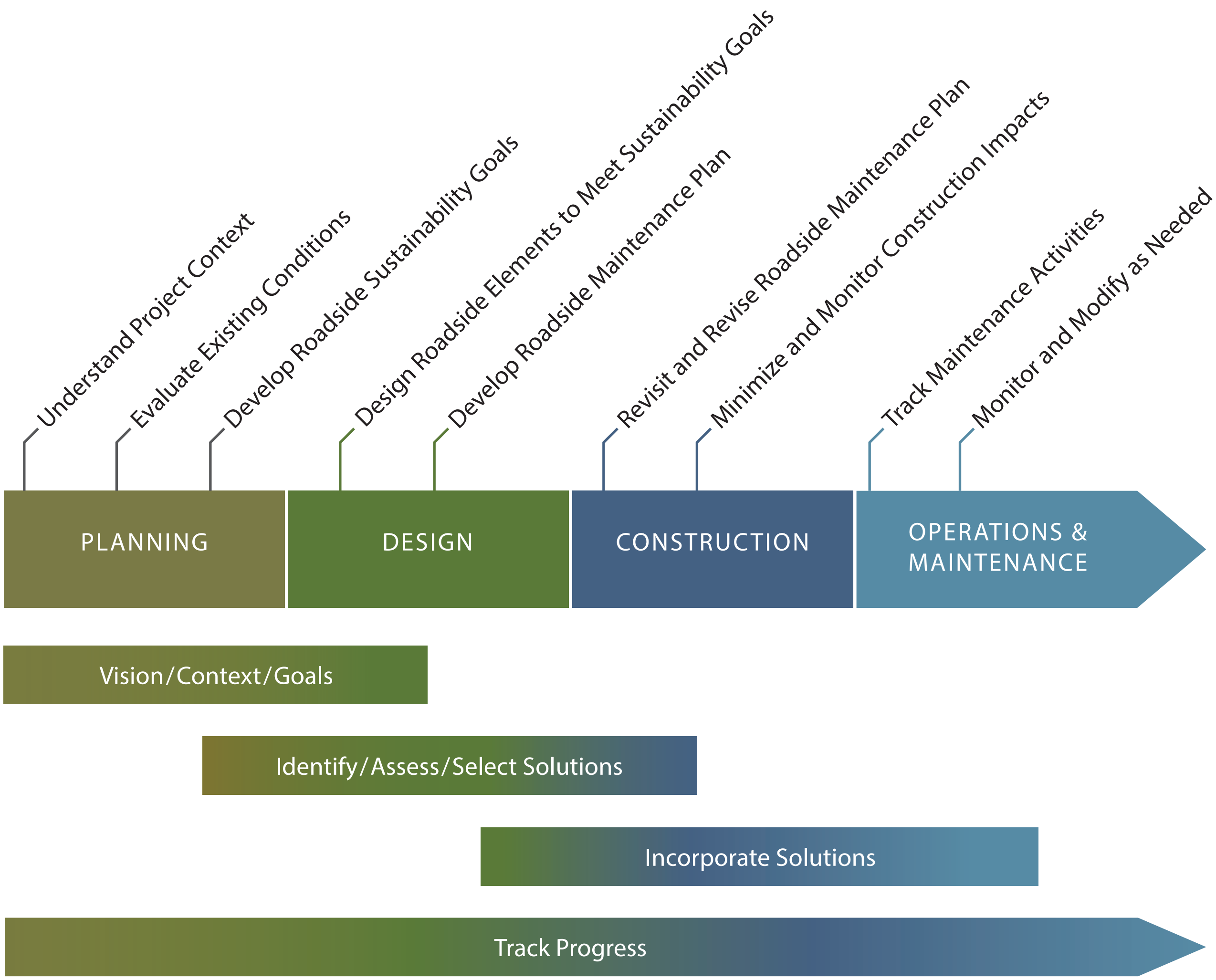


Figure 2-1: Steps to roadside sustainability through the project lifecycle

3. Design Strategies and Tools

This chapter identifies strategies that reach across all disciplines involved in roadside design. It focuses in detail on four of those disciplines: aesthetics, geotechnical (geotech), hydraulic design, and vegetation. Aesthetics is one that is typically thought of as an overarching objective within a project.

Sustainability solutions within the roadway cross-section, such as pavement materials, are not included in this guidebook nor are detailed solutions for bridges and other structures. Safety is considered an integrated component of all disciplines and is addressed within each.

3.1 Aesthetics

Elements of the roadside aesthetic:

- View Planes
- Roadside Signage
- Retaining Walls
- Snow Fencing
- Rock Fencing
- Clear Zones
- Grading

3.1.1 Introduction

Aesthetics, more specifically the roadside aesthetic, is the physical presentation of landforms and the human built environment adjacent to a roadway. Within the context of transportation, aesthetics comprises the visual integration of transportation facilities into the surrounding physical and cultural landscape (Texas DOT, 2009). This relationship can be defined by multiple variables ranging from natural land forms and human-enhanced topography to the design of signage and road-safety elements.

State DOT examples of Aesthetic Guidance described in this guidebook include:

Landscape and Aesthetic Design Manual, Texas DOT (2009)

Pattern and Palette of Place, Nevada DOT (2002)

Aesthetic Design Guidelines, Ohio DOT (2000)

To create an aesthetically pleasing roadside, a balance needs to be struck between the natural world and human-built forms, taking into account the needs of roadway users, the roadway owner, and the preservation or enhancement of the natural and cultural environment. It is important that aesthetics be linked to the functionality of the roadway. Sustainable and aesthetically pleasing roadways not only take into account the preservation of the natural environment but also the economic and social needs of stakeholders (Texas DOT, 2009).

With the growing focus on sustainability comes an emphasis on roadside beautification. Preserving and enhancing the natural environment through the designation of scenic by-ways, highlighting significant cultural resources and creating roadsides that are visually pleasing, has become increasingly important to a diversity of stakeholders (Schauman et al., 1992). As the majority of people interact with natural environments visually via their vehicles, the aesthetics of the roadway become their primary connection to this environment. This focus has not only led to the development of high-quality design elements at the roadside but has also contributed to the fiscal and environmental health of rural communities, enhanced and protected the natural environment, and promoted the importance of natural and historic resources (Figure 3-1). In response to this increased focus, federal and state agencies have begun to develop standards, procedures, and guidelines to address aesthetics of the roadway.


Figure 3-1: Rural roadsides that maximize views

3.1.2 Key Requirements

Detailed regulations for roadside aesthetics are limited. FHWA Title 23, Section 109, of the Code of Federal Regulations requires that "aesthetic or scenic qualities of a place may be taken into account and preserved or enhanced" (Texas DOT, 2009). The FLH *Project Design and Development Manual* states that the most relevant aesthetics guidance and standards can be found within the *National Historic Preservation Act* (NHPA) and the *Wild and Scenic Rivers Act* (WSRA). The NHPA states that designers should work to identify historic elements at the roadside and consider options to minimize adverse effects, including "avoidance, rehabilitation, modified use, marketing and relocation" (NHPA, as amended, 2006). The WSRA of 1966 was implemented to protect rivers that present significant environmental, historic, and scientific value. When designing a road and roadside along a WSR-designated river, designers are required by law to protect the "aesthetic, scenic, historic, archeological, and scientific features" of the river (WSR, 1966). These two acts represent helpful guidance but only pertain to two components of the roadside (historic preservation and protection of rivers). The aesthetics discussion is much broader.

Typically, when roadway engineers begin a design project, the American Association of State Highway and Transportation Officials' (AASHTO) *A Policy on Geometric Design of Highways and Streets*, 2004 (known as the Green Book), is the first resource consulted. The Green Book outlines the design of roads and highways and provides national roadway design standards. Design guidelines within this guidebook are based on user safety and provide the minimum requirements when designing a road. Aesthetics are not a major focus within the Green Book, thus guidance concerning aesthetics is typically driven by the agency or owner of the roadway in question. On projects where agency guidance is not present, it is the responsibility of the roadway/roadside designer to champion sustainable and context-sensitive aesthetic principles.

Some state DOTs have developed statewide aesthetics guidelines. In their report titled *Pattern and Palette of Place: A Landscape and Aesthetics Master Plan for the Nevada State Highway System*, the Nevada DOT established a landscape and aesthetics program for the statewide highway system (Multiple Authors, 2002). The report states that context should be one of the most important factors in determining the aesthetic complexion of a roadside. Ohio DOT's *Aesthetic Design Guidelines* states that the primary goals of the guidelines are to promote a cohesive and uncluttered appearance; consider patterns, colors, textures and relief; and make aesthetics an inherent part of transportation projects. It states that interdisciplinary teams are a crucial part of the design process (Ohio DOT, 2000).

AESTHETICS AND SAFETY

FHWA statistics indicate that vehicle collisions with trees account for more than 4,000 fatalities and 100,000 injuries each year (FHWA, *Safety and Trees: The Delicate Balance,* 2006). In some cases however, these amenities should be protected to preserve and protect the natural roadside aesthetic. Conversation should include the cost of moving the roadway, the aesthetic value of the hazard in question, and the importance of travel speed versus the value of the roadside aesthetic.

3.1.3 Trade-offs and Considerations

Roadside aesthetics is not a singular design problem. Each discipline and project may have varying goals and objectives. This section defines elements that comprise the rural roadside aesthetic and identifies trade-offs that need to be considered when working with other design disciplines to develop a sustainable roadside.

- **View planes:** One of the primary aesthetic elements that motorists and passengers experience as they move along a roadway facility is terrain in the foreground, middle ground, and background (Figure 3-2). The sustainable landscape aesthetic is set within the context of the moving motorist. This condition is very different from that of the relatively stationary pedestrian. Thus, when designing the roadside aesthetic, the moving motorists' cone of vision (COV) must be taken into account. Stark contrasts can be identified when comparing a pedestrian COV to a motorist COV. The pedestrian COV typically consists of 60 degrees of direct sight, with the remaining 120 degrees being peripheral. In contrast, the moving motorists' COV is limited by their pace of movement through the landscape. The moving motorists' direct COV is 30 degrees and the remaining 150 degrees make up their peripheral vision (Schauman, et al., 1992). Objects and geological formations that make up the middle and distant views are the most perceptible to the traveler. Within this context, a motorists' COV is wider, allowing viewers to comprehend a broader section of the roadside thus making an aesthetically pleasing roadside important (Figure 3-3) (Texas DOT, 2009).

  Elements such as oceans, rivers, hills, and mountains provide many of the most interesting sights when traveling in rural areas (Figure 3-4). These views also serve as way-finding elements, giving topographical clues to distance and location. Highlighting these view plane opportunities helps to create a roadside that is visually appealing, safe, and sustainable. The more interest motorists have when traveling, the more apt they are to stay alert and aware (Schauman, et al., 1992).

  Research indicates that a busy roadside that consists of multiple signs and a multitude of travel facilities can distract drivers, leading to increased collisions and accidents (Schauman, et al., 1992). Other studies have shown that a monotonous roadside causes drivers to relax, leading to a loss of concentration and more accidents, negatively impacting the safety of the roadway (Texas DOT, 2009). The development of a balanced rural roadside aesthetic that is interesting but not distracting is imperative in creating safe and sustainable roadsides.

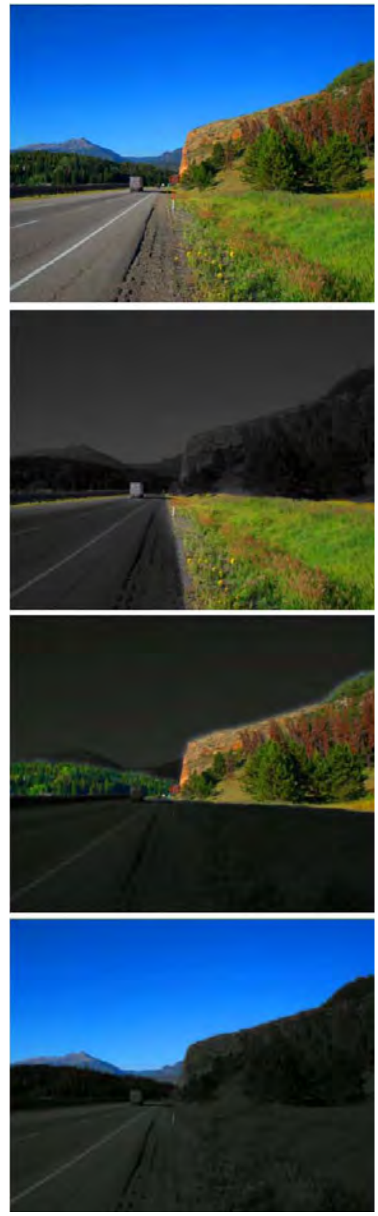


Figure 3-2: Roadway vewplanes

Visualization showing a complete roadside view (at top) followed by the view with a highlighted foreground, middle ground, and background, respectively.

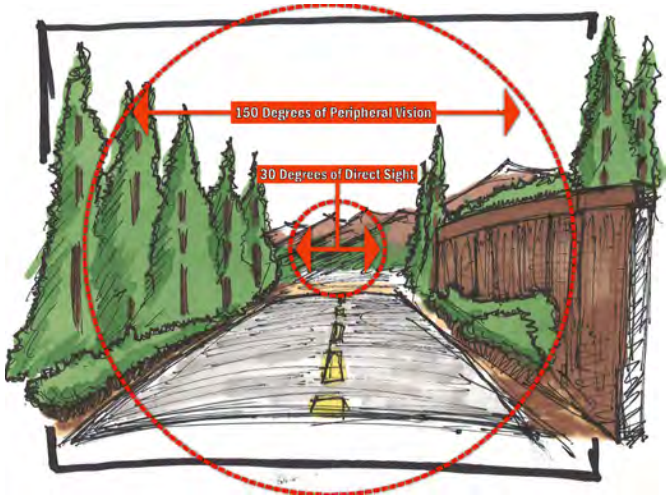


Figure 3-3: Drivers cone of vision at 55 mph

Figure 3-4: Decorative walls and lighting

These add visual interest and help maximize views.

- **Vegetation:** In some cases, existing vegetation may need to be cleared to maintain view corridors, risking an impact to the overall biodiversity of the area. In other cases, vegetation can help to enhance views by screening undesirable elements (Figure 3-5).

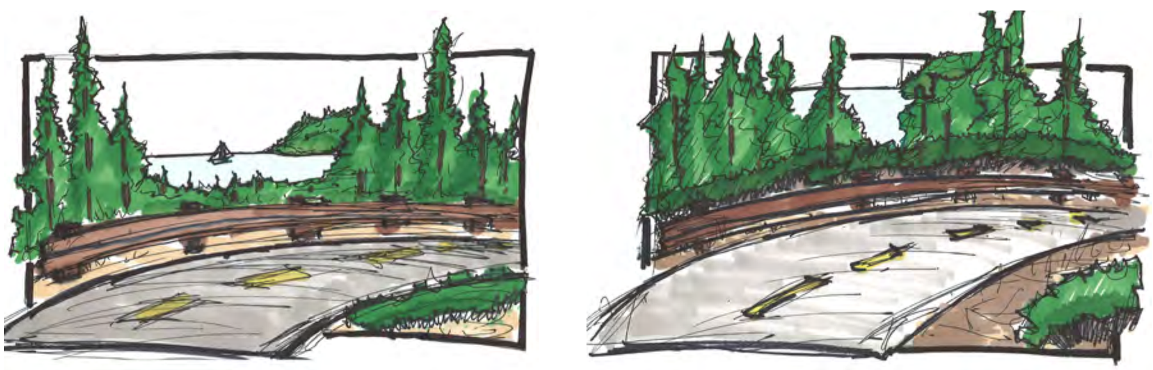


Figure 3-5: Trees framing views (left) and trees blocking views (right)

- **Slope design:** Areas that require cut and fill need to preserve views. In areas of dramatic topographic change, hillside cuts may be used to not only create a roadway that is safer but also to create more accessible vistas. In contrast, some cut-and-fill sites may need to be adjusted to ensure that existing views are not impeded (Figure 3-6). These trade-offs must be measured against the safety requirements of the roadway.

- **Signage:** Collaboration with safety professionals is important in creating view opportunities that are noticeable, safe, and sustainable. Signage notifying motorists of an approaching view is important as it promotes driver-awareness of surroundings and advertises the view.

  In many cases, historical and cultural signage at the roadside is reflective of the local style. While this may be a contextually appropriate approach, the designs are often developed without studying the lifecycle cost. The trade-off between natural and contextual materials and the lower lifecycle costs of standard materials needs to be studied and weighed in an effort to select the most sustainable solution (Figure 3-7).

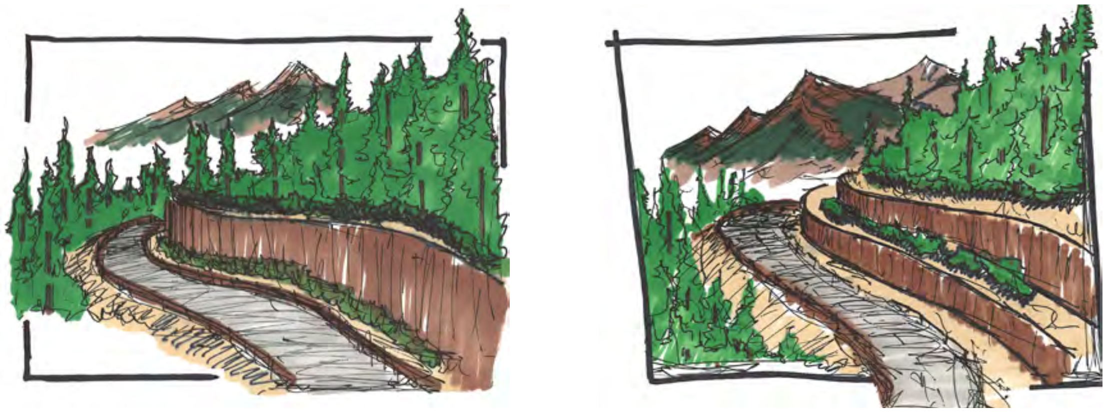


Figure 3-6: A wall detracting from views (left); a terraced wall with reduced scale to accentuate views (right)

*Figure 3-7: High quality and contextually appropriate **signage***

- **Retaining walls:** Many environments require the use of roadside elements that protect travelers from hazards, such as accumulating snow and steep roadside cuts. To mitigate these hazards, retaining walls and snow fences may be installed. Small enhancements, such as choice of color, materials, and placement, can help to develop walls and fences that are visually appealing, sustainable, and—most importantly—safe.

  Retaining walls are utilized on the roadside to protect vehicles from steep slopes. Standard treatments provide adequate safety but, in many cases, are not visually appealing. Multiple aesthetic solutions can help to reduce the impact of retaining walls. Key considerations include lifecycle cost, local materials, and traveler safety (Figure 3-8).

- **Snow fences:** Snow fences are utilized to keep the travel way clear of snow. Standard designs of snow fences are, in some instances, detrimental to the roadside aesthetic. Typical snow fences are constructed of wood, with a standard life span of 5 to 10 years (Figure 3-9). As an alternative, vegetated snow fences have a substantially longer lifecycle and provide a more pleasant roadside aesthetic.

The initial cost of vegetated snow fences is substantially higher than typical snow fences, in part due to the cost of establishing the vegetation during the first 2 to 3 years. However, the longer life of vegetated snow fences may offset this initial cost. A full lifecycle cost analysis of differing options should be conducted to determine the most financially sustainable option.


Figure 3-8: ***Retaining walls*** *enhancing both safety and roadside character*


Figure 3-9: ***Snow fence*** *treatments*

3.1.4 Recommended Approaches

Development of a design approach that is flexible in its response to contextual conditions is imperative in creating specific aesthetic approaches that fit the geological, vegetative, social, and economic conditions of the roadway. This section outlines a suggested approach in developing and designing the aesthetic elements previously discussed.

Step 1: Corridor Principles and Visual Investigation

As with most planning and design processes, the initial scale of work should be at a high, corridor-based level. This area of study is usually defined by the limits of the given project.

> ***"A basic sustainable landscape aesthetic for the roadside should include: well-proportioned and visually pleasing vertical built forms (bridges, monument and walls), well designed slopes and drainage swales, views from the highway to adjacent land uses and the preservation and enhancement of vistas and view planes to natural landforms."***
>
> *(Nevada DOT, 2002)*

However, in some instances, roadside aesthetic principles can be applied to specific historic, geologic, or specially defined regions.

The first step is to define the principles that the design should seek to achieve. Developing a broad "mission" statement at the onset of the project can help to focus detailed design solutions later in the project. In an effort to define the aesthetic principles of the corridor, a visual investigation of the corridor is helpful in understanding the context in which its aesthetics will be defined. An inventory of common features, unique attributes, and historical context can help guide the process. A visual presentation of these qualities can be created to help categorize and illustrate the current conditions of the roadside. These imaging studies can then be delivered to stakeholders in an effort to define the aesthetic principles of the roadway that interventions seek to create, maintain, and protect.

Case Study

I-70 CORRIDOR AESTHETIC PRINCIPLES

COLORADO

In an effort to develop a contextual aesthetic for the I-70 Mountain Corridor between Denver and Glenwood Springs, the Colorado DOT (CDOT) instituted the I-70 Mountain Corridor Context Sensitive Solutions (CSS) process. This intensive process included input and guidance from professionals representing a wide range of disciplines as well as multiple stakeholders who live and work along the corridor. Overarching corridor-wide principles included:

- Connect to the setting, harmonize with the surroundings, and be a "light touch" on the land
- Reflect I-70 as a major regional and national transportation corridor
- Celebrate crossing the Rocky Mountains with a high-country travel experience
- Respect urban, rural, and natural settings
- Draw upon and regenerate the context of place
- Aesthetic design treatments shall:
    - Support safety and mobility
    - Support communities and regional destinations
    - Respect the current time and place
    - Use indigenous and local materials from the landscape
    - Showcase key views while buffering inconsistent views

To streamline the process, CDOT divided the corridor into four zones to reflect the diverse aesthetics: the Western Slope Canyons and Plateau, the Crest of the Rocky Mountains, the Mountain Mineral Belt, and the Front Range Foothills. Specific aesthetic principles were then developed for each zone. Smaller sections were necessary to pinpoint more detailed locations and provide a base map in which to begin to apply aesthetic design solutions consistent with the principles.

Source: www.i70mtncorridorcss.com/corevalues/aethetics/

Step 2: Opportunities, Constraints, Weaknesses, and Strengths

Once the visioning process has been completed, the characteristics of the corridor need to be explored in depth. This process should define important elements along the corridor that aesthetic principles can help to enhance, buffer, or create. This process should occur at two scales: corridor-wide and more detailed sections of the corridor.

Corridor-wide Evaluation

A corridor-level view helps determine areas where sustainable aesthetic elements are best utilized and applied. Elements that should be highlighted include land use, population centers, lakes, rivers, open space facilities, and other natural and human-formed features (Figure 3-10). Once opportunities have been documented, designers can begin to define different design districts along the corridor. The aesthetic design of these districts should reflect the contextual environment of the area. Multiple contextual elements can be distinguished at this level of analysis, including:

- View planes
- Vegetation types
- Geological features
- Points of interest
- Proposed roadway engineering designs (cut and fills, walls, guard rails and associated utilities)
- Ancillary utilities
- Jurisdictional boundaries
- Roads
- Railroads
- View sheds
- Population centers
- Recreational amenities

Once this analysis is completed, application of various treatments can be explored.

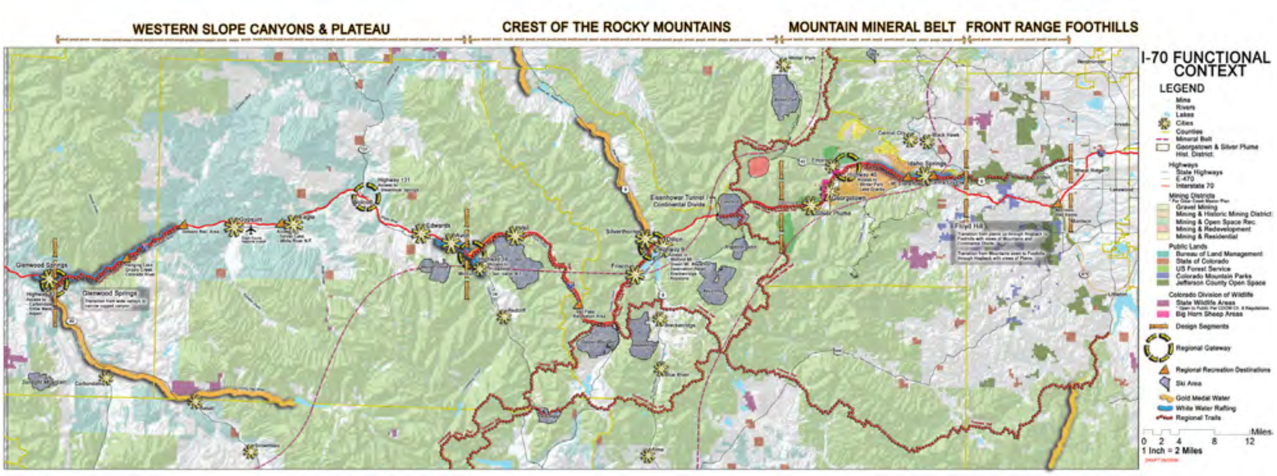


Figure 3-10: Example of corridor-wide evaluation

Step 3: Application of Treatments

This section gives an overview of various treatments and strategies to improve corridor aesthetics. These recommendations serve as a starting point. The selection of these will vary by project context and conditions.

- **Vegetation:** Collaboration with revegetation professionals is required to ensure that threatened and endangered species are not harmed. If revegetation is required, specific species that will not mature to heights that infringe on the view plane should be specified to minimize long-term maintenance.

- **Hydrology:** Water quality features, culverts, and other hydrological features should be screened or blended into the existing context where possible. Vegetated water quality facilities should use regionally appropriate seed mixes and vegetation to blend into the environment. Culverts should use material that reflects the local geological environment to reduce its visual impact. Other sustainable efforts should be explored, including best management practices (BMP), gravel bottom vegetated water filtration systems, etc.

- **Clear zones:** Slower road speeds in select areas, increased signage, safety barriers, and adjustment to road alignment can help avoid sensitive and important roadside hazards. FHWA states that agencies have many options to reduce the potential of vehicles leaving the road (Figure 3-11) (FHWA, *Highway Safety and Trees*, 2006). These options include:
  - Flattening curves
  - Adding signage
  - Improving markings
  - Shielding trees of special significance with guardrail
  - Using smaller trees and shrubs to preserve the clear zone
  - Removing trees

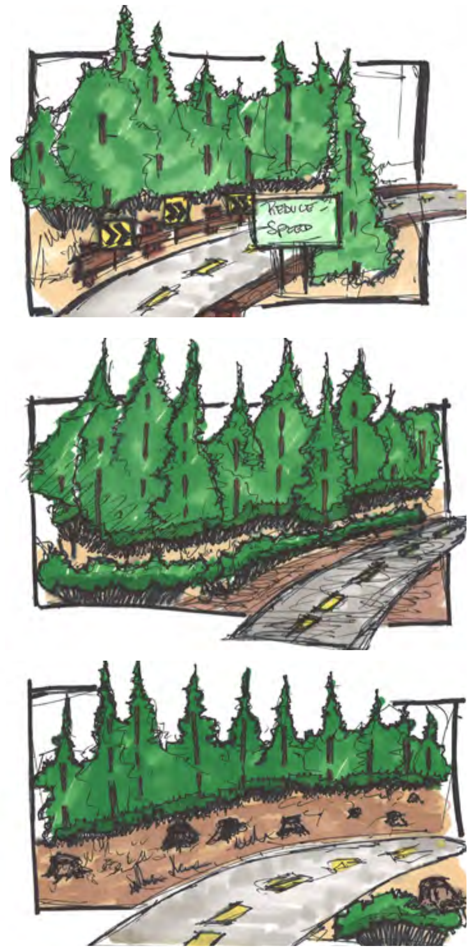


*Figure 3-11: Options for preserving the **clear zone***

- **Signage:** The application of signage varies based on the individual needs and context of a roadside. Signage needs to be adequate to enhance safety, accessibility, and educational opportunities while minimizing motorist distraction. Considerations include:
  - Materials should be durable and contextual to the climate of the roadside. Excessive roadside signage is distracting to drivers and impacts roadway safety (Schauman, et al., 1992). Excessive

signage also negatively affects the roadside aesthetic. Develop signage standards that convey information in the most efficient manner to create less cluttered roadsides.

- During the design phase, a signage lifecycle cost analysis should be conducted to determine the overall lifetime cost of upkeep and maintenance.
- In many cases, information relating to local history, ecology, business, and culture can become outdated, and new signage can be expensive to produce. An alternative to providing physical signage is using intelligent information technologies to convey the information. Smaller signs can be installed at points of interest, directing users to log-on to specific websites using smart devices, such as smart phones or tablet PCs. Another option is to use quick response barcodes, which allow smart phone users to access the information directly. By using these technologies, administrators can update information without having to replace signage at a much higher cost. Drawbacks to using this method may include the increased cost of maintaining a website and, in many rural locations, the lack of mobile and wireless services.
- Signage information pertaining to points of interest, trail heads, rest stops, and scenic views should be highlighted by placing signs in locations that fall within the traveler's COV. Increased visibility will encourage use of these important amenities and contribute to the local economy.

- **Guardrails and retaining walls:** The need for safety features along a roadside should be considered within the context of the roadside aesthetic.
  - Where guardrails are required, simple changes in color and material can help to lessen their visual impact on the contextual environment (Figures 3-12 and 3-13).
  - Tiered walls can help to reduce the vertical scale of retaining walls, narrow the size of the roadway footprint, and minimize cut and fill.
  - Vertical walls can detract from the natural aesthetic of the rural environment. The use of materials that blend into the contextual landscape can help to soften the impact of these walls. Shotcrete (specialized concrete that is applied via spray) can be used to create faux retaining walls that match the surrounding geology. Rockery walls can be used to create a clean but rural aesthetic. Textured, colored concrete can be used to break-up the monotony of single color concrete.
  - Terraced walls can help to mitigate the vertical effect of wall structures. Vegetating spaces between walls can also help to screen wall elements from travelers.
  - A lifecycle cost analysis should be undertaken to measure the cost of aesthetic improvements. The location of distributors can affect the total cost of materials.
  - Where cost is not prohibitive, local, sustainable materials should be used to reduce emissions associated with transportation and construction.
- **Snow fences:** Vegetated snow fences are an alternative to typical snow fencing strategies. A careful analysis of the roadside climate, vegetative norms, and access to water will determine if vegetated snow fences are a viable solution. Intensive maintenance and irrigation is required to develop vegetated snow fences; however, the typical life of a snow fence is five to six times longer than traditional strategies (New York State DOT website).

Aesthetics

Design Strategies and Tools

Figure 3-12: ***Retaining wall*** *enhancing surrounding environment*

Figure 3-13: Rock fall mitigation using shotcrete to prevent erosion

Case Study:

ROCK FENCING ALONG I-70

IDAHO SPRINGS TO GEORGETOWN, COLORADO

One of the major design issues within the Idaho Springs to Georgetown segment of I-70 was the numerous rock fencing elements that existed above the roadway. These rock fencing elements prevented large boulders from falling onto the busy roadway along a section that in the past had been the site of rock/vehicle accidents. While these safety elements were imperative to the safety of the traveler, they distracted from aesthetics of the sheer rock wall grandeur of the mountain side. In an effort to mitigate this visual impact, Colorado DOT experimented with different paint colors. A visual experiment was instituted using large paint chips carried onto the hill side by construction workers. Once the paint chips where placed next to the rock fences, observers from the roadway selected colors that most closely resembled the contextual geology of the site and the structural elements were painted that color.

This simple yet effective aesthetic study helped to develop a sustainable solution that met safety standards while minimizing visual impact. Simple aesthetic solutions such as this are both low cost and effective.

Photo Source: Colorado DOT

3.1.5 Aesthetics Checklist

General

- ❑ Develop materials and designs that blend into the environment.
- ❑ Specify roadside signs that meet the AASHTO standards but also respond to the local cultural and environmental context.
- ❑ Identify important natural features that should be preserved within the clear zone and jointly develop strategies to preserve these features.
- ❑ Develop blowing-snow mitigation designs that are safe and visually appealing.

Geotech

- ❑ Develop cut and fill designs that ensure preservation of open vistas and view corridors.
- ❑ Mitigate the visual effect of cut and fill on the local roadside environment.
- ❑ Construct retaining walls that blend into the natural context.
- ❑ Ensure that rock fencing has the least amount of visual impact.

Hydrology

- ❑ Specify materials and designs that have an extended lifecycle.
- ❑ Develop screening strategies for water-quality facilities.

Vegetation

- ❑ Determine the impact of vegetative clearing on the local environment.
- ❑ Specify plants that will enhance views from the roadway.
- ❑ Identify flora to be preserved in the clear zone.
- ❑ Specify seed mixes and plantings for water-quality features.
- ❑ Revegetate with contextually appropriate plant species.

3.2 Geotech

Geotechnical Design Considerations:

- Slope stabilization and maintenance
- Drainage
- Structure foundations
- Earth pressure data

3.2.1 Introduction

Geotech, or Geotechnical Engineering, is concerned with the behavior of earth materials. In the roadside environment, it is largely a function of the extent to which the design of the roadway impacts the surrounding topography. This must be accomplished both longitudinally along the roadway alignment and laterally from the roadway to the edge of the right-of way. Where the road has a minimal impact on the surrounding terrain, such as a roadway through relatively flat countryside, the engineering of the roadside can be minimal and confined to design issues related to safety, landscaping, and drainage. Where the design of the roadway impacts the surrounding terrain to a greater extent, such as extensive cuts and fills, more intensive design issues are encountered and need to be addressed.

Long-term stability of the slopes is of paramount importance for the safety of the traveling public. Design issues may include slope stabilization and maintenance, drainage, and foundations for structural retaining features, as well as supplying soil pressure data to structural engineers for the design of the walls. Other geotechnical elements of roadside design include roadside structures that might require foundation elements, such as roadside signage or noise-barrier structures.

3.2.2 Key Requirements

The geotechnical discipline is generally seen as having a support role to other design disciplines. Geotechnical professionals have a responsibility to provide geotechnical recommendations to project managers or other designated members of an interdisciplinary team.[1] Sustainability issues can be addressed at any stage of the design or construction process; however, it is generally best to introduce them as early as possible in order to be fully integrated into the design process. Early participation in site investigations can assist in developing sources for materials either disturbed or filled for the purpose of roadside construction.[2] Specifically, early investigations should:

- Identify the potential reuse of materials within the project limits
- Focus on areas where elevation changes may necessitate slope stabilization
- Identify where soil cut or fill may require retaining walls or rock slopes/cuts

Additional geotechnical support may be needed for the structural discipline in the form of input to calculations and designs for retaining wall structures. Other structures needing geotechnical input for foundations along the roadside include signs, noise abatement structures, and large culverts.[3]

3.2.3 Relationship with Other Disciplines

Geotechnical engineering is intimately connected to the geology, geomorphology and the hydrology of a specific site. In this, the built environment must fit into the surrounding environment in such a way that the built environment transitions smoothly to the surrounding landscape. Developing sustainable solutions requires consideration of:

1 PDDM Section 6.1.2
2 PDDM Section 6.3.1
3 PDDM Section 6.3.1.2.3

- The cost involved in grading the roadside transition zone (including drainage considerations)
- What, if any, materials are needed to stabilize this transition and how these materials can be chosen for their sustainability properties
- How the cost and level of effort to maintain the roadside can be minimized within the parameters of safety, environment, and aesthetics

GEOTECH AND SAFETY

Flatter slopes are preferred when it comes to roadside safety; however, designs should take into account potential impacts to the surrounding environment depending on the choice of slope. If steeper slopes are needed to reduce the impact on the natural context, then safety elements, such as guardrails, should be included in the design (AASHTO, 2004).

At the same time, flat shelves can help increase the visibility of wildlife, which is important in rural areas (FHWA, 2008).

Guardrail placed at steep slope

Slope designs are incorporated to create a roadside space that is safe, economical, and aesthetically pleasing. Other disciplines to consult with include primarily hydraulic design and structural engineering.

HYDRAULIC DESIGN: The focus is on drainage, both on the macro-scale of the surrounding terrain and on the meso-scale of the drainage from the roadway itself. Erosion control within the drainage channels is another area where geotechnical and hydrological disciplines must work together.

STRUCTURAL ENGINEERING: Coordination is required to design the structural elements of any retaining wall features needed to stabilize slopes or to manage slides or rock-falls. The selected methods for slope stabilization have to take into account the type of vegetation that the landscape is intended to support.

Other structures may be required in the roadside environment, either for public information, safety, or other purposes. These could include signage, guardrails, animal control, and noise abatement structures. All of these require geotechnical input with regard to their foundation elements.

If soil is amended, the depths of soil treatment and the corresponding effect on slope stability need to be considered. If placed too close to a wall or foundation, plant root systems may eventually cause damage to a structure.

Geotech

Design Strategies and Tools

3.2.4 Trade-offs and Considerations

The following are trade-offs to consider when integrating sustainable solutions into geotechnical design. Each solution will vary in consideration of the unique context of each project.

- **Natural slopes versus retaining structures:** Natural slopes require less input and impact to the landscape but elevation changes may not allow for natural slopes. Retaining structures can help reinforce stable slopes. The drawbacks to retaining structures are the costs, visual impact to the roadside environment, and the need for maintenance over time (depending on material).
- **Sculpted rock cuts versus straight cuts:** This is largely a matter of aesthetics. However, sculpted rock cuts, while more expensive, can be designed such that rockfall mitigation efforts over time can be minimized.
- **Local materials versus imported materials:** In general, local materials are preferred. However, some specifications for materials can be restrictive, prohibiting the use of local materials. In some cases, the specifications for materials can be relaxed to allow for the use of local materials without significant effect on the final product.
- **Consideration of total lifecycle costs versus straight construction cost:** Many design elements that reduce maintenance costs can be incorporated into a design package for little to no extra cost if they are considered and implemented early in the design process. In other cases, additional costs added to the construction budget can result in significantly lower maintenance costs over the life expectancy of a product.

3.2.5 Recommended Approaches

The intent of geotechnical professionals is to leave in place a landform that is safe, stable, and cost-effective. Where slopes must be managed, the structures for this purpose can be designed with the intent of using local products and materials. Other design features should include consideration of the aesthetic quality of the structure, making it blend into the landscape. For this to be sustainable, the following approaches are recommended:

- Use locally available materials, where appropriate (Figure 3-14).
- Consider use of a gabion[4] structure, where appropriate, as a retention structure with locally extracted rock material as a filler, both for aesthetic and sustainability purposes. Gabion structures can also be used as noise mitigation facilities.
- Consider maintenance of the right-of-way environment in the roadside design. This can be achieved by minimizing the area where mowing is required or where irrigation is needed to support desired vegetation.

4 A gabion wall is a retaining wall made of rectangular containers (baskets) fabricated of thick galvanized wire, which are filled with stone and stacked on one another, usually in tiers that step back with the slope rather than vertically.

Figure 3-14: Rock wall material (Manitou Springs, Colorado)

Case Study

HAZEL AVENUE

SACRAMENTO COUNTY CALIFORNIA

In 2010, the Sacramento County Department of Transportation (SACDOT) completed improvements to 2.5 miles of Hazel Avenue from U.S. Highway 50 to Madison Avenue in order to relieve congestion and improve multi-modal mobility. As part of the project, the Hazel Avenue Bridge over the American River was widened, multi-use connectivity was improved, and sound walls and retaining walls were constructed along Hazel Avenue. The Hazel Avenue Bridge is located 500 feet upstream of the Nimbus Fish Hatchery and 1,500 feet downstream of the Nimbus Dam on Bureau of Reclamation right-of-way in an environmentally sensitive area. Though the project is in a more suburban context, sustainable practices were applied.

A soil-nail wall system was installed along Hazel Avenue and the multi-use path. The rocky hillside context was ideal for steep vertical cuts and use of a soil-nail system for stabilizing the slope. The design called for vertical cut excavation to be performed in levels and soil-nails to be installed as the excavation progressed to the final grade. In order to construct the fascia of the wall, pneumatically placed concrete was sprayed on the excavation face and was finished using hand tools. The use of the soil-nail wall system reduced the amount of excavation, minimized the environmental impacts and project footprint, and improved the overall project aesthetics. Other project elements included the extension of the multi-use pedestrian and bike facilities for better connectivity, a multi-use bridge crossing, and emergency vehicle access for enhanced safety and access to the river front path systems. These sustainable features helped create a cost-effective, environmentally responsive, and aesthetically pleasing project that enhanced the community.

Soil-nail wall system as constructed

Case Study

BEAR LAKE ROAD

ROCKY MOUNTAIN NATIONAL PARK (RMNP)

Bear Lake Road extends approximately 9 miles from its intersection with Trail Ridge Road to its terminus at Bear Lake in RMNP. Improvements to Bear Lake Road were needed to correct structural deficiencies in the roadway, address inadequate drainage, enhance safety, facilitate existing and future shuttle bus operation, and improve inadequate intersection and pullout design.

Often the most context-appropriate and sustainable choice is also the most cost-effective. A notable geotechnical feature of Bear Lake Road reconstruction involved installation of a 1,079-foot rockery. Rockeries are gravity walls that are stacked through rocks and boulders. Smaller rocks are placed behind the wall as fill to enhance stability and safety. A rockery was the selected retaining wall design concept for the project since more traditional soil-nail walls were cost prohibitive. Rockeries represent a sustainable solution from a number of perspectives:

- Less expensive and labor-intensive than the more traditional soil-nail walls, which can cost up to $1,000/linear square foot.
- Context-sensitive due to the use of materials (rocks and boulders) from within the project area. This also avoids the need to haul new material from outside the project area.
- Contextually appropriate and aesthetically pleasing.

3.2.6 Geotech Checklist

General

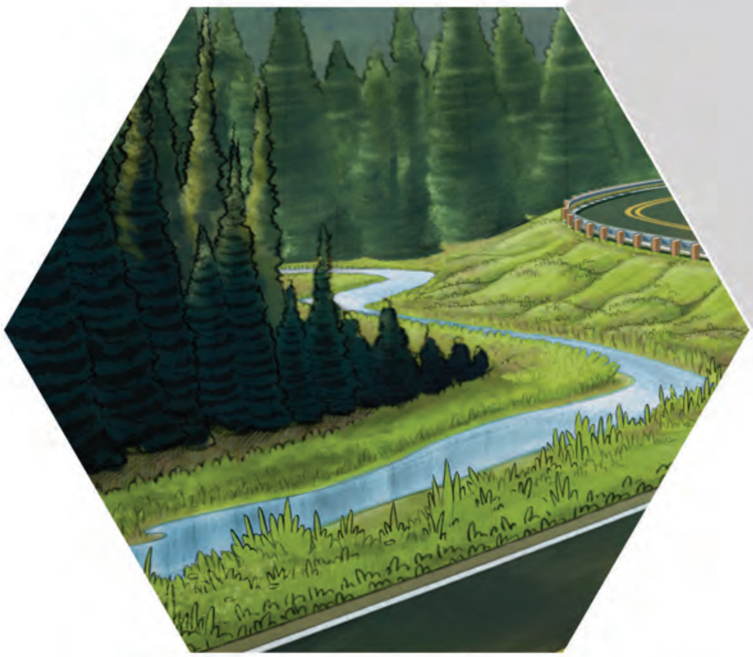
- ❑ Ensure that slope angle can be supported by the roadside material.
- ❑ Design for mitigation and prevention of future rock fall events.
- ❑ Ensure that there is adequate support for the structures. Where possible, minimize the area of the ground to be disturbed by excavation for the foundation.
- ❑ Design for minimal maintenance requirements.

Vegetation

- ❑ Ensure that vegetation, if used to anchor soil, is designed for the long term and will minimize encroachment.
- ❑ Ensure that little to no irrigation is needed after the initial establishment of the vegetation.
- ❑ Consider vegetation as a tool that can bolster the palette of geotechnical strategies. Rockwork and vegetation root structures can significantly increase slope stability when designed together.

Hydrology

- ❑ Verify that the design of the wall system allows for adequate drainage.



3.3 Hydraulic Design

Hydraulic design considerations:

- Conveyance systems
- Channel behavior
- Erosion control

3.3.1 Introduction

The term "hydraulic" refers to the field of science and engineering dealing with liquids. For purposes of this guidebook, hydraulic design covers concepts such as conveyance systems, channel behavior, and erosion control.[1]

This section introduces a key issue that engineers face in working toward environmentally sustainable solutions: smaller, more frequent storms are commonly ignored when designing flood control facilities. And yet, these storms are most often responsible for shaping the long-term health of these facilities and the larger roadside. A number of trade-offs are introduced in this section, followed by a set of strategies to help mitigate smaller, more frequent storm events. Example strategies include microcatchments, micro-terraces, slope transitions, bioretention, and multi-cell box culvert design.

3.3.2 Key Requirements

The traditional approach to hydraulic design involves analysis of prescribed storm events and designing to mitigate such events. A Design Flood Event is typically either the 50- or 100-year storm. Smaller events, known as bank-full events, are responsible for shaping channels and ditches and defining where vegetation will grow. These bank-full events are typically characterized by the 2-year storm, which has a 50-percent chance of occurrence in any given year.

Traditional design practices require that hydraulic systems be designed for events ranging from the 10-year to the 500-year storm. Hydraulic design is based on roadway classification. Applicable design features for low standard roads are shown in Table 1.

Table 1: Low Standard Roadway Design Features

Design Feature	Standard	Flood Event
Culverts	High	50-year
	Low	25-year
Roadside Ditch	High	10-year
	Low	10-year
Longitudinal	High	50-year
Embankment	Low	25-year

Source: FHWA PDDM

Typically, standard design methodologies ignore the lower intensity, more frequent storms since safety and replacement concerns dominate the design requirements. This section details design features which

1 Hydraulic design for roadways constructed by FHWA is dictated by the PDDM. Section 7.1.8 defines the Design and Check Flood for proposed drainage systems.

will enhance the systems for smaller, more frequent events, reducing the need for maintenance and extending the life of the system.

3.3.3 Relationship with Other Disciplines

Defining a sustainable roadside requires identifying the characteristics of a "traditional" roadway and comparing historic techniques to new methodologies. In order to establish new methodologies, relationships with other disciplines must be formed to create innovative techniques to enhance the roadside. This approach mimics a typical FHWA Cross Functional Team (CFT) meeting environment where the Hydraulics Team pulls ideas from each of the other disciplines.

Hydraulics must work together with each of the other disciplines to develop strategies for conveying runoff (rainfall that exceeds infiltration) safely and efficiently. Coordination with revegetation and geotechnical disciplines, among others, is critical.

VEGETATION: In order to create a stable conveyance area, the correct landscape material must be determined. Vegetation can protect slopes by reducing erosion and strengthening soil stability. Utilizing the correct land cover is critical to creating a sustainable roadside. The hydraulics group must determine flow rates and velocities and confer with landscape professionals about materials that can be established in the region and will be stable in the long term. In lieu of or in combination with vegetation, rock material can also be utilized to stabilize drainage ways. A soil-riprap mixture optimizes riprap protection by providing a growing medium that contributes to stability.

Landscape professionals may also be consulted where issues of water quality must be addressed. Bioretention areas provide environmental benefits such as creating ideal growth mediums for filtration processes. Impacts to adjacent vegetation and natural systems need to be considered to ensure that roadway run-off does not overload the

HYDRAULIC DESIGN AND SAFETY

A delicate balance exists between providing structural hydraulic features and ensuring a smooth roadside surface for errant vehicles. Hydraulic obstructions may include, but are not limited to:

- Culvert end sections
- Oversized riprap
- Erosion control devices
- Water settlement facilities
- Water detention facilities

To mitigate these concerns, hydraulic facilities need to provide traversable surfaces to minimize slippages, overturns, and damages to vehicles (AASHTO, 2006).

Culverts should have many purposes in addition to simply conveying run-off. Culverts can serve as safe passages for small- to medium-size wildlife. If culvert or wildlife crossing end sections fall within the clear zone, they must be protected from motorists using barriers or traversable grates. The trade-off is that grates often discourage wildlife crossings, which may result in increased wildlife collisions on the roadway (FHWA, 2008).

landscape with grease, oils, metals, or chlorides. Sediment and increased run-off impacts should also be reviewed.

Planning is critical in mitigating environmental impacts to vegetation and designing a sustainable roadside. Identifying the protected or sensitive areas will help establish the drainage patterns in the project. General concern with roadway impacts, such as grease or oil, metals, and chlorides, can be addressed with proper planning. In addition, run-off from impervious surfaces can generate erosion that increases sediment conveyance. Slowing run-off and spreading flow will help replicate predevelopment patterns.

GEOTECH: Coordination with the geotechnical discipline is needed when addressing slopes and roadside structures. In general, flatter slopes are preferred but need to be balanced with potential impacts to the surrounding environment. Stable slopes that resist erosion and enhance vegetation growth are crucial to a sustainable environment. Detailed analysis and coordination is especially important when a wall is necessary, and optimal layout must be determined. Hydrostatic forces create complex systems. Weepholes are often required for drainage from backfill on the uphill side. Diversion of stormwater run-off using concrete curbs and gutters allows water to be safely diverted around the walls. In some instances, culverts are needed through the wall section to collect runoff. Overall, coordination between disciplines to ensure the proper wall design and stability is vital to enhancing the roadway.

The construction process needs to ensure that hydraulic features are feasible and sustainable. Design of controls to convey run-off during construction can provide a basis for permanent facilities that provide water quality. Utilizing features such as terracing of slopes can increase the length of travel that run-off follows, increasing the ability of run-off to infiltrate. BMPs such as rock check dams also slow velocities, which reduce erosion potential and increase infiltration. Many of the features installed during construction can remain as permanent features, as long as the materials will hold up over time.

3.3.4 Trade-offs and Considerations

Hydraulic design often requires trade-offs when working toward solutions. These trade-offs must consider project context and scale. For example, traditional design typically plans for peak flow; whereas a more sustainable design considers the full spectrum of storm events. Hydrologic criteria for sustainable design must include consideration of flows resulting from more than 10-, 50-, and 100-year storm events. Culvert and bridge hydraulic design should take into account an approximate flow or storm frequency for the channel forming discharge. This is often defined as a 1.5-year to 2-year event. These frequency events are typically published and in many cases are suitable substitutes for estimating the channel forming discharge. In order to minimize impacts to channels (hydraulic and ecological), design of culverts should also account for normal flow by minimizing expansion or contraction of the river or stream within the crossing.

Conventional designs at streams or drainage ways tend to focus on larger precipitation events. However, small events typically generate the highest concentration of pollutants and contribute the most towards erosion. Conventional methods tend to concentrate run-off flows in roadside swales and in culverts. In smaller drainages where no defined channel existed before, the increase in concentration can result in unexpected erosion. When rivers or streams are constricted at crossings, sediment is often accumulated upstream of the road and erosion is increased downstream of the road (Figure 3-15). More specific considerations include the following:

- **Box culverts** that are designed to convey a large storm event (such as a 50- or 100-year storm) without accounting for maintenance of the natural sediment transport condition can result in sediment accumulation in the culvert and increased erosion downstream. Allowing the channel forming discharge to widen and slow within the culvert results in sediment accumulation that will have to be removed frequently in order to maintain the design capacity of the culvert. In addition, increased erosion can result downstream of the box culvert as the flow velocity increases beyond it, picking up new sediment.

Figure 3-15: Large culvert following major storm event

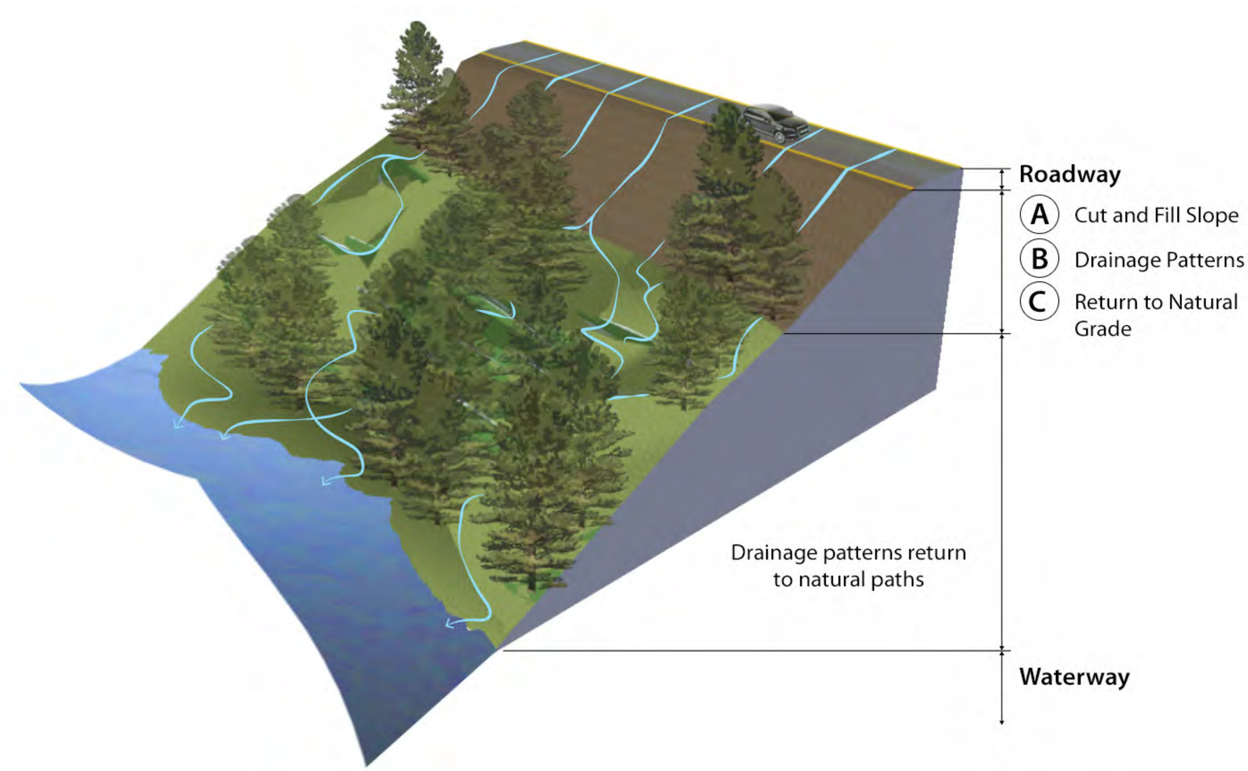
Large culverts tend to collect sediment on the upstream end, limiting the ability to convey flows during major storm events.

  Aquatic organism passage is an important consideration in the design of culverts that convey storm events. Traditionally, culverts have been installed to provide conveyance for stormwater. However, culverts often narrow the channel through the opening, which increases velocity and scour potential, and can create barriers to fish and other organisms. This narrowing reduces the distribution and habitat available and can lead to the inability of fish to access upstream spawning and rearing areas. This can result in decreased production and, in some cases, can eliminate fish populations altogether (Washington Department of Fish and Wildlife, 2003).

  Fortunately, recent guidance has been developed by numerous entities, including FHWA (2010), to provide technical approaches for enhancing the environment for aquatic organisms. In addition to standard culvert requirements, many variables need to be considered, including fish biology, fish passage hydrology, and stream geomorphology. By incorporating features that match the representative stream sections upstream and downstream of the proposed culverts, safe organism passage can be provided. Additional guidance from local jurisdictions can supplement the referenced documentation.

- **Single, large-diameter culvert installations** in drainage ways with wide, shallow flow properties can result in excessive ponding at the inlet and increased sediment accumulation upstream of the inlet. Increased erosion due to plunging flows from the culvert outfall and increased sediment carrying capacity of clear water flows may also result.

Beyond the stream and drainage way crossings, creating a sustainable roadside involves the application of selected low-impact development (LID) strategies. Not all LID techniques work for rural roads and, for those that do, they may not work in every location. When applying LID or other methods in order to achieve increased roadside sustainability, each method should be evaluated carefully. Sample considerations include:



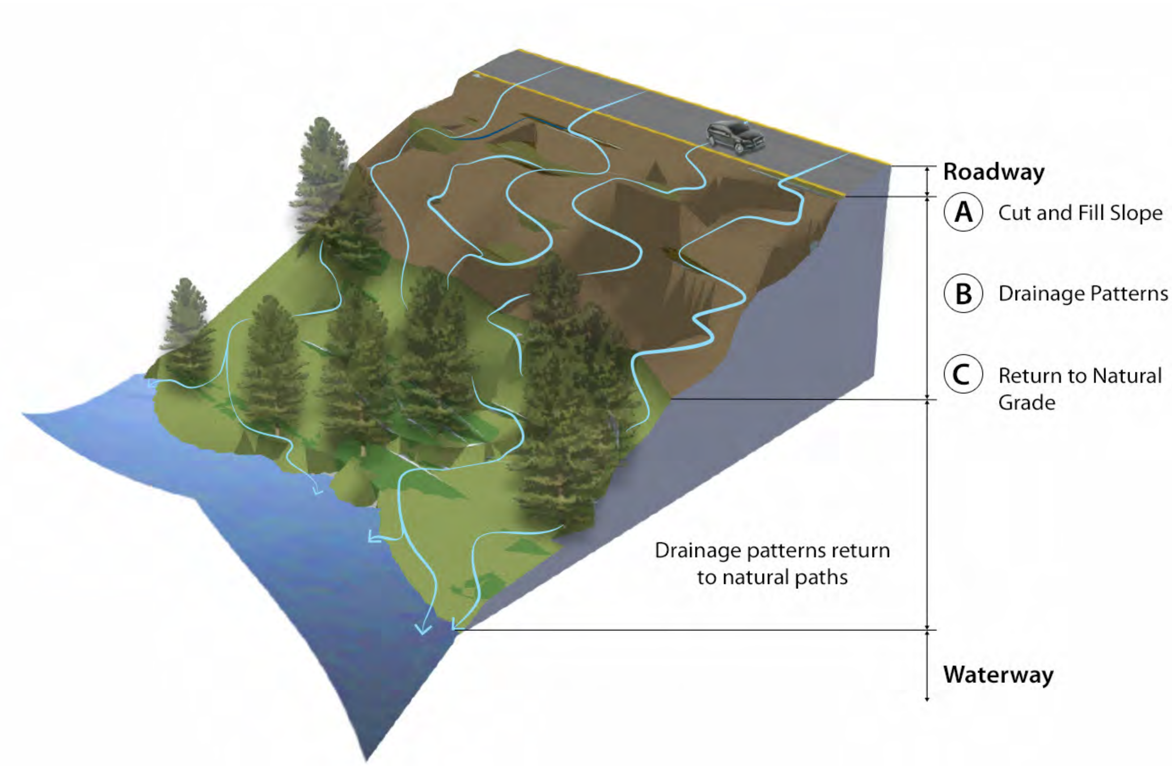


Figure 3-16: Flow paths

Lengthening flow paths (bottom graphic) helps filter drainage before entering waterways.

- ***Can directly connected impervious areas be reduced or altered on the project?*** Rural roads and highways provide very little opportunity for influencing directly connected impervious areas, except in a situation such as a roadway-widening project that has a paved median. Directly connected impervious areas can be reduced when designing safety rest areas and traveler service locations.

- ***Can flow paths be lengthened on the project?*** In cases where roadways are running perpendicular to the prevailing drainage, flow paths are often lengthened as runoff is intercepted by the road and routed to culverts (Figure 3-16). Velocity of run-off can be influenced by using contour bench terraces, run-off strips, and microcatchments (FHWA Roadside Revegetation, 2007).

- ***Can infiltration be increased without nuisance flooding or creating standing water in inappropriate locations?*** The overall change in imperviousness caused by a single road crossing a rural watershed is small. Loss of infiltration is generally caused by an increase in the concentration of run-off and the resulting increase in flow velocity. Measures can be taken to minimize the premature concentration of flow, such as the use of native trees or brush where safe lines of sight and the climate allow. Trees and brush help increase the interception of rainfall and slow the accumulation of run-off.

- ***Does the road interrupt natural drainage patterns, possibly impacting adjacent land extending upstream or downstream? Can the natural drainage patterns be re-established or at least approximated?*** Toe erosion along embankments and in receiving channels can be reduced with the use of additional smaller culverts. The placement of these additional culverts can re-establish an approximation of the natural drainage patterns. In addition to reduced erosion, approximating the natural drainage patterns more closely could help avoid the loss of small habitat communities due to changes in available moisture (Figure 3-17).

Figure 3-17: Drainage directly into a creek without treatment/infiltration strategies

This section demonstrates that drainage solutions cannot take a "one size fits all" approach. Trade-offs need to be considered at a project level basis through the series of questions described above. The next section lists a set of recommended approaches that embrace sustainable design techniques.

3.3.5 Recommended Approaches

Hydraulic facilities must be designed for multiple precipitation events starting with traditional major events but concentrating on the more frequent stream-forming events. This section outlines the design and approach for the hydraulic concepts previously discussed.

After the key requirements have been met for the hydraulic facilities, additional concepts can be designed to enhance the sustainability and the long-term function of the system. It is best to focus on smaller scale strategies, such as microcatchments, micro-terraces, terracing, vegetated buffers, filter strips, pervious paving, bioswales, and native vegetation.

- **Microcatchments:** Roadways typically create a blockage for natural drainage patterns and concentrate flows at discrete locations. One way to minimize the impacts of the roadway section is to place additional, smaller culverts at intervals along the road alignment to allow smaller frequency events to cross the roadway intermittently. This would also allow for smaller facilities at the main culvert crossings.

  Installing culverts in discrete locations can help replicate preconstruction flow patterns. As can be seen on Figure 3-18, returning flow to the downstream side of the road embankment can help restore vegetation and the ecology that often is severed. Combining this feature with micro-terraces can also assist in restoring flow patterns.

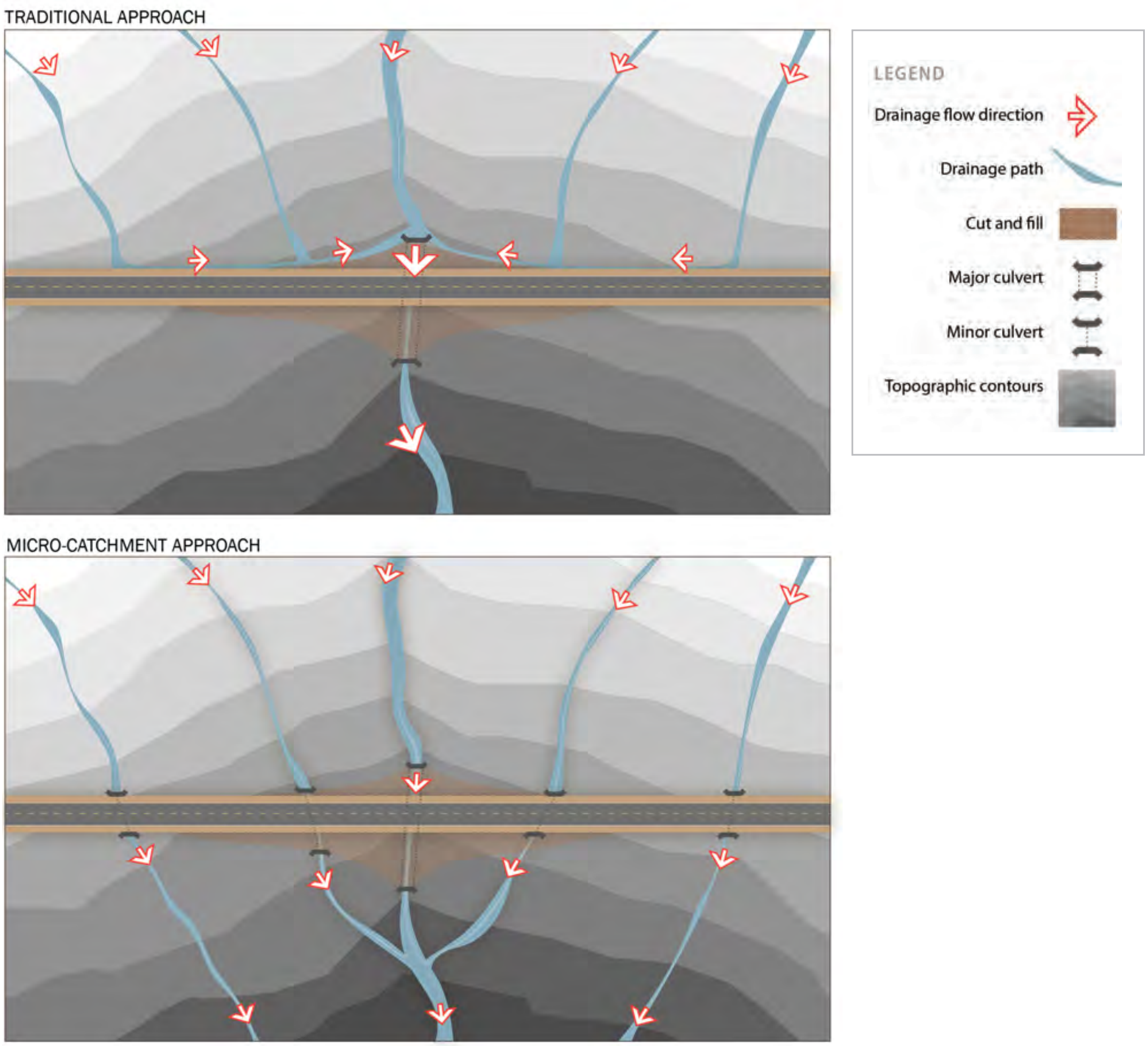


Figure 3-18: Microcatchments

The installation of microcatchments allows smaller frequency events to cross the roadway, and can help reduce overall infrastructure costs.

- **Micro-terraces:** Runoff from the impervious portion of the roadway tends to concentrate and create erosion along embankments. A simple and relatively inexpensive technique utilizes terraced and roughened surfaces parallel to the road surface to slow storm run-off and lengthen the flow path. This also creates a more natural looking surface as opposed to the perfectly symmetrical traditional road embankments.

  Combining the micro-catchment technique with micro-terraces will help restore natural flow patterns. Surface roughening helps to create micro-terracing through replicating the natural undulation in the ground surface with small pools and riffles. Replicating this natural environment not only softens the look of the roadway slope, but promotes infiltration and vegetation growth and reduces erosion due to run-off. The two pictures in Figure 3-19 show the visual difference between a standard, flat, graded roadway embankment versus roughened slopes.

Figure 3-19: Micro-terraces (right)

Micro-terraces replicate the natural environment to soften the roadway slope, promote infiltration and reduce run-off erosion.

- **Slope Transitions:** Placing a roadway in a natural setting will require both cut and fill slopes throughout the project. Typically, slopes are tied into the natural grade as quickly as possible. In theory, this minimizes the impact to the surrounding area, but in reality it separates the improvements from the natural area. Where run-off is concerned, when sheet flow travels across the natural area, it is slowed by native grasses and natural terracing. When run-off encounters the engineered slope, it accelerates, creating erosion. Providing slope transitions that smooth the interface between the existing and proposed slope lessens the acceleration typical to the interface. This helps promote and accelerate vegetation re-establishment, providing lasting benefit and a more naturally blended system (Figure 3-20).

- **Bioretention/Bioslopes:** In locations where run-off from rural roadways may impact ecologically sensitive areas, bioretention or bioslopes may be a practical addition to the standard systems. Both systems provide a filtration medium that can remove unwanted sediment and pollutants before releasing the flows back to the open system. Utilizing ditch sections as a part of the roadway template are key requirements standard to every rural roadway. Enhancements to the typical ditch section can provide tremendous benefits over the standard section. By implementing a filter section of natural materials, such as sand or organic materials, filtering of run-off from the road section can take place before the run-off enters ecologically sensitive areas. Utilizing an underdrain system can increase the efficiency of the system by removing filtered water quickly.

- **Culverts:** There are multiple techniques that can be used at culvert crossings to create systems that will meet key requirements and help create a sustainable system. Culverts can be designed to flow

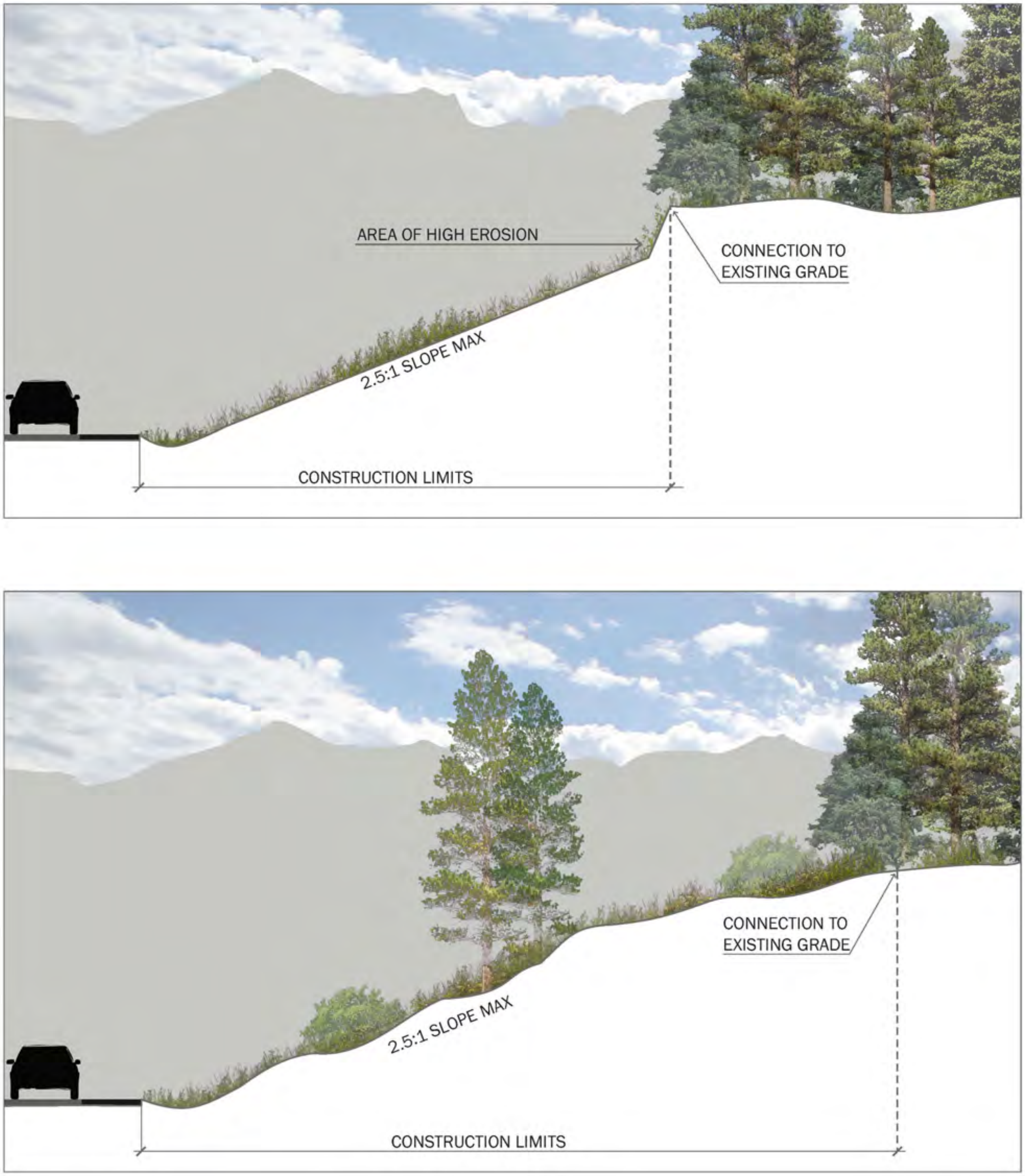


Figure 3-20: ***Slope transitions***

Providing slope transitions that link the interface between the existing and proposed slope by mimicking natural undulations can help lessen acceleration of stormwater and increase natural infiltration.

in a manner that mimics natural flow conditions for the full spectrum of flows (normal flow to design flood) as much as possible. In locations where existing box culverts are continually filling with sediment, inlet improvements can improve the sustainability of the existing crossing by preventing sediment deposition during minor events. One way this can be accomplished is by designing multi-cell box culverts with one cell floor lowered to keep normal channel flows and the channel forming discharge (usually equivalent to a 1- to 2-year event) confined to one cell (Figure 3-21). This reduces the impact on the natural sediment and bedload transport balance. This also reduces the need for maintenance, such as removal of sediment accumulated in the culvert, and reduces the upstream and downstream impact on the water way. Conveying run-off that more closely matches the natural channel will also enhance the area surrounding the roadway. By keeping the bench associated with a natural channel, native vegetation can establish itself, increasing biological benefits.

Figure 3-21: ***Multi-cell box culvert***

This image shows the concept of a multi-cell box culvert, which places one cell floor lower than the other to keep normal channel flows and discharge confined to one cell.

There are multiple opportunities to apply techniques above and beyond the key requirements to create sustainable hydraulic solutions. Soil improvement is one example—when soil is improved, infiltration increases, which absorbs and stores water that would normally run off into water courses. It is important to keep water on the roadside to increase the amount of water available for vegetation, which in turn means better growth and less flooding.

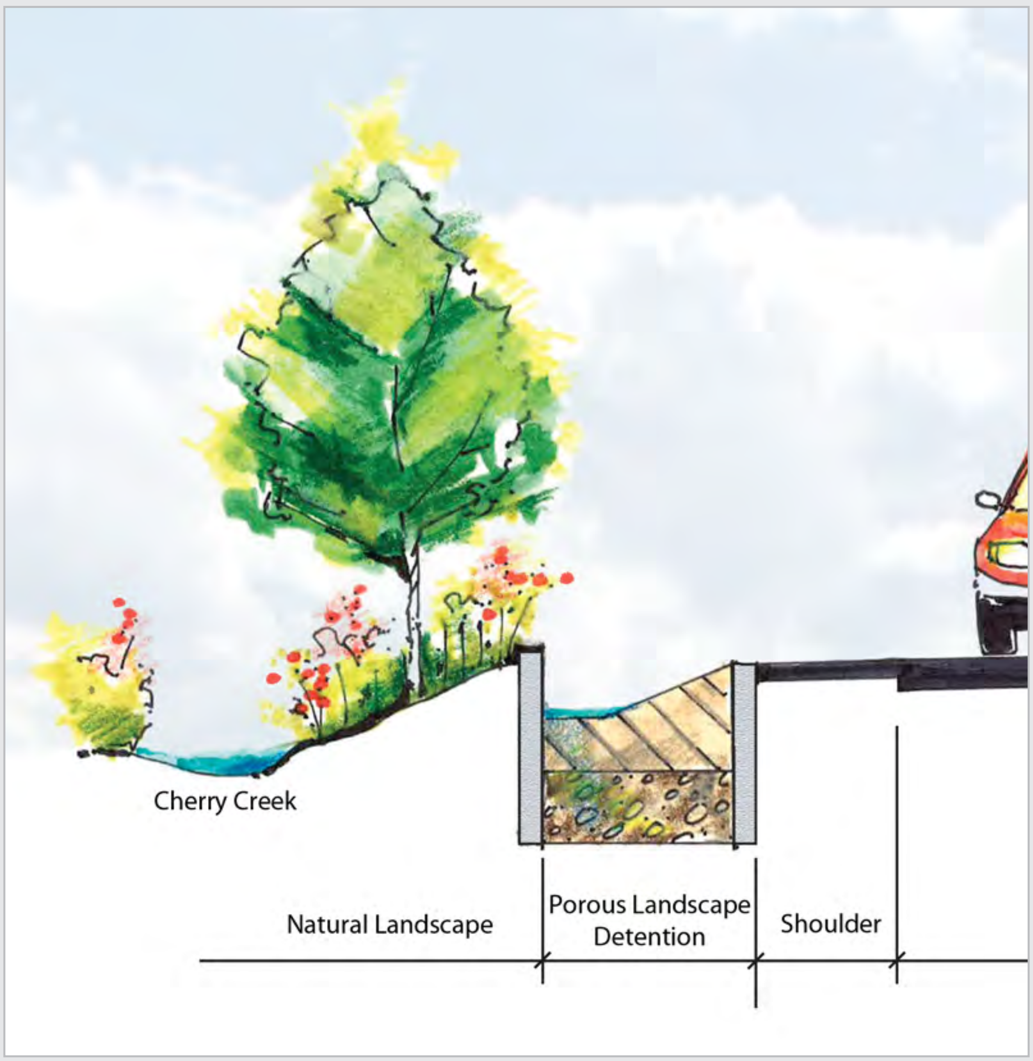
Case Study

CHERRY CREEK DRIVE SOUTH

DENVER, COLORADO

The concept of porous landscape detention (PLD) was used on the Cherry Creek Drive Project in Denver, Colorado. The design of a PLD consists of vegetation growing on a filtration mix underlain with large aggregate and drains. PLDs capture and filter run-off from a roadway before it enters ecologically sensitive areas.

The City and County of Denver installed PLDs on the Cherry Creek Drive project to preserve and protect water quality in Cherry Creek, which runs parallel to the corridor. Other project improvements included overall street reconstruction, new raised landscaped medians, construction of a new sidewalk, and a pedestrian/bicycle ramp connecting the sidewalk to the Cherry Creek trail system. Though this porous landscape detention example was placed in an urban environment, it could be applicable to rural roadsides where protection of sensitive environments (i.e., wetlands or waterways) is important.



Source: www.denvergov.org/Capital_Projects_Center/CherryCreekSouthDriveCorridorPlan/

Case Study

HALSTEAD MEADOWS

SEQUOIA AND KINGS CANYON NATIONAL PARK

The Western Federal Lands Highway Division (WFL), in partnership with the National Park Service (NPS), are constructing a new bridge through Halstead Meadows in Sequoia and Kings Canyon National Park along Generals Highway. The project site is located 30 miles north of Three Rivers, California, and 70 miles east of Fresno, California, in Tulare County. The primary driver for construction of the bridge was to help resolve drainage and erosion issues. The at-grade roadway was functioning as a dam that altered the natural sheet flow condition of the meadow and concentrated water to two 36-inch-pipe culverts. The channelization resulted in creating scour upstream and downstream of the roadway and extended the length of the meadow.

The goal of the project was to restore meadow hydraulics by constructing a 250-foot seven-span concrete bridge to replace the existing roadway. NPS worked on re-grading the meadow, replaced the former vegetation with native vegetation, and filled in the eroded drainage channel. NPS is monitoring the vegetation and ensured that the surface run-off does not drain into the formerly incised channel by using native material such as fill dirt, rocks, and logs to re-establish the sheet flow and prevent future erosion. Colored concrete was used and stone guardrails were placed at the four corners of the bridge to enhance the surrounding environment.

The roadway before project construction

The bridge under construction

Photo Source: National Park Service and Parsons Brinckerhoff

3.3.6. Hydraulic Design Checklist

Detailed Strategies/Low Impact Development Techniques

- ❑ Microcatchments
- ❑ Micro-terraces
- ❑ Slope transitions
- ❑ Bioretention
- ❑ Bioslopes
- ❑ Innovative culvert design
- ❑ Vegetated buffers

Vegetation

- ❑ Identify protected or sensitive areas along corridor to help maintain natural drainage patterns.
- ❑ Use native trees, shrubs, and grasses to maintain natural biodiversity and increase success in establishment in specific environmental conditions.
- ❑ Design revegetation to both follow and mimic natural drainage patterns and to encourage stable slopes that intercept rainfall, slow run-off accumulation, and allow for on-site infiltration.
- ❑ Plan for water movement and capture to sustainably and naturally irrigate vegetation, minimizing the use of additional irrigation past the establishment period for revegetation plantings.

Geotech

- ❑ Evaluate the balance in slopes to preserve natural environment.
- ❑ If right-of-way is available, design drainage ditches to be traversable so that a vehicle leaving the roadway can cross over them without overturning or abruptly stopping.
- ❑ Coordinate between disciplines concerning need for walls and design of walls. Evaluate options to handle or divert run-off with wall design.

Aesthetics

- ❑ Minimize visual impact of water quality features and structures.

Construction Practices

- ❑ Restore streambanks.
- ❑ Provide for soil erosion control.
- ❑ Meet National Pollutant Discharge Elimination System (NPDES) requirements.
- ❑ Stage construction to minimize soil exposure.

- ❑ Provide stormwater detention.
- ❑ Minimize water ponding on the edge of pavement which can contribute to deterioration of the pavement edge and rutting of the soil.

3.4 Roadside Vegetation

Though they differ by project, a few of the primary goals for revegetation include:

- Serve as a buffer, wind, and glare screen
- Blend the roadside into the existing landscape
- Increase slope stability
- Capture carbon
- Minimize soil erosion from precipitation and wind
- Assist with noise abatement
- Enhance ecological diversity
- Preserve and provide wildlife habitat and connection
- Reduce weed infestation
- Reduce fire spread

3.4.1 Introduction

A sustainable roadside landscape is one that is designed, constructed, and maintained with the objective of long-term plant survival while minimizing resource input. This section highlights strategies that help balance long-term maintenance of vegetation to achieve sustainable outcomes. High-level strategies are outlined in this guidebook; more detailed revegetation approaches are provided in FHWA's *Roadside Revegetation: An Integrated Approach to Establishing Native Plants* (2007).

For purposes of this guidebook, revegetation is defined as the process of planting on disturbed areas following roadway construction. Often, the goals for a project's revegetation efforts are to help minimize the visual impact of construction and to help blend the roadside back into the existing landscape. Additional benefits that revegetation provides include:

- Helping to minimize soil erosion
- Protecting water and air quality
- Providing noise abatement
- Enhancing ecological diversity

Minimizing resource input typically involves selecting native or naturalized plants that are adapted for survival to the local climate, elevation, and soil conditions. If a naturalized plant is used, care must be taken to ensure that it does not have invasive or negative interaction with the native ecosystem. Detailed understanding of the site is helpful to evaluate microclimates, solar aspects, soils, and hydrologic patterns that can provide additional clues to the correct selection of plants. For instance, local native vegetation may be the preferred choice on a project with both north- and south-facing slopes. However, that same native plant may require full sun and well drained soils and thus may not establish on the north-facing slope. Decision-making needs to be flexible enough to choose the most appropriate plants with the greatest chance of survival and growth.

There is not a one-size-fits-all solution to revegetation projects, especially for the roadside. Therefore, an understanding of the particular site conditions and also of plant species and communities is critical in the development of a sustainable revegetation plan. With early collaboration between design disciplines and a clear understanding of the project objectives, a functional and aesthetically appropriate revegetation plan can be developed and can help minimize unnecessary maintenance and plant replacement costs. Figure 3-22 shows the project cycle of revegetation from planning and programming through maintenance.

3.4.2 Key Requirements

This section identifies the traditional process of revegetation. First, existing conditions of the site must be inventoried and incorporated into the revegetation plan. The selected plant material for a sustainable roadside revegetation project should be able to establish and survive with as little outside support as possible, such as irrigation and fertilizers, although these can be critical for success in establishing the plant material. The key is to minimize the intensity and dependence on these resources. To help minimize plant mortality rates, the designer must have a solid grasp of the local native and naturalized plant palette. Understanding soil types, solar conditions, hydrologic regime, and beneficial companion plants will provide a greater opportunity for success as the plants become established. A strong understanding of

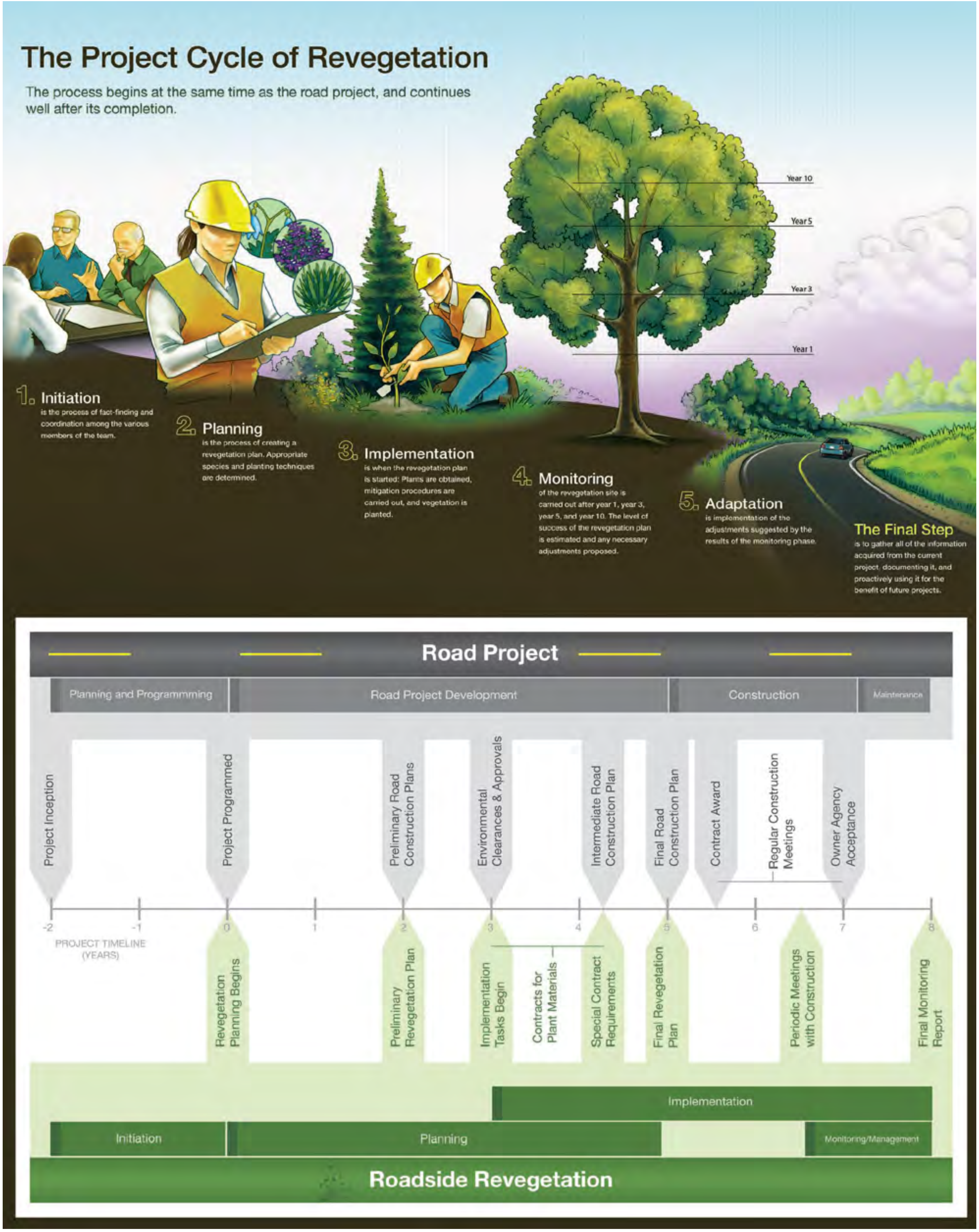


Figure 3-22: Project cycle of revegetation

the attributes of vegetation types can help minimize the need for excess irrigation and replacement. The following must be understood from site evaluation and engineering plans:

- Solar aspect
- Elevation
- Slopes
- Proposed grading
- Drainage patterns
- Local climate
- Easements
- Existing and proposed structures

Soil information is critical to the creation of successful revegetation plans yet is often unavailable or not considered in the engineering plans. In order to maximize the chances of plant survival, the designer must know the type and condition of the soils where the vegetation will be installed. Coordination with the project engineering staff is needed to determine whether topsoil will be salvaged, stockpiled, or reused.

If topsoil is to be reused on the project, considerations should include:

- What is the quality of the topsoil?
- How much will be available for reuse/replacement on finished slopes?
- Will any amendments be required to help establish revegetation?
- How can native flowering plants and grasses be incorporated to encourage quick growth and restoration of indigenous vegetation?
- What special equipment or construction methods may be needed to salvage, stockpile and replace the topsoil?

If existing topsoil is limited, furnished topsoil or topsoil manufactured on the project site should be considered.

VEGETATION AND SAFETY

According to the American Association of State Highway and Transportation Officials (AASHTO) *Roadside Design Guide* (2006), trees are the most commonly struck objects in serious roadside collisions. Crash severity is closely correlated with the speed of vehicles. High-speed roadways should have clear zones free of trees and other fixed object hazards. FHWA encourages highway agencies to work cooperatively with communities to improve safety while enhancing the environment by developing consensus policies related to tree planting, potential removal, or avoidance mitigation. When designing a new roadway tree mitigation measures can include:

- Alignment adjustments
- Reduced roadway speeds
- Structural barriers
- Tree removal

Roadway agencies have a responsibility to maintain vegetation at the roadside. Tall or unmanaged vegetation can obscure driver sight lines, traffic signs and signals, other vehicles, pedestrians, bicyclists, and wildlife. Avoidance of edible vegetation on the roadside edge can help discourage animals from foraging at the roadside and help reduce the potential for vehicle/wildlife collisions (AASHTO, 2006).

Soil samples should be taken and sent to a soils laboratory to analyze the organic and mineral composition of the soils. This will help indicate any soil treatments necessary prior to plant and seeding operations. If the soils are optimized in the most cost-effective manner, vegetation will have a better chance of establishment and survival versus simply planting or seeding on the existing soils. Although there are costs associated with soil testing and the use of soil amendments, having this information prior to plant installation can save long-term costs associated with revegetation. Beyond plant materials and project site conditions, another key requirement is communication and collaboration among other disciplines early in the design process. This promotes an understanding of the different project goals and objectives as seen by each group. Early communication and collaboration provides the opportunity for open discussion and the identification of conflicts.

3.4.3 Relationship with Other Disciplines

Although thriving vegetation can indicate a healthy roadside ecosystem, it is only one part of the roadside environment. The following are examples of the ways in which revegetation can integrate with other disciplines:

AESTHETICS: Vegetation plays a key role in achieving an aesthetically pleasing road-side environment. Proper selection of plant materials as well as their placement, either individually or in groupings, can make the difference in achieving the desired aesthetic. Aesthetic goals for the project should be defined, especially if there are areas of the project that require screening or views that could be highlighted and framed with vegetation. For instance, it may not make sense for a tightly spaced row of evergreen trees to be planted where they may block views. Proper placement of the plants during the design phase (and an understanding of growth, change, and effect over time) as well as field adjustment of plant placement can help enhance the aesthetic quality.

The intensity of landscape treatments should be based on the roadway characteristics. In slow-speed zones and rest areas (turnouts, scenic vistas, etc.), a more detailed approach to plantings is needed. Site-specific slope molding, rock cut sculpturing, and diverse vegetation types can help enhance the roadside environment and provide added interest for the highway user (FHWA PDDM, 2011).[1] On high-speed sections of roadways, vegetation should create interest for motorists but not at an intensity that is distracting.

GEOTECH: The revegetation and geotechnical disciplines need to coordinate placement of vegetation on roadside slopes and along roadside structures. Enhancing roadside slopes and cuts can help mimic natural environmental and aesthetic conditions. The addition of boulders, stumps, and logs on cut and fill slopes (outside of the clear zone) can help replicate the natural appearance and function of the area.[2]

HYDRAULIC DESIGN: Another relationship to consider is integration with drainage plans. A sustainable system will minimize the resources spent on the establishment and maintenance of vegetation. If vegetation is to be used in and near drainage areas, then vegetation should be selected that will withstand the hydraulic conditions. Plants that can tolerate periodic inundation and flowing water need to be selected for use near drainages.

1 FHWA PDDM: Section 9.5.4 Landscaping and Restoration of Vegetation, pp 9-145.

2 FHWA PDDM: Section 9.5.4.7 Slope Enhancements

Case Study

USE OF VEGETATED INFILTRATION SWALES ON THE INTERCOUNTY CONNECTOR

The Intercounty Connector (ICC) is a new 18-mile roadway near Washington, D.C. The design-build contractor was encouraged to incorporate measures of conservation and sustainability within the project limits. The corridor incorporates innovative roadside revegetation practices including the use of:

- Native plant material to revegetate disturbed areas and meet reforestation requirements
- Large masses or groupings of trees or shrubs to create naturalistic plantings that have continuity and provide for genetic diversity
- Plantings for different project zones (forest edge, roadside screening, reforestation, stormwater management areas, etc.)

An interesting practice on the ICC that has multiple benefits is vegetated biofiltration swales, a water quality improvement feature of the highway. The ICC is within the Chesapeake Bay Watershed where surface water quality is a major concern. Additionally, these swales are located in an area designated as a Special Protection Area by the local county. The swales filter, cool, and infiltrate run-off stormwater from the highway before excess run-off is released into high quality local streams located within forested parkland that is crossed by the highway. The biofiltration swales consist of a bioretention soil mix (BSM) that is composed primarily of sand, along with soil and organic matter to accommodate plant growth. Gravel “windows” within the BSM surface allow water run-off to quickly drain through a sand layer before entering filtration, drainage, and infiltration layers. Excess run-off drains via a perforated underdrain pipe in the drainage layer to underground, slow-release holding tanks that discharge to the nearby stream. This process helps to ensure that the water temperature in the stream does not increase, which in turn helps maintain healthy habitat for aquatic species. Due to the extreme wet or dry conditions of the BSM, switchgrass (*Panicum virgatum*) was chosen as the vegetation cover for the biofiltration swales. The fibrous roots of switchgrass are anticipated to stabilize the soil without inhibiting percolation.

Infiltration swale during construction

Infiltration swale after construction

The Maryland State Highway Administration is responsible for designing and constructing the project, and FHWA is a sponsoring agency. The project is owned and operated by the Maryland Transportation Authority.

Project website: www.iccproject.com

Plants that are more adapted to xeric (dry) conditions may not tolerate wet conditions and could require replacement. However, riparian-adapted plants such as willow that is planted in dry conditions, far from a water source may require supplemental irrigation to survive if they do not receive adequate water. Vegetation near drainage ways may need to be cleared if it is inhibiting the flow of water through the system. A choked out ditch can cause flooding on the roadway, leading to safety and, potentially, erosion issues.

The examples provided in this section are not an exhaustive list of the different relationships between revegetation and other disciplines. It does, however, support the need to focus on the interrelationships between disciplines when designing a sustainable roadside.

3.4.4 Trade-offs and Considerations

There are many trade-offs to consider when developing a revegetation plan, such as safety, maintenance, aesthetics, and establishment issues. The following examples are common ones that arise in the design process. They pertain to plant mortality costs, methods to control noxious weeds, and differences in opinion related to aesthetics.

- **Plant mortality costs:** When vegetation is unable to survive on its own, additional resources and materials are required to replace the dead plants or to mitigate other unwanted effects such as weed infestation or erosion. Plant mortality can result from an incomplete understanding of site conditions, plant materials, and the plant's place within the overall context of the roadside project. Substantial lifecycle costs arise when excessive resources must be spent to keep the plants alive.

- **Methods to control noxious weeds:** One of the considerations that can affect the sustainability of the project is the risk of infestation of noxious weeds, which can quickly overwhelm a landscape and out-compete the desired vegetation. Noxious weed infestations occur when invasive seeds are introduced, often unintentionally, and when the opportunity exists for them to establish. One of the best ways to prevent this situation is to establish plants before invasive species can take hold. This is not always possible to achieve, given limited budgets and resources.

  The trade-off to consider when establishing appropriate revegetation is to either use smaller numbers of large-sized plant material or to use larger numbers of smaller-sized plants. The goal is to get desired vegetation established as quickly as possible and to use the least amount of resources in the prevention of noxious weeds. If prevention is difficult, herbicides are often considered to combat noxious weeds. However, herbicides may have an adverse effect on the local ecosystem. Manual weed control is less toxic to the local environment and adjacent water ways, but it may not be feasible given maintenance budget constraints (Figure 3-23).

Figure 3-23: Trade-off example: controlling noxious weeds

- **Differences in Opinion:** Often, a sustainable roadside landscape is established without the use of permanent irrigation systems. This contrasts with the manicured, ornamental, and heavily irrigated roadside landscapes that are often designed. These high-maintenance designs require frequent mowing and trimming. Generally, a more "natural" landscape tends to be unkempt in appearance, which is appealing for its wild or bucolic aesthetic and minimal maintenance requirements. However, a trade-off to consider with this type of landscape is that although it requires less maintenance and resources to establish and maintain, the appearance may not be universally appealing nor appropriate for all roadside environments. A more manicured roadside often marks entry into a community and the alteration of vegetation with flowers, mowing, or designed plantings is maintained by and represents values held by the community members. Single, large-diameter culvert installations in drainage ways with wide shallow flow properties can result in excessive ponding at the inlet and increased sediment accumulation upstream of the inlet. Increased erosion due to plunging flows from the culvert outfall and increased sediment carrying capacity of clear water flows may also result.

STEP BY STEP GUIDE TO CREATING A VEGETATION PLAN:

1. **Set goals for the vegetation plan early in design.**
2. **Bring in a landscape architect or revegetation specialist who has advanced knowledge of plant materials.**
3. **Evaluate the existing and proposed site conditions.**
4. **Develop a vegetation plan in collaboration with all stakeholders and disciplines.**
5. **Execute planting plan during construction; maintain vegetation post-construction.**
6. **Collaborate with other disciplines and stakeholders throughout.**

3.4.5 Recommended Approaches

The approach to developing a sustainable roadside revegetation plan should begin with a clear understanding of the project goals and how the plans will meet the overall project objectives. Having a landscape architect or revegetation specialist on the project who has advanced knowledge of native and naturalized plant materials is an important part of the design process. Vegetation expertise should include knowledge of grasses, perennials, trees, shrubs, groundcovers, wetland vegetation, and soils. The greater the designer's understanding and knowledge of the plant palette, the greater the chance of successful plant selection for the given conditions on the site. This knowledge will also enhance the vegetation's long-term survival and minimize the risk of selecting plants with high-maintenance requirements.

In addition to plant knowledge, a thorough understanding of the existing and proposed site conditions is important. This knowledge helps designers site the correct plants in proper locations and helps minimize the probability of spending resources on plant replacement. In addition, having a thorough understanding of the project site will help inform the designer of the other disciplines' roles in the project so productive discussions can begin during inter-disciplinary project coordination meetings.

Construction activities for roadside restoration and revegetation should create a platform for healthy and successful vegetation growth by producing successful soil conditions. Correct soil preparation encourages full plant establishment with rapid canopy coverage, providing vegetative cover and helping control weeds. Plant care during the construction process is crucial to plant establishment.

Case Study

STATE ROUTE 76 (SR-76) PROJECTS

CALIFORNIA DEPARTMENT OF TRANSPORTATION (CALTRANS)

The SR-76 project is widening and realigning an existing highway which connects the Interstate 5 and the Interstate 15 (I-5 and I-15) corridors in northern San Diego County. The project is funded by TransNet, a voter-approved half-cent sales tax for transportation projects in the San Diego region. The TransNet program includes an innovative *Environmental Mitigation Program* (EMP), which provides $850 million to protect, preserve, and restore habitats near major TransNet-funded transportation projects, including the SR 76 corridor. Instead of mitigating impacts project-by-project, the EMP allows land to be acquired in advance of projects in larger parcels and at lower costs so that habitat areas can be protected and restored earlier.

The EMP has slated $80 million to protect, preserve, and restore habitat adjacent to the SR 76 corridor between I-5 and I-15. To date, 236 acres of freshwater wetlands and 1,356 acres of upland vegetation have been preserved. In total, close to 1,600 acres of property have been purchased to support habitat conservation and the San Luis Rey River Park Plan in this corridor.

By acquiring and restoring unique habitat areas along SR 76, key populations of endangered species will be preserved, land adjacent to existing conserved habitat areas will be connected, and wildlife linkages will be created. The images taken during construction show a sampling of the new wildlife crossings along the corridor.

Source: www.keepsandiegomoving.com

Case Study

SYLVAN PASS

YELLOWSTONE NATIONAL PARK

Construction of a 7-mile segment of the East Entrance Road from the Park entrance to Sylvan Pass began in 2004 as part of a parkwide road improvement program to reconstruct roadways to a 30-foot width. According to FHWA, "the context-sensitive design of this project includes widening a historic road to accommodate visitors and modern vehicles; providing for wildlife viewing without blocking traffic; protecting vertical wetlands native vegetation and bear trails; and including special rails and rock-sculpting used to maintain rustic and natural aesthetics."

Steep slopes affected by the construction near the pass made it difficult for wildlife to cross. Gentle vegetated slopes were built at certain sections which allowed wildlife to cross easily. Trees were placed parallel to the roadway to assist wildlife in climbing slopes and to limit erosion.

Vegetated slopes along the roadway create pathways for wildlife

Pair of bighorn sheep utilize the vegetated slope

3.4.6 Roadside Vegetation Checklist

- ❑ Define revegetation objectives clearly within the context of the larger project objectives.
- ❑ Document physical and environmental features of the site, specifically:
  - Soils
  - Solar aspect
  - Elevation
  - Slopes
  - Grading
  - Drainage patterns
  - Local climate
  - Easements
  - Existing and proposed structures
- ❑ Develop a revegetation plan in collaboration with all stakeholders and disciplines. Consider plant establishment, plant sizes/spacing, and natural forms of weed control.
  - Restore existing habitats that have been degraded through the construction process
  - Create new habitats where possible and restore or create new connections between habitats
  - Design plant groupings to provide contrast and respond to context
  - Promote a sense of place with native vegetation and appropriate site-adapted species
  - Design for vehicular and pedestrian access and circulation
- ❑ Ensure that the selected vegetation supports and enhances, rather than conflicts with:
  - Safety
  - Wildlife
  - Aesthetics
  - Structures and signage
- ❑ Erosion control
  - Drainage and other water resources
- ❑ Execute planting plan during construction; maintain vegetation post-construction
- ❑ Minimize delivery distance of plants to the project site
- ❑ Minimize the costs of the resources and materials required to establish the plants, such as the costs of water, fertilizer, pest control, and labor required
- ❑ Document the success of revegetation efforts during post-construction and through long-term operations

4. Maintenance Considerations

An integrated approach to construction and maintenance is critical to ensuring long-term stability of the roadside system. As with many strategies featured in this guidebook, the best approach is to compare existing practices to sustainability strategies and to test new and innovative maintenance practices to achieve higher efficiency and more sustainable outcomes.

4.1 Introduction

A number of questions concerning maintenance should be asked initially during the design and construction process and revisited post-construction through long-term maintenance (FHWA *Roadside Revegetation: An Integrated Approach to Establishing Native Plants,* 2007):

- What are the maintenance goals for the project, and how will they be achieved?
- Are the financial resources in place to conduct adequate maintenance?
- How can maintenance costs be minimized?
- How will the maintenance process be improved over time through monitoring and feedback?

Maintenance needs to evolve over the life of a project. Thus, agencies need to be flexible and incorporate the capability to revise their approach if a strategy is not successful. Some strategies may need to be removed or reworked entirely, while others may become success stories that need to be recorded and replicated on future projects.

4.2 The Lifecycle

Maintenance is imperative to the long-term longevity of a healthy roadside environment. Often, strategies envisioned in the design and construction phase may present lower costs upfront but prove to be more expensive over a product's lifecycle when long-term (replacement) costs are factored in. This cost-benefit ratio is often measured through lifecycle costs.

Roadside Maintenance Plans are recommended as a way to assign tasks, responsibilities, schedules and funding to ensure long-term roadside health.

A lifecycle is defined as "consecutive and interlinked stages of a product (or project) system, from raw material acquisition or generation from natural resources to final disposal or end of life" (ISO 2006a). Most lifecycle cost analyses are completed for pavement. The FHWA Interim Technical Bulletin *Lifecycle Cost Analysis in Pavement Design* (1998) provides a resource for calculating pavement lifecycle costs; another option is through FHWA's RealCost software.

Lifecycle analyses for elements of the roadside beyond the pavement are rarer. The Environmental Protection Agency (EPA) has a Framework for Responsible Decision-Making (FRED: 2000) which assesses lifecycle impacts by different impact categories, such as global warming potential, acidification, human health, etc. In addition, NCHRP Report 565 provides guidance for the selection of BMPs for highway run-off control (NCHRP, 2006). A spreadsheet model is included that simulates hydrologic impacts on BMP performance. Overall, additional investigation is needed on the lifecycle of roadside elements.

4.3 Recommended Process

To track roadside maintenance and ensure that strategies are executed, it is recommended that agencies complete roadside maintenance plans. Roadside maintenance plans designate tasks, responsibilities, schedules, and funding to ensure that all components of a roadside are considered. This plan should be enforceable but also flexible enough to adapt strategies to changing roadside conditions.

Roadside maintenance plans are typically prepared during the design process and revisited/updated during construction and operations. In order to identify and keep track of maintenance needs, a detailed inspection schedule should be established. An inspection schedule will identify items to be inspected and the frequency of inspection.

Roadside maintenance plans have a series of components, or steps, to ensure a thorough and integrated approach:

- **Step 1—Develop maintenance goals and objectives:** These goals and objectives will vary by project context. Overarching goals should focus on prolonging the life of roadside facilities, minimizing extensive repairs, and ensuring long-term function and safety (Figure 4-1).

Figure 4-1: Example of overgrown vegetation

Vegetation needs to be cleared from the guardrail to ensure safety and visibility (Cherohala Skyway between Tellico Plains, Tennessee, and Robbinsville, North Carolina).

- **Step 2—Develop a maintenance strategy:** A dedicated source of funding for maintenance is needed to understand the true costs of maintenance over time and the feasibility of various roadside features. An initial cost estimate should be prepared at the time of construction and evaluated by all entities responsible for maintenance.
- **Step 3—Develop a "living tool" to track maintenance activities:** A roadside maintenance plan should include a tracking spreadsheet of all sustainable roadside commitments made and the level of maintenance required for each strategy. Supporting documentation to this spreadsheet might include, at a minimum, copies of inspection reports, invoices, financial records, and photographs of roadside facilities. Two of the critical pieces of information shown in Table 2 are the columns titled "Observations" and "Coordination with other disciplines." The "Observations" column is for maintenance personnel to record unusual circumstances or issues that may need attention. "Coordination with other disciplines" reflects a similar need to work with agency groups to ensure an integrated approach to maintenance and upkeep.
- **Step 4—Develop a protocol for tracking successes and failures:** An important part of tracking maintenance activities is learning from sustainability strategies that have worked well and avoiding strategies that are not successful. An example spreadsheet in Table 2 shows how maintenance activities can be tracked over time. Data can be collected and evaluated annually to extract common themes, successes, and failures.

Case Study

NEW YORK STATE DOT (NYSDOT) GREEN AND BLUE HIGHWAYS PROGRAM

The NYSDOT Office of Transportation Maintenance launched the Green and Blue Highways Program in 2005 as a grassroots effort to capitalize on maintenance field staffs' insights and capabilities, strengthening NYSDOT's environmental stewardship and sustainability efforts. Maintenance staff are encouraged to submit recommended practices that could improve sustainability/enhance the roadways, with funding possible to test these ideas.

The NYSDOT website features reports on the Green and Blue Highways Initiative for Fiscal Years 2008–2009 and 2009–2010 (www.dot.ny.gov/divisions/operating/oom/transportation-maintenance/green-blue-highways?nd=nysdot).

Sample activities in these reports include:

- Planting living snow fences to address the safety issue of blowing/drifting snow on highways and in maintenance facility yards.
- Revegetating rights-of-way with native vegetation.
- Improving parking areas' ease of maintenance and aesthetics with new paving, large stones and fencing to discourage littering and picnic tables for parking area users.
- Testing low- and no-mow grasses to simplify right-of-way management.
- Using vegetation to screen facilities.
- Testing innovative vegetation management equipment that allows safer and more productive work.

Cascade Lake, New York

Table 2: Maintenance Tracking Spreadsheet Example

Roadside Feature and Location	Maintenance Category*	Maintenance Strategy	Date Performed	Performed by	Materials Cost	Labor Hours	Observations	Coordination with other disciplines
Box Culvert; MP 101	*Routine*	*Remove accumulated debris*	*6/1/2011*	*DOT Maintenance Division*	*$4,000*	*6*	*Need to visit more frequently*	*Need to work with Landscape Group concerning noxious weeds in culvert*

**Example categories include preventive, routine, and remedial (non-routine).*

Maintenance Considerations

INTEGRATED VEGETATION MANAGEMENT (IVM)

IVM is a coordinated decision-making and action process that uses the most appropriate and effective vegetation management methods and strategies, along with a monitoring and evaluation system, to achieve roadside maintenance program goals and objectives. IVM develops strategies and methods to prevent invasive weeds from overwhelming roadsides and planted roadside vegetation. Washington State DOT has developed Area Integrated Roadside Vegetation Management (IRVM) plans for each of the 24 maintenance areas in the state. These plans serve as a guide to set priorities and direct maintenance actions for roadside vegetation management within each area's highway corridors.

Source: www.wsdot.wa.gov/Maintenance/Roadside/vegetation.htm

4.4 Maintenance Checklist

Each of the disciplines discussed in this guidebook must consider maintenance. Maintenance personnel need to be educated on the selected maintenance strategies, embrace sustainability goals, and be part of the feedback process. The following lists specific items to consider under each discipline.

Hydraulic Design

Maintenance of hydraulic design features includes maintenance of ditches, side slopes, structures (drop inlets, pipe ends, culvert heads, etc.). Maintenance efforts for these features should ensure their long-term effectiveness in handling roadside drainage and keeping the traveling motorist safe. Stormwater facilities should be able to continue their function long-term and as originally designed. Lack of proper operation and maintenance is often cited as the number one reason for failure of stormwater facilities (Chester County Pennsylvania, 2004).

- ❑ Ensure that ditches remain traversable after cleaning.
- ❑ Clean ditches and structural features of debris and sediment regularly to prevent them from clogging and backing water onto the travel way (Figure 4-2).
- ❑ Ensure that side slopes do not become eroded over time. Plant native vegetation to slow erosion.
- ❑ Evaluate stormwater basins and other features for damage by burrowing animals or other wildlife.
- ❑ Avoid drainage features built above the ground which can cause injury if hit. Extend or relocate pipe, culvert, and other feature ends from the roadway to reduce the risk of a crash.

Geotech

Maintenance of side slopes and structural features, such as walls, are the key considerations under the Geotechnical discipline.

- ❑ Evaluate side slopes for any steepening due to erosion.
- ❑ Evaluate any erosion damage around roadside structures, such as walls, columns, abutments, and drainage structures.
- ❑ Evaluate the safety of steep slide slopes for their ability to handle errant vehicles; evaluate the quality of the recovery area (if present) at foot of embankment.

Vegetation

The goal for roadside revegetation is to create a stable, self-regulating vegetation system that requires minimal maintenance and low lifecycle costs. If left alone, vegetation can grow out of control, blocking driver visibility of signs, wildlife, and other potential hazards.

- ❑ Develop an integrated vegetation management (IVM) plan to set priorities and direct maintenance actions.
- ❑ Control invasive weeds.
- ❑ Improve soils to ensure long-term plant health.

- ❑ Manage living snow fences. Regularly inspect and control for insects, disease, and rodent problems and replant trees that do not survive.
- ❑ Keep vegetation away from guardrail to help the driver see the guardrail and to make it easier to inspect for needed repairs (FHWA *W-Beam Guardrail Repair and Maintenance,* 2008).

Safety

Maintenance of structural features along a roadway (guardrail, walls, etc.) helps to maintain driver safety and improve overall aesthetics.

- ❑ Maintain guardrail and fencing in good condition; inspect regularly (Figure 4-3).
- ❑ Repair damaged guardrail promptly to ensure safe travel.
- ❑ Maintain and repair roadside signs, safety devices, etc.
- ❑ Clear litter and collect trash from the roadside.

Figure 4-2: Example of a culvert clogged by sediment

(Source: Parsons Brinckerhoff, Capitol Reef Route 10, Utah)

Figure 4-3: Example of a guardrail not meeting safety requirements

(Source: Parsons Brinckerhoff, Cuba La Cueva, New Mexico)

5. Putting It All Together

The case studies in the following pages show projects in the United States that demonstrate how sustainability is integrated through planning, design, construction, maintenance, and operations.

These case studies were selected because they were either under construction or recently constructed and due to their successful integration of sustainability practices. Site visits to projects that were under construction provided the opportunity to speak directly to FHWA staff, NPS staff, and project contractor(s). These conversations provided valuable insight into the communications between agencies in the field and the on-the-ground implementation of sustainability practices. Additional site visits are planned in the future, and this report will be updated with insights from those projects.

The case studies in this section show how sustainability was integrated into the design and construction process. As described in the Introduction to this guidebook, sustainable solutions should be incorporated early in the planning and design process and then revisited through construction and maintenance to maximize their success over the life of a project.

The concepts described in this guidebook were also observed in the field. A sampling of sustainability concepts within the case studies include:

- **Safety:** Eliminating or mitigating steep slopes; installing appropriate guardrail, lighting, and signage; installing multi-modal facilities.
- **Aesthetics:** Materials that reflect the historic character of the area; use of native and natural materials.
- **Geotechnical:** Retaining walls built from existing roadway materials; use of removable guardrails to avoid damage, rock scaling efforts.
- **Hydraulics:** Mitigation of soil erosion through placement of horizontal trees; grading of steep slopes.
- **Vegetation:** Replacement of native topsoil to ensure preservation and regrowth of native species; widespread application of native vegetation.

The variety of sustainability concepts reflected in these case studies shows that this is not a one-size-fits-all approach. Solutions need to be tailored to the unique project context and conditions.

Case Study

TOWER FALLS TO TOWER CANYON

YELLOWSTONE NATIONAL PARK

The Federal Lands Highway (FLH), in partnership with the National Park Service, initiated reconstruction of a 2.5-mile stretch of road between Tower Junction and Tower Falls in the northeast section of Yellowstone National Park. The project also included reconstruction of the Canyon Village parking lot and replacement of the Obsidian Creek Bridge at the Indian Creek Campground. The road has tight curves, steep hillsides, and natural walls that make construction challenging. The project exhibited sustainable construction practices, including the following:

- To preserve the historic context of the pre-existing guardrail while adding new stone, masons matched the old with the new material.
- Soils from hillside cuts were trucked elsewhere in the project area to recycle and maintain local materials within the project. The Tower parking lot was expanded using recycled soils. Similarly, large boulders extracted during excavation were placed along walkways or crushed for placement as walls.
- To ensure preservation of nutrient-rich topsoil, it was stockpiled at the construction limit edge; this topsoil was then placed back on the hillside after excavation to ensure preservation of native plant species.
- Roadside trees that were cut down were laid back on the slope to help slow erosion, maintain natural biomass, create habitat, while also avoiding the need to haul materials from the site.

***Top left**: Topsoil is pushed to the top of slope for placement following construction. **Top right**: Vertical walls make construction challenging through this area. **Bottom left**: Large boulders are excavated and placed elsewhere in the project area. **Bottom right**: View from the corridor to the valley below*

Case Study

MADISON TO NORRIS

YELLOWSTONE NATIONAL PARK

The Madison to Norris project is located on the western section of the Grand Loop in Yellowstone National Park. This 10-mile project addressed multiple deficiencies in pavement, drainage, alignment, and safety using sustainable construction methods and new features that enhanced the visitor experience. The road was widened to 30 feet. Two miles of new alignment were created upstream of Gibbon Falls, mitigating an impacted area and restoring it to natural conditions—prime riparian habitat. Specific sustainable features included:

- A 2-mile realignment of the roadway restored natural environmental conditions, while a new bridge over the Gibbon River was designed to maintain historic character of the area.
- Retaining walls were built with materials from the existing roadway when possible to create natural looking walls and cut slopes.
- The Gibbon Falls area previously had only a small pullout and minimal parking. The viewing and parking areas were expanded and enhanced with bicycle racks and ADA-compliant ramps and walkways.
- Small rocks were placed along roadside ditches to filter, slow, and percolate run-off.

***Top left**: Little evidence exists of the former roadway alignment along the Gibbon River. **Top right**: New alignment with retaining walls of native stone and bridge over the Gibbon River. **Bottom left and right**: An expanded parking area and pedestrian pathways provide access to the falls viewing area.*

Case Study

TETON PATHWAYS

GRAND TETON NATIONAL PARK

The FLH partnered with Grand Teton National Park to plan and construct a 10-foot wide multi-use pathway for cyclists and pedestrians, connecting Jackson Hole, Wyoming, to Grand Teton National Park. The pathway becomes a visitor experience of its own while augmenting the opportunities and modes that visitors use to experience the park. Elements of sustainability are woven into the construction, the visitor experience, and the maintenance of the pathways.

The route connects the County pathway from Jackson Hole to Moose Junction along approximately 8 miles of a separated pathway through the sagebrush flats east of the Teton Range. Path users can view grazing bison and elk. Interpretive signage helps orient and educate path users who will be traveling at a pace ideal for continual interaction with the landscape. The pathways feed into the visitor circulation systems within the busiest part of the park while signals, signage, and integrated pathway design emphasizes safety for vehicle and non-vehicle users.

Sustainability is integrated into the experience. Instead of visiting the park via automobile, the pathway encourages visitors to experience the park by other modes, lessening the environmental impact caused by vehicles and expanding recreational opportunities. Experiencing the park at a slower pace allows visitors to see more of the environment without potentially harming wildlife. Highlighting wildlife crossings, natural, and historic locations with signage educates visitors—an important step toward cultivating a sense of environmental ethic and responsibility.

Top: *bicycle racks;* ***Middle:*** *trail crossing,* ***Bottom:*** *pathway*

Case Study

GOING-TO-THE-SUN ROAD

GLACIER NATIONAL PARK

The "Sun Road" is a 50-mile two-lane highway that winds through Glacier National Park, up the slopes of the Continental Divide, and over Logan Pass. Mostly built between 1921 and 1937, the road is considered an engineering feat and National Historic Landmark. The roadway and roadside embody sustainable design practices from a number of perspectives:

- New avalanche-resistant guard walls have been constructed with a reinforced concrete foundation and core, then finished with stonemasonry facing to maintain consistency with the historic character.
- Removable guardrails have been installed to allow avalanches to pass over the roadway without roadway/wall damage. The guardrails are both historically authentic and aesthetically pleasing.
- To ensure safety and remove rockfall hazards, rock scaling has been conducted to remove loose and unstable slabs. To help support unstable rock, holes are drilled below the rocks that are to be stabilized, steel dowels are inserted, shotcrete is applied and then shaped, textured, and colored to blend with the surroundings.

***Top left**: Installation of guard walls with reinforced concrete; **Top right**: Roadway construction; **Bottom**: Removable guardrail installation*

Source: "Preserving a Landmark in the Sky: Rehabilitation of the Going-to-the-Sun Road" (2008).

Case Study

KATHERINE ACCESS ROAD

LAKE MEAD NATIONAL RECREATION AREA, ARIZONA

This project involved a combination of widening and overlaying the existing road bed to alleviate unsafe and inadequate lane widths along a 3.8-mile stretch of Katherine Access Road. Safety enhancements included asphalt curbing and guardrail replacements, updating existing culverts, and evaluating and improving the design of the boat launch and parking area to alleviate drainage problems and facilitate safer traffic movements. Initial safety issues documented along the roadway included:

- Culverts in the roadway clear zone
- Steep slopes adjoining the roadway with no associated barriers
- Absence of roadside shoulders
- Steep grading cuts undermining the roadway

To mitigate these roadside safety concerns, the project team instituted sustainable practices:

- Re-aligning and lengthening culverts to remove entrances from clear zones
- Installing contextually designed guardrails along sections of roadway that border steep slopes
- Adjusting roadway curvature to eliminate steep cuts in an effort to minimize erosion and provide for a safe shoulder area
- Re-grading steep side slopes to reduce erosion, encourage re-vegetation, and protect motorists

Steep roadside embankments without shoulder

The images show the pre-existing condition as project construction has not yet begun.

***Left**: culvert entrances located within clear zone, creating a hazard for motorists. **Right**: steep side slopes without guardrails.*

Putting It All Together

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Appendix A

Category	Subcategory	Measure	Implemented	Considered but Not Implemented	Not Applicable to Project	Justification/Notes
Aesthetics	Preservation of Views	Develop materials and designs that blend into the environment.				
		Specify roadside signs that meet the AASHTO standards but also respond to the local cultural and environmental context.				
		Identify important natural features that should be preserved within the clear zone and jointly develop strategies to preserve these features.				
		Develop blowing-snow mitigation designs that are safe and visually appealing.				
		Determine the impact of vegetative clearing on the local environment.				
		Specify plants that will enhance views from the roadway.				
		Identify flora to be preserved in the clear zone.				
		Specify seed mixes and plantings for water quality features.				
		Revegetate with contextually appropriate plant species.				
		Specify materials and designs that have an extended lifecycle.				
		Develop screening strategies for water quality facilities.				
		Develop cut and fill designs that ensure preservation of open vistas and view corridors.				
		Mitigate the visual effect of cut and fill on the local roadside environment.				
		Construct retaining walls that blend into the natural context.				
		Ensure that rock fencing has the least amount of visual impact.				

Category	Subcategory	Measure	Implemented	Considered but Not Implemented	Not Applicable to Project	Justification/Notes
Geotechnical	Materials	Ensure that slope angle can be supported by the roadside material.				
		Design for mitigation and prevention of future rockfall events.				
		Ensure that there is adequate support for structures. Where possible, minimize the area of the ground to be disturbed for the excavation.				
		Ensure that if vegetation is used to anchor soil, that it is designed for the long term and will minimize encroachment.				
		Ensure that little to no irrigation is needed after initial plant establishment.				
		Consider vegetation as a tool that can bolster the palette of geotechnical strategies.				
		Check for the design of adequate drainage in wall systems.				
		Use local materials for roadside elements (embankments, structures, etc).				
		Use recycled materials for roadside elements.				
		Stabilize soils with cementitious and recycled materials.				

Category	Subcategory	Measure	Implemented	Considered but Not Implemented	Not Applicable to Project	Justification/Notes
Hydraulic Design	General	Identify protected and/or sensitive areas along corridor to help establish drainage pattern.				
		Use native trees and brush to ensure stable materials, intercept rainfall and slow runoff accumulation.				
		Evaluate the balance in slopes to preserve natural environment.				
		Evaluate options to handle or divert runoff with wall design.				
		Mimic natural flow conditions.				
		Minimize visual impact of water quality features and structures.				
	Specific Strategies	Microcatchments				
		Micro-terraces				
		Slope Transitions				
		Bioretention				
		Innovative culvert design				
		Bioslopes				
		Vegetated buffers				
	Construction Practices	Restore streambanks.				
		Provide for soil erosion control.				
		Meet NPDES requirements.				
		Stage construction to minimize soil exposure.				
		Provide stormwater detention.				
		Minimize water ponding on the edge of pavement which can contribute to deterioration of the pavement edge and rutting of the soil.				

Category	Subcategory	Measure	Implemented	Considered but Not Implemented	Not Applicable to Project	Justification/Notes
Vegetation	Process	Define vegetation objectives clearly within the context of the larger project objectives.				
		Document physical and environmental features of the site (solar aspect, elevation, slopes, grading, drainage, climate, etc.)				
		Develop a vegetation plan. Consider plant establishment, plant sizes/spacing and natural forms of weed control.				
		Minimize delivery distance of vegetation needs to the project site				
		Minimize the costs of the resources and materials required to establish the plants such as the costs of water, fertilizer, pest control and labor required.				
		Document the success of vegetation efforts during post-construction and through long-term operations.				
	Habitat	Avoid/Minimize/Mitigate Habitat Fragmentation				
		Create new habitats where possible and restore or create new connections between habitats.				
		Restore/Mitigate Wetlands				
		Provide Nesting Locations				
		Provide Wildlife Crossings				
		Provide Fish Passage				
		Schedule Construction to Avoid Wildlife Disruption				
	Trees and Plants	Avoid impacts to trees				
		Design for a net increase in tree species (replacement greater than 1:1 ratio)				
		Re-establish/expand native vegetation in reclaimed work areas				
		Use native plant material as living snow fences, sight screens, etc				
		Design plant groupings to provide contrast and respond to context.				
		Remove invasive and undesirable plant species				
		Balance cut and fill				
		Reduce use of fertilizers and herbicides				
		Reuse and preserve topsoil				

Category	Subcategory	Measure	Implemented	Considered but Not Implemented	Not Applicable to Project	Justification/Notes
Maintenance	Hydraulic Design	Ensure that ditches remain traversable after cleaning.				
		Clean ditches and structural features of debris and sediment regularly to prevent them from clogging and backing water onto the travel way.				
		Ensure that side slopes do not become eroded over time. Plant native vegetation to slow erosion.				
		Avoid drainage features built above the ground which can cause injury if hit. Extend or relocate pipe, culvert and other features.				
	Geotechnical	Evaluate side slopes for any steepening due to erosion.				
		Evaluate any erosion damage around roadside structures such as walls, columns, abutments and drainage structures.				
		Evaluate the safety of steep slide slopes for their ability to handle errant vehicles; evaluate the quality of the recovery area (if present) at foot of embankment.				
	Vegetation	Develop an Integrated Vegetation Management (IVM) plan to set priorities and direct maintenance actions.				
		Control invasive weeds.				
		Improve soils to ensure long-term plant health.				
		Manage living snow fences.				
		Maintain clear zones.				
		Keep vegetation away from guardrail.				
	Safety	Maintain guardrail and fencing in good condition; inspect regularly.				
		Repair damaged guardrail promptly to ensure safe travel.				
		Maintain and repair roadside signs, safety devices, etc..				
		Clear litter and collect trash from the roadside.				

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